AN ASSESSMENT OF FISH AND FISHERIES IN IMPOUNDMENTS IN THE UPPER ORANGE-SENQU RIVER BASIN AND LOWER VAAL RIVER BASIN

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DOCTOR OF PHILOSOPHY

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by

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Abstract

South Africa is an arid country that, as a result of the need to store water for domestic, industrial and agricultural use, has invested heavily in the construction of impoundments which now cover a total of approximately 3 000 km^2. Faced with high levels of poverty and unemployment, South Africa is increasingly considering developing fisheries in freshwater impoundments to provide economic opportunities and food security in rural areas. To be effective, such development needs to be guided by information on current utilisation, fish species composition and abundance, as well as the impact of potential harvest methods. Unfortunately, inland fisheries have received limited interest in a country with large marine fisheries and a history of failures in developing inland commercial fisheries. As a result, there is a general lack of even basic information on fish communities in impoundments and their utilisation. This thesis attempts to address this paucity of information in the Free State Province (FSP) by conducting a rapid appraisal of the fisheries potential of impoundments using empirical approaches; collating a 35 year time series of catch returns from recreational angling tournaments and commercial fisheries; conducting surveys to determine fish species composition in 21 impoundments and testing a new fishing gear.

The FSP has the largest inland water surface area (145 677 ha) in South Africa and is situated centrally within the Orange-Senqu River Basin that is drained by the Orange-Senqu and Vaal River Systems. As a result of complete lack of data on inland fisheries in the FSP, a scoring system (based on empirical estimations of potential fish yield and water level fluctuations) was developed to provide information on the potential of impoundments for the development of commercial fisheries. Applying different models to Morphoedaphic index (MEI) data provided the first estimates of yields ranging from very conservative to highly opportunistic (e.g. for Gariep Dam from 5.0 to 58.5 kg ha^{-1} y^{-1}). As predicted by most MEI-based models, impoundments situated at high altitudes with large average depth, with least fluctuation in water levels, had the least potential for the establishment of fisheries.

Data on commercial fisheries were collated from various field stations and digitised. This provided the first complete database of commercial fisheries yields in South Africa. Between 1979 and 2014, a total of 9 036 tons of fish were harvested by commercial fishery enterprises operating sporadically at seven impoundments. Commercial fisheries yields were dominated by Bloemhof Dam (73%) and Kalkfontein Dam (23%) with sporadic attempts to develop commercial fisheries in the five other impoundments, contributing only 4% to the total yield over the 35 year period. The gear used to harvest fish determined which species were caught, with the indigenous cyprinids, namely Orange River mudfish *Labeo capensis,* moggel *Labeo umbratus* and smallmouth yellowfish *Labeobarbus aeneus* dominating catches when gill nets were used, while common carp *Cyprinus carpio* dominated when seine nets were used. Only two commercial ventures operated at one impoundment (Bloemhof Dam) on a continuous basis for more than 32 years. Prior knowledge, skills and experience and most importantly a pre-existing and self initiated market were identified as determinants of success.

Data from license sales demonstrate that the recreational fishery sector in the FSP comprises 7 710 licensed recreational anglers. Of these, 748 are affiliated with 30 angling clubs. An analysis of historical data indicated that there has been a decrease of 76% in the number of recreational anglers since 1971 (based on license sales). Over the period 1974 to 2014 available data show that at least 4 817 angling tournaments were held at 17 impoundments. Historical analysis of participation indicates a decline in angling tournament participation. This was in support of the trends observed using license sales data. The total recorded catch for these tournaments was 414 tons. The recreational fishery was dominated by *C. carpio* that contributed 81% to the total weight and 77% of the total number of fish landed.

Experimental fishing surveys conducted during this study, sampled 23 831 fish from the 21 impoundments surveyed. Sixteen species were sampled, with the bulk of the catches consisting of four large cyprinid species (*L. capensis, L. umbratus, L. aeneus* and *C. carpio*), and the sharptooth catfish *Clarias gariepinus.* On average, 7.6 ± 1.4 and 6.0 ± 1.1 species were sampled per impoundment in the Vaal River and Orange-Senqu River Systems respectively. Fish assemblages in different impoundments were similar (average Jaccard's Index of Similarity of 64.2%). Examination of population structure (using length frequencies) indicated that most species sampled were established with evidence of several year classes of adults as well as young of year.

An assessment of fyke nets as a potential harvesting gear demonstrated that this gear might be a suitable passive gear for small-scale fisheries. Eleven fish species were caught with fyke nets, with catches dominated by four large cyprinid species (*L. capensis, L. umbratus, L. aeneus* and *C. carpio*), and *C. gariepinus* of which most are important angling species, except *L. umbratus*. The preliminary assessment of the suitability of fyke nets as gear for small-scale fisheries has revealed a number of research questions and once these have been addressed, fyke nets might become the gear of choice in future inland fisheries development in central South Africa.

With the new interest in the development and promotion of inland fisheries in South Africa to address government's policy objectives of job creation and poverty alleviation, this thesis will contribute to the knowledge base, as for the first time in South Africa such a comprehensive study on an assessment of fish and fisheries within impoundments has been done. This thesis will provide baseline information which may support and inform the policy development process for inland fisheries in South Africa that was initiated during February 2015 by the National Department of Agriculture, Forestry and Fisheries.

Keywords: assessment; fish; commercial, recreational fisheries; 21 impoundments; Orange-Senqu River Basin.

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List of some acronyms used in text

CPUE	Catch per unit effort
CSIR	Council for Scientific and Industrial Research
DAFF	Department of Agriculture, Forestry and Fisheries
DNEC	Directorate of Nature and Environmental Conservation
DSO	Dam Safety Office
DWS	Department of Water and Sanitation
EC	Electrical conductivity
FAO	Food and Agricultural Organisation of the United Nations
FL	Fork length
FS DESTEA	Free State Department of Economic, Small Business Development, Tourism and Environmental Affairs
FSFBAA	Free State Freshwater Bank Angling Association
FSL	Full supply level
FSP	Free State Province
IUCN	International Union for the Conservation of Nature
LHP	Lesotho Highlands Project
MD	Mean depth
MEI	Morphoedaphic Index
MMM	Mangaung Metropolitan Municipality
NCO	Nature Conservation Ordinance
NCR	Nature Conservation Regulations
NEM:BA	National Environmental Management: Biodiversity Act
NEM:PAA	National Environmental Management: Protected Areas Act
NEPAD	New Partnership for Africa's Development
NWA	National Water Act
ORASECOM	Orange-Senqu River Commission
ORDP	Orange River Development Project
OSRB	Orange-Senqu River Basin
OSRS	Orange-Senqu River System
OVRS	Orange Vaal River System
PAF	Partnership for African Fisheries
PEC	Permit Evaluation Committee
PNR	Provincial Nature Reserve
RHP	River Health Programme
RMP	Resource Management Plan
SABAA	South African Bank Angling Association
SACSCF	South African Casting and Surf Casting Federation
SADC	Southern African Development Community
SAFALFA	South African Federation of Artificial Lure and Fly Anglers
SAFBAF	South African Freshwater Bank Angling Federation
SAFSSA	South African Federation of Sport and Sea Anglers
SAMSA	South African Maritime Safety Authority
SASACC	South African Sport Anglers and Casting Confederation
SASCOC	South African Sport Confederation and Olympic Committee

SL	Standard length
TDS	Total dissolved solid
TL	Total length
VRB	Vaal River Basin
VRS	Vaal River System
WMA	Water Management Area
WRC	Water Research Commission
WUA	Water Users Association

Chapter 1 General introduction and thesis outline

South Africa's inland fisheries from a food security and harvesting perspective are poorly developed (Bruton *et al.,* 1982; Potts, 2003; Ellender *et al.,* 2009; Ellender *et al.,* 2010a; McCafferty *et al.*, 2010; McCafferty *et al.,* 2012; Weyl, 2012), and the Free State Province (FSP) is no exception. This province is situated within the Orange-Senqu River Basin (OSRB), the largest river basin in southern Africa with the Orange-Senqu and Vaal River Systems the two most important systems in South Africa. The two systems contain five of the largest impoundments in South Africa (Gariep, Vanderkloof, Bloemhof, Vaal and Sterkfontein Dams), and the FSP has an estimated 145 677 ha of inland water surface. These inland waters are thought to be under-utilised from a harvest perspective because historically freshwater fish were utilised mostly for recreational angling (Marshall and Maes, 1994; McCafferty, 2012; McCafferty *et al.*, 2012).

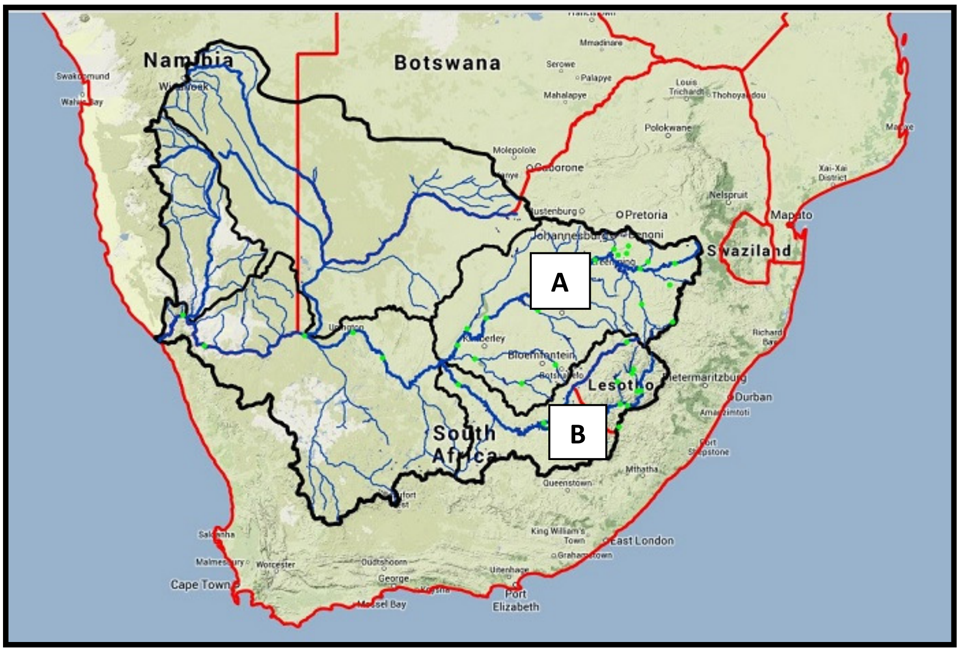
There is an increased interest in South Africa to investigate the possibility of the development of capture fisheries to address the South African National Policy objectives of job creation, poverty alleviation, economic development and food security (Rouhani, 2001; Weyl *et al.,* 2007; Ellender, 2008; Ellender *et al.,* 2009; Ellender *et al.*, 2010a; McCafferty *et al.*, 2010; Ellender, 2011; Water Research Commission [WRC], 2011; McCafferty *et al.*, 2012; Weyl, 2012; Britz *et al.,* 2015). This has resulted in an increased interest to develop fisheries in South Africa. However, it is important that South Africa pays attention to lessons learned from inland fisheries, especially on the continent of Africa and in Asia. Many of these fisheries are over-utilised with the subsequent depletion in high value species and catch rates, and a decrease in individual fisher catches (Allan *et al.,* 2005). This has resulted in many fishermen being among the poorest of rural communities (Béné, 2003). The relative low levels of use of the current fisheries resources therefore provide a unique opportunity for the development of inland fisheries in South Africa and the FSP in an appropriate and sustainable manner.

Since 2009 inland fisheries in South Africa fall under the mandate of the Department of Agriculture, Forestry and Fisheries (DAFF) which is the national lead agent for the development of this sector (McCafferty *et al.,* 2010; McCafferty, 2012). Implementation, however, resides at provincial level and in the FSP, the Department of Economic, Small Business Development, Tourism and Environmental Affairs (FS DESTEA) is currently responsible for the management of all matters pertaining to the fauna and flora at state impoundments located in provincial nature reserves (PNR) within the Province's borders. Because PNR management is guided by the National Environmental Management: Protected Areas Act (NEM: PAA, 2003), which emphasises sustainability and stipulates that an alien species management strategy needs to be developed, it is therefore essential that management guidelines are developed for the fisheries within the impoundments and that a fisheries development strategy is formulated at a provincial and national level.

To develop such a fisheries development strategy requires knowledge not only of the current state of the resource, but also of the harvesting fisheries because sustainable fisheries development requires that realistic goals be set for the scale of operation. A recent literature review by McCafferty (2012) and McCafferty *et al.* (2012) demonstrated that there is a general lack of information on inland fisheries in South Africa. Data on previous fisheries developments are usually kept in files at government institutions where they are mostly inaccessible or difficult to obtain. Despite this lack of information there have been various initiatives to investigate and promote inland fisheries in South Africa. In reality there are few examples where fisheries were able to operate for more than only a few years. This is quite evident with previous fisheries projects in the FSP. Similarly, in the aquaculture sector there are few positive outcomes from initiatives in the FSP.

Information on previous and current fishery operations is not available for many South African impoundments (Weyl *et al.,* 2007; Britz *et al.,* 2015). The situation is no different in the FSP where the last provincial fish surveys were conducted 20 years ago. It was therefore essential that a research project had to be initiated to gather new scientific data and information to ensure the resource is protected, conserved, managed and utilised in a sustainable manner.

The scope for this study and the study area are 21 large and medium impoundments within the OSRB, all of which lie on or within the borders of the centrally situated FSP. The geographical defined Upper OSRB is the area including the Caledon and Orange-Senqu Rivers and tributaries. The lower Vaal River Basin (VRB) referred to in this study falls within the geographical defined VRB and is limited to the impoundments situated within the lower VRB and tributaries of the VRS within the borders of the FSP (see Figure 1.1).



(Source: http://wis.orasecom.org)

Figure 1.1: The geographical defined Vaal River Basin indicated as A and the Upper Orange-Senqu River Basin indicated as B.

The term "impoundment" (dam) referred to throughout this study, is the artificially man-made structure (dam wall) as well as the water impounded behind the structure. In comparison to the rest of Africa and the world, there are no natural lakes in the FSP.

Thesis outline

A study on the assessment of fish and fisheries in impoundments of the Upper OSRB and lower VRB within the borders of the FSP was initiated during which five key aspects were investigated, namely:

- A review of the physical characteristics of selected impoundments and their suitability for commercial fisheries;

- A historical analysis of commercial fisheries in the FSP;

- An analysis of recreational fisheries in the FSP;
- Freshwater fishes in selected impoundments in the FSP;
- Suitability of fyke nets for use in small-scale fisheries in the FSP.

The Orange-Senqu River Basin (OSRB), Orange-Senqu River System (OSRS) and impoundments in South Africa and the FSP and the four most important inter-basin water transfers within the basin will be introduced in the general literature review in Chapter 2. Indices and models and their application to determine potential fish yields of impoundments will be highlighted, with an indication of the value of these to set inland fishing quotas. The various inland fisheries sectors will be defined based on the most recent published literature. The importance of inland fisheries and freshwater fish in the livelihoods of millions of people, as well as the extent of the recreational fisheries on a global and national scale, will also be highlighted. An overview of the biology and ecology of fish species, historic records on the occurrence and distribution and artificial stockings of fish in impoundments in the FSP will further be highlighted.

The study area and the physical, morphometric and general characteristics of the 21 selected impoundments, which can be viewed as the most important impoundments in the FSP for the different water sectors and inland fisheries, will be introduced in Chapter 3. Based on these characteristics, first time estimates of the potential fish yield for the 21 selected impoundments will be determined based on the Morphoedaphic Indices (MEI) and models as developed by Ryder (1965) and adapted by Bruwer and Claassens (1978), as well as the temperate adapted MEI of Schlesinger and Regier (1982), and the MEI for African impoundments as developed by Marshall and Maes (1994). Based on the results of these, a scoring and ranking system has been implemented, providing baseline information on the impoundments in the FSP with the highest importance and suitability for the implementation of commercial fisheries. The chapter will be concluded with a review of the major fluctuations of water levels that is characteristic of most impoundments in the highly regulated OSRS and Vaal River System (VRS).

Chapter 4 will provide a historical analysis of commercial fisheries in the FSP based on historic catch data of fisheries that were established at 11 impoundments in the province since

1979. The literature review by McCafferty *et al.* (2012) demonstrated the general lack of historic and current information on inland fisheries in South Africa and the difficulty of obtaining historic data. For this study, it was possible to obtain most of the historic records of the daily and monthly catches of commercial fisheries and this chapter will provide the first ever provincial overview of inland commercial fisheries in South Africa. The management complexities of these fisheries, especially those of the seven previous fishery projects at Gariep Dam, will be highlighted. The first ever records of the catch compositions and landings based on the historic catch data will also be presented. The major impact and effect of fluctuation water levels at Kalkfontein and Bloemhof Dams, and the extent to which this influenced the total catches of the fisheries, will further be highlighted.

The first ever comprehensive overview and analysis of the freshwater angling sector in the FSP, indicating the number of sport and recreational anglers, angling clubs and the most preferred and important impoundments for recreational angling in the province, will be presented in Chapter 5. An overview of historic tournament catch data dating back from 1974 and most recent data will be highlighted, indicating catch compositions and landings, and which fish species were the most targeted, and important angling species.

As indicated by the work of Weyl *et al*. (2007), Ellender *et al*. (2009; 2010a), WRC (2011), McCafferty *et al.* (2012) and Britz *et al.* (2015), there is new interest in South Africa to promote and implement inland fisheries, but there is currently no national policy or guidelines for this sector. On a provincial level it is therefore important that a fisheries development strategy is formulated based on information on the current state of the fish stocks. The last provincial fish assessment was done more than 20 years ago, and due to the absence of most recent data, 41 comprehensive fish surveys during which a variety of sampling gear were used, were done at the selected impoundments. Included as sampling sites were impoundments for which no historic fish distribution records existed. Chapter 6 will provide the most recent data and records on the presence, absence and relative abundance of fish species in the FSP, highlighting the spread and new distribution records for a number of alien and invasive species. Results of the application of Jaccard's Index of Similarity (Jaccard, 1912) will be presented, providing the first ever records on the similarity of fish assemblages between impoundments. Results will also be presented on an investigation with regards to the fish species diversity amongst impoundments in the OSRS and VRS.

As both gill and seine nets were used to sample fish during the study period, the species composition of the inshore and off-shore areas was investigated, which will in future guide which gear will be allowed and be most suitable to be used in future inland fisheries. Concurrently, it was also critical to determine the current population structures of the most important fisheries species and determine which species are established. In order to determine which environmental and morphometric variables drive the distribution of the different fish species at impoundments, a Canonical Correspondence Analysis and linear regressions were applied providing baseline information of the factors influencing fish distributions in the OSRB. The chapter is concluded with a historic overview and comparison of species diversity and catches at impoundments based on catch data since 1965, highlighting the increase in fish species diversity.

The South African Maritime Safety Authority (SAMSA) requires all skippers of boats on inland waters to have a valid Certificate of Competence (skipper license), while all vessels used for commercial operations, must be issued with a Local General Safety Certificate (SAMSA, 2002). Previous commercial fishing operators mostly used gill and seine nets, which are expensive, and with the worsening economic conditions, it has become increasingly difficult for small-scale operators to start a small-scale business or fishery. In Chapter 7 the suitability of fyke nets for possible use in the establishment of future small-scale fisheries will be discussed. The species composition of fyke, gill and seine nets as well as recreational tournament catches are compared to determine the most suitable gear future small-scale fisheries can use. The chapter is concluded with the results of a multi-variate analysis to determine which environmental and morpho-metric variables impact on species catches. The advantages and disadvantages of using this gear will be highlighted and recommendations for further research presented.

A general discussion and conclusion, management recommendations and need for future research based on the results and research findings of the study on an assessment of fish and fisheries in impoundments of the Upper OSRB and lower VRB will be presented in Chapter 8. The critical question if impoundments and the fish resources within it will be able to address some of the government's economical and social developmental goals will be addressed. Based on the results of this study management recommendations towards the development of a Provincial Inland Fisheries Policy, that can serve as the basis for the development of a National Inland Fisheries Policy, is presented.

Chapter 2 General Literature Review

2.1 Introduction

It is estimated that more than 25% of the population in South Africa are unemployed (StatSa, 2014). As a rural province, the Free State Province (FSP) contains only 5.3% of the 54 million people currently residing in South Africa. With opportunities for formal employment that are limited, the unemployment rate in this province is at 35%. As a result the Provincial Government is desperately trying to address the national policy objectives of economic empowerment, food security and poverty alleviation as referred to in the Free State Growth and Development Strategy (https://www.govpage.co.za/free-state-office-of-the-premier20142015-budget-vote.html). As is the case elsewhere in the country (Britz *et al.,* 2015), inland fisheries in the FSP are receiving considerable attention as potential avenues for providing such opportunities. Of particular interest are the 412 impoundments that are situated within or on the borders of the FSP.

Compared to the rest of the continent of Africa (e.g. Marshall and Maes, 1994; Tweddle *et al.,* 2015; Weyl and Cowley, 2015) and the rest of the world, inland fisheries have shown limited growth in South Africa (Weyl *et al.,* 2007; McCafferty *et al.,* 2012; Britz *et al.,* 2015). Prior to 2009, the mandate for inland fisheries resorted under the conservation and environmental authorities at provincial level within the different provinces in South Africa. After the third democratic elections in South Africa during 2009, the Department of Agriculture, Forestry and Fisheries (DAFF) was established and the mandate for inland fisheries was moved from the conservation and environmental authorities to this National Department (Britz *et al.,* 2015). At a National workshop at the South African Water Research Commission in Pretoria during 2011, it was agreed that DAFF must take the lead with the development of a National Inland Fisheries Policy, but no mention is made with regards to the development of such a policy in the DAFF Strategic Plan for the period 2013/14 to 2017/18 (DAFF, 2013). What is evident, however, is that the *de facto* management of access to impoundments will remain a responsibility of local municipalities and authorities. Biodiversity matters will still remain the responsibility of provincial authorities such as the Free State Department of Economic, Small Business Development, Tourism and Environmental Affairs (FS DESTEA). To allow for sustainable development, decisions on inland fisheries development will need to be informed by information on the distribution, abundance and biology of potential target species as well as by knowledge of the harvesting fisheries. Unfortunately, such information is extremely limited in South Africa (McCafferty *et al.,* 2012) and particularly for the FSP, where results of previous fishery projects were mainly published as internal departmental reports. The purpose of this literature review is therefore to provide background information on research undertaken on the fishes and fisheries in impoundments in the FSP and Orange-Senqu River Basin, the largest inland water basin in southern Africa.

2.2 Orange-Senqu River Basin

The Orange-Senqu River System comprises 2 300 km of river (Cambray *et al.,* 1986) that forms the border between Lesotho, South Africa, Namibia and Botswana, and which has a total catchment of more than 1 000 000 km² that covers the central part of southern Africa. The river originates in the highlands of Lesotho at an altitude of 3 200 m in an area with an average annual rainfall of more than 1 800 mm per year and ends in the Atlantic Ocean at the South Africa/Namibia border where the rainfall is < 50 mm per year (Milzow and Arroyo, 2005). The main tributary of the Orange-Senqu River System (OSRS) is the Vaal River System (VRS), which drains large parts of the FSP and former Transvaal, currently divided in the Gauteng, North West, Limpopo and Mpumalanga Provinces.

The Vaal River is often referred to as the hardest working and most anthropogenic impacted river in Africa (Brand *et al.,* 2009). Nearly 50% of the country's wealth and more than 80% of the country's electricity are produced by industries which receive water from the Vaal River (Milzow and Arroyo, 2005). A large number of municipal waste water treatment works, gold mines and major industries are situated in this area and together with storm water drainage from major urban areas, discharge large quantities of polluted water into this system (Wepener *et al*., 2011). This eventually spread to the rest of the Vaal River where in the past it has caused major fish kills (De Villiers, 2007a).

2.3 Impoundments

South Africa is a dry country with an average annual rainfall of between 450 mm and 500 mm per annum (Snaddon *et al.*, 1999; CSIR, 2010; King *et al.,* 2011) which is well below the world average of 860 mm per annum (CSIR, 2010; King *et al.*, 2011). There is also a distinctive gradual decline in annual rainfall from the wetter eastern parts to the drier and warmer western parts of the country (Richardson *et al.,* 2010).

While the number of impoundments increased slowly between 1900 and the 1960's, there was a sharp increase during the 1970 and 1980's with the implementation of the Orange River Development Project (ORDP) and Vaal-Tugela Pump Scheme (Roberts, 2009; Stone, 2011). During the period 1969 until 1989, more than 1 800 impoundments of varying sizes were built in South Africa. By 1989 all the constructed impoundments in South Africa were able to store nearly 60% of the total annual runoff, increasing to 65% by 2009 (Rowlston, 2011). As a result natural flows and ecology of the rivers were altered. Aquatic systems became increasingly fragmented by interrupted flows and the construction of impoundments.

During a recent survey it was estimated that there are only 4% of river stretches in South Africa that can be viewed as "free-flowing", with no weirs or impoundments (FFSG, 2014). The impacts and effects of impoundments on aquatic systems have been well documented (e.g. Baxter, 1977; Stone, 2011; Jellyman and Harding, 2012). Stone (2011) highlighted the impacts of impoundments on downstream habitats leading to the eroding of riverbanks, the deepening of river channels and the destruction of gravel beds that are important habitats for fish and aquatic invertebrates. A study done in New Zealand found distinct differences in the fish community structure above and below impoundments. Sites above impoundments had lower species diversity and a higher number of non-native species which benefitted from the newly created lentic habitats. Cambray (1984) noted the effects of stream regulation and change in stream flow on fish in the highly regulated OSRS, especially the middle and lower sections below Vanderkloof Dam and that the known distribution range of 12 species has extended. Benade (1993) did a study on fish populations in the highly regulated OSRS within the borders of the former Cape Province and noted that most of the larger Cyprinidae species had reached a bottleneck and consisted mostly of large individuals. This was attributed to the artificial manipulation of water levels upstream at the hydro-power plant at Gariep Dam, which impacted on the species' natural spawning. The author further reported on the disappearance of species that preferred lotic systems.

Impoundments created lentic habitats suitable for the establishment of especially recreational fisheries and on a global scale it became a major social and recreational activity for millions (Cooke and Cowx, 2004; Arlinghaus *et al.,* 2010; Cowx *et al.,* 2010). Cooke and Cowx (2004) estimated the global number of people involved in recreational angling on 700 million. With the development of the ORDP, which included the building of a number of large impoundments, Opperman (1965) noted the vast potential the project had for the development of recreational facilities and fisheries in central South Africa. This indeed happened from the early 1970's and in South Africa recreational fisheries have been the dominant inland fishery sector for the last hundred years (McCafferty *et al.,* 2012).

The importance of the OSRS and the VRS in sustaining the lives of millions as well as the economies of the four countries within the OSRB cannot be ignored. Parallel to this, the 5 030 impoundments in South Africa (DSO, 2014) play a critical and essential role in ensuring sufficient water is available for all the different economical and agricultural sectors within the country.

With the developmental focus of DAFF and the various national and international programmes promoting inland fisheries, the 5 030 impoundments in South Africa are seen as one of the "vehicles" to address poverty and food security. In reality, 75% of the 5 030 impoundments are classified as "small" (DSO, 2014) and will not be able to sustain any long term or major fisheries projects. It is also uncertain whether the remaining medium and large impoundments will be able to provide enough fish on a sustainable basis for use in large-scale inland fisheries.

2.4 Inter-basin water transfer schemes

With the development of impoundments in South Africa and especially within the OSRB, a number of inter-basin transfer schemes were established. The four major inter-basin water transfer schemes within the borders of the FSP are:

(i) the Orange Fish Tunnel transferring water for mostly irrigation purposes from the OSRS and Gariep Dam to the Great Fish River and from there via another scheme to the Sundays River in the Eastern Cape;

(ii) the Vaal Tugela hydro-power pump scheme where water from the upper reaches of the Tugela River in Kwazulu Natal is pumped over the escarpment to Sterkfontein Dam situated in the Nuwejaarspruit in the FSP;

(iii) the Lesotho Highlands water scheme transferring water from the Malibamatso River in the upper reaches of the Senqu River in Lesotho to the Ash River in the upper reaches of the VRS to augment water supply for the Gauteng Province, and

(iv) the Caledon-Modder River transfer scheme transferring water from the Caledon River via the Tienfontein pump scheme to the Knellpoort Dam and from there via the Novo pump scheme to the Modder River System to supply water to the Mangaung Metropolitan Municipality (Snaddon *et al.*, 1999).

Inevitably some of these inter-basin water transfer schemes have lead to the spread of alien and indigenous fish species to areas outside their natural distribution range. This is evident in the case of the Orange Fish Tunnel which has a total length of 82.5 km and diameter of 5.3 m which delivers water at 54 m³ per second to the dry Eastern Cape (Milzow and Arroyo, 2005). Cambray and Jubb (1977) provided the first report of the transfer of fish, notably *Labeo capensis* (A. Smith, 1841), but also *Labeobarbus aeneus* (Burchell, 1822), *Barbus anoplus* Weber, 1897, *Labeo umbratus* (A. Smith, 1841) and *Cyprinus carpio* Linnaeus, 1758 from the OSRS to the Great Fish River System in the Eastern Cape.

2.5 Indices and models to determine potential fish yield of impoundments

In the FSP, research on freshwater fish started during the early 1970's following the construction of major impoundments and the establishment of provincial nature reserves and protected areas around, or adjacent to impoundments. Research during the middle to late 1970's focused mostly on the occurrence, distribution and community structure of fishes at state impoundments at provincial nature reserves and within tributaries of the OSRS and VRS. However, a limited number of studies were done on the impoundments' fishery potential. The 1980's and 1990's saw an increase interest in the development of commercial fisheries at a number of impoundments, which necessitated research to be done on the population and community structure of fish. Unfortunately the research reports compiled were in most cases descriptions of short surveys, with the main purpose to inform management authorities who allocated commercial fishing quotas ranging from 50 to 650 tons per annum for certain impoundments. A comprehensive review of these reports yielded no information on how these quotas were determined.

Internationally various models and indices were developed to determine the potential fish yield of lakes and impoundments. The Morphoedaphic Index (MEI) originally developed by Ryder (1965) was used extensively throughout the world. Ryder (1965) recommended using the mean depth and total dissolved solids in mg ℓ^{-1} within an impoundment as the two parameters to determine the potential fish yield in lakes and impoundments in the north temperate region. This model was used extensively and appeared in more than 100 publications (Ryder, 1982) in which it was critiqued or appreciated for its simplicity. In his review on the use, abuse and fundamental concepts of the MEI, Ryder (1982) noted that the average depth seemed to be the variable that is directly linked to productions processes within impoundments.

For use on a global level, however, due to variations in climate, Ryder (1982) recommended that temperature should be included in the MEI. Schlesinger and Regier (1982) developed such a model in which the average annual air temperature was identified as an important variable to apply in the MEI model for use on a global scale.

In the study to develop a fisheries management plan for Gariep Dam, Hamman (1981) used various indices and models as proposed by Ryder (1965), Henderson and Welcomme (1974) and Toews and Griffith (1979) (cited in Hamman, 1981) to determine the potential fish yield. Using the different indices and models, the potential estimated fish yield for Gariep Dam was estimated between 19 to 45 kg ha^{-1} and 526 to 1 245 tons (Hamman, 1981). Malan (1988) reported after a study on the fish populations in four impoundments in the former Transvaal Province that significant differences in results were obtained when using different models and indices to determine potential fish yields.

Kerr and Ryder (1988) noted that the annual variability of individual fish stocks should be considered and that fisheries managers need to understand the reasons thereof so to set realistic fish quotas to be harvested. Crul (1992) provided a summary of the different models and indices to predict potential fish yields in lakes and impoundments on the African continent and provided a list of 12 different models that have been used extensively by various authors for lakes in Africa. A complete synthesis of simple empirical models for the prediction of fish yields has been compiled by MRAG (1995). This provided a review of existing empirical yield models and an introduction to a database containing datasets of information on the morphology, hydrology, chemistry, biology, fisheries and catchment demography for tropical and sub-tropical lakes, as well as reservoirs, swamps and coastal lagoons.

Because most of the impoundments in the OSRB and southern Africa are situated at an altitude higher than 1 000 m, temperature effects needed to be incorporated. Marshall and Maes (1994) noted that temperature will have a significant impact on the productivity of impoundments. The authors further listed the following factors that may impact on the productivity of small impoundments: the morphometry of the impoundment, droughts and water fluctuations, siltation due to severe erosion in catchments, salinisation, pollution and subsequent eutrophication, and the community structure of fish.

Kolding and Van Zwieten (2012) noted that the fluctuating water levels in impoundments have a substantial impact in the addition and re-suspension of nutrients that can have a major impact on the whole aquatic ecosystem and production. The authors further observed that impoundments and shallow lakes undergo the largest fluctuations in water levels, while having the highest fish yield per unit area. Assessment of potential fish yields of impoundments in South Africa and the FSP therefore need to take cognisance of this in order to ensure realistic goals and objectives, as well as fishing quotas are set for impoundments.

One of the major challenges when using the MEI to determine the potential fish yield of impoundments is the fact that most impoundments' water level vary significantly. As the MEI is based on the mean depth of the impoundment at full supply level, it thus cannot give an accurate estimate as impoundments' water level may fluctuate significantly over a period of time. Most studies using MEI indices based their results on the impoundments at full supply level. Care should therefore be taken when potential fish yields are determined so not to set unrealistic goals for fisheries development.

2.6 Distribution of freshwater fish within the Orange-Senqu River System

One of the earliest works on freshwater fish in Africa and South Africa was by Harrison *et al*. (1963), who provided a comprehensive overview of the distribution of freshwater fish as well as the introduction and spread of alien and invasive fish species to the four former provinces (Cape, Orange Free State, Transvaal and Natal) in South Africa. The authors noted that the reasons for the importation of the many alien species to the country was because it was thought there were no suitable indigenous fish species for angling and table fish.

The first lists of indigenous freshwater fish species occurring within the OSRS was compiled by Jubb (1964; 1972) and Jubb and Farquharson (1965) which is summarised in Table 2.1.

Table 2.1: Indigenous species recorded in the OSRS according to Jubb (1964; 1972) and Jubb and Farquharson (1965).

Species	Common name
Labeobarbus aeneus (Burchell, 1822)	Smallmouth yellowfish
Labeobarbus kimberleyensis (Gilchrist and Thompson, 1913)	Largemouth yellowfish
Barbus trimaculatus Peters, 1952	Three spot barb
Barbus hospes Barnard, 1938	Namaqua barb
Barbus pallidus A. Smith, 1841	Goldie barb
Barbus anoplus Weber, 1897	Chubbyhead barb
Labeo capensis (A. Smith, 1841)	Orange River mudfish
Labeo umbratus (A. Smith, 1841)	Moggel
Austroglanis sclateri (Boulenger, 1901)	Rock catlet
Clarias gariepinus (Burchell, 1822)	Sharptooth catfish
Tilapia sparrmanii A. Smith, 1840	Banded tilapia
Pseudocrenilabrus philander (Weber, 1897)	Southern mouthbrooder
Mesobola brevianalis (Boulenger, 1908).	River sardine

Jubb (1972) recorded the following alien and invasive species within the OSRS: the brown trout *Salmo trutta* Linnaeus, 1758, the rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792), the largemouth black bass *Micropterus salmoides* (Lacépède, 1802), the smallmouth black bass *Micropterus dolomieu* (Lacépède, 1802), the bluegill sunfish *Lepomis macrochirus* Rafinesque, 1819 and the common carp *Cyprinus carpio* Linnaeus, 1758.

Benade (1993) listed a total of 26 fish species occurring in the OSRS, of which five are estuarine species, six are endemic, one a translocated indigenous species, and five alien and nine indigenous species. Skelton (1986) highlighted the low number of indigenous fish species in the OSRS and noted that only 16 indigenous species, mostly belonging to the Family Cyprinidae, have been recorded.

In contrast to the low fish species diversity in the OSRS, Coke (1990) reported that 79 freshwater fish species are found in Kwazulu Natal. Hay (1991) recorded 13 fish species in the Fish River System, the main tributary of the OSRS in Namibia, with *L. aeneus*, *L. kimberleyensis*, *B. trimaculatus*, *B. paludinosus*, *B. hospes*, *L. capensis*, *L. umbratus*, *C. gariepinus*, *T. sparrmanii* and *M. brevianalis* been indigenous, and the Mozambique tilapia *Oreochromis mossambicus* (Peters, 1852), *C. carpio* and the red breasted tilapia *Tilapia rendalli* (Boulenger, 1896) been alien. Hay (1991) also recorded hybrids of *L. aeneus* and *L. kimberleyensis*, as well as *L. capensis* and *L. umbratus* in the Fish River System in Namibia.

In the former Cape Province from the late 1960's until early 1980's, research on fish focussed on the occurrence of species in the OSRS within the border of the province (today referred to as the Eastern and Northern Cape Provinces). From 1970 until 1982 research focused on the fisheries potential of the Hendrik Verwoerd Dam (Gariep Dam) for the establishment of inland fisheries (Hamman, 1981; Benade, 1993), while a major study on the limnology and fishery potential of the former Lake le Roux (Vanderkloof Dam) was done from 1977 until 1983 which was concluded by the work of Allanson and Jackson (1983).

In the former Orange Free State Province fisheries research focussed on the occurrence and distribution on fish species in ten tributaries of the VRS and OSRS within the borders of the Province and Janse van Vuuren (1978) provided a summary of the surveys done in eight systems.

In the former Transvaal Province, fish surveys were done in the VRS during 1956, 1969 until 1970 as well as 1978. A number of fish surveys were also done during 1972 and 1981 until 1982 in the OSRS (Skelton, 1986). These surveys mostly focused on the occurrence, distribution and relative abundance of fish species within these systems.

2.7 Historic records on the occurrence and distribution of freshwater fish in the Orange-Senqu River and Vaal River Systems with notes on the value of the different species for inland fisheries

Skelton (1986) did a number of fish surveys in the OSRS, while Benade (1993) investigated the impact of the regulated OSRS within the borders of the Cape Province (currently Eastern and Northern Cape Provinces), on freshwater fish. During a recent study by O'Brien (2010), fish sampling was done at five sites in the OSRB with three sites in the VRS main stem and two in the OSRS main stem. Wepener *et al.* (2011) reported on fish species that were recorded in the VRS, while Ramollo (2011) provided a list of fish species recorded in the Middle and Lower OSRS.

The first River Health Programme (RHP) in the FSP was launched during 1996 and a multi-stakeholder team was established to drive the process in the Province (RHP, 2003). This was followed by another major RHP study during 2012 during which fish sampling were done at 23 predetermined sites in the Orange, Caledon, Riet and Modder Rivers in the Upper Orange River Water Management Area (WMA), and 33 sites in the VRS within the borders of the Free State Province (Avenant, 2012; Dlomo and O'Brien, 2012).

The historic records and results on the occurrence and distribution of freshwater fish within the OSRS and VRS are summarised in Table 2.2.

Table 2.3 provides a summary of the value of the freshwater fish species that are found in the OSRS and VRS for commercial, recreational and subsistence fisheries with notes on the species' conservation status.

Table 2.2: Historic distribution records of fish in the Orange-Senqu River and Vaal River Systems.

Family	Species	In	En	Es	Al	Skelton (1986)[1] HWO	Skelton (1986)[2] UOSR&CR	Skelton (1986)[3] MORS	Skelton (1986)[4] VRS	Benade (1993)[5] ORS	O'Brien (2010)[6] VRS	O'Brien (2010)[7] ORS	Wepener *et al.*(2011)[8] VRS	Ramollo (2011)[9] MORS & LORS	Avenant (2012)[10] ORS&CR	Dlomo & O'Brien[11] (2012) VRS
Cyprinidae	*Labeobarbus aeneus*		X				X	X	X	X	X	X	X	X	X	X
	Labeobarbus kimberleyensis		X				X	X	X	X	X	X	X	X	X	
	Barbus trimaculatus	X						X	?	X	X	X	X	X		X
	Barbus paludinosus	X						X	X	X	X	X	X	X		X
	Barbus hospes		X							X				X		
	Barbus anoplus	X					X	X	X	X				X	X	X
	Barbus pallidus	X					X		X							X
	Labeo capensis		X				X	X	X	X	X	X	X	X	X	X
	Labeo umbratus	X					X	X	X	X	X	X	X	X	X	X
	Pseudobarbus quathlambae		X			X				X						
	Mesobola brevianalis	X								X				X		
	Cyprinus carpio				X		X	X	X	X	X	X	X	X	X	X
	Ctenopharyngodon idella				X							X	X			
Austroglanididae	*Austroglanis sclateri*		X			X	X	X	X	X	X		X	X		X
Clariidae	*Clarias gariepinus*	X					X	X	X	X	X	X	X	X	X	X
Anguillidae	*Anguilla mossambica*	X					?	?	?	X						
Cichlidae	*Oreochromis mossambicus*■				X					X	X			X		
	Tilapia sparrmanii	X					X	X	X	X	X	X	X	X	X	X
	Pseudocrenilabrus philander	X						X	?	X	X	X	X	X	X	X
Salmonidae	*Oncorhynchus mykiss*				X	X	X			X					X	
	Salmo trutta				X	X	X			X						
Centrarchidae	*Micropterus salmoides*				X		X		X?	X			X		X	X
	Lepomis macrochirus				X		X		X?	X						
Poeciliidae	*Gambusia affinis*				X								X	X	X	X
Sparidae	*Lithognathus lithognathus*			X						X						
Sciaenidae	*Argyrosomus hololepidotus*			X						X						
Mugilidae	*Liza richardsonii*			X						X						
	Mugil cephalus			X						X						
Clinidae	*Clinus* spp.			X						X						
Total spp.		**10**	**6**	**5**	**8**	**4**	**14**	**12**	**11**	**26**	**12**	**11**	**14**	**16**	**12**	**14**

Key to Table 2.2

In: Indigenous to southern Africa
En: Endemic to the Orange-Senqu River and Vaal River Systems
Es: Estuarine species whose distribution is limited to the Orange-Senqu River mouth/estuary
Al: Alien species
▪ Although indigenous to some parts of southern Africa the natural distribution range of *O. mossambicus* does not include the Orange-Senqu River and Vaal River Systems.

[1]: Head waters of Orange-Senqu River in Lesotho
[2]: Upper Orange-Senqu River and Caledon River
[3]: Middle Orange-Senqu River System
[4]: Vaal River System
[5]: Occurring in Orange-Senqu River within the borders of former Cape Province (including the river mouth where it enters the Atlantic Ocean) and Lesotho. Sampling was done with gill and seine nets and an electro-fisher.
[6]: Based on sampling at three sites in the Vaal River System using gill, cast, seine and fyke nets as well as an electro-fisher and long lines.
[7]: Based on sampling at two sites in the Orange-Senqu River System using same gear as in 6.
[8]: Based on sampling in four regions in the Vaal River between Vaal Dam and Vaal Barrage. No mention is made of sampling gear.
[9]: Based on sampling done at seven sites in the Middle and Lower Orange-Senqu River System. Sampling was done with an electro-fisher and a seine net.
[10]: Based on sampling done at 23 predetermined sites in the Upper Orange Water Management Area in the following tributaries: Oranje, Caledon, Riet and Modder Rivers. Sampling was done with seine and cast nets and an electro-fisher.
[11]: Based on sampling done at 33 predetermined sites in the Vaal River System and the following tributaries: Ash, Klip, Kromelmboog, Leeu, Liebenbergsvlei, Meul, Renoster, Sand, Taaibos, Vaal, Vals, Vet, Wilger and Yster Rivers. Fish were collected with seine, fyke and gill nets and an electro-fisher.

Table 2.3: Value and use (0 – no/none; 1 – significant; 2 – major) of fish species occurring within the Upper Orange-Senqu River Basin and lower Vaal River Basin within the borders of the FSP in terms of commercial fisheries (CF), sport and recreational fisheries (SRF) and subsistence fisheries (SF).

Fish species	CF	SRF	SF	Notes	References
Labeobarbus aeneus	0	1	0	Protected in FSP according to provincial legislation; may catch and keep 10 fish >450 mm/day; catch-and–immediate release for individuals <450 mm; supports multi-million rand yellowfish fly fishing industry in Vaal River estimated at ZAR 133 million.	Personal observations; NCR, 1983; Brand *et al.,* 2009.
Labeobarbus kimberleyensis	0	1	0	Listed as Protected species in South Africa. Targeted by yellowfish fly fishers, but compulsory catch-and-immediate release. Has been listed on the IUCN (2014) Red list of Threatened species as "Near Threatened".	NCR, 1983; NEM:BA, 2004 IUCN, 2014
Barbus paludinosus	0	0	0	Maximum size 150 mm SL. No value as fisheries species.	Bruton *et al.,* 1982;
Barbus anoplus	0	0	0	Maximum size 130 mm TL. No value as fisheries species.	Bruton *et al.,* 1982;
Labeo capensis	1	1	1	Was dominant species in previous commercial fishing catches when gill nets were used, also popular angling species and readily caught on hook and line.	Personal observations
Labeo umbratus	2	0	0	Very seldom caught with hook and line. Previous commercial fishing catches were dominated by this species especially when gill nets were used.	Personal observations; Skelton, 1993
Cyprinus carpio	2	2	2	Alien species that has invaded all aquatic systems and spread throughout the FSP. Dominated commercial catches when seine nets were used. Preferred angling species by bank and recreational anglers and table fish for subsistence fishers.	Personal observations
Ctenopharyngodon idella	0	1	0	Currently spreading and invading large parts of the Wilger River and main stem of VRS. Becoming important part of recreational catches in Vaal and Bloemhof Dams.	Personal observations
Carassius auratus	0	0	0	Only recorded in Modder River and Krugersdrift Dam in very low numbers.	Personal observations
Austroglanis sclateri	0	0	0	Current occurrence and distribution unknown. Catch-and–release recommended by FS DESTEA. Seldom caught by recreational anglers.	Personal observations; Skelton, 1987 and 1993
Clarias gariepinus	2	2	2	Wide spread throughout the FSP and important species for all fishery sectors.	Personal observations; Skelton, 1993
Tilapia sparrmanii	0	0	0	Maximum size 200 mm TL; 230 mm SL. No value as fisheries species.	Bruton *et al.,* 1982; Skelton, 1993
Pseudocrenilabrus philander	0	0	0	Maximum size 130 mm TL. No value as fisheries species.	Bruton *et al.,* 1982; Skelton, 1993
Oncorhynchus mykiss	0	1	0	Distribution limited to only a few localities in mountainous eastern Free State. Targeted by fly fishers at mostly trout still waters at lodges.	Personal observations
Salmo trutta	0	1	0	Distribution limited to only a few localities in mountainous eastern Free State. Targeted by fly fishers at mostly trout still waters at lodges.	Personal observations
Micropterus salmoides	0	1	0	Distribution limited to a few large impoundments (Knellpoort, Sterkfontein, Bloemhoek and Erfenis Dam) and especially farms dams. Spreading in OSRB. Targeted mostly by artificial lure anglers.	Personal observations
Gambusia affinis	0	0	0	Maximum size 60 mm TL. No value as fisheries species.	Skelton, 1993

The literature review has revealed a wealth of knowledge on the historic and recent records on the occurrence, distribution and relative abundance of freshwater fish species within the main stems of the OSRS, VRS and some tributaries. It also revealed the limited knowledge available on fish stocks in impoundments in the Upper OSRB and lower VRB and at impoundments throughout South Africa in general. For the FSP this will, however, be addressed in the current study.

2.8 Fish stocking at impoundments in the Free State Province

During 1958, 500 black bass, presumably *M. salmoides* that were bred by and donated by the former Cape Nature Conservation, were stocked in the Allemanskraal Dam. On 28 August 1965, approximately 20 000 *C. carpio* fingerlings donated by the former Transvaal Provincial Administration were also released into the dam (Willem Pretorius Game Reserve Management Plan, [WPGRMP] (2011).

During 1973, 4 000 *O. mykiss* were released into Sterkfontein Dam (Le Roux, 1975). This were followed by more stockings during December 1981 (Dörgeloh, 1986) and February 1984 when 36 000 *O. mykiss* were introduced by the former Orange Free State Directorate of Nature and Environmental Conservation (Dörgeloh, 1995). Sterkfontein Dam lie at a high altitude (1 750 m) in the mountainous eastern Free State and has a very small catchment with very limited natural inflow. This impoundment is part of a major inter-basin water transfer scheme where water is pump over the escarpment from the Upper Tugela River in Kwazulu Natal. Before water enters Sterkfontein Dam, it is pumped into Driekloof Dam situated in the upper reaches of Sterkfontein Dam and when Driekloof Dam is at full capacity, cleaner water overflows into Sterkfontein Dam.

The decrease in catches of popular angling species at Koppies Dam during the middle 1980's, especially that of *C. carpio*, was attributed to the negative impact of the commercial fishery that operated there. Due to pressure from anglers, during 1987, 25 000 *C. carpio* fingerlings were stocked in the impoundment (Barkhuizen, 1993d).

During 1994, an unknown number of *L. kimberleyensis* that were artificially spawned at the former Gariep Dam State Fish Hatchery, were introduced into Sterkfontein Dam and during 2007 it was reported that a specimen in excess of 4 kg was caught (De Villiers, 2007b).

2.9 Overview of the biology, ecology and distribution of fish species in the Orange-Senqu River Basin

2.9.1 Endemic species

Six fish species are endemic to the Orange-Senqu and Vaal River Systems, namely *L. aeneus, L. kimberleyensis*, *L. capensis, B. hospes*, the Maluti minnow *Pseudobarbus quathlambae* (Barnard, 1938) and *A. sclateri.* The ecology and biology of *L. aeneus* and *L. capensis*, which are two of the six important fishery species in the FSP, are summarised in Table 2.4, while the distribution range of *B. hospes* and *P. quathlambae* does not fall within the current study area.

The largemouth yellowfish *Labeobarbus kimberleyensis*

Adults of *L. kimberleyensis* are mostly piscivorous while juveniles feed on a wide variety of aquatic organisms (Bruton *et al.,* 1982; Mulder, 1969; Mulder, 1973a; Kotze, 2002; De Villiers, 2007b). The largest specimen recorded weighed 22.2 kg at 825 mm FL (Skelton, 1993), while Jubb (1972) reported on a dead specimen of 27.5 kg that was found after a severe flood in 1915 at the confluence of the Orange and Caledon Rivers. This species is listed on the IUCN Red list under the category “Near Threatened” (IUCN, 2014) and has also been listed as a protected species in South Africa under the category “Protected species” (NEM:BA, 2004). Concerns regarding the poor catches of this species in parts of the VRS were already raised during 1956 (Mulder, 1969) and during the 1960’s (Mulder, 1971; Mulder, 1973a).

As the largest cyprinid fish in South Africa, *L. kimberleyensis* prefers lotic systems with clear water with a gravel or sand bottom (Mulder, 1973a; Skelton, 1993; Kotze, 2002; De Villiers, 2007b). Tomasson and Allanson (1983) noted that the species spawns after the first spring floods, but that low water temperatures have a negative impact on spawning, the rate of growth and survival of juveniles. Females can carry up to 60 000 eggs which hatch after two to three days and juveniles grow very slowly only reaching 100 mm FL after two years and 300 mm after five years (Skelton, 1993). Kotze (2002) noted spawning to take place from mid to late summer in lotic systems and that eggs hatch within two to three days.

Males are sexual mature at six years (350 mm) and females only at eight years (460 mm) (Mulder, 1973a; Skelton, 1993; Kotze, 2002). Benade (1993) estimated the size at sexual maturity at 430 mm and 500 mm for males and females respectively. The author further attributed the low numbers of this species in the OSRS to the highly regulated nature of the system as well as activities within the system's catchment causing a decline in water quality.

Noting the small sample size of *L. kimberleyensis* collected in Gariep Dam, Ellender (2008) and Ellender *et al.* (2012) proposed a maximum age of 17 years at 690 mm FL for a male caught, which confirms with studies of Mulder (1973a) and Tomasson and Allanson (1983). Kotze (2002) noted the maximum age for the species at 12 years. According to Ellender (2008), sexual maturity in males is reached at 337 mm at an estimated age of four years, and 390 mm in females at an age of six years. Mulder (1971) found that males reached sexual maturity at six years and females at eight years while De Villiers (2007b) noted that females of this species are sexually mature at 450 mm at an approximate age of eight years.

Due to the slow growth rate and reaching sexual maturity at a late stage and longer life span than most other cyprinids, various authors (e.g. Mulder, 1971; 1973a; De Villiers, 2007b; Ellender, 2008; Ellender *et al.,* 2012) motivated for the continuous conservation and protection of this species and highlighted this species' vulnerability. Mulder (1971) reported on an experiment done during 1969 when *L. aeneus* eggs were fertilised with sperm from *L. kimberleyensis,* indicating the possibility of hybridisation of the species in nature.

The rock catlet *Austroglanis sclateri*

According to Jubb (1967), *A. sclateri*, which is viewed as an omnivore, occurs widely in the OSRS, but its distribution is limited to rocky areas in lotic systems (Kotze, 2002). Hamman (1974) noted the decline in the numbers of *A. sclateri* caught during surveys done from 1972 until 1973 in the Hendrik Verwoerd Dam (Gariep Dam) and attributed this to the flooding of rocky areas, lack of streams and the depositing of silt and mud which destroyed the preferred habitat of this species. Bruton *et al.* (1982) observed that this species, that can attain a maximum length of 300 mm, prefer rocky areas where it feeds on aquatic invertebrates. The authors also noted the absence of this species in large impoundments.

The conservation status of *A. sclateri* was listed as "Rare – Indeterminate" during 1987 in the South African Red Data Book for fishes (Skelton, 1987). The lack of information for this species was attributed due to its specific habitat requirements and because it was seldom caught by anglers and during fish surveys. Skelton (1987) listed the major threats to the future survival of the species, notably the construction of impoundments, large-scale water abstraction and siltation of the preferred habitats of the species due to soil erosion in the catchments of rivers. Benade (1993) only sampled six specimens in the OSRS and noted that this species might have specific habitat requirements with regard to substrate (rocks/sand/gravel) and specific water quality parameters. Swartz *et al.* (2007) noted the lack of information on the occurrence, distribution, population size and relative abundance of the species in the OSRS and because of the decrease in water quality, the species might have become extinct in certain parts of the VRS.

2.9.2 Indigenous species

The following indigenous species have been recorded in the OSR and VRS, namely *L. umbratus, C. gariepinus,* two cichlid species *T. sparrmanii* and *P. philander,* and three minnow species *B. anoplus, B. paludinosus* and *B. trimaculatus.* The two cichlid species and three minnow species, due to their smaller size and maximum attainable length, have no importance for inland fisheries in South Africa or the FSP. Skelton (1986) and Benade (1993) speculated on the presence of long fin eel *Anguilla mossambica* Peters, 1852 in the

OSRS, while Marshall (1972) reported on two *A. mossambica* that were caught by anglers in 1945 at the confluence of the Tierpoort and Riet Rivers in the FSP. More recently during 2011, one specimen of approximately 450 mm was caught below the dam wall at Gariep Dam.

The ecology and biology of *L. umbratus* and *C. gariepinus* are summarised in Table 2.4.

The banded tilapia *Tilapia sparrmanii* and southern mouthbrooder *Pseudocrenilabrus philander*

Obtaining a maximum length of 200 mm and been an omnivore, *T. sparrmanii* has a wide distribution range throughout central and southern Africa (Bruton *et. al.,* 1982). Being common in parts of the VRS, this species was introduced during 1964 to the higher parts of the Caledon River (Jubb, 1972). Being monogamous, breeding starts during spring when eggs are fertilised and some level of parental care is present (Jubb, 1967; Le Roux and Steyn, 1968). Multiple spawning takes place per season (Le Roux and Steyn, 1968). Benade (1993) noted the species' preference for pools and backwaters of rivers with limited flow and ample aquatic vegetation for cover (Skelton, 1986; Kotze, 2002).

The only indigenous mouthbrooder, the predatory *P. philander*, is wide spread within the OSRB (Skelton, 1986). Occurring in a wide variety of habitats, the species has a preference for areas with aquatic vegetation (Jubb, 1967; Kotze, 2002). Being multiple spawners, males excavate a nest and lures females to the nest where the eggs are laid (Skelton, 1986). The eggs are incubated within the female's mouth where the fry is released after two weeks (Bruton *et al.,* 1982; Skelton, 1986). A maximum age of four to five years is estimated for the species (Kotze, 2002).

2.9.3 Alien and invasive species

A detailed report was provided by Hey (1944) on the initial importation of *S. trutta* and *O. mykiss*, and other alien fish species to the Jonkershoek hatchery in the former Cape of Good Hope (Western Cape). The importation of most of the alien and invasive species was based on the assumption that there were no suitable indigenous angling species present in the rivers and streams. Hey (1944) further provided in-depth reports on the first introductions of *M. salmoides*, *M. dolomieu*, *L. macrochirus* and mosquito fish *Gambusia affinis* (Baird and Girard, 1853) to Jonkershoek hatchery, from where it was spread to the other three former provinces in South Africa, Rhodesia (Zimbabwe) and South West Africa (Namibia).

Bruton and Merron (1985) produced the first comprehensive overview and list of alien and translocated aquatic animals in southern Africa and noted the detrimental effects especially alien and translocated fish species (approximately 69% of the total alien and translocated aquatic species) can have on aquatic systems and indigenous biodiversity. On the other hand, certain sectors like recreational angling, commercial fisheries and aquaculture have benefitted from these introductions. The work of Bruton and Merron (1985) was followed by a more comprehensive and in depth review on alien and translocated indigenous aquatic organisms by De Moor and Bruton (1988).

De Moor and Bruton (1988) discussed the reasons for the introduction of alien and translocated fish species and noted it was mostly for the purpose of aquaculture, sport and recreational fishing, fodder fish for alien and invasive fish species, intentional stockings and spread, through inter-basin water transfer schemes, the pet trade and for use in bio-control programmes. Coke (1988) observed an increased interest in conserving the indigenous fish species in South Africa that started during the 1980's and noted that the earlier settlers viewed the indigenous fish species of South Africa as of no value for angling or as food and table fish.

Reporting on an intensive literature review on the current knowledge, risk and ecological impacts associated with alien fish introductions in South Africa, Ellender and Weyl (2014) mentioned that of the 55 introduced species in South Africa, 27 species are alien and 28 translocated species. Ellender and Weyl (2014) noted that of the 44 species that were able to become established, 37% were deemed as fully invasive species. Of the fully invasive species, 55% were imported for recreational purposes, 15% due to inter-basin water transfer schemes, 15% for bio-control, 10% for the ornamental pet trade and 5% for fish farming (Ellender and Weyl, 2014).

The common carp *Cyprinus carpio* and grass carp *Ctenopharyngodon idella*

Originally introduced to the Cape Province in 1896 (Jubb, 1967), *C. carpio* is today the most wide spread alien and invasive species throughout most of southern Africa and has been declared a pest species in many countries around the globe (Skelton, 1993; Kotze 2002). As early as 1944 concerns were raised about the detrimental effect *C. carpio* can have on the aquatic organisms and systems into which it was imported (Hey, 1944). The ecology and biology of *C. carpio* are summarised in Table 2.4.

Indigenous to the Amur region in Asia (De Moor and Bruton, 1988), the alien and invasive grass carp *Ctenopharyngodon idella* (Valenciennes, 1844) was originally imported to South Africa during 1967 and 1975 as a bio-control agent for aquatic weeds in impoundments (Schoonbee *et al.*, 1978; Skelton, 1993). It was thought that this species will not be able to breed naturally within the aquatic systems in South Africa due to the species' specific breeding requirements (Schoonbee *et al.,* 1978; De Moor and Bruton, 1988; Skelton, 1993). Unfortunately this species has now invaded the upper reaches of the VRS and has spread as far as Bloemhof Dam and the lower VRS.

Due to the invasive nature of this species, currently only sterile triploid *C. idella* is allowed to be stocked as part of bio-control programmes in South Africa (South African National Grass Carp Policy, 2004) and only in isolated ponds and small impoundments. This species seems to have the same life strategies as common carp, i.e. preference for lentic systems, very fast growth rate, high fecundity, early maturation and ability to adapt to a wide range of aquatic habitats. Due to the fact that juveniles and adults feed exclusively on aquatic plants which serves as shelter for a variety of other aquatic organisms, the species may have a detrimental effect on aquatic systems in areas it invade.

Largemouth black bass *Micropterus salmoides*

Preferring clear water and adapting well to lentic systems, *M. salmoides,* which is indigenous to North America, has a wide distribution range in southern Africa (Bruton *et al.,* 1982). Wasserman *et al.* (2011) noted that the species has invaded various aquatic systems in South Africa where it has become invasive and established, posing a threat to the natural biodiversity. Juveniles of the species feed mostly on insects while adults prey predominantly of fish and frogs (Kotze, 2002). The species was first introduced during 1928 into the former Cape Province and subsequently in 1952 to Natal from where it rapidly spread (De Moor and Bruton, 1988). Breeding in shallow water, the male guards the nest where more than one female may deposit her eggs (De Moor and Bruton, 1988). Females reach sexual maturity at two years, producing up to 5 000 eggs (Le Roux and Steyn, 1968). This species is a very popular game fish and has been released, in some cases legally, but mostly illegally, by farmers and artificial lure anglers into water systems in the FSP. Jubb (1972) noted the introduction of *M. dolomieu* into lentic systems in the middle OSRS, but no confirmed records of this species presence in the OSRB could be found.

The rainbow trout *Oncorhynchus mykiss* and brown trout *Salmo trutta*

Predatory *O. mykiss*, indigenous to the western parts of the United States and Canada, was first introduced into South Africa during 1897 (De Moor and Bruton, 1988). Since then it has spread throughout South Africa, but its distribution is mostly limited to the head waters and colder streams in the mountainous areas in the country. Also a predator, *S. trutta*, with its natural range in Europe and western Asia, was first introduced to the Cape in 1892 for mostly fly fishing purposes from where it was spread to similar areas as for *O. mykiss* (De Moor and Bruton, 1988). Both trout species' distribution range within the Upper OSRB and lower VRB is limited to a few trout lodges in the mountainous eastern Free State, notably in the Clarens and Fouriesburg areas, and the upper reaches of the OSRS in Lesotho. During extensive work at Gariep Dam during 1972 and 1973, Hamman (1974) sampled 13 *O. mykiss*, but noted that some specimens were in a bad condition with six specimens with no food in their stomachs, while the stomach content of the rest consisted mostly of zooplankton.

Table 2.4: Summary of the ecology, biology and life strategies of the important fisheries species occurring in the Orange-Senqu River Basin within the borders of the FSP.

	Labeobarbus aeneus	*Labeo capensis*	*Labeo umbratus*	*Cyprinus carpio*	*Clarias gariepinus*
Maximum age	15 years[4,10,11]; 12 years[12, 20]; Males – 19 years, females 16 years[27];	12 years[4, 20]; eight to nine years[13,26];	Five to six years[13,26];	20 years[5]; Three to 28 years[28];	Eight years or longer[13,26];
Maximum length	Males – 427 mm, females – 496 mm[12]; 500 mm[13];	500 mm TL[5,13]; Males:370 – 400 mm, females: 400 – 450 mm[3];	500 mm TL[5,13];	438 – 1 037 mm FL[28];	1.4 m[5,13];
Maximum weight	7.8 kg[5,13,]; 9 kg[14, 29];	3 kg[5]; 3.8 kg[13];	2.8 kg[5,13];	36 kg[5];	59 kg[5,13];
Preferred habitat	Lotic and lentic[5]; prefer lotic systems with clear water[13,26];	Lotic and lentic with rocks[5]; Large flowing rivers and impoundments[26];	Lentic[2,5,13,26];	Lentic [4,26,]	Lentic[5];
Food preference	Bottom feeder, feeding on aquatic organisms and plants[4]; water fleas to small fish[5]; juveniles prefer zooplankton and invertebrates, adults more herbivorous[6,7]; Omnivore[22, 26]; Macrophytes, zooplankton, zoobenthos[25];	Bottom feeder, feeding on algae and detritus[5,26]; specialised bottom feeders scraping algae form rocks[16]; Bottom feeder, feeding on plant detritus[21]; Diatoms, algae and plant rests[22];	Bentic algae, zooplankton and detritus[1,2,5,13,26]; Bottom feeder[4];	Bottom feeder, causing water to become turbid; feed on aquatic organisms and vegetation; omnivore[1,4,5,15,22,26]; Benthos[16];	Omnivore and scavenger[1,5,13,26]; prefers animal matter[4]; bottom feeder – insects, detritus and fish[16]; carnivorous, becoming piscivorous with increase size[18]; Zoobenthos, zooplankton, micronekton[25];
Growth rate	Slow, ±120 mm/year [4]	Fast: 80 – 90 mm SL in year one[13]; Rapid[26];	Fast – 100 mm in year 1[13]; Rapid[26];	Fast[13;] Rapid[26];	Rapidly[5,29] ; 200 mm TL in year one[13];
Age at sexual maturity	Males – four years, females – five years[6]; Late maturity[10,11]; Seven years at 300 mm[14]; 100% sexual maturity at 5 years[20]; Males: five to six years, females: six to seven years[24]; Males at 254 mm at three years, females at 375 mm at five years[27];	Early[13]; four years, 100% sexual maturity at five years[20]; Males – four years, females five years[22]; Males: five to six years, females: six to seven years[24];	Three years[4]; two to three years[13]; Males – three years, females – four years[22]; Males: four years, females: five years[24];	Two years[3,22]; Males: four years, females: four to five years[24]; One to > 5+ years[28];	Two years[8,22]; one to two years[13,26];

Table 2.4: (cont.): Ecology, biology and life strategies of main fishery species.

	Labeobarbus aeneus	*Labeo capensis*	*Labeo umbratus*	*Cyprinus carpio*	*Clarias gariepinus*
Length at sexual maturity	Males – 300 mm, females 390 mm[9]; males – 200 mm SL, females – 240 SL mm[13,26]; 285 mm FL, 100% sexual maturity – 330 mm FL[20]; Males – 280 mm, females – 340 mm[22]; Males: 260 – 300 mm, females: 310 – 350 mm[24];	Males: 330 – 350 mm, females: 370 – 400 mm[18]; 244 mm FL[20]; 100% sexual maturity – 300 mm FL; Females – 320 mm, males 260 mm[3]; Males – 260 mm, females – 310 mm[22]; Males: 260 – 300 mm, females: 310 – 350 mm[24];	Males – 150 mm SL, females – 250 SL mm[13]; males: 330 – 350 mm, females: 370 – 400 mm[18]; Females: 340 – 370 mm, males 320 mm[3]; Males – 220 mm, females – 350 mm[22]; Males: 260 – 300 mm, females: 310 – 350 mm[24];	Males – 300 mm, females – 350 mm[22]; Males: 260 – 200 mm, females: 310 – 350 mm[24]; 273 – 420 mm[28];	Males – 790 TL mm, females – 720 TL mm; Males - 820 mm, females – 740 mm[18]; Males – 440 mm, females – 460 mm[22]; Males: 460 – 600 mm, females: 410 – 450 mm[24];
▪ **Number of eggs**	300 mm FL – 6 000; 500 mm FL – 60 000[13]; 350 mm – 7 500, 400 mm – 11 700, 450 mm – 18 300[18]; On average 15 278[3]; 420 mm – 29 000, 510 mm – 37 000[22]; 350 mm – 7 429, 450 mm – 18 272, 550 mm – 44 943[24]; 410 mm – 33 063, 450 mm – 41 621, 500 mm – 24781[25];	200 000[4]; 350 mm – 47 000, 400 mm – 110 000, 450 mm – 257 000[18]; On average 133 475[3]; 315 mm – 63 000, 485 mm – 277 000[22]; 350 mm – 46 945, 400 mm – 109 834, 450 mm – 256 972[24]; 360 mm – 68 492, 400 mm – 85 111[25];	40 000 – 173 000[2]; 300 000[4]; 250 000[13]; 2 kg female – 600 000[19]; On average 173 592[3]; 304 mm – 29 000, 453 mm – 225 000[22]; 350 mm – 37 404, 400 mm – 87 513, 450 mm – 204 750[24]; 410 mm – 175 063, 450 mm – 199 649, 470 mm – 430 649[25];	2 kg female – 400 000[15]; 7.5 kg female – 2 million[15] 2 kg female – 600 000[19]; On average 509 353[3]; 423 mm – 198 000, 608 mm – 819 000[22]; 400 mm – 157 641, 500 mm – 287 240, 600 mm – 523 385[24];	800 mm – 110 000[18]; On average 50 173[3]; 485 mm – 38 000, 818 mm – 93 000[22;] 450 mm – 38 500, 900 mm – 74 400[23]; 450 mm – 24 854, 850 mm – 82 519, 1 200 mm – 235 812[24]; 650 mm – 19 650, 700 mm – 49 099, 760 mm – 99 064[25];
Eggs detach or attach to substrate	Loose amongst rocks/gravel[1,4]		Semi-attach to flooded vegetation and substrate[5,13];	Attach to submerged vegetation[13],[15,26]	Attach to submerged vegetation with adhesive disk[1];
▫**Time until eggs hatch**	Two to five days[8]; Three to eight days[13,26];	Three to four days[13]; 48 hours[18]; 30 hours[22];	40h[13,26]; 48 hours[18];	Four to eight days[13,26]; Three to six days[15]	36h[1]; 25 to 40h[13,26]; 24h[18];
Mono or multi spawner per season	May spawn intermittently between October and February[14]; once per season[17]	Once per season[18];	Once per season[18]; Four spawning seasons per year[3];		Once per season[18];

Table 2.4: (cont.): Ecology, biology and life strategies of main fishery species.

	Labeobarbus aeneus	***Labeo capensis***	***Labeo umbratus***	***Cyprinus carpio***	***Clarias gariepinus***
Required habitat for spawning	Well oxygenated water in lotic systems with gravel beds[1,5];	Shallow rocky lotic areas[13]; floodplains[18];	Lentic systems and pools[1]; floodplains[5,18];	Submerged plants in littoral zone [4,22,26]	Flooded vegetated littoral zones[1,26];

References

[1] - Jubb (1967); [2] – Marshall (1972); [3] – Göldner (1967); [4] - Le Roux and Steyn (1968); [5] - Bruton *et al.* (1982); [6] – Mulder (1973a); [7] – Eccles (1983); [8] – Skelton (1986); [9] – Benade (1983); [10] – Hamman (1981); [11] – Tomasson and Allanson (1983); [12] – Ellender (2008); [13] – Skelton (1993); [14] – De Villiers (2007a); [15] – De Moor and Bruton (1988); [16] – Hart *et al.* (1983); [17] – Tomasson *et al.* (1983); [18] – Tomasson *et al.* (1985); [19] – Fouché (1988); [20] – Nthimo (2000); [21] – Baird (1971); [22] – Mulder (1971; 1973b); [23] – Batchelor (1974); [24] – Hamman (1981); [25] - Dörgeloh (1986); [26] – Kotze (2002); [27] – Gerber *et al.* (2012); [28] - Winker *et al.* (2011); [29] – Jubb (1972).

Abbreviations:

SL = standard length; FL = fork length; TL = total length

▪ Number of eggs dependent on size and age of female
▫ Time until eggs hatch, dependent on water temperature

2.10 Defining inland and small-scale fisheries

Defining current stakeholders is an important aspect of fisheries management. The National Policy for small-scale fishing in the marine sector of DAFF (2012) defines small-scale fishing as: *"Means the use of marine living resources on a full-time, part-time or seasonal basis in order to ensure food and livelihood security"*. Small-scale fishers are defined as: *"Means persons that fish to meet food and basic livelihood needs, or are directly involved in harvesting / processing or marketing of fish, traditionally operate on or near shore fishing grounds, predominantly employ traditional low technology or passive fishing gear, usually undertake single day trips, and are engaged in the sale or barter or are involved in commercial activity"*. (DAFF, 2012; p. iv and v).

As with marine fisheries, inland fisheries can also be divided into three sectors, namely commercial, recreational and subsistence fisheries. Weyl *et al.* (2007) define the different inland fishery sectors as: <u>Community-managed subsistence fishery</u>: *"This type of fishery is managed by a local community to maximise sustainable yield, food security and employment. The harvest is primarily consumed locally and excess may be sold"* (Weyl *et al.,* 2007; p. 2 – 3); *"A <u>commercial fishery</u> is operated by a private individual who is granted access at provincial level to harvest a pre-determined yield from a dam. The enterprise is profit-oriented, striving to minimise production costs and to maximise efficiency in production"* (Weyl *et al.,* 2007; p. 3). *"In a <u>recreational fishery</u> the resource is used exclusively for recreation by anglers using hook and line. Users are neither dependent on the resource for survival, nor for economic gain"* (Weyl *et al.,* 2007; p. 3).

The report by the World Bank (2008) noted that due to the diverse and differences in dynamics between the different fisheries sectors, there is no "one-fit-all" definition for "small-scale" fisheries. Different countries, due to their local context may decide what is deemed as small and large-scale fisheries. The World Bank (2008) defined an artisanal and subsistence fishery and recreational fishing as: "*An <u>artisanal fishery</u> is commonly used when describing a traditional fishery"* (World Bank, 2008; p. 6). This term has been used interchangeably to refer to small-scale fishery and is thus not deemed to refer to any specific type of fishery. *"A <u>subsistence fishery</u> is a fishery where the fish caught are shared and consumed directly by the families and kins of the fishers rather than being bought by middle–*

(wo)men and sold at the next larger market" (World Bank, 2008; p. 6). *"Recreational fishing, also called sport fishing, is fishing for pleasure or competition, with a possible second objective to catch fish for own consumption"* (World Bank, 2008; p.6).

Ellender (2008) defined subsistence and recreational fishers at Gariep Dam as: *"Lake Gariep subsistence fishers are individuals that live on or near the lake, use basic transport methods to access the lake (walk, bicycle, and lift), predominantly use artisanal type gear (handlines), and the primary motivation to fish is as a source of food. A subsistence fisher is an individual who is reliant on the resource as a primary or supplementary source of income"* (Ellender, 2008; p. 61 – 62). *"Recreational anglers utilise the resource primarily for leisure purposes but may sell some of their catch. They access the resource by vehicle and sometimes lift; they have permanent employment, use high technology gear, and may consume or sell a portion of their catch"* (Ellender, 2008; p. 62).

In the proposed global Code of Practise for recreational fisheries, Arlinghaus *et al.* (2010) defined recreational fishing as: *"Recreational fishing is fishing of aquatic animals that do not constitute the individual's primary resource to meet nutritional needs and are not generally sold or otherwise traded on export, domestic or black markets"* (Arlinghaus *et al.,* 2010; p. 149).

Britz *et al.* (2015) highlighted the lack of information in the published literature on small-scale fishing and fisheries at impoundments in South Africa, and noted that in many instances small-scale fishing were done by poor, unemployed people in rural areas who used it as an adaptive strategy in response to deteriorating economic conditions. The authors further highlighted the major economic contribution of the recreational fishery sector and estimated that more than 1.5 million anglers are involved in this sector in South Africa.

Therefore, it can be concluded that the main social and economic needs addressed through subsistence fisheries and by subsistence fishermen, is "survival". Recreational fisheries and angling can be broken down into different sectors from bank angling to fly fishing, but the main focus and social aspect been satisfied by this type of fisheries is "leisure", while a small portion may be kept for own use or may be sold. The focus of commercial fisheries is "profit" with a view of making money, but keeping costs low.

The different fisheries sectors are well defined and the literature review has highlighted the lack of knowledge with regards to the three fisheries sectors in South Africa and the FSP. Although many studies were done on recreational fisheries and angling during the 1950's and 1970's, the focus was mostly on the former Transvaal Province.

2.11 Importance of small-scale and inland fisheries

In the former homeland areas during the Apartheid regime in South Africa, freshwater fish and aquaculture were seen as a means of creating jobs and providing the rural poor with a source of protein and income (Batchelor, 1988; Andrew *et al.*, 2000; Britz *et el.,* 2015)**.** Batchelor (1988) provided an overview of fisheries development in the former homelands in South Africa and highlighted the lack of information on catches as a major challenge. According to Batchelor (1988), during 1984, 469 tons of fish were harvested from impoundments in the former Orange Free State Province and the author commented on the sound administrative procedures and management guidelines that were in place in the Province during that time.

With limited development of inland fisheries in South Africa pre-1994, inland fisheries were a major activity in various countries on the continent of Africa as shown by a study of Henderson and Welcomme (1974). The authors reported on the total number of fishermen and their catches at 31 lakes throughout the continent of Africa. Crul (1992) noted the economical importance of inland waters in Africa in providing food for millions. De Silva (1988) provided a detail overview of the fisheries in man-made impoundments in Sri Lanka which was mainly based on the harvesting of alien *O. mossambicus*. The annual inland fisheries yield was estimated between 27 000 and 30 000 tons with the potential yield of the impoundments estimated between 283 to 305 kg ha^{-1} year^{-1} (De Silva, 1988).

Marshall and Maes (1994) did a major study on the small water bodies and their potential for the development of inland fisheries in the 11 countries that are part of the Southern African Development Community (SADC). The authors noted the previous lack of management and development of inland fisheries, but highlighted the new interest given to this sector because of the decline in freshwater and marine fish stocks due to overexploitation. According to reports of the FAO on inland fisheries in southern Africa, the total potential fish yield from inland fisheries in South Africa was estimated at 2 300 tons y^{-1} (Marshall and Maes, 1994). Weyl (2012) provided an optimistic, albeit unrealistic, maximum yield of 15 000 tons y^{-1} based on a yield of 50 kg h^{-1} from all of South Africa's 3 000 km^2 of inland water surface area.

More recently, Sarch and Allison (2000) reported on the importance of Africa's inland fisheries as a source of protein for millions, while also creating work and an income for the rural poor. Allan *et al.* (2005) noted that of the total catch of 8.7 million tons from inland fisheries during 2002, 65% of fish were caught in Asia, 24% in Africa, and 4% in South America while Europe, the USSR, North America and Oceania contributed less than 7%. In seven large river basins in West and Central Africa, an estimated 227 000 people are full time involved in fishing with an estimated catch of 570 000 tons y^{-1}. It is estimated that in the whole of Africa more than 10 million people are supported by inland fisheries (NEPAD, 2014).

Hossain *et al.* (2006) attributed the continuous decline in inland fisheries catches that threaten the livelihoods of nearly 12 million subsistence fishers in Bangladesh, on the government's policies of open access and leasing. With the increase in population and free access to inland waters, more pressure was put on already heavily exploited fish resources that threatened the sustainability of the fisheries resources.

The World Bank (2008) noted that the small-scale fisheries provided work for between 25 to 27 million people on a full or part time basis and that another 68 to 70 million people are involved in post-harvesting activities. Welcomme *et al.* (2010) reported that during 2008 more than 10 million tons of fish were caught globally in inland waters. The authors highlighted the different external and internal drivers that regulate inland fisheries. They also noted that the real impact of this sector may be much higher as anticipated due to the fact that many catches from informal subsistence fishers are not reported on because of a lack of management and policy guidelines. Welcomme *et al.* (2010) noted that inland fisheries in Africa and Asia are heavily exploited, mostly by the poor for food, and that these small-scale fisheries might be under threat due to over-exploitation. The inland fisheries sector in the Americas, the northern and southern temperate zones seems to move more towards an increase in recreational angling without the focus on providing food (Welcomme *et al.,* 2010).

In contrast to inland subsistence fisheries in South Africa, Schmidt (2005) reported that there are approximately 30 000 subsistence fishermen that are dependent on marine fish for their livelihoods around the South African coast, while another 3 500 small-scale fishermen also utilise this resource. Schmidt (2005) further noted the challenges faced by the marine subsistence fishers in terms of obtaining permits, excessive permit fees and expensive equipment, their previous exclusion from obtaining fishing rights during the Apartheid era in South Africa, and the general problems associated with ownership and access to fishing resources.

The study by Andrew *et al.* (2000) on the establishment of small-scale fisheries in the Fish River and impoundments in the Eastern Cape Province based on the use of long lines to target *C. gariepinus* and gill nets to target *L. umbratus*, has shown the positive impact such fisheries can have in rural areas. Andrew *et al.* (2000) noted that the fisheries had the potential to make an approximate profit of over ZAR50 000 per annum (based on *L. umbratus* sold at ZAR4 and *C. gariepinus* sold at ZAR25 per fish), but the authors highlighted the need for the continuous involvement of the implementers and facilitators of fishery projects to ensure sustainability and for further capacity building amongst the local fishermen.

Doing an assessment on recreational and subsistence fisheries in Gariep Dam, Ellender *et al.* (2010a) found that 67% of the fishermen were subsistence anglers, the rest been recreational anglers. The total annual catch per year was estimated at 71.4 ton, while 7.5 tons per year was harvested by recreational anglers during angling competitions.

The importance on inland fisheries in the livelihoods of millions of people in the developing world is clear, but the extent to which inland fisheries will be able to develop in South Africa is an open question. This is especially important due to the fact that freshwater fish were never a main part in the diet of most people in South Africa, especially in the FSP.

2.12 Recreational fisheries

Recreational fisheries are major social and recreational activities for millions (Cooke and Cowx, 2004; Arlinghaus *et al.,* 2010; Cowx *et al.,* 2010). Cooke and Cowx (2004) estimated the global number of people involved in recreational angling on 700 million, while Arlinghaus *et al.* (2013) estimates that 140 million people in North America, Europe and Oceania are involved in this sector. Unfortunately recreational fisheries and angling have lead to the spread of large numbers of alien and invasive species. Cambray (2003) highlighted the extent and range of threats these sought after alien species had on the indigenous biodiversity and endemic fish species. Cooke and Cowx (2004) also argued that recreational fishing can have a considerable negative impact on fish stocks and fisheries and that conservation agencies worldwide need to recognise the extent thereof.

Globally, Cowx *et al.* (2010) noted that with the increase in industrialisation there is a general decline in commercial fisheries and that inland impoundments are used more by recreational anglers and fisheries. Arlinghaus *et al.* (2013) called for a more interdisciplinary approach with regard to research in recreational fisheries as most research on this sector so far has focussed on the human aspect or ecology of the fisheries. By focusing on the interactions between the human and ecological aspects of recreational fisheries, will improve the understanding how recreational fisheries will react to social and ecological change (Arlinghaus *et al.,* 2013).

Marshall and Maes (1994) and Welcomme (2011a; 2011b) noted that recreational fishing (angling) is one of the most important types of fishery in South Africa, with Schmidt (2005) estimating that there are more than 500 000 recreational fishermen in the country. There are, however, few published articles on this sector. Cochrane (1987) reporting on a study in the hypertrophic Hartbeespoort Dam, estimated the potential annual average yield by recreational fisheries for *C. carpio* at 449 tons and for *C. gariepinus* at 144 tons. The author noted the popularity of this impoundment as an angling venue due to its proximity to two major urban areas (Pretoria and Johannesburg). Brand *et al.* (2009) reported that the economic value of the fisheries industry focussing on the Orange Vaal River yellowfish species in the middle Vaal River is worth approximately ZAR 133 million. In their study of the trout fly fishing industry in the northern Eastern Cape Province, Du Preez and Lee (2010) found that the trout industry contributes nearly ZAR5.6 million to the local economy of Rhodes, while sustaining employment for 39 community members.

The first overview of recreational fisheries in the former Orange Free State Province was presented by Yates (1963) who noted the limited angling opportunities in the Province due to the seasonal flows of the rivers. Yates (1963) reported the best angling was in the rivers (presumably the OSRS and VRS) on the borders of the province where after rains carp and yellowfish appeared in large numbers. Yates (1963) reported that at Maselspoort Dam near Bloemfontein, the capital of the FSP, anglers caught black bass, yellowfish, carp and sharptooth catfish and noted the presence of the same species as well as trout in impoundments near Bethlehem in the Eastern Free State. With the development of the ORDP, Opperman (1965) noted the vast potential the project had for the development of recreational facilities in the central part of South Africa.

2.13 Conclusion and knowledge gaps

To develop inland fisheries in South Africa to address government's economic and social imperatives requires baseline information, not only of the potential fish species to be harvested, but also of the impoundments and its potential for the establishment and sustainable development of the different inland fishery sectors. In most instances, this baseline information is not available for impoundments within the different provinces in South Africa. Of particular concern is the lack of information on the suitability of, and potential fish yields of impoundments. In the past, limited to no attention was given to the different environmental and morphometric variables at impoundments and how it might impact on fish, fish distribution, production and fisheries.

The former Orange Free State Province was the first in South Africa to allow the commercial harvesting of freshwater fish at 11 impoundments, with most enterprises that failed after a few months or years. Only one impoundment sustained two commercial fishery enterprises for 32 years. The records and catch data of these commercial fisheries have never been reviewed or assessed, mainly because of its inaccessibility. However, during this study most of the catch data and records were found and the first ever provincial assessment of commercial fisheries in the South Africa will be presented. This will provide baseline information and highlight valuable lessons learned.

Although recreational fishing is the dominant fishery sector in the FSP, this sector has never been quantified or assessed on a provincial level and no baseline information exists for this sector in the province with the largest inland water surface area in South Africa. As highlighted by various studies, the recreational sector will have to play an important role and must be included as a role player in the future development of inland fisheries and any national policy development processes. Prior to this study, no information was available on the participation of anglers, composition of anglers' catches and factors driving catch rates of this sector.

With rivers being some of the most threatened ecosystems in the world, many studies as indicated in the literature review, have focussed on the occurrence, distribution and relative abundance of fish species within lotic systems, with limited fish surveys and studies done in impoundments. In the FSP the last provincial fish assessments at impoundments were done 20 years ago. The new interest in the development and promotion of inland fisheries necessitated investigations on the current occurrence, distribution and relative abundance as well as health of stocks at impoundments. For the current study, the 21 most important and largest impoundments in the major tributaries of the OSRS and VRS have been selected as study site. For many of these impoundments, no baseline information is available on fish stocks and the suitability of these impoundments for the establishment of inland fisheries. This study will provide the most recent and updated results and data on the current state of fish stocks, the population and community structure of the most important fisheries species and their potential for use in future inland fisheries.

Commercial fisheries that operated in the FSP mostly used gill and seine nets to harvest fish. Using these gear types required for commercial enterprises to have access to a boat, trailer and vehicles. With the implementation of the South African Maritime Safety Authority's inland water safety guidelines and regulations as from 2002, that required for all skippers to have a Certificate of Competence (skipper license) and that boats must be issued with a Local General Safety Certificate, make it difficult and even impossible for small-scale fishers to establish a small-scale fisheries. During this study, three Dutch type fyke nets were included as sampling gear during the 2013/2014 summer seasons' fish surveys. No literature could be found during this review on the use of fyke nets in small-scale fisheries in the South Africa, although this gear type is being used extensively in other countries. The suitability of this type of gear to be used in small-scale fisheries within the OSRB was thus investigated, providing the first ever concrete results on the effectiveness and suitability of fyke nets in inland fisheries in South Africa.

The study on the assessment of the fish and fisheries at impoundments of the Upper OSRB and lower VRB will address most of the identified research caps as revealed during the literature review and introductory chapter of the thesis and will therefore contribute significantly to the knowledge base of the fishes and inland fisheries in South Africa.

Chapter 3 Review of the physical characteristics of selected impoundments and their suitability for commercial fisheries

3.1 Introduction

A review of the list of registered impoundments in South Africa has revealed that 412 of the 5 030 registered impoundments are within or on the borders of the centrally situated Free State Province (FSP). The different size classes and ownership of the impoundments as well as the total surface area and storage capacity of the 412 registered impoundments are summarised in Table 3.1.

Table 3.1: Summary of the 412 registered impoundments in the Free State Province.

Size	N	Owner						SA (ha)	Average SA (ha)	SC (1 000 m³)	Average SC (1 000 m³)
		W	M	A	O	S	B				
Small	334	11	35	269	7	7	5	5 696.6*	17.1	124 279	372.1
Medium	57	10	20	25	0	2	0	15 260.5*	267.7	246 868	4 331
Large	15	13	1	0	1	0	0	124 636	8 308.1	15 901 201	1 060 080
Not classified	6	0	0	5	0	1	0	84.3	14.1	752	125.3
Total	412	34	56	299	8	10	5	145 677.4*		16 273 100	

(Based on information from the DSO, 2014)

Abbreviations:
SA = surface area; SC = storing capacity; N = total number; W = Department Water and Sanitation (DWS) impoundments; M = municipal impoundments; A = agricultural impoundments – mostly farm dams; O = other impoundments (e.g. industries or mines); S = state impoundments (other than DWS impoundments); B = impoundments belonging to Water Boards.

* Estimates are given as the total surface area in ha for a number of impoundments have not been provided in the DSO (2014) list of registered dams

With the renewed interest for the promotion of inland fisheries, these impoundments and the fishes that they contain are seen as potential resources to address government's economic and developmental objectives (Britz *et al.*, 2015). Despite this interest, little is known about the physical characteristics of these impoundments or their potential for sustaining commercial or small-scale artisanal fisheries (McCafferty *et al*., 2012). There is also a paucity of data on the fish populations, fish communities and potential fish yields from these impoundments because most historic research in the FSP was focused on impoundments located within, or in close proximity of protected areas (Barkhuizen, 1995; 1996).

The focus of this chapter is to provide a qualitative and quantitative overview of impoundments on the OSRS and VRS and their potential for the establishment of commercial fisheries. The impoundments were mostly built to provide water to the municipal, domestic, irrigation, industrial and hydro-power sectors, and as part of inter-basin water transfer schemes. Due to the highly regulated water levels at state impoundments, which is managed and controlled by the Department of Water and Sanitation (DWS) and different Water Users Associations (WUA), the fluctuation of water levels for the period April 2008 to April 2014 will be highlighted for a number of impoundments.

As a result of the lack of available data, the current study uses empirical approaches to provide first estimates of productivity and fisheries suitability for 21 larger impoundments. Due to the absence of fisheries at these impoundments, first estimates of the potential fish yields will be derived by applying empirical approaches that were developed using relationships between morphological and chemical (edaphic) characteristics of water bodies and actual fish yields in a variety of situations. These MEI models, summarised in Chapter 2, are useful for providing first estimates of potential fish yield when no prior data are available. The literature review presented in Chapter 2, summarised indices and models that are available to provide first estimates of the potential fish yield (e.g. Ryder, 1965; Bruwer and Claassens, 1978; Schlesinger and Regier, 1982; Marshall and Maes, 1994). These models, derived from empirical relationships yield highly variable results depending on whether a more conservative or optimistic model was used (e.g. Hamman, 1981; Malan, 1988; Weyl *et al.,* 2007; Ellender, 2008; Fouchè *et al.,* 2013). Ellender (2008) for example estimated the total potential yield for all fish species in Gariep Dam at full supply level at between 412 tons y^{-1} and 2 275 tons y^{-1}, based on the models of Schlesinger and Regier (1982) and Marshall and Maes (1994) respectively. Fouchè *et al.* (2013) conducted a study to determine the fishery potential of Lake Nandoni and estimated the potential fish yield to be between 26.5 kg ha^{-1} y^{-1} and 57.4 kg ha^{-1} $year^{-1}$, using the models of Schlesinger and Regier (1982) and Ryder (1965). As the suitability of these models have not been established for South African temperate reservoirs and to obtain an estimate of the variability inherent in the different approaches, four models will be used: Ryder (1965), Bruwer and Claassens (1978), Schlesinger and Regier (1982) and Marshall and Maes (1994). These results will provide first estimates for potential yields for the 21 impoundments under consideration

3.2 Materials and Methods

Eleven of the 21 selected impoundments were within the borders or in close proximity of provincial nature reserves managed by the Free State Department of Economic, Small Business Development, Tourism and Environmental Affairs (FS DESTEA). The other 10 impoundments are surrounded by or lie next to farm land or land managed by municipalities. An attempt was made to include at least one impoundment in each of the tributaries of the Orange-Senqu River System (OSRS) and Vaal River System (VRS) within the borders of the FSP in the study area and it was achieved with the selection of 21 impoundments for which the localities are indicated in Figure 3.1.

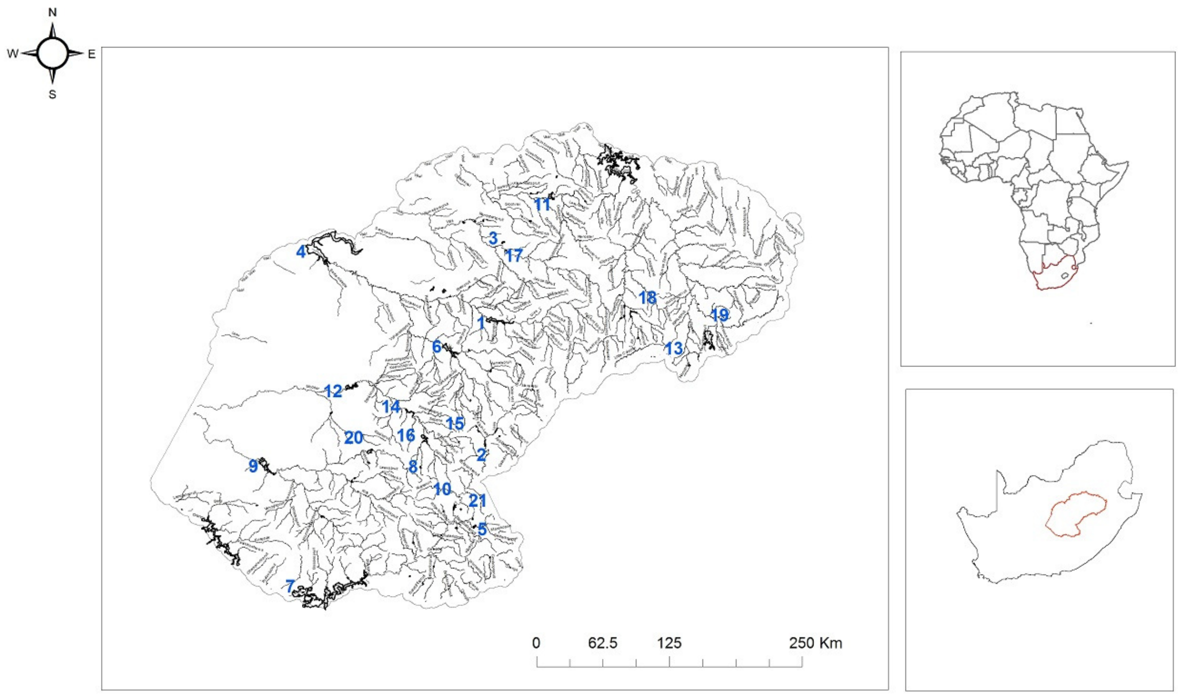


Figure 3.1: Map indicating the locality of the 21 impoundments that were selected as study area (1 – Allemanskraal; 2 – Armenia; 3 - Bloemhoek; 4 – Bloemhof; 5 – Egmont; 6 – Erfenis; 7 – Gariep; 8 – Jimmie Roos; 9 – Kalkfontein; 10 – Knellpoort; 11 – Koppies; 12 – Krugersdrift; 13 – Metsi Matso; 14 – Mockes; 15 – Moutloatsi Setlogelo; 16 – Rustfontein; 17 – Serfontein; 18 – Sol Plaatje; 19 – Sterkfontein; 20 – Tierpoort; 21 – Welbedacht).

3.2.1 Data sources

The 21 impoundments that were selected as study area can be viewed as the most important in providing water for municipal, domestic, irrigation and industrial use in the FSP. Four of the 21 impoundments are part of important inter-basin water transfer schemes. Most of the 21 impoundments are also listed on the webpage of the Hydrology website of the DWS and for which hydrological data are updated on a weekly basis (www.dwa.gov.za).

Data on the environmental and morphometric characteristics and general information on the registered impoundments were obtained from the official website of the Dam Safety Office (DSO) of the DWS (www.dwa.gov.za) and the 2013/2014 annual report of the DSO (DSO, 2014).

Some data on the physical characteristics of impoundments and general information and personal observations used in tables in this chapter were obtained during 41 fish surveys that were done during the 2012/2013 and 2013/2014 summer seasons (see Table 3.2). Water parameters (total dissolved solids [TDS] and electrical conductivity [EC]) used in the formula of the MEI was measured with a hand held Crison MM40+ multi-meter. The GPS coordinates and altitude of the impoundments was determined using a handheld Garmin GPSmap 62. Data on the mean annual air temperature were obtained from the South Africa Weather Service, while data on the monthly average water levels of impoundments were obtained from the Hydrology Section of the DWS (www.dwa.gov.za). A summary of when and how many measurements were done is provided in Table 3.2.

Table 3.2: Time frame of fish surveys done during the 2012/2013 and 2013/2014 summer seasons and number of measurements done.

Impoundment	2012/2013 summer season	Number of sample sites (TDS, EC, GPS)	2013/2014 summer season	Number of sample sites (TDS, EC, GPS)
Allemanskraal	28 – 31 January 2013	27	11 – 13 December 2013	13
Armenia	-	-	20 – 22 January 2014	14
Bloemhoek	-	-	10 – 12 February 2014	15
Bloemhof	18 – 21 February 2013	33	7 – 9 January 2014	15
Egmont	-	-	27 – 29 January 2014	15
Erfenis	21 – 24 January 2013	21	9 – 11 December 2013	13
Gariep	4 – 8 March 2013	33	22 – 24 February 2014	15
Jimmie Roos	-	-	19 – 21 February 2014	15
Kalkfontein	10 – 14 December 2012	20	27 – 29 November 2013	14
Knellpoort	13 – 15 February 2013	18	18 – 20 November 2013	13
Koppies	3 – 7 December 2012	24	2 – 6 December 2013	13
Krugersdrift	26 – 30 November 2012	21	20 – 22 November 2013	14
Metsi Matso	-	-	13 – 15 January 2014	11
Mockes	-	-	17 – 19 February 2014	10
Moutloatsi Setlogelo	5 – 9 November 2012	14	4 – 6 November 2013	12
Rustfontein	19 – 22 November 2012	31	6 – 9 November 2013	16
Serfontein	-	-	12 – 13 February 2014	7
Sol Plaatje	-	-	4 – 6 March 2014	7
Sterkfontein	25 – 28 November 2012	14	17 - 19 December 2013	12
Tierpoort	-	-	25 – 26 November 2013	13
Welbedacht	11 – 12 February 2013	6	-	-

<u>Abbreviations:</u>

TDS = total dissolved solids; EC = electrical conductivity; GPS = global positioning system.

3.2.2 Models and indices used to determine the potential fish yields

Four morphoedaphic models were used to derive first estimates of potential fish yields from chemical and physical data. These were the models proposed by Ryder (1965), Bruwer and Claassens (1978), Schlesinger and Regier (1982) and Marshall and Maes (1994).

The original morphoedaphic (MEI) model as developed by Ryder (1965)

$$MEI = \frac{TDS\ (mg\ \ell^{-1})}{MD\ (m)}$$

where TDS is the total dissolved solids in mg ℓ^{-1} and MD is mean depth of the impoundment in meters.

The adapted MEI model of Bruwer and Claassens (1978)

Due to the higher water temperature of impoundments in South Africa in comparison to those for which Ryder (1965) originally developed the MEI, Bruwer and Claasens (1978) proposed the following model to determine the potential fish yield (Y) in kg ha^{-1} year^{-1}.

$$\text{Y (kg ha}^{-1}\text{ year}^{-1}) = \frac{\sqrt{TDS\ (\text{mg}/\ \ell)\ x\ 28}}{\text{MD (m)}} \text{ x } 1.92$$

where TDS is the total dissolved solids in mg ℓ^{-1} and MD is mean depth of the impoundment in meters.

The more globally applicable temperature adapted MEI model of Schlesinger and Regier (1982)

$$Log_{10}\, Y\,(kg\ ha^{-1}\ year^{-1}) \;=\; 0.044T + 0.482\, Log_{10} \frac{TDS\ (mg\ \ell^{-1})}{MD\ (m)} + 0.021$$

where T is mean annual water temperature (°C), which in the current case study was taken to approximate mean annual air temperature in °C for the period 1994 until 2014 based on the average maximum and average minimum annual air temperature at weather stations situated at, or close to impoundments as provided by the South Africa Weather Service.

The MEI model of Marshall and Maes (1994) as developed for impoundments in Africa

$$Yield\ (kg\ ha^{-1}\ year^{-1}) = 23.281 * \left(\frac{EC}{MD\ (m)} \right)^{0.447}$$

where EC is the mean conductivity measured in µS m^{-2} and MD is mean depth of the impoundment in meters.

3.3 Results

3.3.1 General characteristics of selected impoundments

Of the 21 impoundments that were selected for this study, 11 are classified as medium and 10 as large according to the DSO (2014) list of registered dams. Six of the large impoundments (Allemanskraal, Bloemhof, Gariep, Rustfontein, Sterkfontein and Welbedacht Dams) and three of the medium size impoundments (Koppies, Krugersdrift and Moutloatsi Setlogelo Dams), are surrounded by provincial nature reserves managed by the FS DESTEA, where access to the water surface is controlled. Although only small parts of Erfenis and Kalkfontein Nature Reserves lie adjacent to the similar named impoundments, the water and land surface up to the high water mark is managed by the FS DESTEA. One large (Sol Plaatje Dam) and two medium size (Bloemhoek and Mockes Dams) impoundments are surrounded by municipal and farm land, with mostly open access and limited control. Knellpoort Dam is surrounded by land which is managed by a water board with open access while five of the medium size impoundments (Armenia, Egmont, Jimmie Roos, Serfontein and Tierpoort Dams), are surrounded by farm land with no to limited access to the water. The land adjacent to Metsi Matso Dam is part of tribal land, with open access.

A summary of the general information of the 21 impoundments is provided in Table 3.3 while the physical characteristics of the impoundments are summarised in Table 3.4.

Table 3.3: General information of the 21 impoundments selected for this study. Refer to Figure 3.1. for the locality of the impoundments.

Name of impoundment	No. as in Figure 3.1	Size class	Surrounded by:	Purpose of dam/water					Fisheries			Own.	Water course	OSRS	VRS	Nearest town	Distance from town (km)	* Year comp-leted	Age (No. of years)
				Ir	D	M	I	H	C	R	S								
Allemanskraal	1	L	Willem Pretorius PNR	X					X	X	X	W	Sand River		X	Ventersburg	22	1960	54
Armenia	2	M	Farmland	X	X					X	X	W	Leeu River	X		Hobhouse	18	1954	60
Bloemhoek	3	M	Municipal and farm land			X	X			X	X	M	Jordaan Spruit		X	Kroonstad	3	1995	19
Bloemhof	4	L	Sandveld and Bloemhof PNR	X					X	X	X	W	Vaal & Vet Rivers		X	Bloemhof	1.3	1970	44
Egmont	5	M	Farmland	X						X		W	Wit Spruit	X		Van Standensrus	8	1937	77
Erfenis	6	L	Erfenis PNR and farmland	X					X	X		W	Vet River		X	Theunissen	15	1960	54
Gariep	7	L	Gariep and Oviston PNR	X	X		X	X	X	X	X	W	Orange River	X		Gariep Dam	2	1971	43
Jimmie Roos	8	M	Farmland	X						X		S	Onder-Krom Spruit	X		Dewetsdorp	15	1920	94
Kalkfontein	9	L	Kalkfontein PNR and farmland	X	X				X	X	X	W	Riet River	X		Koffiefontein	23	1938 (1971)	76
Knellpoort	10	L	Water board's land			X	X			X	X	W	Riet Spruit	X		Wepener	15	1989	25
Koppies	11	M	Koppies PNR	X	X				X	X		W	Renoster River		X	Koppies	12	1911 (1969)	103
Krugersdrift	12	M	Soetdoring PNR	X					X	X		W	Modder River	X		Bloemfontein	42	1970	44
Metsi Matso	13	M	Tribal land		X		X			X		W	Metsi Matso River		X	Phuthaditjhaba	18	1976	38
Mockes	14	M	Municipal and farm land			X	X					M	Modder River	X		Bloemfontein	22	1948 (1995)	66
Moutloatsi Setlogelo	15	M	Maria Moroka PNR			X	X			X	X	W	Kgabanyane Spruit	X		Thaba Nchu	7	1981	33
Rustfontein	16	L	Rustfontein PNR		X		X		X	X	X	W	Modder River	X		Bloemfontein	40	1955	59
Serfontein	17	M	Municipal and farm land			X	X			X		M	Vals River		X	Kroonstad	12	1942	72
Sol Plaatje	18	L	Municipal and farm land		X	X				X	X	M	Liebenbergsvlei River		X	Bethlehem	8	1968	46
Sterkfontein	19	L	Sterkfontein PNR		X		X	X		X	X	W	Nuwejaar Spruit		X	Harrismith	16	1980 (1986)	34
Tierpoort	20	M	Farmland	X						X	X	A	Tierpoort River	X		Bloemfontein	35	1923 ■(1990)	91
Welbedacht	21	L	Caledon PNR			X	X					W	Caledon River	X		Wepener	27	1973	41

(Based on information from DSO (2014) and own observations during 2012/2013 and 2013/2014 fish surveys.)

<u>Abbreviations:</u>

L = large; M = medium (size class according to DSO [2014]); PNR = provincial nature reserve; Ir = irrigation; D = domestic; M = municipal; I = industrial; H = hydro-power; C = large-scale commercial fisheries allowed during previous years; R = important for sport and recreational fisheries; S = subsistence fishermen observed at impoundments during 2012/2013 and 2013/2014 summer seasons' fish surveys; W = DWS impoundment; M = municipal impoundment; A = agricultural impoundment; S = state impoundment (other than DWS impoundments); * = year in brackets indicate the year in which the impoundment's wall was raised to increase capacity); ■ = Tierpoort Dam was completely destroyed during the floods of 1988, and rebuild in 1990.

Large-scale commercial fisheries were established during the period 1979 to 2014 at eight of these impoundments, (Allemanskraal, Bloemhof, Erfenis, Gariep, Kalkfontein, Koppies, Krugersdrift and Rustfontein Dams). A historical analysis and synthesis of these commercial fisheries are provided in Chapter 4. Recreational fisheries were observed as an important activity at all the impoundments, except at Mockes, Serfontein and Welbedacht Dams where due to dense riparian vegetation, limited to no access to the water surface exists. Chapter 5 provides an overview of the extent of recreational fisheries at these impoundments. Subsistence fishermen using artisanal fishing gear and that accessed the shoreline and fishing areas on foot or bicycle, were observed at most impoundments, except Egmont, Erfenis, Jimmie Roos, Koppies, Krugersdrift, Metsi Matso, Mockes, Serfontein and Welbedacht Dams.

With an average age of 56 years, the selected impoundments for this study can be viewed as old, with Koppies Dam been the oldest at 103 years and Bloemhoek Dam the youngest at 19 years. Eleven of the selected impoundments are older than 50 years, while three of the younger impoundments (Bloemhoek – 19 years; Knellpoort – 25 years; Sterkfontein – 34 years) were built as part of inter-basin water transfer schemes to augment water supply for municipal and industrial use.

Table 3.4: Summary of the physical characteristics of the 21 impoundments.

Name of impoundment	Surface area (ha)	Capacity (1 000 m³)	Av. depth at FSL (m)	Catchment area (km²)	Latitude	Longitude	Altitude (m)	Wall type	Wall height (m)	Crest length (m)
Allemanskraal	2 667	178 136	6.7	3 628	28°17’17”	27°08’44’	1 361	Earthfill & gravity	37.7	1 347
Armenia	393	13 183	3.4	861	29°21’51”	27°07’44”	1 514	Arch	24	110
Bloemhoek	370	26 400	7.1	66	27°38’50”	27°16’28”	1 366	Earthfill	26	1 251
Bloemhof	23 067	1 269 000	5.5	108 125	27°40’15”	25°37’01”	1 222	Earthfill and gravity	33.7	4 270
Egmont	244	9 784	4	310	30°03’09”	27°01’39”	1 475	Arch	24	107
Erfenis	3 291	212 340	6.5	4 724	28°30’39”	26°46’42”	1 326	Gravity	34	489.2
Gariep	35 216	5 342 932	15.2	70 665	30°37’23”	25°30’23”	1 255	Arch	73	884
Jimmie Roos	115	3 601	3.1	*No data*	29°32’04”	26°35’17”	1 506	Earthfill	9	146
Kalkfontein	3 769	258 274	6.9	10 264	29°29’46”	25°13’18”	1 221	Rockfill	36	317
Knellpoort	977	136 900	14	766	29°46’54”	26°53’19”	1 442	Arch & gravity	50	200
Koppies	1 439	40 000	2.8	2 142	27°15’25”	27°40’22”	1 396	Arch & gravity	25	2 056
Krugersdrift	1 853	66 000	3.6	6 331	28°53’01”	25°57’30”	1 241	Arch & gravity	25	4 956
Metsi Matso	66	4 380	6.6	15	28°35’20”	28°56’17”	1 872	Gravity	22	62
Mockes	147	4 165	2.8	2 968	29°03’04”	26°27’38”	1 306	Earthfill & gravity	15	805
Moutloatsi Setlogelo	250	14 000	5.6	116	29°18’10”	26°50’50”	1 484	Gravity	29	330
Rustfontein	1 159	72 200	6.2	937	29°16’15”	26°36’56”	1 361	Earthfill & gravity	33.4	182
Serfontein	142	4 200	2.9	3 420	27°42’10”	27°18’06”	1 355	Gravity	14	1 480
Sol Plaatje	356	15 676	4.4	*No data*	28°13’02”	28°21’47”	1 673	Earthfill & gravity	19	70
Sterkfontein	6 937	2 616 000	37.7	195	28°23’15”	29°01’01”	1 705	Earthfill	97	3 060
Tierpoort	911	34 000	3.7	922	29°25’18”	26°08’09”	1 376	Earthfill	20	365
Welbedacht	1 018	10 330	1	15 270	29°54’34”	26°51’37”	1 402	Gravity	32	230

Based on information from the DSO (2014) and own observations during 2012/2013 and 2013/2014 fish surveys.

The catchment areas of the three impoundments (Knellpoort – 766 km^2, Sol Plaatje – 195 km^2 and Sterkfontein – 66 km^2) that are part of inter-basin water transfer schemes are in comparison to the other 18 impoundments' catchments, relatively small. The two largest impoundments, Gariep and Bloemhof Dams, have the largest catchment areas of 70 665 and 108 125 km^2, respectively.

The three impoundments in the cooler mountainous eastern parts of the province namely Metsi Matso, Sterkfontein and Sol Plaatje Dams are situated at the highest altitudes at 1 872, 1 705 and 1 673 m, respectively. Four impoundments (Bloemhof, Gariep, Kalkfontein and Krugersdrift Dams) lie at an altitude between 1 201 and 1 300 m, eight impoundments (Allemanskraal, Bloemhoek, Erfenis, Koppies, Mockes, Rustfontein, Serfontein and Tierpoort Dams) lie at an altitude between 1 301 m to 1 400 m, four impoundments (Egmont, Knellpoort, Moutloatsi Setlogelo and Welbedacht Dams) lie at an altitude between 1 401 and 1 500 m, and two impoundments (Armenia and Jimmie Roos Dams) lie at an altitude between 1 501 and 1 600 m above sea level.

3.3.2 First estimates of potential fish yields

The variation of the results of the application of the four different MEIs and models for the 21 impoundments is shown in Table 3.5.

Table 3.5: First estimates of the potential fish yields for the 21 selected impoundments based on the use of four different MEIs and models based on measurements done of TDS, EC and mean annual air temperature during fish surveys.

Name of impoundment	Surface area (ha)	Average depth at FSL (m)	TDS (mg ℓ^{-1})	Mean annual air temp. (°C)	EC (µS m^{-2})	PFY (Ryder, 1965)		PFY (Bruwer & Claasens, 1978)		PFY (Schlesinger and Regier, 1982)		PFY (Marshall and Maes, 1994)	
						kg ha^{-1} y^{-1}	Tons y^{-1}	kg ha^{-1} y^{-1}	Tons y^{-1}	kg ha^{-1} y^{-1}	Tons y^{-1}	kg ha^{-1} y^{-1}	Tons y^{-1}
Allemanskraal	2 667	6.7	154.1	18.3	238.3	22.9	61.3	18.9	50.4	30.4	81	114.9	306.4
Armenia	393	3.4	239.4	15.9	374.1	70.4	27.7	46.2	18.2	40.8	16.1	190.4	74.8
Bloemhoek	370	7.1	213.3	17.2	333.3	30	11.1	20.9	7.7	30.9	11.4	130.1	48.1
Bloemhof	23 067	5.5	458.3	17.8	589.9	83.3	1 922.1	39.5	912.2	53.7	1238.8	188.2	4 341.1
Egmont	244	4	360.2	15.8	237.1	90	21.9	48.2	11.8	45.5	11.1	144.4	35.2
Erfenis	3 291	6.5	170.4	18.3	266.3	26.2	86.3	20.4	67.2	32.4	106.5	122.4	402.8
Gariep	35 216	15.2	76.2	17.2	119.4	5	176.6	5.8	205.5	13	459.2	58.5	2 060
Jimmie Roos	115	3.1	270.1	15.8	421.9	87.1	10	53.9	6.2	44.8	5.2	209.3	24.1
Kalkfontein	3 769	6.9	377.5	16.3	590.9	54.7	206.2	28.6	107.8	37.7	141.9	170.2	641.4
Knellpoort	977	14	105.7	15.8	165.2	7.6	7.4	7.5	7.3	13.8	13.5	70.2	68.6
Koppies	1 439	2.8	308	15.4	481.3	110	158	63.7	91.6	48.1	69.3	232.4	334.4
Krugersdrift	1 853	3.6	383.7	16.6	597.9	106.3	196.9	55.3	102.4	53.5	99	228.8	424
Metsi Matso	66	6.6	13.8	15.1	21.5	2.1	0.1	5.7	0.4	6.9	0.5	39.5	2.6
Mockes	147	2.8	144.9	15.9	226.5	51.8	7.6	43.7	6.4	35.2	5.2	165.9	24.4
Moutloatsi Setlogelo	250	5.6	179.2	15.9	279.4	32	8	24.3	6.1	27.9	6.9	133.7	33.4
Rustfontein	1 159	6.2	169.7	15.9	265.1	27.4	31.7	21.4	24.7	25.9	30	124.8	144.6
Serfontein	142	2.9	79.4	17.2	124.1	27.4	3.9	31.2	4.4	29.6	4.2	124.8	17.7
Sol Plaatje	356	4.4	58.5	14.3	91.4	13.3	4.7	17.7	6.3	15.6	5.5	90.4	32.2
Sterkfontein	6 937	37.7	37.5	15.1	58.6	0.9	6.9	1.7	11.4	4.8	33.6	28.4	199.7
Tierpoort	911	3.7	267.8	16.7	418.3	72.4	65.9	44.9	40.9	44.9	40.9	192.7	175.5
Welbedacht	1 018	1	190.4	15.8	297.5	190.4	193.8	140.2	142.7	65.3	66.5	296.9	302.3

Abbreviations:

FSL – full supply level; TDS – total dissolved solid; EC – electrical conductivity; PFY – potential fish yield.

The main criteria which is used in most of the MEI and models to determine the potential fish yield is the average depth at full supply level. Three impoundments that are part of inter-basin water transfer schemes had the highest mean depth at full supply level, i. e. Sterkfontein Dam – 37.3 m; Knellpoort Dam – 14 m and Bloemhoek Dam – 7.1 m. These impoundments are also the youngest (Bloemhoek Dam – 19 years; Knellpoort Dam – 25 years; Sterkfontein Dam – 34 years). The oldest impoundments have the lowest mean depth at full supply level (Koppies Dam, 103 years – 2.8 m; Jimmie Roos Dam, 94 years – 3.1 m; Tierpoort Dam, 91 years – 3.7 m; Egmont Dam, 77 years – 4 m). Serfontein Dam (72 years – 2.9 m).Welbedacht Dam (41 years – 1 m) has an extremely high silt load which necessitated the building of inter-basin water schemes to augment water supply to urban areas.

A substantial variation in potential fish yields using the four different MEI and models were obtained for each of the 21 impoundments. The very conservative model of Schlesinger and Regier (1982) predicted the lowest potential fish yields, e.g. for Metsi Matso Dam at 0.5 tons per year to 459.2 tons per year for Gariep Dam, the largest impoundment in South Africa. Using the model of Marshall and Maes (1994) provided much more optimistic potential fish yields, e.g. 2.6 tons per year for Metsi Matso Dam and 2 060 tons per year for Gariep Dam.

The results obtained, when using the models and indices of Ryder (1965) and Bruwer and Claassens (1978) were also conservative, but with less significant variations in the predicted potential fish yields when compared to the results when using the model of Marshall and Maes (1994).

3.3.3 Potential of selected impoundments for establishment of commercial fisheries

In order to determine which of the 21 impoundments have the potential for the establishment of commercial fisheries based on the results of the four MEIs and models, the potential fish yields per impoundment were ranked from the highest predicted potential fish yield to the lowest predicted potential fish yield. A score was allocated to each impoundment based on the position in the ranking, with 21 the highest, and one the lowest.

The total scores for each impoundment were then calculated, with a score of 84 indicating the highest potential for establishing commercial fisheries, and 4 the lowest. The results are summarised in Tables 3.6 and 3.7.

Table 3.6: Ranking and scoring of the potential fish yield per impoundment to determine the potential of the impoundment for the establishment of commercial fisheries.

Name of impoundment	Tons y^{-1} (Marshall and Maes, 1994)	Score	Name of impoundment	Tons y^{-1} (Schlesinger and Regier, 1982)	Score	Name of impoundment	Tons y^{-1} (Bruwer and Claassens, 1978)	Score	Name of impoundment	Tons y^{-1} (Ryder, 1965)	Score
Bloemhof	4 341	21	Bloemhof	1 239	21	Bloemhof	912	21	Bloemhof	1 922	21
Gariep	2 060	20	Gariep	459	20	Gariep	206	20	Kalkfontein	206	20
Kalkfontein	641	19	Kalkfontein	142	19	Welbedacht	143	19	Krugersdrift	197	19
Krugersdrift	424	18	Erfenis	107	18	Kalkfontein	108	18	Welbedacht	194	18
Erfenis	403	17	Krugersdrift	99	17	Krugersdrift	102	17	Gariep	177	17
Koppies	334	16	Allemanskraal	81	16	Koppies	92	16	Koppies	158	16
Allemanskraal	306	15	Koppies	69	15	Erfenis	67	15	Erfenis	86	15
Welbedacht	302	14	Welbedacht	67	14	Allemanskraal	50	14	Tierpoort	66	14
Sterkfontein	200	13	Tierpoort	41	13	Tierpoort	41	13	Allemanskraal	61	13
Tierpoort	176	12	Sterkfontein	34	12	Rustfontein	25	12	Rustfontein	32	12
Rustfontein	145	11	Rustfontein	30	11	Armenia	18	11	Armenia	28	11
Armenia	75	10	Armenia	16	10	Egmont	12	10	Egmont	22	10
Knellpoort	69	9	Knellpoort	14	9	Sterkfontein	11	9	Bloemhoek	11	9
Bloemhoek	48	8	Bloemhoek	11	8	Bloemhoek	8	8	Jimmie Roos	10	8
Egmont	35	7	Egmont	11	7	Knellpoort	7	7	Moutloatsi Setlogelo	8	7
Moutloatsi Setlogelo	33	6	Moutloatsi Setlogelo	7	6	Mockes	6	6	Mockes	8	6
Sol Plaatje	32	5	Sol Plaatje	6	5	Sol Plaatje	6	5	Knellpoort	7	5
Mockes	24	4	Mockes	5	4	Jimmie Roos	6	4	Sterkfontein	7	4
Jimmie Roos	24	3	Jimmie Roos	5	3	Moutloatsi Setlogelo	6	3	Sol Plaatje	5	3
Serfontein	18	2	Serfontein	4	2	Serfontein	4	2	Serfontein	4	2
Metsi Matso	3	1	Metsi Matso	1	1	Metsi Matso	0.4	1	Metsi Matso	0.1	1

Table 3.7: Summary of the final scores and ranking of the impoundments with regards to their potential for the establishment of inland commercial fisheries.

Name of impoundment	Final score	Ranking	Comment
Bloemhof	84	1	Only impoundment in FSP that sustained commercial fisheries for more than 32 years.
Gariep	77	2	All seven commercial fisheries for which data were found, failed after a few months or years.
Kalkfontein	76	3	Sustained commercial fisheries for a number of years.
Krugersdrift	71	4	Only when dam level reached critical levels, commercial fisheries were allowed twice for limited periods of time, but with limited success.
Erfenis	65	5	Commercial fisheries failed after two years.
Welbedacht	65	6	Ranking at number six not appropriate as dam is 94% silted up. Due to thick riparian vegetation and extremely high silt load (average depth estimated at 1 m) there is no access to the water surface.
Koppies	63	7	Sustained commercial fisheries for 10 years.
Allemanskraal	58	8	Two fisheries established but both failed after a few weeks.
Tierpoort	52	9	Water level regular drops below to 5% due to over-abstraction of water for irrigation purposes.
Rustfontein	46	10	Commercial fisheries were allowed, but failed after a few years.
Armenia	42	11	Large number of subsistence fishers from nearby community of Thaba Patswa.
Sterkfontein	38	12	Deepest dam in FSP.
Egmont	34	13	Limited recreational fisheries.
Bloemhoek	33	14	Part of water transfer scheme.
Knellpoort	30	15	Part of inter-basin transfer scheme and third deepest of selected impoundments.
Moutloatsi Setlogelo	22	16	Water level decreases rapidly as result of over-abstraction for domestic use.
Mockes	20	17	River channel dam with very dense riparian vegetation and very limited access to water surface.
Sol Plaatje	18	18	Dense riparian vegetation and steep banks prevent access to most of water surface; nearly permanent in- and outflow due to water from Lesotho Highlands Project
Jimmie Roos	18	19	Small dam with small catchment and second oldest of selected impoundments.
Serfontein	8	20	River channel dam with very dense riparian vegetation that prevent access to water surface. High silt load and silted up with limited capacity.
Metsi Matso	4	21	Very small catchment and situated in mountainous area at highest altitude of all selected impoundments.

Based on the ratings of the potential of impoundments for the establishment of commercial and inland fisheries, the two largest impoundments namely Bloemhof and Gariep Dams are placed first and second, respectively. The fact that Bloemhof Dam is rated as number one correlates with the fact that it was also the only impoundment in the FSP that sustained commercial fisheries for 32 years (see Chapter 4). Although ranked number two, the seven commercial fisheries at Gariep Dam, for which data were obtained, failed after a few months or years, and the fact that it is ranked at number two may be attributed to the impoundment's large size and not necessarily the impoundments primary production.

Kalkfontein Dam was the only other impoundment that sustained commercial fisheries for a substantial number of years and is ranked correspondingly at number three. The ranking of Welbedacht Dam at number six may be attributed to the impoundment's shallow mean depth of 1 m due to the high silt load with limited capacity. However, this impoundment is no more suitable for any type of fishery as indicated in Table 3.7.

Impoundments that are part of inter-basin water transfer schemes (Sterkfontein, Bloemhoek, Sol Plaatje and Knellpoort Dams) and impoundments situated at high altitudes (Sterkfontein, Sol Plaatje and Metsi Matso Dams) are ranked within the range of the 10 impoundments with the least potential for the establishment of commercial fisheries, with Metsi Matso Dam ranked the lowest as number 21.

3.3.4 Fluctuation of water levels

Data on the mean monthly water level (expressed as %) for the period April 2008 to April 2014 were obtained from the Hydrology Section of the DWS and these are presented in Figures 3.2 and Figure 3.3. No time series data were available for Bloemhoek, Serfontein, Jimmie Roos and Mockes Dams, while limited data were available for Metsi Matso Dam.

As Kalkfontein and Bloemhof Dams sustained commercial fisheries for the longest period of time, time series data for these two impoundments were obtained for the period April 1979 to March 2014 and these are presented in Figures 3.4 and 3.5.

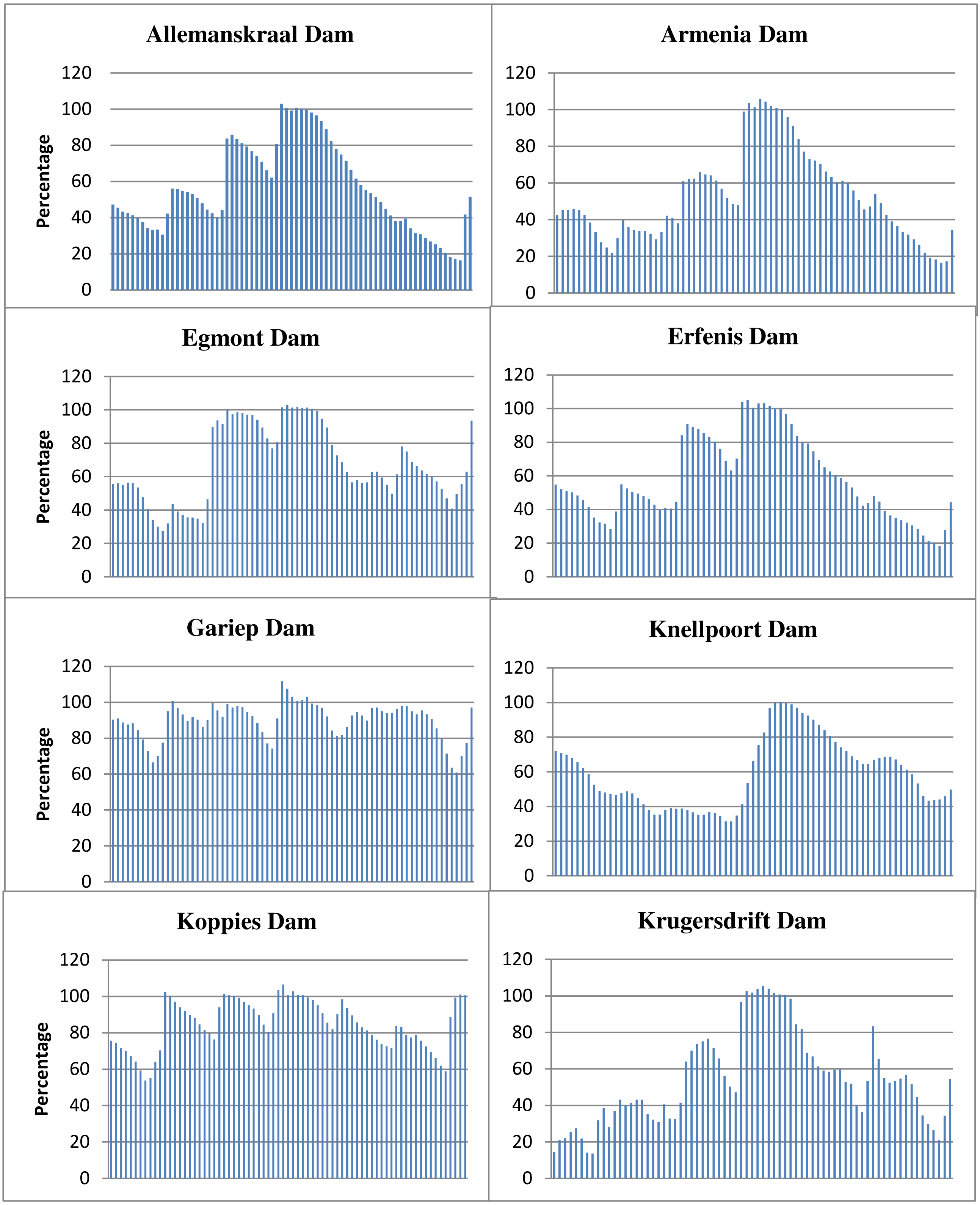


Figure 3.2: Water levels (based on the percent full) for the period April 2008 to March 2014 for Allemanskraal, Armenia, Egmont, Erfenis, Gariep, Knellpoort, Koppies and Krugersdrift Dams.

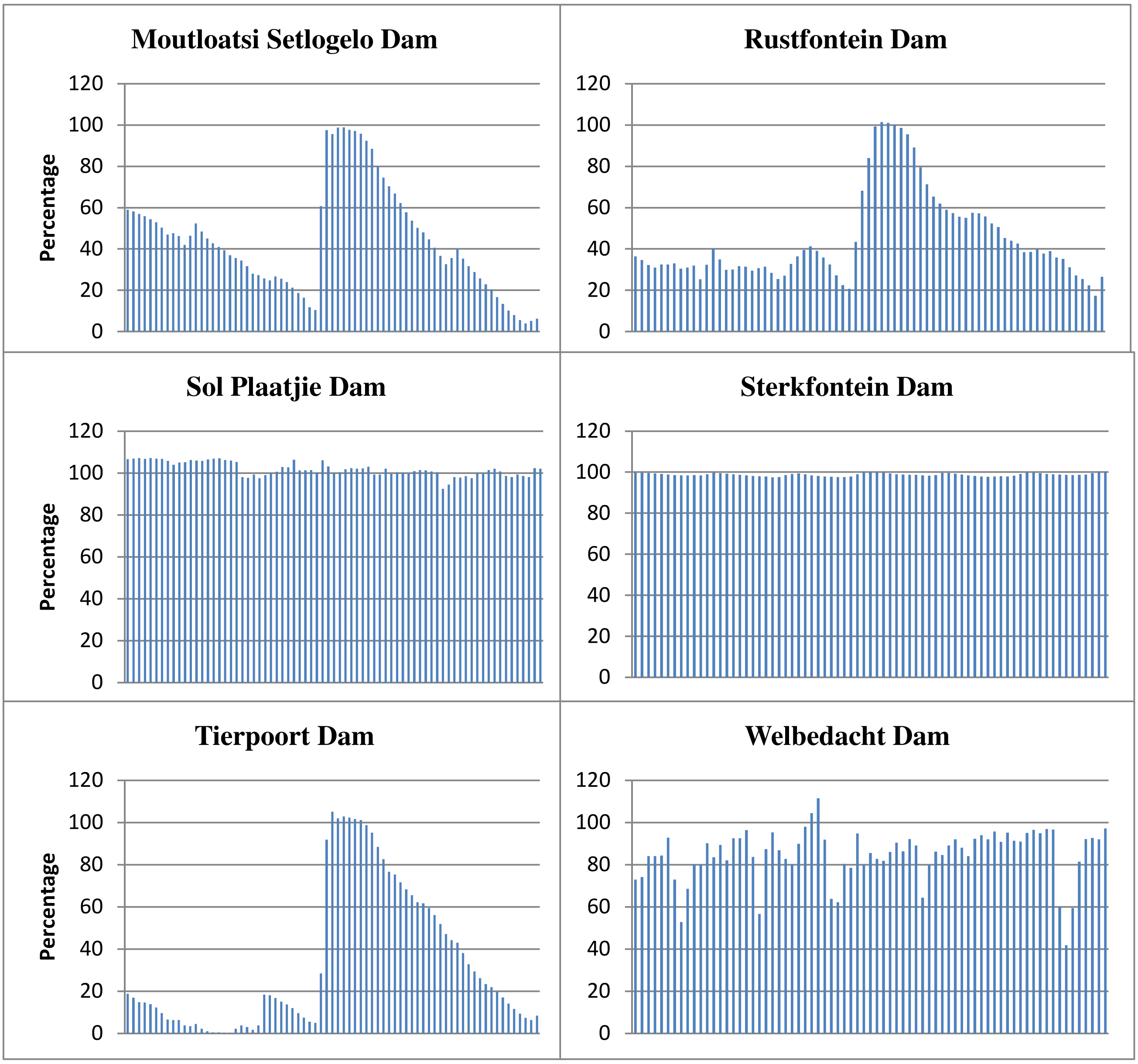


Figure 3.3: Water levels (based on the percent full) for the period of April 2008 to March 2014 for Moutloatsi Setlogelo, Rustfontein, Sol Plaatje, Sterkfontein, Tierpoort and Welbedacht Dams.

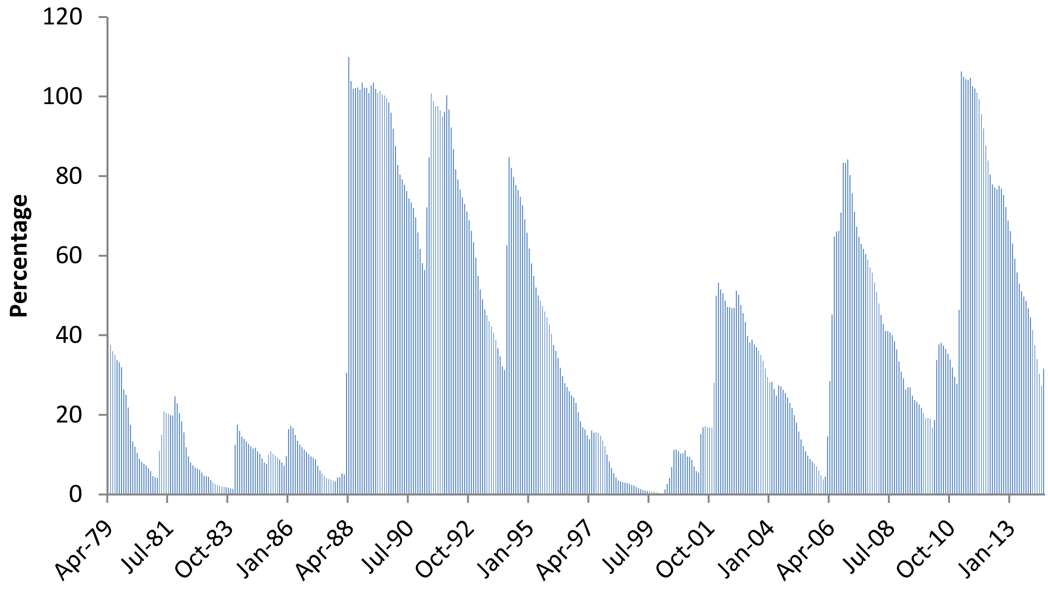


Figure 3.4: Water level (based on the percent full) for the period April 1979 to March 2014 for Kalkfontein Dam.

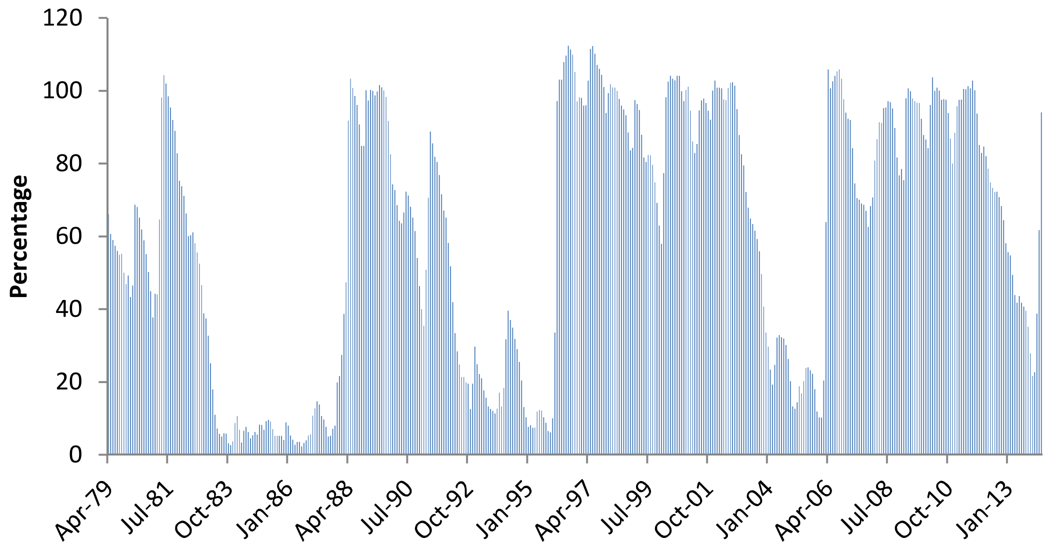


Figure 3.5: Water level (based on the percent full) for the period April 1979 to March 2014 for Bloemhof Dam.

The average water level for the six year period under consideration (April 2008 to March 2014) for the 14 impoundments, and in the case for Kalkfontein and Bloemhof Dams for the period 1 April 1979 until 1 April 2014 and for Metsi Matso Dam for the period February 2011 until January 2014, as well as comments on the trophic status of the impoundments based on personal observations, as well as other important aspects with regards to the water use of the impoundments, are summarised in Table 3.8.

Table 3.8: Average monthly water level for the 21 impoundments for the period April 2008 to April 2014 and the proposed trophic state (* For Kalkfontein and Bloemhof Dams the time data series are April 1979 to April 2014, and Metsi Matso Dam from February 2011 to January 2014).

Impoundment	Average water level (%)	Trophic state based on personal observations since 1993	Personal observations
Allemanskraal	56.3	Meso- to eutrophic in summer	Major erosion in catchment, water with high silt load. Large parts of dam silted up and shallow. Regular algal blooms in summer.
Armenia	52.7	Mesotrophic	Two medium size dams upstream from dam in Leeu River. Water release regulated by Leeu River Water User Association (WUA) for irrigation.
Bloemhoek	*No data*	Mesotrophic	Water transferred from Serfontein Dam situated in Vals River to Bloemhoek Dam (small catchment and limited natural inflow) to ensure water supply for Kroonstad.
Bloemhof	60	Eutrophic to hypereutrophic in summer	Water rich in nutrients, nitrogen and phosphates. Inflow mostly from waste water treatment works in Gauteng. Often untreated sewerage from rural towns, also waste water from mines and industries and irrigation sector. Regular fish kills in mid-summer. Highly regulated and regular release for irrigation downstream.
Egmont	67.5	Mesotrophic	Completely surrounded by sheep and cattle farms. WUA manage water release for irrigation.
Erfenis	58.4	Meso- to eutrophic	Three small dams situated upstream that provides water for Winburg. Regular sewerage spills in catchment.
Gariep	90	Mesotrophic	Highly regulated system due to generation of hydro-power and daily releases as well as water transfer to Eastern Cape via Orange Fish Tunnel. Water level intensely regulated by DWS.
Jimmie Roos	*No data*	Oligotrophic	Completely surrounded by farmland. Owned by agricultural school.
Kalkfontein	37.6	Mesotrophic	Water level drops very fast due to release for irrigation. Water release regulated by WUA but due to unreliable supply of water from dam, irrigation farmers now get water from Orange-Riet Water Scheme.
Knellpoort	59.4	Mesotrophic	Part of inter-basin transfer scheme transferring water from Caledon River above Welbedacht Dam to Knellpoort Dam and via Novo pump scheme over escarpment to upper reaches of Modder River to augment water for Mangaung Metropolitan District Municipality (MMM). Highly regulated.
Koppies	84.9	Mesotrophic	Only large dam in Renoster River. Water level does not show major fluctuations.
Krugersdrift	54.4	Eutrophic to hypereutrophic in summer	Receive treated waste water from MMM, rich in nutrients, nitrogen and phosphates. Regular pollution events and subsequent fish kills. Water level regulated by Modder Riet WUA.
Metsi Matso	96.9	Oligotrophic	Situated high in Drakensberg with small catchment. Fed by springs and rain water.
Mockes	*No data*	Mesotrophic	Water from Caledon River via Knellpoort Dam via Rustfontein Dam reaches Mockes Dam. Water used at water purification plant downstream at Maselspoort for domestic supply for the northern suburbs of Bloemfontein. Highly regulated.
Moutloatsi Setlogelo	44.3	Mesotrophic	Small catchment in dry area. Limited inflow. Water treatment works at dam provide water for domestic use in Thaba Nchu.
Rustfontein	45.1	Meso- to eutrophic	Highly regulated in order to supply water to Mockes Dam for domestic use in Bloemfontein.
Serfontein	*No data*	Mesotrophic	Highly silted with limited capacity, Water transferred to Bloemhoek Dam.
Sol Plaatje	101.9	Oligo- to mesotrophic	Nearly permanent in- and outflow of water due to water from the Lesotho Highlands Water Scheme en route to Vaal Dam for use in Gauteng.
Sterkfontein	98.8	Oligotrophic	Natural inflow limited to two very small natural streams. Part of Vaal Tugela Hydropower Scheme. Receives water from Upper Tugela via Driekloof Dam in upper reaches of dam. “Emergency” reservoir should water be needed in Gauteng.
Tierpoort	33.2	Meso- to eutrophic in summer	Regular dries up. Water level regulated by Tierpoort Irrigation Scheme, independent from government.
Welbedacht	84.9	Oligotrophic	Earlier years provided most of the water for Bloemfontein. Currently nearly 94% silted up.

Data indicate that the water levels of the impoundments fluctuate significantly due to the artificial manipulation of water levels to provide water to various users. The time data series for the period April 1979 to April 2014 for Bloemhof and Kalkfontein Dams, indicate the highly regulated and fluctuating water levels with periods of very low water levels followed by periods when levels increased rapidly with levels reaching over 100%, followed by periods of rapid decrease (see Figures 3.3 and 3.4).

The water levels of Sterkfontein, Sol Plaatje and Metsi Matso Dams, located at high altitudes show the least fluctuation. In addition, impoundments that are part of inter-basin water transfer schemes (Sterkfontein, Sol Plaatje, Rustfontein and Knellpoort Dams) are highly regulated. Although the average water level for Welbedacht Dam for the six year period was above 80%, the impoundment has a very limited capacity due to severe siltation.

The water levels of impoundments supplying water to the irrigation sector (i.e. Allemanskraal, Armenia, Egmont, Erfenis, Krugersdrift and Tierpoort Dams) show significant variations with peaks of water level increase followed by periods of continuous decrease. The sharpest decrease in water level is noticed for Tierpoort Dam. The same pattern is noticed for Moutloatsi Setlogelo Dam, where the water levels decreases on a continuous basis as water is pumped to the water works that provide water to the large urban and rural area of Thaba Nchu.

The water level of South Africa's largest impoundment, Gariep Dam is highly regulated but does not show the rapid increases and decreases as at the other impoundments, with an average level of 90% during the six year period. As the impoundment supply water to the dry Eastern Cape Province via the Orange Fish tunnel and as water is used at the hydro-power pump station below the dam wall, the DWS closely monitors and control the in- and outflow at this impoundment.

The key morphometric, physical and general characteristics, previous and current fisheries at selected impoundments that need to be considered in future fishery developments, as well as potential yield and monetary value of fish resources within impoundments, are summarised in Table 3.9.

Table 3.9: Summary of key morphometric, physical and general characteristics, and previous and current fisheries at selected impoundments that needs to be considered in future fishery developments.

	Impoundments																				
Characteris-tics	**AL**	**AR**	**BK**	**BF**	**EG**	**ER**	**GA**	**JR**	**KF**	**KT**	**KO**	**KR**	**MM**	**MO**	**MS**	**RF**	**SN**	**SP**	**SF**	**TP**	**WB**
C	Yes	No	No	Yes	No	Yes	Yes	No	Yes	No	Yes	Yes	No	No	No	Yes	No	No	No	No	No
R	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No
S	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes	No
NR	Yes	No	No	Yes	No	Yes	Yes	No	Yes	No	Yes	Yes	No	No	Yes	Yes	Y	No	No	No	Yes
FL	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	No	No	Yes	Yes	No	No	No	Yes	Yes	Yes	No
ORS	No	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes
VRS	Yes	No	Yes	Yes	No	Yes	No	No	No	No	Yes	No	Yes	No	No	No	Yes	Yes	Yes	No	No
Age (years)	54	60	19	44	77	54	43	94	76	25	103	44	38	66	33	59	72	46	34	91	41
Size (ha)	2667	393	370	23067	244	3291	35216	115	3769	977	1439	1853	66	147	250	1159	142	356	6937	911	1018
Av. Water level (%)	56	53	N/d	60	68	58	90	N/d	38	59	85	54	97	N/d	44	45	N/d	102	99	33	85
MEI Yield (kg/ha/y)	23 - 30	41 - 70	30 - 31	54 – 83	46 – 90	26 – 32	5 - 13	45 - 87	38 - 55	8 – 14	48 - 110	54 - 106	2 - 17	35 - 52	28 - 32	26 - 27	27 - 30	13 - 16	1 - 5	45 - 72	65 – 190
Potential yield (t/y)	61 - 81	16 - 28	11 - 12	1 239 - 1 922	11 – 22	86 - 107	177 - 459	5 - 10	143 - 207	7 – 14	69 - 158	100 - 196	0.1 - 1	5 - 8	7 - 8	30 - 32	4 - 4	5 - 7	7 - 35	41 - 66	66 – 194
Potential income (ZAR'000)	1 067	280	192	21 683	192	1 505	3 098	88	2 503	123	1 208	1 750	2	88	123	525	70	88	123	718	1 155

Abbreviations and key: AL – Allemanskraal; AR – Armenia; BK – Bloemhoek; BF – Bloemhof; EG – Egmont; ER – Erfenis; GA – Gariep; JR – Jimmie Roos; KF – Kalkfontein; KT – Knellpoort; KO – Koppies; KR – Krugersdrift; MM – Metsi Matso; MO – Mockes; MS – Moutloatsi Setlogelo; RF- Rustfontein; SN – Serfontein; SP – Sol Plaatje; SF – Sterkfontein; TP – Tierpoort; WB – Welbedacht Dams; C – commercial fisheries; R – recreational fisheries; S – subsistence fisheries; NR – Within borders, or adjacent to nature reserve; FL – surrounded by or adjacent to farm land; ORS – Orange River System; VRS – Vaal River System; Age – age of impoundment as on 1 December 2014; Size – surface area in ha; Av. water level – average water level for period 1 April 2008 until 1 April 2014; MEI Yield – range of potential fish yield expressed as kg ha^{-1} y^{-1}, using the MEI and models of Ryder (1965) and Schlesinger and Regier (1982); Potential yield – range of the potential yield expressed as tons y^{-1}, using the MEI and models of Ryder (1965) and Schlesinger and Regier (1982); Potential income – monetary value of the potential yield using the conservative MEI and based on the current selling price of freshwater fish at ZAR17.50 $kg\text{-}^{1}$ in the FSP.

3.4 Discussion

With impoundments with a total water surface of 145 677 ha, the FSP has the largest inland water surface in South Africa. The 21 impoundments selected for this study represent 58% of this water surface and are of extreme importance for irrigation, domestic, municipal and industrial use. In determining fishery suitability it is important to consider the effects of the age, mean depth, catchment area and fluctuation of water levels of impoundments as well as climatic factors on the potential productivity and fish stocks before the establishment of fisheries are to be considered.

For large impoundments in Africa where substantial inland fisheries operate, Jackson and Marmulla (2001) noted fish yields of 27 to 65 kg ha^{-1} y^{-1}. For medium and small size impoundments the authors estimated the average fish yield at 80 kg ha^{-1} $y^{-1}$and 329 kg ha^{-1} y^{-1} respectively. The potential fish yields determined for the 21 impoundments using the MEI and models of Ryder (1965), Bruwer and Claassens (1978) and Marshall and Maes (1994) fall within this range as proposed by Jackson and Marmulla (2001), although none of the commercial fisheries in the FSP were able to achieve such large catches (see Chapter 4). The FSP is situated within the central Highveld of South Africa and within the southern temperate zone, which is characterised by mild to cold winters. In order to determine first estimates of potential fish yields of impoundments, the MEI and models as developed by Ryder (1965) and Schlesinger and Regier (1982) might therefore be more appropriate than models developed in warmer climates.

Baxter (1977) noted that at new impoundments in the temperate regions, there is usually a decline in fish populations after a few years. Baxter (1977) further commented on the three phases in the development of impoundments' ecology as observed in Russia. The first phase is characterised by high productivity, due to benthos feeding on newly submerged and decomposing plant matter. This is followed by a phase of low productivity that may continue for years where no more decaying plant material is available with an increase in the silt load. After the second phase there is a gradual increase in productivity with an increase in plankton that, when it dies and decomposes, forms a new organic layer on the bottom.

Increased siltation that decreases the storage capacity and average depth of impoundments which leads to direct impacts on the littoral zone is the main aging process in impoundments (Miranda, 2001). This is particularly relevant for the OSRS, the most turbid system in Africa (Compton *et al.,* 2010) and the fourth most turbid river in the world (Bremner *et al.,* 1990). As a result, the physical characteristics of the impoundments and water quality parameters will change, while nutrients contained in the silt might become available for primary production (Miranda, 2001). As siltation continues with the aging process and the subsequent increase in nutrients from the silt, there is a shift in the phytoplankton community from green algae to blue-green algae, which may lead to severe algal blooms and decrease in water quality (Miranda, 2001). As this will impact the zooplankton community which does not feed on the blue-green algae, it can lead to an increase of bottom feeding fish species that might be undesirable, while predatory species might disappear.

Another aspect associated with the aging of impoundments is the change of the different shoreline habitats into barren homogenous mudflats (Miranda, 2001) which is already evident at most impoundments in the FSP. This is evident at the impoundments that undergo major fluctuations in water level, e.g. Kalkfontein, Bloemhof, Tierpoort, Moutloatsi Setlogelo, Rustfontein and Krugersdrift Dams. It is therefore likely that even the more conservative yields estimated by temperate models may be overestimates. This will, however, only be possible to demonstrate with the development of fisheries.

Another major consideration is water level fluctuations. Here, as is the case in many other studies (Hamman, 1981; Malan, 1988; Weyl *et al.,* 2007; Ellender, 2008; Fouchè *et al.,* 2013), potential yield estimates are based on surface areas of impoundments at full supply level. Except for a few impoundments situated at high altitudes the water levels of most of the selected impoundments showed significant fluctuations. This has a major impact on the littoral zones that are extensively used by many fish species to forage and spawn. The sudden decrease in water levels during fish species' spawning seasons can lead to the destruction of entire year classes, as eggs and fry can be exposed and destroyed. The water fluctuations may be daily, monthly, seasonal or annual, depending on the purpose for which the impoundment was built (Miranda, 2001).

Due to unpredicted rainfall patterns, flood events and other climatic conditions and demands for water by the different sectors at different times in a year, it is nearly impossible to ensure a constant water level year round at impoundments. Water level fluctuations are therefore unavoidable (Bernacsek, 1984). Bernacsek (1984) argued that water level fluctuations are advantageous from a fishery perspective. As the levels of water regulations and the seasons of peak in and out flows are known, the fluctuation in water levels can be predicted and managed. The fluctuation in water levels for the six year period for 14 impoundments and 35 years for Bloemhof and Kalkfontein Dams have indicated the extent of water level fluctuations which are not predictable and in most cases difficult to manage, especially during drought periods.

As water levels fluctuate, the littoral zones are often exposed for a considerate period of time, providing an opportunity for terrestrial plants to grow that ultimately attract a variety of herbivores. This is most evident at impoundments in the FSP, which are surrounded by protected areas where large herds of especially springbuck *Antidorcas marsupialis* (Zimmermann, 1780) occur. On farmland, these areas are frequented by large herds of domestic cattle and sheep where these herbivores graze and defecate. Bhukaswan, (1980) and Bernacsek, (1984) noted that when these littoral zones are inundated again, nutrients in the faeces contribute to an increase in the productivity of the impoundment.

Bhukaswan (1980) and Miranda (2001) observed that the regulation and subsequent fluctuation in water levels at impoundments have a major impact of fish populations and fish communities. The authors further noted that the timing and degree of water increase and decreases can have major effects on the aquatic systems by entrapping aquatic organisms, destroying the benthos and aquatic plants, impacting on spawning and the destruction of fish's nests and spawning areas. Fluctuating water levels, however, can also contribute positively as indicated by Bhukaswan (1980) and Miranda (2001). The authors noted that the flooding of terrestrial plants when water levels rise, create spawning areas for fish species as well as a new food source for benthic feeders and fry as these plants start to decompose. These areas are mostly frequented by fish fry and fingerlings, which feed on the decomposed plants which in turn release nutrients into the water that stimulates the growth of phytoplankton and the subsequently increase in zooplankton. In the more temperate regions in the world, exposed littoral zones that lie bare for a number of years may, once inundated again, release a substantial amount of nutrients back into the water (Baxter, 1977), thereby enhancing productivity. During periods of droughts when impoundments dry up, most zooplankton species form dormant stages which may survive for years (Dahms, 1995; Arnott and Yan, 2002). When areas are inundated again, these dormant stages will hatch quickly and coupled with an increase in nutrients in the water that will stimulate algal growth, which is the food for many zooplankton species, may further enhance the productivity.

Based on the assessment of the fisheries potential for 425 impoundments in South Africa, Weyl *et al.* (2015) concluded that only 52 are large enough to yield more than 100 ton y^{-1}, while some might have the potential to yield up to 400 ton y^{-1}. For the latter Weyl *et al.* (2015) proposed that only small-scale commercial fisheries would be able to be established. The authors further concluded that at only 29 impoundments in South Africa large-scale commercial fisheries with a potential yield of more than 400 tons y^{-1} can possibly be established. Based on a GIS analysis, Weyl *et al.* (2015) proposed that most productive impoundments are possibly situated in the warmer Limpopo and Mpumalanga Provinces, and the lower lying Eastern and Western Cape Provinces in South Africa.

Weyl *et al.* (2015) listed the following impoundments in the FSP with a potential production of more than 400 tons y^{-1}, namely Gariep, Bloemhof, Sterkfontein and Vaal Dams. Impoundments with a potential production of less than 400 tons y^{-1} are Allemanskraal, Erfenis, Kalkfontein, Krugersdrift and Welbedacht Dams, while no commercial fishery is proposed for Rustfontein Dam. Bloemhof, Gariep and Kalkfontein Dams were ranked as the top three of the 21 selected impoundments, after the scoring and ranking were done based on the predicted fish yields using the four different MEI and models that had the potential for the establishment of commercial fisheries. Large-scale commercial fisheries were established at Allemanskraal, Erfenis, Krugersdrift and Vaal Dams, all of which failed after a few months or years (see Chapter 4), while Welbedacht Dam, due to the extreme high silt load is no more suitable for any type of inland fisheries. Sterkfontein Dam with a total surface of nearly 7 000 ha and mean depth of 38 m is also listed by Weyl *et al*. (2015), but according to the scoring and ranking exercise, falls within the range of the 10 selected impoundments with the least potential for the establishment of commercial fisheries.

3.5 Conclusion

Investigating the physical characteristics of impoundments and determining the potential of impoundments for the establishment of commercial fisheries, requires a multi-facet approach. The local context and conditions, physical and morphometric characteristics of individual impoundments need to be taken into consideration and requires attention before commercial fisheries are established. Essential to this process will be a better understanding of the dynamics of the fish populations in impoundments. The estimates of yield provided here should be seen as only very preliminary estimates and should be applied with caution. To contribute towards better understanding the fish and fisheries in these impoundments, historical data of attempted commercial fisheries were assessed in Chapter 4, sport and recreational fisheries in Chapter 5, and the freshwater fish populations and community structures of fishes in Chapter 6.

Chapter 4 Historical analysis of commercial fisheries in the Free State Province (Upper Orange-Senqu River Basin and lower Vaal River Basin)

4.1 Introduction

With the construction of large reservoirs in the 1960's in South Africa, it was realised that freshwater fish could be harvested on a commercial basis to create employment and to be utilised as a food source (McCafferty *et al.,* 2012). Subsequently various projects were initiated to determine the fisheries potential of impoundments in South Africa (Hamman, 1974; Bruwer and Claasens, 1978; Whitehead, 1978; Koch and Schoonbee, 1980; Hamman, 1981; Allanson and Jackson, 1983; Cochrane, 1987; Marshall and Maes, 1994; Rouhani, 2001; Ellender *et al*., 2009; Fouchè *et al*., 2013). These studies all concluded that impoundments in South Africa, if utilised correctly, could become important contributors to the economy through the development of commercial fisheries. Despite several development attempts after 1970, this sector has, however, shown limited growth (Koch and Schoonbee, 1980; Allanson and Jackson, 1983; Cochrane, 1987) when compared to the rest of Africa and Asia where inland fisheries are well established (McCafferty *et al*., 2012).

With the mandate for the development of inland fisheries and freshwater aquaculture being moved from provincial nature conservation authorities to the national Department of Agriculture, Forestry and Fisheries (DAFF) in May 2009 (McCafferty *et al.,* 2012; Britz *et al.,* 2015) there has been a renewed interest for the promotion and development of commercial fisheries in South Africa. While recreational fisheries are the most important inland fisheries sector in South Africa (Marshall and Maes, 1994; Weyl *et al.,* 2007; Leibold and Van Zyl, 2008; Welcomme, 2011a; 2011b; McCafferty *et al.,* 2012), subsistence participation in fisheries has been growing on certain impoundments (Ellender *et al*., 2009; 2010a; 2010b; Ellender, 2011). This is mostly evident at impoundments in the Free State Province (FSP) where local communities have easy access to the water surface.

The registered impoundments in South Africa are seen as potential sources for the establishment of inland fisheries (McCafferty *et al*., 2012; Hara and Backeberg, 2014; Britz *et al*., 2015). To ensure the success and sustainability of inland fisheries, McCafferty *et al.* (2012) highlighted the need for further research on the socio-economic, biodiversity and management aspects in order to successfully address government's social and economic developmental goals.

McCafferty *et al.* (2012) demonstrated the paucity of literature on inland fisheries in South Africa, noting the lack of data on previous attempts to develop fisheries as a severe bottleneck in understanding the potential of these fisheries for development. In their review, McCafferty *et al*. (2012) mentioned that there is an urgent need to evaluate previous fisheries in order to determine not only the potential fish yields, but also to enable policy makers to make the right decisions with regards to the establishment of inland fisheries. Most important, is to determine the economic viability of these fisheries and assessing the determinants for their success and failures.

The objective of this Chapter was to use available fisheries data to provide a quantitative and qualitative assessment of the commercial fisheries that operated on impoundments in the FSP from 1979 until 2014, in order to provide the first provincial assessment of inland commercial fisheries in South Africa.

4.2 Materials and Methods

4.2.1 Data sources

According to Provincial Legislation (see NCO, 1969; NCR, 1983), people interested in establishing a commercial fishery had to apply for a permit from the former Directorate of Nature and Environmental Conservation (DNEC) and current Free State Department of Economic, Small Business Development, Tourism and Environmental Affairs (FS DESTEA), the environmental managing authority in the Province. All applications were investigated and processed by aquatic scientists who made recommendations to the Permit Evaluation

Committee (PEC), who subsequently approved and issued permits with fishing quotas based on the recommendations from the aquatic scientists employed in the province. All commercial fishing operations were managed and controlled based on the permit conditions which are summarised in Table 4.1. The complete set of conditions of permits for commercial fisheries is presented in Appendix 1.

Table 4.1: Summary of the permit conditions for commercial fisheries in the Free State Province based on Nature Conservation Ordinance No. 8 of 1969 (NCO, 1969).

Aspect	**Notes**
Species	No restrictions on *Labeo capensis, Labeo umbratus* and *Clarias gariepinus* and alien fish species. *Labeobarbus aeneus* and *Labeobarbus kimberleyensis* may not be caught, kept or killed but immediate catch-and-release. When *L. aeneus* and *L. kimberleyensis* were caught or injured, or found dead in nets, operators were allowed to keep it and had to note this on the record forms. Due to the difficulty experienced by fisheries' personnel to distinguish between individuals of *L. aeneus* and *L. kimberleyensis*, catches of the two species were recorded as yellowfish.
Total allowable catch	Annual fish quotas were set by the aquatic scientists of former DNEC and FS DESTEA. Operators had to ensure to not exceed the annual quotas.
Reporting	Daily and monthly record forms had to be completed indicating the total number and weight per fish species. Examples of forms presented in Appendix 2 and 3.
Payments	Annually Provincial Treasury approves the concession fee to be paid per kilogram weight of fish. Ranged from ZAR0.07 kg^{-1} during 1979/1980 to ZAR0.40 kg^{-1} in 2014/2015.
Gear	From 1979 until 2005, gill nets with a stretched mesh size of 100 mm and larger, long lines, electro-fishers and seine nets with a stretched mesh size of 50 mm and larger were allowed. From 2005, only seine nets with a stretched mesh size of 50 mm and larger were allowed.
Boats and vehicles	All skippers must have a valid Certificate of Competence (skipper license). Boats must be issued with Local General Safety Certificate (including Buoyancy Certificate) by the South African Maritime Safety Authority (SAMSA). Drivers of vehicles had to submit copies of their driving licenses to reserve management.
Access	Fisheries and personnel must adhere to all the rules and regulations of provincial nature reserves. Access to water and entrance are controlled by reserve management. Commercial fishing only allowed in areas as zoned by reserve management, and only allowed on weekdays from 06:30 until 17:30. Copies of identity documents of all fishery personnel must be submitted to reserve management. Fishermen must wear identity tags when fishing within the borders of nature reserves.

With the promulgation of the NCO (1969) and NCR (1983) in the former Orange Free State Province, bag limits and size restrictions were put in place for *Labeobarbus aeneus* and *Labeobarbus kimberleyensis*. With the issuing of the first permit for a commercial fishery in 1979 until present, commercial fisheries were and are not allowed to target and catch any of the Orange Vaal River yellowfish species. If any of these species were caught as a by-catch or were injured or found dead in nets, it had to be reported and in instances where too many yellowfish were caught, fisheries were to be stopped. All catches of the yellowfish species in the records of catches are deemed as by-catch and was never allowed to be one of the fisheries' target species.

The permit conditions stipulate that daily catches and monthly summaries had to be captured on prescribed record forms (see Appendixes 2 and 3). Unfortunately there has never been a central database for these records and all raw data were kept in hard copy at the offices of the relevant provincial nature reserves, where the commercial fishing took place. This necessitated a survey of all offices at provincial nature reserves as well as the Permit Office of the FS DESTEA to determine whether data were still available, and if so, to collect the data. Data that were found in hard copy format were subsequently reviewed, processed and entered into MS EXCEL spreadsheets.

4.2.2 Key informant interviews and inspections

Key informant interviews and inspections were done four to six times per year during the period 2011 until the end of December 2014, at the two commercial fisheries that operated at Bloemhof Dam, and at the last remaining community based fishery project at Gariep Dam. On site investigations were done where the fisheries operated while harvesting fish as well as at the two fish processing plants that were situated in Bloemhof in the North West Province and the one at Oviston in the Eastern Cape Province. During these inspections, the permit holders or project beneficiaries were interviewed to determine how the fisheries operated, to obtain historic information on the fishery projects and what problems and challenges they experienced.

Regular interviews were also held with the former and current reserve managers at provincial nature reserves where commercial fisheries operated. This was done to ensure all relevant historical information, data and records of catches were obtained as well as to determine the challenges been experienced by reserve management with regards to the commercial fisheries.

All information obtained during these interviews, inspections and investigations provided the basis for the synthesis of the commercial fisheries that operated at 11 impoundments for the period 1979 until 2014 which is summarised in Table 4.2.

4.2.3 Analysis of data

For Kalkfontein and Bloemhof Dams, the monthly summaries on the total number and total weight for each species caught were compiled based on the daily catch records. Subsequently the annual summaries were compiled using the monthly summaries, while for other impoundments the annual summaries of data that were found in historic internal departmental reports, were used. These data sets and summaries were compiled and entered into tables using MS EXCEL. In order to determine each fish species' contribution to the total catch as well as total weight of the total catch, data are presented in stacked column graphs using MS EXCEL. These are presented in Appendixes 4 until 13.

The original annual allowable fishing quotas made available by the DNEC and FS DESTEA were compared to the actual total annual catch made. No historic records or reports could be found on how the original allowable fishing quotas were determined. Due to the limited success of commercial fisheries, it is the opinion of the author that the original allowable fishing quotas were unrealistic for the majority of the impoundments and that most commercial fisheries would not have been able to attain or sustain the predicted harvests on a continuous basis.

For providing baseline information of the potential fish yields of the seven impoundments for which historical commercial fisheries data were available, the quotas and yields were compared to results of the MEI and models presented in Chapter 3.

4.3 Results

4.3.1 Description of commercial fisheries

A search of records showed that the first commercial fishery project established in the FSP during 1979 obtained fishing quotas of 200 tons per year for Kalkfontein Dam, 500 tons for Gariep Dam and 150 tons each for Rustfontein and Krugersdrift Dams. Thereafter, commercial fisheries were permitted at 11 impoundments. Six of these (Bloemhof, Koppies, Rustfontein, Krugersdrift, Gariep and Allemanskraal Dams) are surrounded by protected areas. At two impoundments (Kalkfontein and Erfenis Dams) only certain sections of the shoreline falls within protected areas. Vaal Dam is managed by the Department of Water and Sanitation, Rhoodepoort Dam is surrounded by farmland, while Witpan lie within the Free State Goldfields.

Preliminary assessments of available data demonstrated that for some impoundments the original daily and monthly record forms and data sets were available, while for others information and records of catches were found in historic internal departmental reports. In the case of Gariep Dam, a lack of administrative control and management of the fisheries resulted in incomplete and limited historic records and data for the seven attempts to develop commercial fisheries on the dam. This was also the case for the seven commercial fisheries that operated at Vaal Dam. The quality of the data was also variable. In the early stages Nature Conservation personnel were generally present when fish landed and data recorded but later, due to personnel shortages, inspections could not be done as regularly as required. As a result the data may well include some discrepancies. As it was difficult to determine causes for missing data, the data used in this chapter are based only on the official daily and monthly records received and reviewed by reserve personnel, and the copies of receipts that were issued after payments were made by the commercial fisheries.

Based on catch data the commercial fisheries that operated at impoundments were categorised as follows:

(i) **Continuous:** commercial fisheries that operated on a continuous basis for more than 20 years at an impoundment;

(ii) **Opportunistic:** commercial fisheries that operated over a substantial period of time with periods when no fishing was done;

(iii) **Failed:** commercial fisheries that lasted only a number of months or years and once stopped no effort were made to re-start the fisheries.

(iv) **Once off:** commercial fisheries that as an emergency measure, removed as many fish as possible over a short period of time to prevent major fish kills due to low water levels of impoundments.

A synthesis of the commercial fisheries that operated at the 11 impoundments for the period 1979 until 2014, highlighting the characteristics of each fishery and how long it operated as well as the category (continuous, opportunistic, failed, once-off), is provided in Table 4.2. The locality of the impoundments where the commercial fisheries operated is presented in Figure 4.1.

Table 4.2: Synthesis of the commercial fisheries that operated at 11 impoundments for the period 1979 until 2014.

Impoundment	**Surface area (ha)**	**Summary of the commercial fisheries**	**Number of operators**	**Annual allowable fish quota (ton y^{-1})**	**Potential fish yield (ton y^{-1})***	**Monitoring data available for:**	**Category of fisheries**
Kalkfontein	3 769	Fisheries started during January 1979. During 1979 and 1982 there were two enterprises. One enterprise fished here from 1982 until 1989, 1993 until 1994, 1997 until 1999, during 2005 and 2009. Fishery was closed temporarily during 1989 due to concerns of the threat it held for the yellowfish (Barkhuizen, 1994a). Total concession fee paid to government for the period 1979 until 2009 was ZAR316 373.59. For more information on the fish species and weight per species caught, equipment used, days fished, CPUE, refer to Appendix 4 and 5.	1 – 2 private enterprises	100 – 450	206 – 641	1979 – 2014	Opportunistic
Bloemhof	23 067	Only impoundment that sustained two commercial fishery enterprises on a continuous basis for 32 years. Most fish caught 1982 until 1997 were salted, dried and exported via Cape Town to countries in central Africa. By 1997 this market collapsed and one fishery cancelled its operations. Immediately afterwards, permit was issued to one of the fishery's employees. Later years, market in central Africa was re-established. One enterprise continued to sell dry and salted fish. Other enterprise sold mostly fresh or frozen fish. Entrepreneurs as far as Polokwane, Limpopo Province and Baberton, Mpumalanga Province regularly travelled to Bloemhof to buy frozen fish, mostly *C. carpio*. This fishery sustained a large number of small businesses where women, (sometimes up to 30 per day), from the local community of Bloemhof on a daily basis came to buy fresh fish which they processed, baked and sold. Due to the non-adherence of permit conditions, both fisheries' permits were cancelled and withdrawn during March 2014. Total concession fee paid by the fisheries for the period 1982 until 2014 to government was ZAR1 440 211.90. For more information on the fish species and weight per species caught, equipment used, days fished, CPUE, refer to Appendix 6, 7, 8 and 9.	2 private enterprises	400	1 922 – 4 341	1982 - 2014	Continuous
Koppies	1 439	Limited historical data were found. Initial annual quota of 50 tons which was later decreased to 25 tons. Regular conflict between commercial fishery and recreational anglers. Decrease in catches of popular angling species, especially *C. carpio*, was attributed to the impact of commercial fishery on the fish populations. Due to pressure from anglers, 25 000 *C. carpio* fingerlings were released during 1987 (Barkhuizen, 1993d). Total concession fee paid to government by the fishery for the period 1982 until 1993 was ZAR20 480.03. For more information on the fish species and weight per species caught, equipment used, refer to Appendix 10 and 11.	1 private enterprise	25 – 50	158 – 334	1982 – 1993	Failed
Rustfontein	1 159	Limited historic data were found. Total concession fee paid to government by the fisheries for the period 1983 until 2000 was ZAR12 713.36. For more information on the fish species and weight per species caught, equipment used, refer to Appendix 12 and 13.	1 private enterprise	50 – 100	31 – 144	1983 – 2000	Failed

Table 4.2 (cont.): Synthesis of commercial fisheries.

Impoundment	Surface area (ha)	Summary of the commercial fisheries	Number of operators	Annual allowable fish quota (ton y^{-1})	Potential fish yield (ton y^{-1})*	Monitoring data available for:	Category of fisheries
Erfenis	3 291	Only 3.3 tons of fish were harvested during a two year period, despite annual quota of 200 tons. Total concession fee paid to government by the fishery for the two year period was ZAR228.66. From 2007 until 2012 a fishing quota of 10 tons per annum was allocated to an enterprise from Odendaalsrus, but no commercial fishery was started.	2 private enterprises	10 – 200	86 – 402	1982 – 1983	Failed
Gariep	35 216	**Refer to section 4.3.4.**	4 private enterprises 3 community based projects	20 – 200	176 – 2 060	1998 – 2013	Failed
Allemanskraal	2 667	Two fisheries were started but both failed within a few weeks. No historic data were found.	2 private enterprises	*No data*	61 – 306	No data found	Failed
Rhoodepoort	80.2	Temporary permit was issued to prevent fish deaths due to critical low water level. No records of catches were found.	1 private enterprise	5	-	No data found	Once off
Krugersdrift	1 853	Water level often reaches critical low levels. To prevent major fish kills on two occasions the commercial fishery that operated at Bloemhof Dam was requested to remove as many fish as possible when the water level reached critical levels.	1 private enterprise	*No quota set*	196 – 424	No data found	Once off
Witpan	-	Commercial fishery at Bloemhof Dam obtained permit to harvest fish. No catch records were found.	1 private enterprise	*No data*	-	No data found	Failed
Vaal	32 275	Although there is no provincial nature reserve near the Vaal Dam and as the DWS is the managing authority, permits were issued by the FS DESTEA. As far as can be determined few of the permit holders actually started fishery projects. Limited records and data were found.	7 private enterprises	1.5 – 200	571 – 3 215	Limited data found	Failed

* The lower values of the MEI are based on the use of the model of Ryder (1965), while the upper values of the MEI is based on the use of the model of Marshall and Maes (1994).

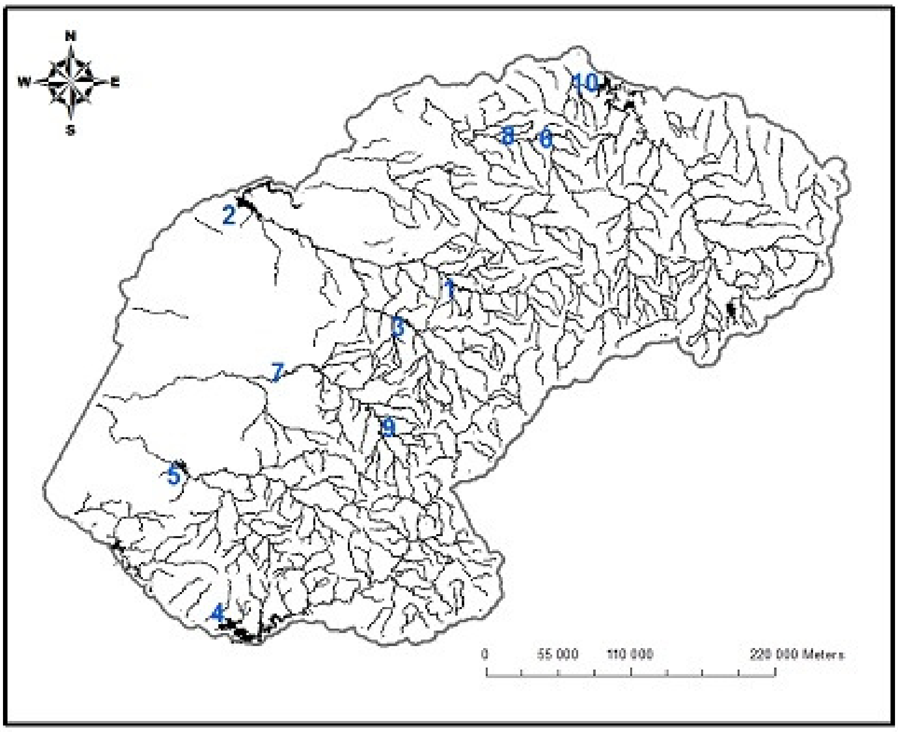


Figure 4.1: Locality of impoundments where commercial fisheries operated in the Free State Province (1 – Allemanskraal; 2 – Bloemhof; 3 – Erfenis; 4 – Gariep; 5 – Kalkfontein; 6 – Koppies; 7 – Krugersdrift; 8 – Rhoodepoort; 9 – Rustfontein; 10 – Vaal Dams). Witpan not indicated as no GPS coordinates were found.

Following initiation, few fisheries were able to meet their quotas. For example the first commercial fishery on four dams was only able to process 35 tons of fish (mostly *Cyprinus carpio* and *Labeo umbratus*) per annum due to the limited capacity of the fish processing plant (Anon., 1982). From 1979 until 1998, commercial fisheries were mostly owned and managed by individuals that provided temporary employment for local people. The first government funded poverty alleviation fishery project was initiated after 1998 at Gariep Dam, with the main focus of providing a source of income and much needed jobs in an area with a high unemployment rate and high levels of poverty. Government provided these projects with all the necessary equipment and materials and in some cases a monthly stipend was paid to project beneficiaries until such time the projects became self sustainable.

Although opportunities for the establishment of inland commercial fisheries at state impoundments were created, only a few individuals benefitted and almost no permanent employment were created. As most of the impoundments in the FSP are surrounded by farm land with limited or no access to the water surface, inland commercial fisheries operated at impoundments where access to the water surface and fish resources were managed and controlled mostly by the former DNEC and the FS DESTEA.

4.3.2 Catch compositions and landings

Landings and catch composition of the commercially important fish species at Kalkfontein, Bloemhof, Koppies, Rustfontein, Erfenis, Gariep and Vaal Dams in terms of weight and numbers is summarised in Tables 4.3 and 4.4, respectively. Table 4.5 provides an overview and summaries of the commercial fisheries catches for the impoundments for which data were available. Table 4.6 provides a summary of the annual combined catches of commercial fisheries at seven impoundments for which data were obtained for the period 1979 until 2014. No data were available for the commercial fisheries that operated at Allemanskraal, Krugersdrift and Rhoodepoort Dams, and Witpan.

The average annual catch, and total catch per ha per year (kg ha^{-1} y^{-1}) compared to the potential fish yields (kg ha^{-1} y^{-1}) as determined when using the MEI of Ryder (1965) and Marshall and Maes (1994) is provided in Table 4.7.

Table 4.3: Fish species' composition of the total catch of commercial fisheries in the Free State Province in South Africa expressed as a % of the total number.

Impoundment	Total catch (number)	*Cyprinus. carpio* (%)	*Labeo capensis* (%)	*Labeo umbratus* (%)	*Clarias gariepinus* (%)	*Labeobarbus* spp. (%)	*Ctenopharyngodon idella* (%)
Kalkfontein	2 009 131	10.3	9.7	79.5	0.3	0.2	-
Bloemhof	4 022 566	47.9	7.9	39.3	3.7	0.5	0.7
Koppies	157 425	3.4	9.9	78.9	7.7	0.1	-
Rustfontein	49 955	10.3	13.4	71.9	3.1	1.3	-
Erfenis	2 892	7.1	41.1	36.4	9.3	6.1	-
Gariep	42 970	36.1	29.6	27.6	6.7	0	-
Vaal	32 344	55	5.6	29.2	9.7	0.5	-

Table 4.4: Fish species' composition to the total catch of commercial fisheries in the Free State Province of South Africa expressed as a % of total weight.

Impoundment	Total catch (tons)	*Cyprinus carpio* (%)	*Labeo capensis* (%)	*Labeo umbratus* (%)	*Clarias gariepinus* (%)	*Labeobarbus* spp. (%)	*Ctenopharyngodon idella* (%)
Kalkfontein	2 042	13.3	8.4	77	1.2	0.1	-
Bloemhof	6 634	58.9	5.3	25.9	8.8	0.4	0.7
Koppies	193	4.8	9.3	68.3	17.5	0.1	-
Rustfontein	51	14.8	12.6	60.2	10.9	1.5	-
Erfenis	3	9.8	34.2	31.4	22	2.6	-
Gariep	49	52.8	16.2	14.3	16.7	0	-
Vaal	65	69.2	2.5	13.9	14.1	0.3	-

The total catch and total weight of the total catch at Bloemhof and Vaal Dams, the two largest impoundments on the main stem of the VRS, and Gariep Dam, the largest impoundment in South Africa that lies on the main stem of the OSRS were dominated by *C. carpio*. The total catch and total weight of the total catch at impoundments situated on the tributaries of Vaal and Orange-Senqu Rivers were mostly dominated by the *Labeo* species with *L. umbratus* been the dominant species at Kalkfontein, Rustfontein and Koppies Dams.

Table 4.5: Overview of the total catches of commercial fisheries for the impoundments for which data were obtained. Refer to Figure 4.1 for the locality of the impoundments.

Impoundment, and number in Figure 4.1 (#)	**Summary of catches**
Kalkfontein (5)	Fishery categorised as "opportunistic". Operational for 16 years during period 1979 until 2009. Total of 2 009 131 fish with total weight of 2 042 tons caught. Catch dominated by *L. umbratus* (79.5%) followed by *C. carpio* (10.3%). Total weight of catch dominated by *L. umbratus* (77%) and *C. carpio* (13.3%). Most fishing done and most fish caught during dry periods when the impoundment's water level < 20%, sometimes reaching critical low levels.
Bloemhof (2)	Since 1982 until 2014, two commercial fishery enterprises. Only fisheries categorised as "continuous". Total catch of 4 022 566 fish was dominated by *C. carpio* (48%) followed by *L. umbratus* (39%). In 32 years, just over 6 600 tons of fish, of which *C. carpio* contributed 59% to the total weight of the total catch, followed by *L. umbratus* at 26%, were caught. Significant number of yellowfish was caught during certain periods. As gill nets were replaced by seine nets since 1998, there was a gradual decrease in the number of yellowfish and *L. capensis* caught. Catches of *L. umbratus* also decreased significantly with the onset of the use of seine nets. With the increase use of seine nets, the annual total catch of *C. carpio* and *C. gariepinus* increased to point that the two species dominated the total annual catches as from 2007. From 2007 *C. idella* became the third most important fisheries species, nearly completely replacing *L. capensis* and *L. umbratus* in the total catch. Due to the evasive nature for fishing gear and bottom dwelling habits of *C. gariepinus*, this species was never caught in large numbers.
Koppies (6)	Original data sets and historic records of fishery that is categorised as "failed" could not be found. Total of 157 425 fish with *L. umbratus* (79% of the total catch) followed by *L. capensis* (10%) were caught. Total weight of total catch was dominated by *L. umbratus* (68%) and *C. gariepinus* (7%). From 1982 until 1985 mostly seine nets were used with *C. carpio* part of catch. Only gill nets were used since 1989 and *C. carpio* gradually disappeared from total catch.
Rustfontein (9)	Limited effort was done to harvest fish. During first year, just over 15 tons of fish were caught while just over 25 tons during 1986. A total of 49 955 fish dominated by *L. umbratus* (72%) and *L. capensis* (13%), were caught. Total weight of total catch dominated by *L. umbratus* (60%) and *C. carpio* (15%) to the total weight of the total catch.
Erfenis (3)	Despite annual quota of 200 tons, only 2 892 fish with total weight > 3 tons were caught. Fishery categorised as "failed". Total catch dominated by *L. capensis* (41.1%) and *L. umbratus* (36.4%).
Gariep (4)	Management complexities of all "failed" fisheries highlighted summarised in section 4.3.4. Total catch dominated by *C. carpio* (36%), *L. capensis* (30%) and *L. umbratus* (28%). None of fisheries, however, noted or recorded any catches of the two yellowfish species, especially *L. aeneus* which is abundant. Can thus be assumed that the catch records of the commercial fisheries at Gariep Dam are incomplete as during fish surveys done during the 2012/2013 and 2013/2014 summer seasons by author of current study at Gariep Dam (see Chapter 6) large number of especially *L. aeneus* were caught in gill nets.
Vaal (10)	Seven fisheries caught in total of 32 344 fish with total weight of 65 tons. All fisheries categorised as "failed". Total catch was dominated by *C. carpio* (55%), *L. umbratus* (29%), while *C. carpio* contributed 69%, *L. umbratus* 14% and *C. gariepinus* 14% to the total weight of the total catch.

Table 4.6: Summary of all the commercial fisheries' annual catches for the period 1979 until 2014 based on the data and historic records that were found.

Year	Kalkfontein Dam total catch (tons)	Bloemhof Dam total catch (tons)	Koppies Dam total catch (tons)	Rustfontein Dam total catch (tons)	Erfenis Dam total catch (tons)	Gariep Dam total catch (tons)	Vaal Dam total catch (tons)	Total (tons)
1979	1.4	0	0	0	0	0	0	1.4
1980	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0	0
1982	281.3	5.8	6.3	15.6	1.7	0	0	310.7
1983	471.3	282.5	21.2	2.8	1.6	0	0	779.4
1984	128.3	250.6	22.3	3.8	0	0	0	405
1985	144.1	556.2	21.7	25.9	0	0	0	747.9
1986	67.4	442.9	20.9	2.6	0	0	0	533.8
1987	83.6	241.4	23.2	0	0	0	0	348.2
1988	7.8	97.3	18.1	0	0	0	58.9	182.1
1989	30.5	6.7	11.5	0	0	0	5.1	53.8
1990	0	122.4	17.3	0	0	0	0	139.7
1991	0	167.9	14.7	0	0	0	0	182.6
1992	0	117.8	13.9	0	0	0	0.2	131.9
1993	53.1	142	1.6	0	0	0	0.4	197.1
1994	226.1	176.7	0	0	0	0	0	402.8
1995	0	256.1	0	0	0	0	0	256.1
1996	0	154.9	0	0	0	0	0	154.9
1997	81.4	237.1	0	0	0	0	0	318.5
1998	141.3	280	0	0	0	2.3	0	423.6
1999	76.8	280.4	0	0	0	8.6	0	365.8
2000	0	65.3	0	0.2	0	10.9	0	76.4
2001	0	216.2	0	0	0	0.9	0	217.1
2002	0	324	0	0	0	0	0	324
2003	0	481.2	0	0	0	0	0	481.2
2004	0	422.9	0	0	0	1	0	422.9
2005	152.9	124.7	0	0	0	0	0	277.6
2006	0	163.8	0	0	0	0	0	163.8
2007	0	442.1	0	0	0	0	0	442.1
2008	0	80.6	0	0	0	0	0	80.6
2009	94.4	48.5	0	0	0	1.3	0	144.2
2010	0	64	0	0	0	20.3	0	84.3
2011	0	60.8	0	0	0	3	0	63.8
2012	0	114.6	0	0	0	0	0	114.6
2013	0	186.9	0	0	0	0.9	0	187.8
2014	0	18.9	0	0	0	0	0	18.9
TOTAL	2 041.7	6 633.2	192.7	50.9	3.3	49.2	64.6	9 035.6

This assessment shows that only commercial fisheries that were able to harvest on average more than 100 tons y^{-1} were able to sustain their enterprises. The annual average total catch for Kalkfontein Dam was 128 tons y^{-1}, and for Bloemhof Dam, 201 tons y^{-1}, the latter for two operators, thus 100 tons y^{-1} each. Although fishing quotas ranging from 100 and 200 tons were also issued for fisheries at Rustfontein, Erfenis, Gariep and Vaal Dams, there is no indication that any of the fisheries were able to harvest their quotas.

Based on existing data (1979 until 2014), a total of 9 036 tons of fish were harvested from seven impoundments over the 35 year period, equating to an average of 258 ton y^{-1}. The fisheries at Bloemhof Dam contributed 73% to the total catch, followed by Kalkfontein and Koppies Dams at 23% and 2%, respectively. The fisheries from the other four impoundments contributed a total of only 2% to the total catch.

The average annual catch and catch per ha per year (kg $ha^{-1}y^{-1}$) of all species compared to the potential fish yields (kg ha^{-1} y^{-1}) as determined when using the MEI of Ryder (1965) and Marshall and Maes (1994) are summarised in Table 4.7.

Table 4.7: The average annual catch and catch per ha per year (kg $ha^{-1}y^{-1}$) of all species compared to the potential fish yields (kg ha^{-1} y^{-1}) as determined when using the MEI of Ryder (1965) and Marshall and Maes (1994).

Impoundment	Surface area (ha)	Av. annual catch (tons)•	Catch at FSL (kg ha^{-1} y^{-1})	MEI Ryder (1965) (kg ha^{-1} y^{-1})	MEI Marshall and Maes (1994) (kg ha^{-1} y^{-1})
Kalkfontein	3 769	127.6	33.9	54.7	170.2
Bloemhof	23 067	201	8.7	83.3	188.2
Koppies	1 439	16.1	11.2	110	232.4
Rustfontein	1 159	8.5	7.3	27.4	124.8
Erfenis	3 291	1.6	0.5	26.2	122.4
Gariep	35 216	5.5	0.2	5	58.9
Vaal	32 275	16.2	0.5	17.7	99.6

Abbreviations:
FSL = full supply level; MEI = morphoedaphic index.

● Based on the number of years the commercial fishery/ies operated at an impoundment.

None of the results of the actual annual catch ha^{-1} y^{-1} for the seven impoundments, for which historic data were found, falls within the ranges of potential fish yield when applying the original models of Ryder (1965) and of Marshall and Maes (1994). As the fisheries were either quota managed or have failed, yields appear not to be useful for evaluating the applicability of the models. They do however indicate that in most cases higher levels of harvest could have been sustained.

4.3.3 Effects of water level fluctuations on fisheries

The only two impoundments that sustained commercial fisheries for a substantial period of time and for which the original historic data sets were available, are Kalkfontein and Bloemhof Dams. The data allowed for an assessment on the impact of fluctuating water levels on these commercial fisheries as indicated in Figures 4.2, 4.3, 4.4 and 4.5.

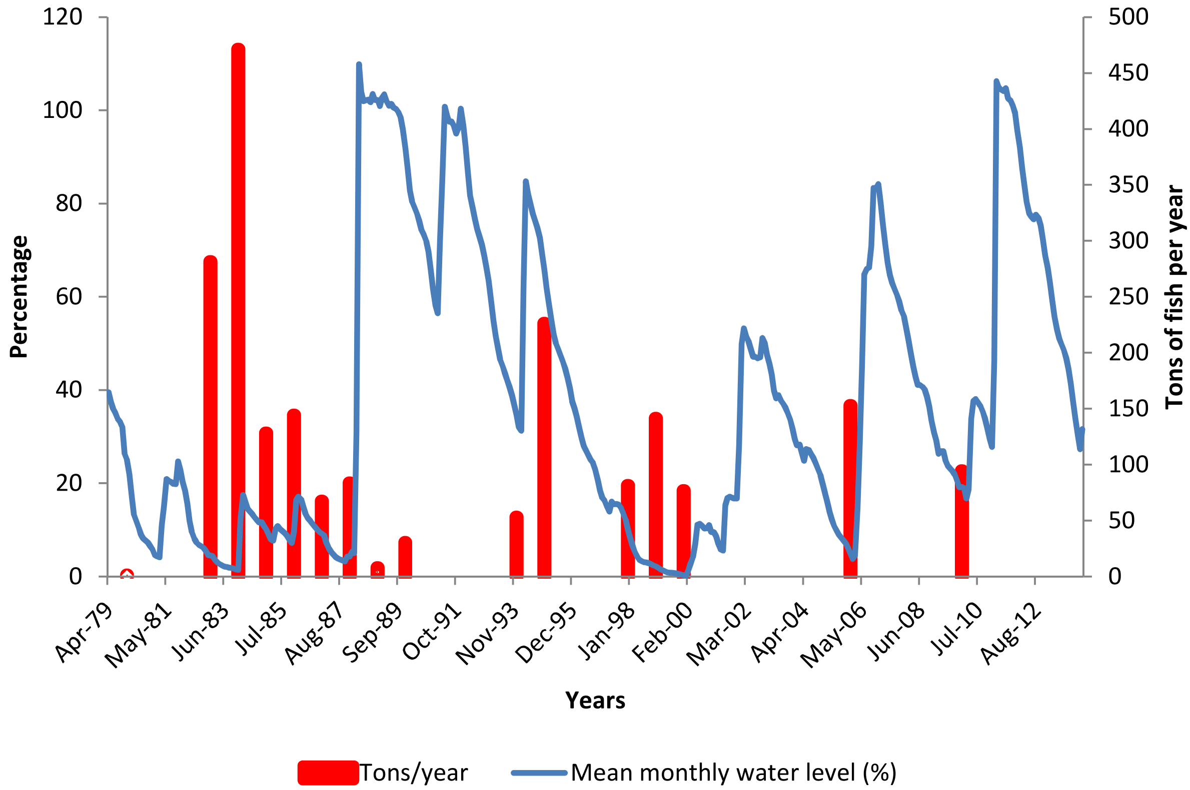


Figure 4.2: Total catch per year in tons in relation to the fluctuation of the water level at Kalkfontein Dam.

Significant fluctuations in the water level of Kalkfontein Dam are observed for the period April 1979 until April 2014, with the average annual water level for the 35 year period only

37.6%. The commercial fishery mostly harvested fish during periods of very low water levels, i.e. from 1982 until early 1988, 1997 until 1999 (when the impoundment dried up), and then again during 2005 and 2009. The major flood event during February 1988 had an impact on the total annual catch as it decreased to only 7.7 tons with a slight increase to 30.5 tons in 1989, after which it was only re-started again in 1993 when the water level decreased again. Hardly any harvesting of fish was done during periods when the dam's water level was above 40%, except for 1989 and 1994.

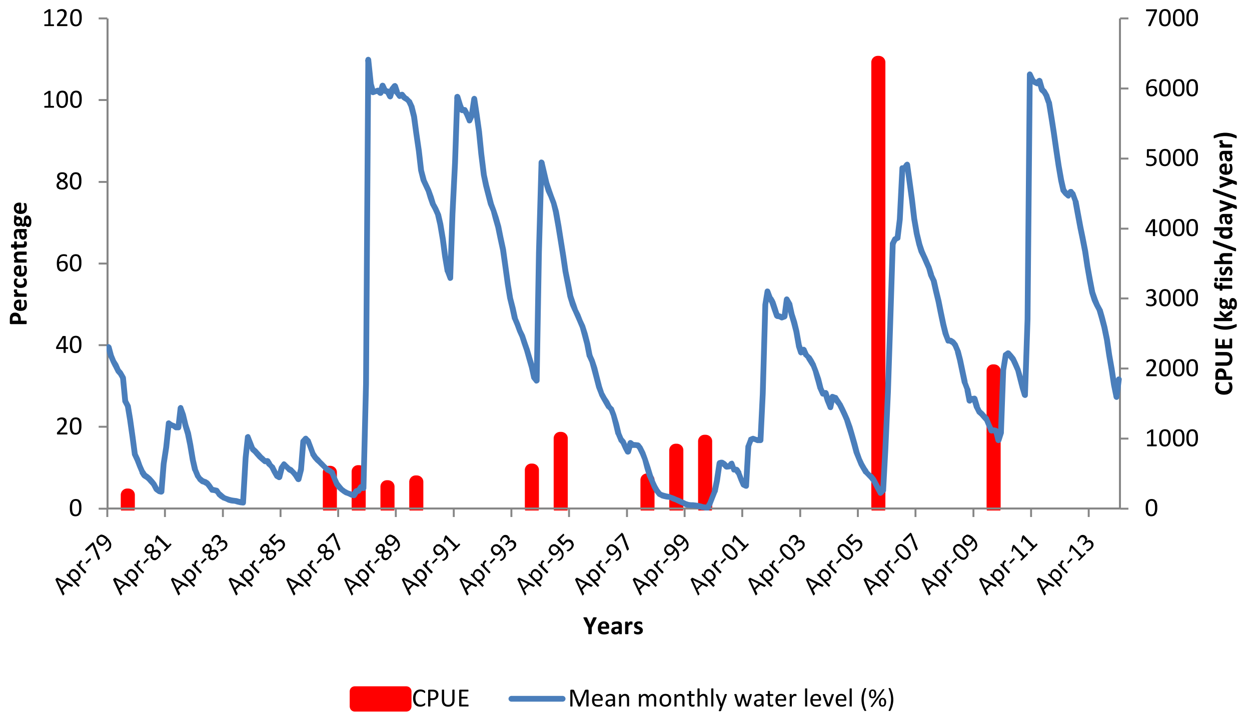


Figure 4.3: Catch per unit effort (CPUE) indicated as kg fish day^{-1} y^{-1} compared to the fluctuation of the water level at Kalkfontein Dam.

The number of days per year that fishing was done for the period 1982 until 1985 could not be found. The CPUE based on the kg fish caught day^{-1} y^{-1} ranged from 311 to 6 371 kg fish day^{-1} year^{-1}, with an average of 1 257 kg fish day^{-1} year^{-1}. The highest CPUE was recorded during 2005 when the water level decreased rapidly and 24 days were spend fishing while the water level was critical low, enabling large catches to be made with the least effort.

As this enterprise also operated a fishery at Bloemhof Dam, the number and weight of fish caught per day might have been limited due to the capacity of fishery to process a certain number or weight of fish per day. The processing of the fish entailed transporting it to the processing plant, slaughtering, removing the intestines, washing and salting the fish carcasses and placing it in tanks for two days. After two days, the carcasses were removed and stacked on racks for drying in the sun before it was packed and transported to the market. The fishery at Kalkfontein Dam had no refrigerating facilities and therefore most fish were salted and dried.

Bloemhof Dam

Bloemhof Dam is situated in the highly regulated VRS and a large portion of its inflow originates from the waste water treatment works from Gauteng and other urban areas within the catchment. In order to ensure sufficient water for irrigation schemes downstream, the water level is highly regulated and shows significant fluctuations. Increase catches are also associated with decreases in water level or when the water level is less than 20%, i.e. for the periods 1984 until 1988, 1993 until 1996 and 2003 until 2005 (see Figures 4.4 and 4.5). The fisheries exceeded the allowable annual quota of 400 tons during three periods, namely 1985 and 1986 when the water level was less than 10%, 2003 when there was a drastic decline in water level to less than 20% by 2004, and during 2007 when the water level dropped to just above 60%.

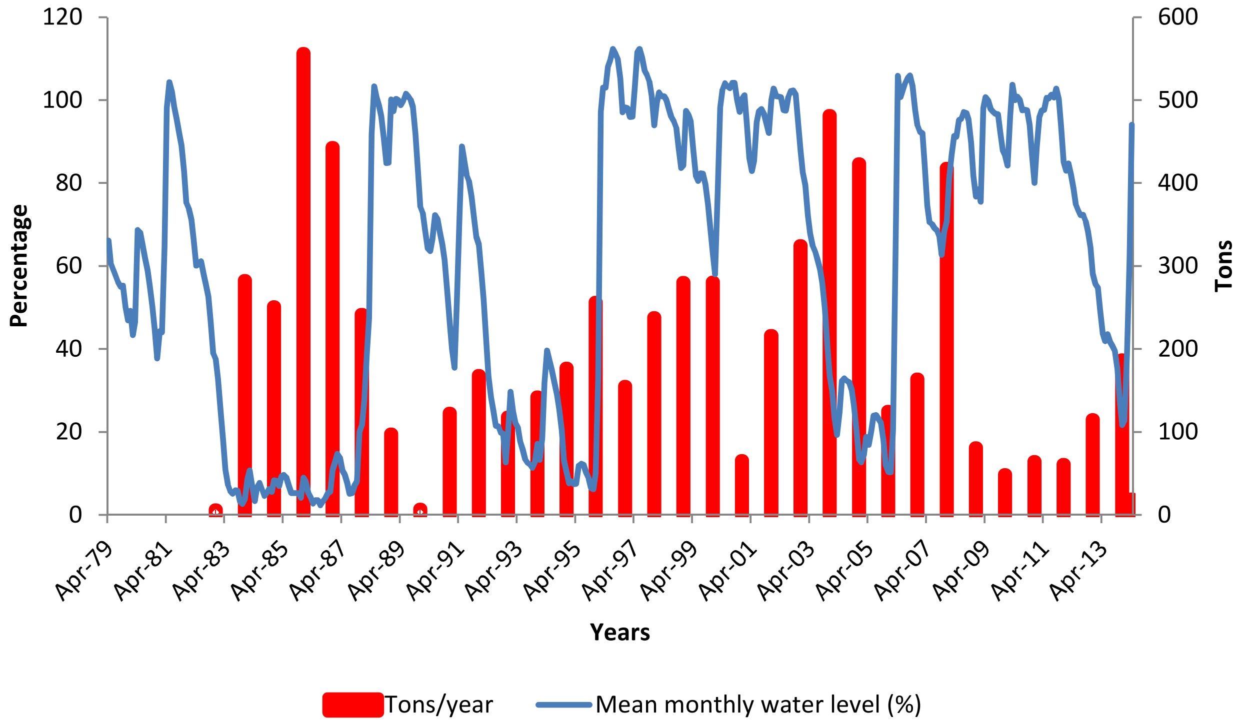


Figure 4.4: Total catch per year in tons in relation to the fluctuation of the water level at Bloemhof Dam.

Both fisheries experienced major challenges when the water level was above 80%, as the flooded littoral zones were covered with a variety of weeds that grew in these zones especially during periods as the water level decreased. At full supply level, dense reed beds in the areas zoned for commercial fisheries were flooded that made access to the water surface extremely difficult. The influx and rapid spread of water hyacinth *Eichhornia crassipes* (Mart.) Solms posed further problems for the fisheries that mostly used seine nets. This is evident for the periods 1988 to 1989, 1996, 2001 and 2008 until the beginning of 2013.

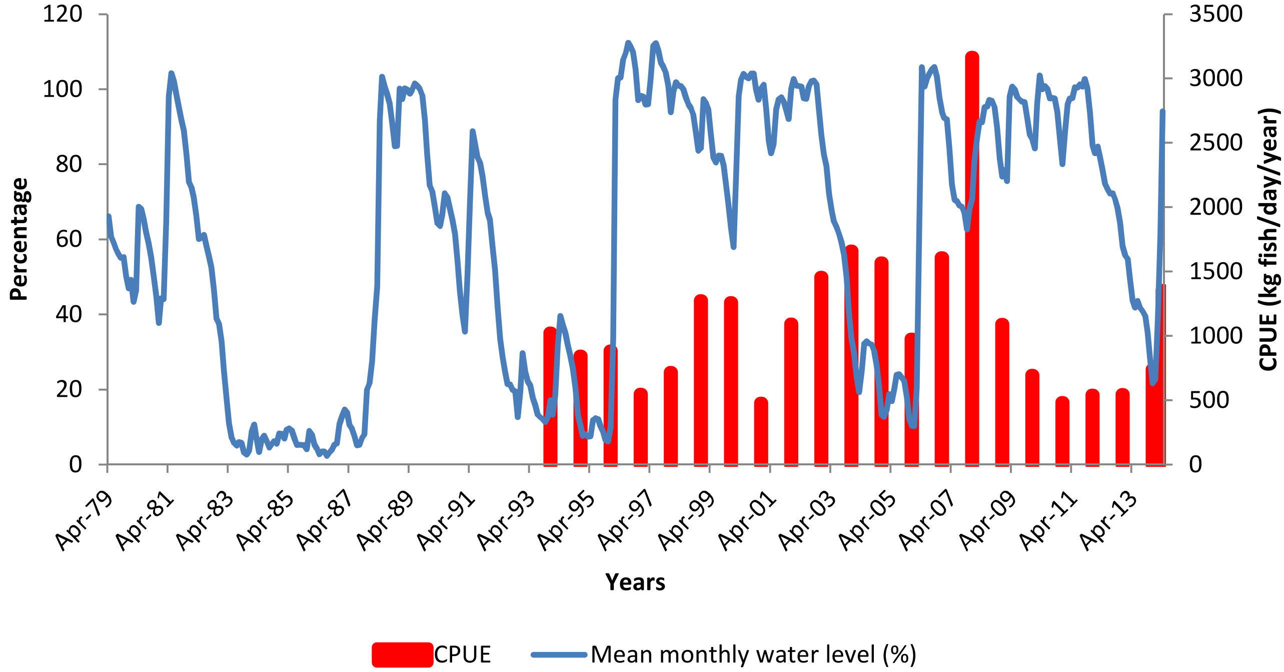


Figure 4.5: Catch per unit effort (CPUE) indicated as kg fish day^{-1} y^{-1} compared to the fluctuation of the water level at Bloemhof Dam.

The number of days that fishing was done for the period 1982 until 1992 could not be found in historic reports. For the period 1993 until 2013 the CPUE ranged from 477 to 3 163 kg fish day^{-1} year^{-1} as indicated in Figure 4.5. It should be noted that this is for both fisheries that operated at the impoundment. As the one fishery at Bloemhof Dam also operated the commercial fishery at Kalkfontein Dam, the CPUE was influenced by the capacity of the fisheries to process a certain amount of fish per day as well as the need for fish from the markets. This fishery at Bloemhof Dam also salted and dried fish which was transported to Cape Town from where it was exported. The other fishery mostly sold fresh or frozen fish and due to the limited capacity of the refrigerating facilities, it was only able to process and stock a limited amount of fish that directly influenced the CPUE. The CPUE was mostly influenced by the capacity of the fisheries to process or freeze, and sell the fish due to limited facilities at the processing plants.

4.3.4 Operational complexities

Key informant interviews indicated that commercial fisheries have had limited success. Most fisheries failed soon after their initiation (Erfenis, Rustfontein and Vaal Dams). The reasons for this appear to have been financial. According to the previous reserve manager at Koppies Dam, the fishery that operated there for 12 years closed down as it was no more financially viable and the enterprise experienced severe financial problems (J.J. Joubert[1], personal communication, 12 November 2014). Fisheries that have continued to operate, do so as a result of continued government support (e.g. Gariep Dam) or were relatively high yielding commercial enterprises (Bloemhof and Kalkfontein Dams) existed.

Gariep Dam was the focus of numerous fish and fishery related studies (see Hamman, 1974; 1981; Tomasson *et al.,* 1985; Ellender, 2008; Ellender *et al.,* 2009; 2010a; 2010b; 2012; Winker *et al.,* 2011). A comprehensive fishery operational plan was developed by Hamman (1981) for Gariep Dam and an annual fishing quota of 886 tons was proposed. According to McCafferty *et al*. (2012) the first small-scale fishery project at Gariep Dam was established during 1992, which only lasted a few years. During the search for historic data, no information could be found about this project.

Due to a lack of administrative control and management, and the lack of record keeping, a limited amount of historic data and information of the commercial fisheries that operated at Gariep Dam could be found. McCafferty *et al*. (2012) also commented on the lack of management, control and record keeping of the different fishery projects at Gariep Dam. A summary of the information that was obtained after investigations is provided in Table 4.8.

([1] J.J. Joubert, former reserve manager of Koppies Dam Nature Reserve; currently reserve manager of Sterkfontein Dam Nature near Harrismith in the FSP).

Table 4.8: Summary of the commercial fisheries at Gariep Dam.

Type of fisheries	Permits issued and fishery operational during:	Operating from:	Fishing quota allocated per annum	Comment
Private enterprise #1	1998 – 2000	Bethulie	20 tons	Stopped after two years.
Funded community based poverty alleviation project #1	1998 – 2007	Bethulie	50 tons	Stop due to conflict amongst project beneficiaries and not financial viable due to large number (50 people) of beneficiaries. Did not fish on a continuous basis but only a few months per year.
Private enterprise #2	2000	Venterstad	10 tons	No proof that fishing was done.
Private enterprise #3	2001	Bethulie	20 tons	Stopped after 3 months.
Private enterprise #4	2001 – 2011	Oviston	50 tons	Latter years only fished when fish was needed for personal use. Permit withdrawn in 2011.
Funded community based poverty alleviation project #2	2008 – 2011	Bethulie	50 tons	Break-away group from community based fishery project #1. Fishing limited to few months, and project stopped during 2011.
Funded community based poverty alleviation project #3	2004 until 2014	Oviston	Originally 200 tons; from 2013 only 20 tons	Was in major conflict with recreational and subsistence anglers. Project experienced major challenges with infighting and lack of administration and management. No fishing allowed during hunting season in reserve i.e. for six month per year. Project was stopped on a number of occasions but then new funds were invested by government and project was forced to start over again.

Based on the limited information, during the 16 year period that commercial fisheries operated at Gariep Dam, a total of 42 970 fish with a combined weight of 49.4 tons were caught, with an average of 4 774 fish with a total weight of 5.5 tons per annum. Seine nets with a stretched mesh size of 50 mm and larger were used by most fisheries, while during the late 1990's and early 2000's, some fisheries used gill nets. All the government funded poverty alleviation projects were exempted from paying a concession fee, as it was deemed as developmental projects.

One of the community based fishery projects at Gariep Dam received funding totaling ZAR216 000, with all infrastructure, equipment, boat and a building (fish processing plant) been provided. The original idea was to create employment for 50 people. As the project experienced a number of challenges, strict record keeping was done from January until December 2000. During this period 11.2 tons of fish were caught and the total income from selling the fish was ZAR21 437,50, with an average price charged for fish at ZAR1.90 kg^{-1}. The total expenses for this period were ZAR9 750 which left a balance of ZAR11 687,50. By the end of 2000, only 12 people remained in the project which meant each earned ZAR81 per person per month.

Bloemhof and Kalkfontein Dams

It was not only community development projects that faced financial constraints. Key informant interviews demonstrate that even those fisheries which were able to sustain a total harvest of 100 tons y^{-1} (Kalkfontein and Bloemhof Dams) experienced major financial challenges. Expenses for nets, vehicles, fuel, boats, outboard motors, processing plants, electricity and salaries for employees impacted on the economic viability of the fisheries. Maintenance of equipment, nets, vehicles and boats placed an extra burden on these enterprises. It must be noted that success also appears to be largely dependent on the operator. The enterprise at Kalkfontein Dam for example, was initiated by the same operator whom initiated commercial fisheries at Bloemhof, Krugersdrift, Vaal Dams and Witpan. This enterprise first started a commercial fishery at Darlington Dam (Lake Mentz) in the Eastern Cape during the 1970's after which the operation moved to Kalkfontein Dam (Dr. A. Bok[2], personal communication, 19 November 2014).

4.4 Discussion

The total fish harvest of 9 036 tons from seven impoundments for a 35 year period is miniscule when compared to total annual catches from other countries in Africa that harvested more than 2.5 million tons y^{-1} during 2008 (Welcomme, 2011b). Skelton (1993) reported on 16 000 tons of fish caught annually at Lake Kariba. Crul (1992) noted the

([2] Dr. A. Bok, former Senior Researcher at the Eastern Cape Department of Environmental Affairs and Conservation).

economic importance of inland waters in Africa in providing food for millions and on the presence of more than 450 commercial fishers in the Zambezi-Chobe floodplain. A detail overview of the fisheries in man-made impoundments in Sri Lanka based on the harvesting of alien *Oreochromis mossambicus* was provided by De Silva (1988) who noted that the annual inland fisheries yield, which contributed 20% to the total fish production, was estimated between 27 000 and 30 000 tons. Marshall and Maes (1994) reported that during 1987, 8 000 tons of fish were caught in Angola, 88 485 tons in Malawi, 265 735 tons in Tanzania, 66 980 tons in Zambia, 17 344 tons in Zimbabwe, and only 2 300 tons in South Africa. A total catch of more than 1.4 million tons of fish were reported by Witte *et al.* (2009) from the main lakes and reservoirs in the Nile River System after the 1990's.

The reasons for these low yields are likely to be due to both a lack of developmental interest, as conservation and environmental agencies in South Africa never had a developmental focus. Permitting of commercial fisheries in the former Orange Free State Province was not to address poverty, unemployment, rural development and food security, as this was deemed to be the mandate of other government departments (e.g. Agriculture, Social Development). For example, the main driving force behind early attempts to establish inland commercial fisheries in the former Orange Free State Province was to decrease the numbers of *L. umbratus* in impoundments (Marshall, 1972). Research had indicated that this species largely dominated fish communities, possibly out-competing the more suitable angling species like *L. capensis* and *C. carpio* (Jordaan, 1982; Mitchell and Jordaan, 1985; Fouchè, 1988).

Only one commercial fishery operator, that established the first inland fishery in the Eastern Cape during the 1970's and who subsequently moved to the former Orange Free State Province, was able to sustain commercial fishery operations for 35 years. This enterprise operated at five different impoundments and its success might be attributed to the fact that the operator had the knowledge, expertise, skills, equipment and most importantly an established market to sustain operations. The inland fisheries sector (including commercial and recreational fisheries) in the FSP tends to be more similar to the inland fisheries in the developed world, especially with reference to coarse fish, where the focus is more on recreational fisheries than fishing for food as reported by Welcomme *et al*. (2010) for the north and south temperate zones. Allan *et al*. (2005) noted that in North America, Europe and the former Soviet Union many commercial fisheries ceased to exist and were replaced by recreational fisheries.

The commercial fisheries in the FSP that did develop were, generally small and of limited economic viability that did not contribute significantly to economic development or job creation in the province. No historic data could be found on how many people were employed by the different commercial fisheries and as far as can be determined, no permanent jobs were ever created. During inspections at the two fisheries at Bloemhof Dam during 2012 and 2013 it was found that one fishery employed eight people on a temporary basis who was paid ZAR80 per day. The other fishery at Bloemhof Dam employed between eight to 12 people and seemingly they were paid on a commission basis based on the total weight of the catch per day. At Kalkfontein Dam where the latter fishery also operated, between 20 and 30 people were employed, also on a temporary basis, but it is not known how much they earned.

There is, however, large political pressure to develop inland fisheries. The African Union for example has identified inland fisheries as one of the most important sectors for future investment (New Partnership for Africa's Development [NEPAD] 2005). It is estimated that in the whole of Africa more than 10 million people are supported by inland fisheries (NEPAD, 2014). The Partnership for African Fisheries (PAF) under NEPAD, aims to enhance the sustainability of and strengthen inland fisheries in Africa, with a vision where fish play an important role in the wealth and development on the continent (NEPAD, 2014). The importance of fish, inland fisheries and aquaculture in Africa is highlighted by an UN News Serving on 10 May 2014, which noted that more than ever before fish are central in creating jobs and providing food for millions on the continent of Africa (UN News Serving, 2014). South Africa is part of the African Union and member state of NEPAD, and this might be one of the reasons for the renewed interest and development initiative focussing on the promotion of inland fisheries in the country.

Despite the high unemployment rate in FSP, and due to the fact that most fish caught by the fisheries especially at Kalkfontein and Bloemhof Dams was salted, dried and exported to other countries, might imply that there was never a high demand for freshwater fish in the

Province. Opposite to this, the fact that there was limited to no open access for local communities to most impoundments might have forced people to focus more on alternative and more accessible small-scale agricultural projects rather than fishing and small-scale fishery projects, which may well have been suitable avenues for development.

Béné (2003) argued that globally, small-scale fisheries are characterised by poverty and dispossession and that the various social and institutional arrangements that guide people's access to fish resources, play a key role in their risk to poverty. Globally it seems to be accepted that fisheries and poverty go hand in hand and that key to the problem are the biological and economical features of the fisheries (Béné, 2003). In a study by Béné *et al.* (2003) on inland fisheries and poverty in the Lake Chad Basin, the authors noted that in many instances the poorest of the poor, due to their limited economic and social resources, resort to fisheries. This is usually of an open access nature and because of their limited resources they were unable to enter into other economical activities.

Béné and Friend (2009) mentioned that small-scale fisheries are critical to the lives and livelihoods of households which stay in close proximity of aquatic systems. This has also been highlighted by the work of Ellender (2008; 2010a; 2010b) at Gariep Dam, where 448 subsistence fishermen fished on a regular basis to sustain or supplement their livelihoods. During the fish surveys conducted by the author during 2012/2013 and 2013/2014, an increase in the number of subsistence fisheries was observed at 12 impoundments. The importance of inland fisheries in sustaining livelihoods and providing food for the rural poor especially in Africa and Asia was also highlighted by the study of Suuroren and Bartley (2014).

There is currently no provincial or national inland commercial fishery policy that guides the development of this sector in South Africa. Weyl *et al*. (2007) noted that this is one of the major stumbling blocks for the development of this sector in South Africa. This has also been noted by Hara and Backeberg (2014) as well as in the study on the development and sustainable utilisation of inland fisheries in South Africa by Britz *et al*. (2015). On an international level and due to the importance of inland fisheries in sustaining livelihoods, Suuroren and Bartley (2014) also noted that inland fisheries are neglected and do not receive proper attention in national and international developmental policies.

The only guiding document that controlled and managed commercial inland fisheries in the former Orange Free State Province, was the set of conditions issued with the permits for commercial fisheries which was informed by the NCO (1969) and NCR (1983). During May 2012, due to problems and challenges experienced with regards to the management and control of inland commercial fisheries and to make it more accessible to more enterprises, the FS DESTEA developed Operational Guidelines for this sector. Despite the fact that the responsible government department for the promotion of inland fisheries in the FSP after May 2009 is the Free State Department of Agriculture and Rural Development, which lack the personnel, finances, skills and experienced personnel to implement inland commercial fisheries, it is foreseen that for the near future it will still be managed and controlled by the FS DESTEA.

The Department of Water and Sanitation (DWS) has developed guidelines for the development of Resource Management Plans (RMP) for state dams in South Africa. The main aims of RMPs is to provide guidance on the management, control, protection and conservation, development of, and utilisation of water resources for recreational purposes which is based on principles of sustainability and equity. The RMPs need to address the historic lack of access to impoundments, and use of impoundments by historical disadvantaged communities that stay around the impoundments, and to ensure that all have regulated and approved access to the water surfaces, as well as fish resources and recreational opportunities. Four main areas are addressed in these RMPs, namely resource management, utilisation management and benefit flow management, as well as institutionalisation of the RMP (DWA, 2006). The guiding document for RMPs does not focus on the establishment of commercial or small-scale inland fisheries, although these were highlighted and discussed at the public participation meetings held for the drafting of the RMPs for Gariep and Allemanskraal Dams.

4.5 Conclusion

The literature review done by McCafferty *et al*. (2012), based on all available published and grey literature on inland fisheries in South Africa, noted the historic failure of commercial fisheries. This is also evident from the situation in the FSP, where only two private enterprises were able to sustain fisheries on a continuous basis for 32 years. Although the focus of this Chapter was on an analysis of the historic records of commercial fisheries, it needs to be noted that recreational fisheries have been and are currently the most important fisheries sector in the FSP. The results of the current Chapter have highlighted the high failure rate of most private enterprises and community based poverty alleviation fishery projects. Preliminary results of fish surveys done at 21 impoundments in the FSP by the author indicated that there is an emergence of subsistence fisheries at some impoundments. In reality most impoundments have a healthy fish community which is a resource that could be utilised. It is recommended that efforts should rather be focussed on promoting and facilitating the establishment of small-scale subsistence fisheries with suitable gear, for example fyke nets. This will be the focus of Chapter 7. The use of fyke nets might change the inland fisheries sector in the FSP and provide opportunities for achieving some of the government's imperatives of job creation, poverty alleviation and food security.

The importance on inland fisheries in the livelihoods of millions of people in the developing world is clear, but the extent to which inland fisheries will be able to develop in South Africa is an open question. This is especially important due to the fact that freshwater fish were never a main part in the diet of most people in South Africa, especially in the FSP. Britz *et al.* (2015) concluded their report on the scoping study on the development and sustainable utilisation of inland fisheries in South Africa, by noting that the value of inland fisheries does not lie with the value of the tonnage of fish caught, but rather in the benefits it provides for the rural poor in sustaining their livelihoods. Recreational angling and its associated social and economic benefits and large tourism industry that it directly and indirectly support, also contribute significantly to the value of the inland fisheries sector in South Africa. This will be highlighted and discussed in the next chapter on an analysis of recreational fisheries in the FSP.

Chapter 5 Analysis of freshwater angling in the Free State Province

5.1 Introduction

Globally the number of people involved in recreational angling is growing (Granek *et al.,* 2008). Arlinghaus *et al.* (2013) estimated that 140 million people in North America, Europe and Oceania are involved in this sector. Recreational fisheries are the primary utilisation of freshwater fishes in North America, Europe and Australia, while in Africa, Asia and South America small-scale fisheries dominate (Miranda, 2001). Recreational fisheries are economically important as they contribute to local and regional economies, through associated expenditure in the tourism and hospitality industry and sales of fishing gear (Du Plessis and Le Roux, 1965; Cadieux, 1980; Leibold and Van Zyl, 2008; Brand *et al*., 2009; Du Preez and Lee, 2010).

Cooke *et al.* (2013) demonstrated that the harvest by recreational anglers was a significant contributor to fish mortality globally. Due to the importance of, and possible effects and impacts of recreational fishing on global freshwater fish resources, Arlinghaus *et al.* (2010) proposed and introduced the Code of Practice for recreational fisheries in support of the Code of Conduct for Responsible Fisheries of the Food and Agricultural Organisation of the United Nations (FAO). Arlinghaus *et al.* (2010) noted for this code to be implemented globally, it will have to be adopted by the international community and the FAO, to ensure that recreational fisheries receive the necessary attention as one of the world's most important fisheries sectors.

In South Africa recreational fisheries have been the dominant inland fishery sector and are considered important role-players in future development of inland fisheries in the country (McCafferty *et al.,* 2012). Recreational fisheries also play an important role in the future conservation, protection and co-management of inland fisheries (Granek *et al.,* 2008). While this sector has never been quantified, a limited number of studies have attempted to describe and quantify this sector in South Africa (see Du Plessis and Le Roux, 1965; Cadieux, 1980; Leibold and Van Zyl, 2008; Brand *et al*., 2009; Du Preez and Lee, 2010; McCafferty *et al.,* 2015). Most information, however, is on organised angling, of which key aspects have been described by McCafferty *et al.* (2015).

In brief, recreational angling can be divided into a more formal sector, that comprises anglers affiliated to angling clubs and the informal sector where anglers are not affiliated. The formal sport fishery sectors in South Africa are controlled and managed by the South African Sport Anglers and Casting Confederation (SASACC), which resorts under the South African Sports Confederation and Olympic Committee (SASCOC). According to the SASACC official website, 19 787 members from 581 clubs are affiliated with the Confederation (www.sasacc.co.za). The structure of SASACC is presented in Figure 5.1.

National Department of Sport and Recreation, South Africa

↓

South African Sports Confederation and Olympic Committee (SASCOC)

↓

South African Sport Anglers and Casting Confederation (SASACC)

↓

1. South African Federation of Sport and Sea Anglers (SAFSSA)
2. South African Casting and Surf Casting Federation (SACSCF)
3. **South African Freshwater Bank Angling Federation (SAFBAF)**
   - **3.1 Match angling**
   - **3.2 Carp angling**
   - **3.3 Feeder angling**
   - **3.4 Bank angling**
4. South African Federation of Artlure and Fly Anglers (SAFALFA)

(Redrawn from: http://www.sasacc.co.za/cp/14567/structure)

Figure 5.1: The organisational structure of the South African Sport Anglers and Casting Confederation (SASACC).

SASACC comprises four federations, i.e. the South African Federation of Sport and Sea Anglers (SAFSSA), the South African Casting and Surf Casting Federation (SACSCF), the South African Freshwater Bank Angling Federation (SAFBAF) and the South African Federation of Art Lure and Fly Anglers (SAFALFA). According to McCafferty *et al.* (2015), 5 309 members nationally are affiliated with 169 angling clubs under SAFBAF making it the largest freshwater angling federation in South Africa.

Four different bank angling sectors resort under the SAFBAF, namely match, carp, feeder and bank angling (see Figure 5.1), and all are presented by fixed committees on SAFBAF. In the different provinces in South Africa, angling clubs with registered members form provincial membership associations, which are represented in the structures of the different fixed committees. These clubs are guided by, and must adhere to the constitution, policies, rules and regulations of SASACC. These angling clubs and their members can be viewed as sport anglers, as one of their aims is to qualify for provincial or national colours and to represent South Africa at national and international angling tournaments. In the Free State Province (FSP) all affiliated angling clubs resorts under the Free State Freshwater Bank Angling Association (FSFBAA), with representation in all five district municipalities in the province.

The majority of recreational anglers, however, do not belong to any official association or club, and fish mostly for leisure and at own will. It is therefore difficult to quantify and qualify this sector. Two studies have attempted to quantify and qualify recreational angling effort. Cochrane (1987) investigated the biomass and yield of the dominant fish species in the eutrophic Hartbeespoort Dam, and noted that *Cyprinus carpio* and *Clarias gariepinus* populations were heavily exploited by recreational anglers. The annual recreational yield for *C. carpio* was estimated at 449 tons and for *C. gariepinus,* 102 tons (Cochrane, 1987).

Ellender (2008) investigated the effect of recreational angling on *Labeobarbus aeneus* and *L. kimberleyensis* populations at Gariep Dam where recreational anglers comprised 40% of the total fishermen with 60% being subsistence anglers. Anglers' catches were dominated by *C. carpio* (74%), followed by *Labeo capensis* (13%) and *L. aeneus* (8%) while *L. kimberleyensis* contributed less than 0.5% to the total catch (Ellender, 2008). Ellender *et al.* (2010a) reported that 7.5 tons of fish were caught during recreational angling tournaments at Gariep Dam and noted the value of fish for subsistence and recreational use. The authors noted that it was therefore important that the value of recreational angling for communities near impoundments should be taken into consideration when an inland fishery project or policy is to be developed. Weyl *et al.* (2007) and Ellender *et al.* (2009; 2010b) also observed an increase in subsistence fisheries at impoundments in South Africa where fish are mostly caught to sustain and support the livelihoods of people staying close to impoundments.

The aim of this chapter was therefore to provide the first assessment of recreational angling in the FSP. To do this, historic and current data on license sales and angling tournaments were compiled (mostly from hard copies filed in local offices) to assess participation and use tournament catch data and to determine target species.

5.2 Materials and Methods

5.2.1 Data sources: recreational angling

Freshwater angling and recreational fisheries in the FSP are controlled and managed according to the provisions of the Nature Conservation Ordinance 8 of 1969 (NCO, 1969) and the Nature Conservation Regulations of 1983 (NCR, 1983). These provisions are summarised in Table 5.1.

Table 5.1: Summary of the provisions and restrictions with regards to the conservation and utilisation of freshwater fish in the Free State Province according to the NCO (1969) and NCR (1983) as amended on 17 March 1995.

Aspect	Notes
Angling license	All anglers must have a valid angling license which must be with an angler whenever fishing. An angling license cost ZAR40 and is valid for a period of one year, i.e. 1 January until 31 December. Private landowners, their families and employees are exempted from having an angling license when fishing is done in constructed impoundments not situated in a natural water way on farm land.
Access	Permission must be obtained prior to entering any angling area.
Restrictions	Restrictions may be put in place for the catch of certain species during certain periods. Spawning fish, their ova and fry and spawning areas may not be disturbed and these areas may not be entered into.
Gear	Anglers may only use two lines to which: no more than two hooks with natural bait; one or more non-spinning artificial flies; not more than one artificial lure or spoon, are attached. No jigging may be done, while the setting of a long line is prohibited. Feeding and angling places may not be marked.
Possession of fish nets and traps	Only people with the necessary permits and authorisation may sell, or be in possession of any type of nets, except for keep and landing nets.
Import, sell and release of live fish	All activities prohibited unless an approved permit has been issued by the FS DESTEA.
Bag and size limits	No angler may catch and keep more than 10 *Labeobarbus aeneus* per day which is larger than 450 mm. All *L. aeneus* smaller than 450 mm must be released. Immediate catch-and-release applicable for *Labeobarbus kimberleyensis* and none may be kept or killed. No more than six trout larger than 300 mm may be caught and kept per day (*was only applicable at Sterkfontein Dam where trout was stocked*). There are no further bag or size limits for the other fish species occurring in the FSP.
Bait	No live fish may be used as bait.
Angling tournaments	May only be arranged and presented after an official permit has been issued. During 2014/2015 a permit costed ZAR100.00 and is valid for a period of one year. Only anglers in possession of angling licenses are allowed to partake in angling tournaments.

The NCR requires all recreational anglers to have a valid angling license. Angling licenses are sold at most offices of provincial nature reserves and resorts, the head office of the FS DESTEA in Bloemfontein and historically at a few retail stores. Duplicates of angling licenses are kept in the license books. Unfortunately these statistics have never been compiled and were only available in hard copy. After an initial investigation of the offices where angling licenses were sold, data on license sales were obtained for the 2013 and 2014 calendar years.

Regulations with regards to the fish species that may be caught as well as bag and size limits for certain species appear on the back of the FSP's angling license. Regular inspections are done by law enforcement officials, reserve personnel and Environmental Management Inspectors at impoundments during which anglers must show proof of having obtained an official angling license.

5.2.2 Tournament angling

Exploratory interviews with members of angling clubs affiliated with the FSFBAA were used to provide an understanding of the organisational structure of tournament angling. In summary, all angling clubs and their members that are affiliated with the FSFBAA are guided and controlled by the constitution and rules of the SAFBAF. When angling clubs arrange and present angling tournaments, they are guided by these rules. It controls the participation at tournaments, management of club tournaments, zoning of angling areas during tournaments, duration of tournaments, allowable angling gear, handling of angling gear, conservation of fish, weighing and counting of fish, allocation of points based on the number and weight of fish caught, general conduct during tournaments and finally the enforcement of official rules. An important rule of SAFBAF, with regards to the allocation of points for anglers based on the number and weight of fish caught during tournaments, is that all fish weighing less than 150 g are not counted and no marks allocated to the tally of an angler. All fish weighing less than 150 g are eventually added to the total weight of the total catch to further increase the tally of an angler. In reading and interpreting the catch data of the angling tournaments in this Chapter, cognisance must be taken of this rule. On completion of an angling tournament, record forms of catches are submitted to the provincial conservation officer of the FSFBAA.

Data regarding the number of anglers and angling clubs affiliated with the FSFBAA for the period January 2013 until December 2014 were obtained from the executive committee of the association. This data that were in hard copy, were processed and summarised in MS EXCEL spreadsheets.

One of the permit conditions for hosting an angling tournament is that the results and records of catches must be submitted on a prescribed form to the FS DESTEA within two weeks after the event has taken place (see Appendix 14). These record forms had to be sent to the permit office at the head office of the FS DESTEA in Bloemfontein, where it was kept as a hard copy in a filing system. These data were obtained and digitised using MS EXCEL.

5.3 Results

5.3.1 Angling licenses sold during 2013 and 2014

The number of angling licenses sold in the FSP during each calendar month of 2013 and 2014 is presented in Figure 5.2 and the distribution of license sales at individual offices is shown in Table 5.2. License sales peak during the December/January and March/April school holiday periods and decrease during the cold winter months (May until August). In total 8 256 and 7 710 angling licenses were sold in 2013 and 2014 respectively, with most licenses sold in December and January.

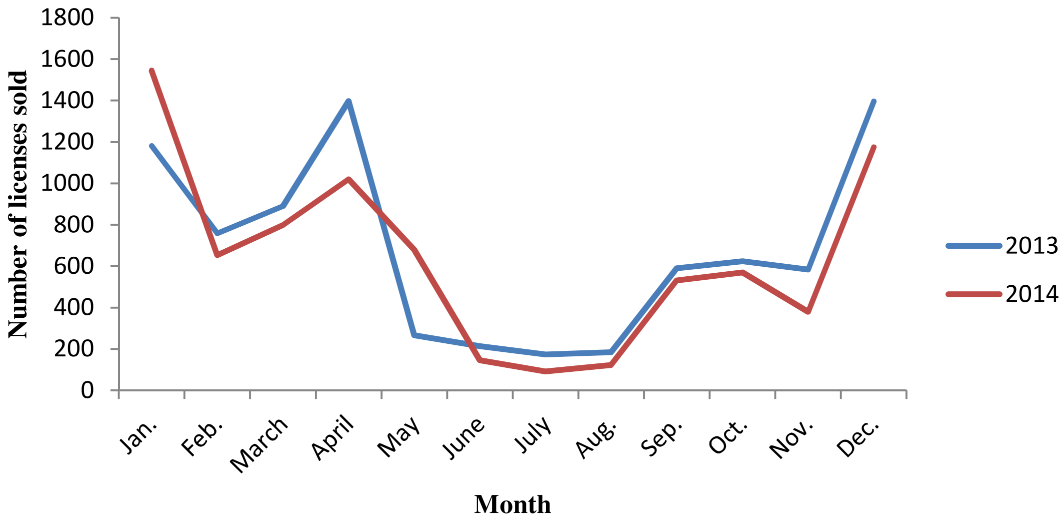


Figure 5.2: Number of angling licenses sold in the Free State Province during 2013 and 2014.

Table 5.2: Summary of the number of angling licenses sold in the Free State Province for during 2013 and 2014.

Name of reserve/regional office/retail store	Impoundments nearby	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec		Total	
		'13	'14	'13	'14	'13	'14	'13	'14	'13	'14	'13	'14	'13	'14	'13	'14	'13	'14	'13	'14	'13	'14	'13	'14	'13	'14
Caledon N.r.	Welbedacht, Knellpoort, Egmont	10	12	1	1	0	6	5	1	2	0	0	0	2	0	2	3	0	2	0	0	0	3	15	0	**37**	**28**
Erfenis N.r.	Erfenis	82	133	34	75	30	54	81	100	11	32	12	8	5	7	9	10	49	24	37	39	38	43	40	34	**428**	**559**
Gariep N.r.	Gariep	14	89	13	7	42	28	27	19	24	9	5	1	5	8	3	6	26	26	77	76	67	11	38	48	**341**	**328**
Kalkfontein N.r.	Kalkfontein	23	60	17	17	33	32	35	46	6	11	1	6	3	0	6	7	2	9	9	11	9	2	67	34	**211**	**235**
Kloppers Retail, Bloemfontein	Krugersdrift, Rustfontein, Mockes, Moutloatsi Setlogelo, Tierpoort, Armenia	94	86	29	31	39	55	17	41	0	16	9	10	1	6	10	2	18	12	20	34	29	16	85	87	**351**	**396**
Koppies N.r.	Koppies	190	245	147	147	245	147	98	217	49	81	49	40	0	9	0	28	147	120	147	113	98	86	245	147	**1 415**	**1 380**
Maria Moroka N.r.	Moutloatsi Setlogelo	6	6	5	1	2	0	0	0	2	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	**18**	**7**
Permit office, Bloemfontein	Krugersdrift, Rustfontein, Mockes, Moutloatsi Setlogelo, Tierpoort, Armenia	71	105	24	21	16	24	5	20	6	4	1	3	8	3	3	2	3	7	4	10	4	3	19	13	**164**	**215**
Rustfontein N.r.	Rustfontein	78	42	11	26	15	9	15	14	16	8	2	1	6	0	6	9	2	11	9	14	0	0	22	8	**182**	**142**
Sandveld N.r.	Bloemhof	241	331	235	162	244	238	781	261	63	455	85	51	58	40	109	40	235	186	171	172	147	121	348	524	**2 717**	**2 581**
Seekoeivlei N.r.	-	3	3	0	1	0	0	5	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	2	**10**	**7**
Soetdoring N.r.	Krugersdrift	151	175	49	54	72	74	101	141	44	21	14	12	20	3	13	6	53	65	79	44	84	16	318	83	**998**	**694**
Sterkfontein N.r.	Sterkfontein	143	165	121	81	90	76	145	88	24	17	20	4	28	8	7	6	19	46	42	21	65	53	146	104	**850**	**669**
Welkom Regional office	Erfenis, Bloemhof, Allemanskraal	13	8	13	8	20	7	9	5	2	0	1	0	0	0	2	0	6	4	2	19	11	4	13	11	**92**	**66**
Willem Pretorius N.r.	Allemanskraal	61	85	60	21	42	48	73	66	18	26	14	9	37	8	14	3	27	18	26	17	31	22	39	80	**442**	**403**
TOTAL		1 180	1 545	759	653	890	798	1 397	1 019	267	680	213	145	173	92	184	122	589	531	624	570	584	380	1 396	1 175	**8 256**	**7 710**

N.r. – Nature Reserve

The most angling licenses were sold at Sandveld Nature Reserve adjacent to Bloemhof Dam (2013 – 2 717; 2014 – 2 581). This impoundment is viewed as the best angling venue for *C. carpio* in South Africa and most of the FSFBAA provincial, and SAFBAF's national as well as international angling tournaments are held here annually. The second most licenses (2013 – 1 415; 2014 – 1 380) were sold at Koppies Dam Nature Reserve at Koppies Dam. The third most licenses (2013 – 998; 2014 – 694) were sold at Soetdoring Nature Reserve that surrounds Krugersdrift Dam that is situated 35 km from Bloemfontein, the capital of the FSP. The fourth most licenses (2013 – 850; 2014 – 669) were sold at Sterkfontein Dam Nature Reserve that surrounds Sterkfontein Dam and this can be attributed to the impoundment's popularity as the best fly fishing venue for *L. aeneus* in South Africa.

5.3.2 Angling clubs

The number of angling clubs that were established per district municipality for the period 1994 until 2014 in the FSP and the angling clubs affiliated with the FSFBAA during 2014 are summarised in Table 5.3. Most of the angling clubs that were established from 1994 until 2014 were not officially affiliated with the FSFBAA. Many church denominations, non-governmental organisations, pre-primary and other schools used angling tournaments as a fund raising activity. Most of these churches and schools registered as angling clubs, but then held a once-off angling tournament and in most instances, no records of catches as stipulated on the permit conditions were submitted.

Figure 5.3 provides a demographic map of the FSP indicating the most populous district municipalities within the province with the number of angling clubs in each district.

Table 5.3: Number of angling clubs that were established in the Free State Province for the period 1994 until 2014, and clubs officially affiliated with the Free State Freshwater Bank Angling Association (FSFBAA) during 2014.

Municipality	Number of angling clubs established	Number of angling clubs affiliated with FSFBAA during 2014	Main large to medium size impoundments situated close to or within municipality's borders
Mangaung Metropolitan (include urban areas of Bloemfontein, Mangaung, Botshabelo and Thaba Nchu)	74	6	Mockes, Rustfontein, Krugersdrift, Moutloatsi Setlogelo, Armenia, Tierpoort, Jimmie Roos
Fezile Dabi District (northern Free State)	25	12	Vaal, Koppies, Bloemhoek, Serfontein
Lejweleputswa District (western and northern parts of the FSP)	21	6	Allemanskraal, Erfenis, Bloemhof, Krugersdrift
Thaba Mofutsanyane District (eastern Free State)	20	4	Sterkfontein, Sol Plaatje, Allemanskraal, Armenia
Xhariep District (lower eastern, southern and western part of Free State Province)	17	2	Welbedacht, Knellpoort, Egmont, Gariep, Kalkfontein
TOTAL	**157**	**30**	

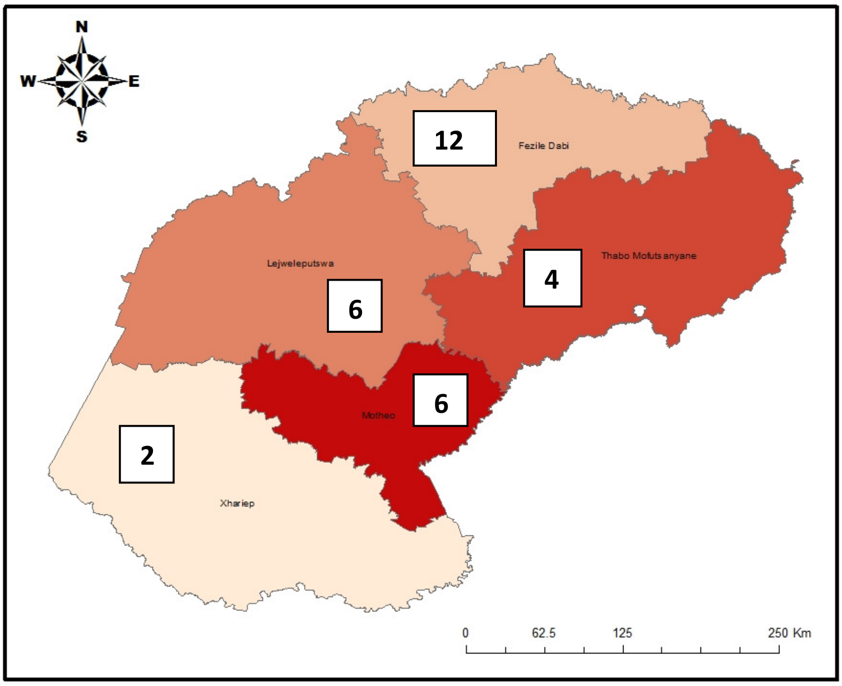


Figure 5.3: The five district municipalities in the Free State Province, with the number of angling clubs in each district. The intensity of the red color indicates the most populous district municipalities.

Most angling clubs affiliated with the FSFBAA are situated in the Fezile Dabi District Municipality, which may be attributed to the fact that the Vaal Dam lies within the municipal borders and in very close proximity to the large Vaaldriehoek urban area, including the urban areas of Vanderbijlpark and Vereeniging in the Gauteng Province, and Sasolburg in the FSP. The Mangaung Metropolitan and Lejweleputswa District Municipalities each have six angling clubs which may be linked to the fact that these areas include the major urban areas of Bloemfontein, and Welkom and Kroonstad, respectively. Despite the presence of the largest impoundment in South Africa and a number of other large impoundments in the Xhariep District Municipality, only two angling clubs exist here that can be attributed to the lack of any major urban areas and the high rate of urbanisation.

According to the membership records of the FSFBAA, 804 anglers were affiliated with the 30 angling clubs in the FSP in 2013. The number decreased to 688 affiliated and 60 social members by December 2014. When expressed as a percentage of total license sales it is evident that about 10% of anglers licensed to fish in the FSP are affiliated to clubs.

5.3.3 Catch compositions and landings of angling tournaments

During this study the results and records of angling tournaments dating back to 1974 for 17 impoundments were obtained. Of the 21 selected impoundments for this study, no angling tournament data were available for Armenia, Egmont, Metsi Matso, Mockes and Serfontein Dams as these impoundments have no to limited importance for recreational fisheries. The distribution of tournament effort between impoundments is summarised in Table 5.4.

Table 5.4: Distribution of tournament effort between impoundments in the Free State Province.

Impoundment	Mean number of anglers per year	StDev	Average number of tournaments per year	Mean number of anglers per tournament
Allemanskraal	216	218	8.4	25.8
Bloemhoek	279	137	13.3	20.9
Bloemhof	622	568	20.8	29.9
Erfenis	74	55	3.2	23.1
Gariep	92	80	6	15.4
Jimmie Roos	42	57	2.3	18.3
Kalkfontein	89	81	4.3	21
Knellpoort	18	11	1.3	14.6
Koppies	507	635	18.7	27.1
Krugersdrift	502	462	24.8	20.3
Moutloatsi Setlogelo	68	52	4	17.1
Rustfontein	604	451	24.7	24.5
Sol Plaatje	193	214	10.5	18.4
Sterkfontein	147	122	7	21
Tierpoort	42	36	2.3	18.6
Vaal	599	520	25.3	23.6
Welbedacht	122	116	4.8	25.2
Total	4 218			

StDev – standard deviation

Bloemhof Dam, followed by Rustfontein, Vaal, Koppies and Krugersdrift Dams had the largest number of anglers participating in angling tournaments per year. On average, most tournaments were held at Vaal Dam, followed by Krugersdrift, Rustfontein, Bloemhof and Koppies Dams. The most anglers per tournament were observed for Bloemhof, Koppies, Allemanskraal, Rustfontein and Vaal Dams. The high effort and participation of recreational anglers at Bloemhof Dam, can be attributed to the fact that this impoundment is the most important and popular venue for bank angling in South Africa. Krugersdrift and Rustfontein Dams are situated close to the Mangaung Metropolitan Municipality and are the preferred choice for angling tournaments. Koppies Dam is preferred by angling clubs in the Northern Free State as a tournament venue. Because of its large surface area and close proximity to the Gauteng Province, Vaal Dam is also one of the most preferred angling tournament venues.

The total number of tournament angling days is summarised in Figure 5.4. The trends in the numbers of anglers illustrate a general increase in the number of tournament days between 1974 and 2000. There were limited records submitted in 1994, the year that South Africa changed to a democracy. After 2000, a limited number of record forms for the period 2001 until 2008 were available due to improper record keeping and the permit office that moved a number of times, during which files were misplaced,. However, due to data for 2013 and 2014 being collected personally, it is believed that the 2013 and 2014 data are accurate. This indicates a general decline of tournament angling effort in the FSP between 2000 and 2014.

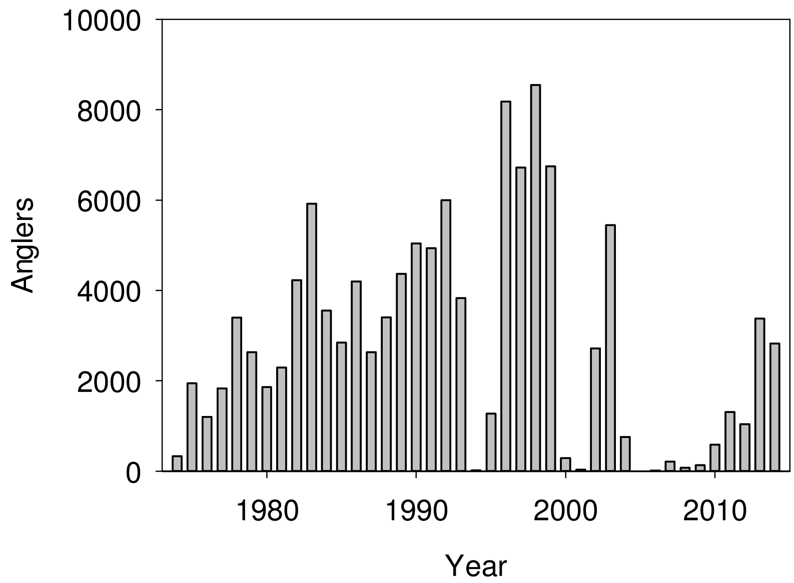


Figure 5.4: Total number of angling days based on angling tournament records of 17 impoundments in the Free State Province from 1974 to 2014.

5.3.4 Catch composition

Species composition data from tournament submissions are shown in Tables 5.5 and 5.6 while annual catch data are available in Appendixes 16 to 32.

In total, 429 261 fish weighing 414 tons were reported for 4 817 angling tournaments that were held at 17 impoundments for the period 1974 to 2014. The fish species caught during these angling tournaments were *Labeobarbus* spp. (mostly *Labeobarbus aeneus*), *Labeo umbratus, Labeo capensis, Clarias gariepinus, Cyprinus carpio* and *Ctenopharyngodon* *idella*. Due to the restrictions enforced by the FSP's NCO (1969) and NCR (1983), very few *Labeobarbus* spp. were reported as these fish were normally released immediately.

Table 5.5: Catch composition and total weight (%) per species caught during angling tournaments at 17 impoundments in the Free State Province for the period 1974 to 2014.

Impoundment	Total weight of total catch (kg)	*Labeobarbus* spp. (%)	*Labeo umbratus* (%)	*Labeo capensis* (%)	*Clarias gariepinus* (%)	*Cyprinus carpio* (%)	*Ctenopharyngodon idella* (%)
Allemanskraal	14 868	3.3	0.1	7.6	33.1	55.8	0.0
Bloemhoek	1 102	0.1	0.1	19.9	2.9	77.0	0.0
Bloemhof	158 068	0.3	0.0	0.9	7.5	91.1	0.3
Erfenis	5 183	2.2	0.0	1.6	54.1	42.2	0.0
Gariep	3 289	2.4	0.0	1.0	13.0	83.6	0.0
Jimmie Roos	1 382	0.0	0.7	0.5	0.9	97.8	0.0
Kalkfontein	5 898	5.6	0.2	3.0	7.2	84.1	0.0
Knellpoort	504	0.4	0.0	7.2	4.9	87.4	0.0
Koppies	36 993	5.7	0.1	30.1	18.1	46.1	0.0
Krugersdrift	68 539	0.4	0.1	1.1	10.5	88.0	0.0
Moutloatsi Setlogelo	1 469	0.0	0.0	10.5	15.6	73.8	0.0
Rustfontein	59 599	2.0	0.1	11.5	5.3	81.0	0.0
Sol Plaatje	1 433	1.3	0.0	24.1	17.5	57.1	0.0
Sterkfontein	3 913	7.7	1.3	65.1	5.1	20.8	0.0
Tierpoort	1 210	0.0	0.0	0.0	2.3	97.7	0.0
Welbedacht	657	0.6	0.0	0.4	65.0	34.1	0.0
Vaal	50 018	1.1	0.0	10.9	7.5	77.7	2.6
TOTAL	414 125						

Table 5.6: Catch composition and total number of fish per species caught during angling tournaments (expressed as %) at 17 impoundments in the Free State Province for the period 1974 to 2014.

Impoundment	Total number fish caught	*Labeobarbus spp.* (%)	*Labeo umbratus* (%)	*Labeo capensis* (%)	*Clarias gariepinus* (%)	*Cyprinus carpio* (%)	*Ctenopharyngodon idella* (%)
Allemanskraal	17 445	4.4	0.2	14.6	27.1	53.7	0.0
Bloemhoek	2 289	0.0	0.0	32.1	2.1	65.7	0.0
Bloemhof	140 539	0.4	0.0	1.7	5.7	91.7	0.5
Erfenis	3 254	5.2	0.0	4.9	43.8	46.2	0.0
Gariep	2 535	2.1	0.0	1.6	8.6	87.7	0.0
Jimmie Roos	1 467	0.0	1.4	1.3	2.3	95.0	0.0
Kalkfontein	5 594	6.3	0.2	3.9	5.9	83.7	0.0
Knellpoort	1 155	0.3	0.0	8.5	2.7	88.6	0.0
Koppies	45 878	6.9	0.1	35.7	10.1	47.3	0.0
Krugersdrift	63 829	0.7	0.1	2.2	6.3	90.7	0.0
Moutloatsi Setlogelo	1 452	0.0	0.0	33.3	5.9	60.8	0.0
Rustfontein	67 875	2.8	0.1	17.2	4.7	75.2	0.0
Sol Plaatje	1 849	0.8	0.0	32.6	17.1	49.5	0.0
Sterkfontein	6 629	3.5	0.8	84.1	2.2	9.4	0.0
Tierpoort	878	0.2	0.0	0.1	0.9	98.7	0.0
Welbedacht	471	1.9	0.0	0.6	90.9	6.6	0.0
Vaal	66 122	1.2	0.0	17.1	8.6	70.8	2.2
TOTAL	429 261						

At most impoundments sport angling catches were dominated by *C. carpio* which made up between 42 and 98% of the weight, and 9 and 99% of the total catch in number. Overall this species comprised 81% of the weight and 77% of the numbers of all fish landed by tournament anglers making it the most important angling species.

Other important angling species were *L. capensis, C. gariepinus* and *L. aeneus.* The total catch at Sterkfontein Dam was dominated by *L. capensis* (84%) with only 9% of the total catch consisting of *C. carpio*. The second most important angling species caught at most impoundments after *C. carpio* was *L. capensis* with a contribution of 33% at Moutloatsi Setlogelo, 33% at Sol Plaatje and 32% at Bloemhoek Dams to the total catch.

The total catch at Welbedacht Dam was dominated by *C. gariepinus* (91%) with the second most *C. gariepinus* (44%) caught at Erfenis Dam. Except for these two impoundments, *C. gariepinus* contributed between 1% (Tierpoort Dam) to 27% (Allemanskraal Dam) to the total catch. This may be attributed to the fact that the main target species during angling tournaments using ground bait was *C. carpio* and that *C. gariepinus* does not readily pick up this type of bait.

It is a well known fact that *L. umbratus* is not an angling species as it is very seldom caught on hook and line. The highest percentage of this species was caught at Jimmie Roos Dam (>1%), which has an extremely large population of *L. umbratus* (see Chapter 6) and at Sterkfontein Dam (<1%) with its clear water.

At Bloemhof Dam, *C. idella* was recorded for the first time in sport anglers' catches during 2003, while at Vaal Dam this species was already caught during 1999 (see Appendix 18 and 32). Since 2012 there was a gradual increase in the number of *C. idella* caught by sport anglers and this species might become another popular target species for sport and recreational anglers in the future.

5.3.5 Catch Rates

Preliminary analysis of catch per unit effort (CPUE) data within impoundments did not detect any consistent trends with age or water level. As a result, data for all years were grouped with mean CPUE calculated from annualised data (Appendix 16 to 32). The relationship between total CPUE and CPUE for the primary target species *C. carpio* is shown in Figure 5.5. This demonstrates that this species drives CPUE and subsequent comparisons were performed using species aggregated CPUE data only.

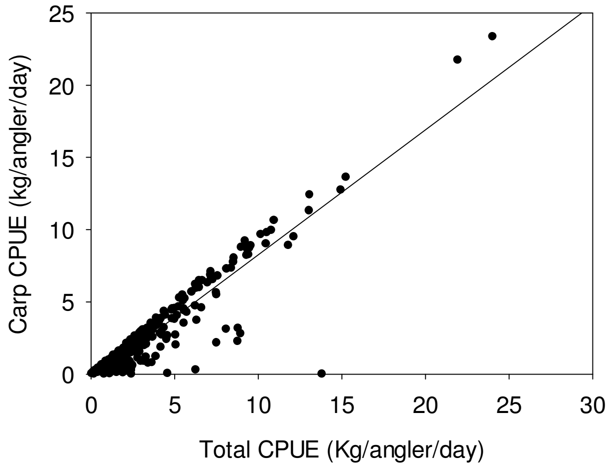


Figure 5.5: Total catch per unit effort (CPUE) versus CPUE for *Cyprinus carpio*.

In comparison, CPUE was surprisingly consistent between impoundments with only the CPUE from Bloemhof Dam being significantly higher (Kruskall Wallis non parametric ANOVA, $p < 0.05$) than that from all other impoundments (Figure 5.6).

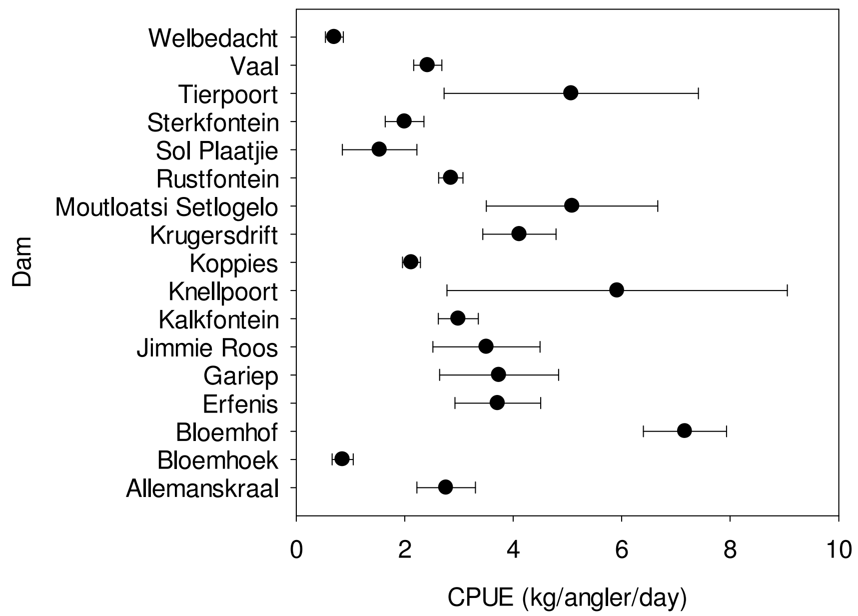


Figure 5.6: Comparison of catch per unit (CPUE) effort between impoundments.

5.4 Discussion and conclusion

In South Africa and the FSP, recreational fisheries have historically been the most important inland fisheries sector (Marshall and Maes, 1994; Weyl *et al.,* 2007; Welcomme, 2011a; 2011b; McCafferty *et al.,* 2012), with subsistence fisheries increasing on a number of impoundments (Ellender *et al.*, 2009; 2010b).

Yates (1963) provided the first overview of recreational fisheries in the former Orange Free State Province and noted the limited angling opportunities that existed in the Province due to the seasonal flows of the rivers. The author reported that the best angling was done in the rivers on the border of the Province where after rains, carp and yellowfish appeared in large numbers.

With the development of the Orange River Development Project (ORDP) which included the building of a number of large impoundments, Opperman (1965) noted the vast potential the project had for the development of recreational facilities and fisheries in central South Africa, which indeed happened from the early 1970's.

McCafferty *et al*. (2015) commented that despite the substantial economic value of the recreational fishery sector in South Africa, a limited number of studies were done to quantify and qualify the sector. A study by Du Plessis and Le Roux (1965) reported that during 1951/1952, 29 012 angling licenses were sold in the former Transvaal Province (today Limpopo, Mpumalanga, Gauteng and North West Provinces) which increased to 61 380 during 1962/1963. Skelton (1993) noted that during 1964 the number of angling licences sold in that province increased to 68 000, while Mulder (1971) estimated the number of recreational anglers during 1970 at 100 000 and Cadieux (1980) reported on 117 093 angling licenses sold during the 1977/1978 angling season for that province.

The only available historic information on the number of recreational anglers in the FSP is from Marshall (1972) who reported that there were 23 708 recreational anglers in the former Orange Free State Province during 1970 with the number increasing to 32 065 in 1971. The current enumeration of license sales shows that during 2014, there were 7 710 recreational anglers in the FSP. This shows that there has been a 76% decrease in the number of recreational anglers since 1971. This decrease in the number of recreational anglers is supported by an almost identical decrease in reported tournament effort between a maximum of 8 548 tournament days in 1998 to 2 828 days in 2014, which is 33% of the 1998 levels. The applicable regulation for hosting angling tournaments according to the Nature Conservation Ordinance have not changed and the decreases are an indication of a decrease in the number of recreational anglers and not any change in legislation. Although there is an increase in the number of subsistence anglers at many impoundments, these anglers do not obtain angling licenses unless they fish within the borders of a formally protected area where regular inspections are done by law enforcement officials.

During 2013 and 2014, 8 256 and 7 710 angling licenses were sold in the FSP. All anglers that are affiliated with angling clubs are obliged to obtain an angling license. The majority of subsistence anglers, however, are unlicensed. This is evident as reported by Ellender (2008) who noted the presence of nearly 450 subsistence fishers at Gariep Dam, most of which did not have an angling license. Of the total anglers at Gariep Dam, only 40% were recreational anglers with 60% being subsistence fishers. It was estimated that the total catch of subsistence and recreational anglers were 71 tons during the survey period, while another eight tons were caught during angling tournaments (Ellender *et al.,* 2010a). This indicates that angling effort at impoundments where both subsistence and recreational anglers fish, urgently need to be evaluated as it is clear that angling license sales may not provide a true reflection of angling effort.

Du Plessis and Le Roux (1965) noted that during 1956/1957 an estimated 49 000 recreational anglers exerted a total of 1.7 million man-days of fishing effort in the former Transvaal Province. The primary target species were *C. carpio*, *Tilapia* spp. and *C. gariepinus*. Cochrane (1987) after a study in the hypereutrophic Hartbeespoort Dam estimated the potential annual average yield by recreational fisheries for *C. carpio* at 449 tons and 144 tons for *C. gariepinus*. Based on the results of a postal survey in the late 1970's, Cadieux, (1980) noted than an estimated 9.5 million fish with a total biomass of 9.7 tons were caught in the former Transvaal Province. The recreational anglers' catches were dominated by *Tilapia* spp. (33.6%), *C. carpio* (28.9%), *Labeo* spp. (12%) and *C. gariepinus* (9%), but most anglers' (29%) preferred angling species was *C. carpio*. Based on the tournament data for the FSP, *C. carpio* remains the dominant target species for recreational anglers and constituted overall

81% of the total weight and 77% of the total numbers of all fish landed, with other native species making up a small proportion of catches. This was surprisingly consistent with results from the only comprehensive creel survey based on more than 700 angler interviews and catch inspections done by Ellender *et al.* (2009; 2010a; 2010b) that found that angler catches comprised mainly of *C. carpio* (74%), followed by *L. capensis* (13%) and *L. aeneus* (8%), while *L. kimberleyensis* contributed less than 0.5% to the total catch.

It is evident that *C. carpio* was able to invade and become established in all the major water systems and large impoundments in many parts in South Africa (Bruton and Merron, 1985; De Moor and Bruton, 1988; Skelton, 1993). This species has been listed on the new Alien and Invasive Species list (AIS, 2014) which prohibits the further spread of the species into areas where it does not occur. It also requires that an invasive species management plan must be drafted to control and manage the current populations in impoundments. Due to *C. carpio* being the most popular and targeted bank angling and recreational fishery species in the FSP, this has been met by some resistance from the recreational fishery sectors. Four different bank angling sectors, i.e. match, carp, feeder and bank angling that resorts under SAFBAF mostly targets *C. carpio* and after most tournaments, all *C. carpio* are released. There is thus a conflict between the mandate of environmental and conservation agencies to stop the spread of *C. carpio*, while the recreational angling sector wants to see the species protected and conserved, ensuring the survival of their most popular angling species, as well as leisure and sport associated with this species.

Considerations for fisheries development

Based on the number of angling licenses sold at provincial nature reserves and resorts and where angling tournaments were held, the most important impoundments in the FSP for bank angling are Allemanskraal, Bloemhof, Erfenis, Koppies, Krugersdrift and historically Rustfontein Dams. These impoundments' surface areas at full supply level, except for Rustfontein Dam, are larger than 1 400 ha. During the current study, a total of 33 impoundments in the FSP were identified as of low importance for recreational fisheries. If the seven impoundments ranked as of high importance are included, it can be concluded that out of the 412 registered impoundments in the FSP, only 40 are deemed as important recreational fisheries.

Impoundments located close to urban areas (e.g. Krugersdrift, Rustfontein, Allemanskraal, Erfenis, Koppies and Vaal Dams) were visited by the most recreational anglers. Cadieux (1980) also noted that the most popular angling venues in the former Transvaal Province were those close to major urban areas. The popularity of Hartbeespoort Dam as an angling venue was attributed by Cochrane (1987) as being due to its close proximity to two major urban areas, namely Pretoria and Johannesburg in the Gauteng Province.

Unfortunately no quantative assessment has ever been done on the economic value of the sport and recreational fisheries sector and its contribution to the economy of FSP. Previous attempts during the 1990's to investigate and determine the monetary contribution of angling and all associated activities to the annual income of reserves and resorts failed due to a lack of participation from anglers and visitors to reserves (P. Bosch[3], personal communication, 12 November 2014).

The contribution is, however, likely to be considerable. Cadieux (1980) estimated the value of the fishing equipment used by recreational anglers at ZAR130 million. Brand *et al.* (2009) reported that the economical value of the fly fishing industry targeting the two Orange Vaal River yellowfish species in sections of the middle Vaal River was worth approximately ZAR133 million. In their study of the trout fly fishing industry in the north Eastern Cape, Du Preez and Lee (2010) found that the trout industry contributed nearly ZAR5.6 million to the local economy of Rhodes, while sustaining employment for 39 community members. The extent to which recreational fisheries contribute to the local economy of the FSP thus needs further investigation as no official data and information is available. It is therefore important that government recognises the contribution of this sector to the local, provincial as well as national economy and that this sector's place in future policies and guidelines, are secured. An important part of this is to attempt to limit conflicts between recreational anglers and new fisheries.

Anglers also appeared to be highly selective in target species and Ellender (2008) and Winker *et al.* (2012) have shown that recreational anglers' catches can differ considerably from those

([3] P. Bosch, Resort manager at Sandveld Nature Reserve at Bloemhof Dam) in survey and commercial gear, and therefore fisheries independent surveys were conducted to determine the relative abundance, population and community structure of freshwater fish at 21 impoundments within the borders of the FSP. These are reported on in Chapter 6.

Chapter 6 Freshwater fishes in Orange-Senqu and Vaal River System impoundments

6.1 Introduction

The southern African fish fauna is dominated by cyprinids (Bruton *et al.,* 1982). Most species occur in the more tropical areas to the north, while very few species are found in the more temperate regions in South Africa (Bruton *et al.,* 1982), including the centrally situated Free State Province (FSP). Skelton (1993) estimated that there are 270 freshwater fish species in southern Africa, and 112 in South Africa of which 94 are indigenous and 18 established alien species (Skelton *et al.,* 1995). Conversely, the ichthyofauna of the Orange-Senqu River System (OSRS) is known for the low species diversity. Jubb (1972) noted the presence of 13 indigenous and six alien species within the OSRS, while Skelton (1986) noted the presence of only 16 indigenous species. Benade (1993) recorded 26 fish species in the OSRS within the borders of the former Cape Province of which five were estuarine species, six endemic species, one translocated indigenous species, five alien and nine indigenous species. Jackson *et al.* (1983) attributed the low species diversity to the geological history of southern Africa and the cold temperatures experienced especially during winter.

The larger cyprinids in the Orange-Senqu River and Vaal River Systems are adapted to the unpredictable flow and the increase flow and flooding events during spring, while the summer rainfall months are the stimulus for spawning to take place (Skelton, 1986). As a result, Skelton (1986) noted the difficulty in predicting the fish population trends within impoundments in the Orange Vaal River Systems (OVRS) and attributed this to the unique characteristics of each impoundment and the highly regulated nature of water levels within impoundments. This is particularly pertinent because cyprinids often fail to adapt to impoundment conditions. Various studies in North America also reported on a decline in number of cyprinids after impoundments were built. Quist and Hubert (2004) observed the major influence of impoundments on the distribution and abundance of cyprinids in the Missouri River System that preferred lotic systems. Eley *et al.* (1981) noted the extirpation of 28 fish species, mostly cyprinids, from the lower reaches of the Mountain Fork River System in Oklahoma, as 20 cyprinid species were recorded before the impoundment started, which decreased to only 11 species.

The understanding of fish populations in FSP's impoundments is further complicated by the lack of recent data. Most studies (e.g. Hamman, 1974; 1981; Allanson and Jackson, 1983; Tomasson and Allanson, 1983; Tomasson *et al.,* 1983; Dörgeloh, 1986) were conducted soon after water was impounded. Hamman (1981) noted the lack of information on the occurrence and distribution of freshwater fish in the area of the Orange-Senqu River before the building of the former Verwoerd Dam (Gariep Dam) started. The author mentioned that historic reports have indicated that *Labeobarbus aeneus* and *Labeo capensis* were the dominant species, while *Labeobarbus kimberleyensis, Labeo umbratus, Cyprinus carpio* and *Clarias gariepinus* contributed less than 5% to the total catches. After impoundment, it was noted that *L. aeneus* and *L. capensis* were also the dominant species in catches, but that the new lentic habitats created more favorable habitats for *C. carpio* and *L. umbratus,* while *C. gariepinus* also benefitted from the newly created lentic system (Hamman, 1981). The only studies done after maturity of Gariep Dam were by Ellender (2008) and Winker (2010). Ellender (2008) found that the dominant species in gill net catches were *L. capensis* and *L. aeneus*, while the other four fisheries species (*L. kimberleyensis, C. carpio, C. gariepinus* and *L. umbratus*) only contributed 21% to the total catch. Winker (2010) noted that the establishment of *C. carpio* in Gariep Dam did not impact negatively on the successful establishment of *L. capensis* and *L. aeneus*, although the establishment of the latter two species happened over a longer period of time.

Despite having the largest inland water surface area in South Africa, since the mid 1970's limited research was done on the fish stocks and fish communities at state impoundments in the FSP, even after the establishment of commercial fisheries during the late 1970's. Only during the mid 1990's were fish surveys done at 11 state impoundments of which the results have been summarised by Barkhuizen (1995; 1996). Understanding establishment success and fish species compositions in the FSP are extremely important due to the recent interest in the promotion and development of inland fisheries. Britz *et al.* (2015) also noted the limited information available on fisheries and fish communities at impoundments in South Africa. The authors motivated for in depth and detailed research surveys to determine the potential fish yield, fish stocks as well as potential social and economic aspects of fisheries and fish at impoundments to ensure sustainability.

As a result, a survey of 21 medium and large impoundments situated in the main stems and tributaries of the OVRS were done to determine current species composition and population structure, and where possible, compare it to historical survey data. To determine the similarity of fish assemblages amongst the 21 selected impoundments, Jaccard's Index of Similarity (Jaccard, 1912), was applied. An investigation was done to determine possible differences in species composition within the off-shore and littoral zones at impoundments, and which fish species are established. Lastly, an investigation was done to determine the possible environmental and morphometric variables driving the distribution of fish species within the impoundments.

6.2 Materials and Methods

6.2.1 Fish surveys done during 2012/2013 and 2013/2014 summer seasons

In total 21 impoundments were sampled over the two year research period. Twelve of these, which were sampled during the 2012/2013 summer season, are situated within the borders of, or adjacent to provincial nature reserves. For the 2013/2014 season, 11 of these impoundments were sampled again. Further study sites were selected to ensure that at least one large or medium size impoundment within the main tributaries of OSRS and VRS was included. The dates when the fish surveys were done, are presented in Table 6.1, while the location of the 21 impoundments is indicated in Figure 6.1

Table 6.1: Location of impoundments within the Orange-Senqu and Vaal River Systems and dates when fish surveys were done.

River System	Impoundment	Locality within system	Date/s of surveys
Vaal	Allemanskraal	Main dam in Sand River	28 – 31/01/2013 11 – 13/12/2013
	Bloemhoek	Jordaan Spruit: part of inter-basin transfer scheme and receives water from the Vals River	10 – 12/02/2014
	Bloemhof	In main stem of Vaal River but Vet River also enters dam	18 – 21/02/2013 7 – 9/01/2014
	Erfenis	Main dam in Vet River	21 – 24/01/2013 9 – 11/12/2013
	Kalkfontein	Third main dam downstream in Riet River	10 – 14/12/2012 27 – 29/11/2013
	Koppies	Only main dam in Renoster River	3 – 7/12/2012 2 – 6/12/2013
	Krugersdrift	Fourth main dam downstream in Modder River	26 – 30/11/2012 20 – 22/11/2013
	Metsi Matso	Metsi Matso River which is head water stream that eventually enters tributary of Wilger River	13 – 15/01/2014
	Mockes	Second main dam downstream in Modder River	17 – 19/02/2014
	Moutloatsi Setlogelo	Kgabanyane Spruit which is tributary of Modder River	5 – 9/11/2012 4 – 6/11/2013
	Rustfontein	First main dam downstream in Modder River	19 – 22/11/2012 6 – 9/11/2013
	Serfontein	Vals River	12 – 13/02/2014
	Sol Plaatje	Ash and Liebenbergsvlei Rivers, main tributary of Wilger River – receive water from Lesotho Highlands Project	4 – 6/03/2014
	Sterkfontein	Nuwejaarspruit – small tributary of Wilger River; receive water from Upper Tugela via hydro-power pump scheme	25 – 28/11/2012 17 – 19/12/2013
	Tierpoort	Main dam in Tierpoort River which is tributary of Riet River	25 – 26/11/2013
Orange-Senqu	Armenia	Third impoundment downstream in Leeu River which is main tributary of Caledon River	20 – 22/01/2014
	Egmont	Wit Spruit: tributary of Caledon River	27 – 29/01/2014
	Gariep	Main stem of Orange-Senqu River	4 – 8/03/2013 22 – 24/02/2014
	Jimmie Roos	Onder Krom Spruit	19 – 21/02/2014
	Knellpoort	Riet Spruit: upstream in small tributary leading to Welbedacht Dam; receives water from Caledon River	13 – 15/02/2013 18 – 20/11/2013
	Welbedacht	Main stem of Caledon River which is main tributary of the Orange-Senqu River	11 – 12/02/2013

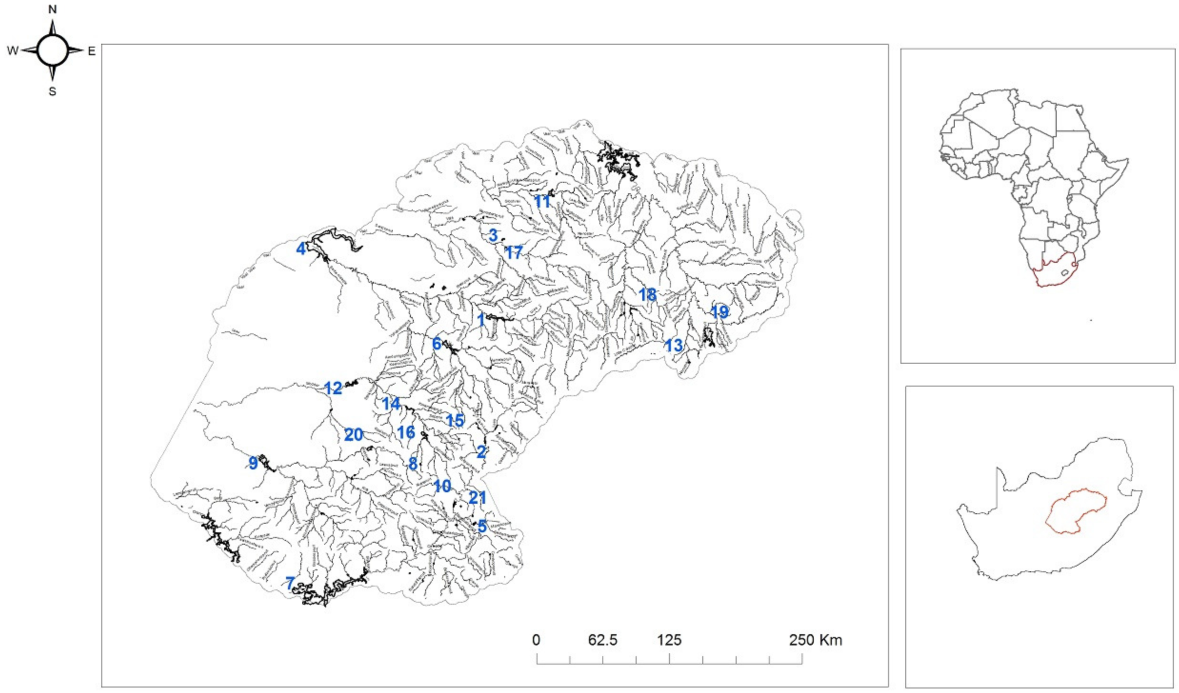


Figure 6.1: Location of the 21 impoundments within the OSRS and VRS: (1 – Allemanskraal; 2 – Armenia; 3 – Bloemhoek; 4 – Bloemhof; 5 – Egmont; 6 – Erfenis; 7 – Gariep; 8 – Jimmie Roos; 9 – Kalkfontein; 10 – Knellpoort; 11 – Koppies; 12 – Krugersdrift; 13 – Metsi Matso; 14 – Mockes; 15 – Moutloatsi Setlogelo; 16 – Rustfontein; 17 – Serfontein; 18 – Sol Plaatje; 19 – Sterkfontein; 20 – Tierpoort; 21 – Welbedacht).

6.2.2 Fish sampling methods

Fisheries independent sampling using gill, seine and fyke nets was done. In order to ensure consistency, all fieldwork, collection and sampling of fish, all data recording and processing were done by the author. Experimental gill netting was done during the research period as indicated in Table 6.1. Three fleets of multifilament gill nets that consisted of green nylon netting material with stretched mesh sizes of 28, 44, 50, 75, 100 and 144 mm, as prescribed to and requested from the manufacturer of the nets, were used. Each fleet was 120 m long x 3 m deep and consisted of 20 m panels of each mesh size. The mesh panels were distributed from the smallest mesh (28 mm) to the largest (144 mm) in each fleet. All gill nets were set parallel to the shore in water with a depth between 3 to 5 m. During the 2012/2013 fish surveys, all gill nets were set between 14:30 and 16:00, and lifted the next morning between 08:00 and 10:00 after which the soaking time was recorded. For net night one, the fleets were set randomly in the vicinity of the dam wall, for net night two nets were set in the main lake area, and for the last night near the river section. During the 2013/2014 fish surveys, the three fleets were set randomly in the main lake area and included two netting nights during which nets were set between 14:30 and 16:00 on day one, checked on day two, and lifted on day three between 08:00 and 10:00. The soaking times were also recorded for each fleet.

A 100 m x 3 m seine net, consisting of green, multifilament nylon netting material with a stretched mesh size of 75 mm, was used to sample fish in the littoral zone. The net, to which 100 m of 20 mm polyethylene rope was added to each end to ensure a larger area is covered during seining, was set from a boat in semi-circle and pulled to the shore by two teams. A 10 m x 2 m seine net, consisting of green, multifilament nylon netting material with a stretched mesh size of 10 mm was used in the shallower littoral zones. Sections of 50 m were measured on the shore line and the net was pulled parallel to the shoreline until the end of the section was reached.

Three double ended Dutch type fyke nets, which were covered in multifilament light brown netting material with a stretched mesh size of 20 mm covering both hoops, and 25 mm mesh size covering the entrances, were included as sampling gear during the 2013/2014 surveys. Each net consisted of a guiding (leader) net between the two sections, with nine hoops in each section to which cone shape netting bags were attached. The fyke nets, which were not baited, were set parallel to the shore in water with a depth of 1 to 1.5 m and were in the water for two netting nights (Refer to Chapter 7 for more information on the measurements of the fyke nets). The fyke nets were lifted, and fish removed on day three and the soaking time recorded.

At each sampling site during both seasonal fish surveys the following parameters were recorded:

- GPS coordinates and altitude using a handheld Garmin GPSmap 62.
- Notes were made of the prevailing weather conditions and interesting features.
- Water temperature, pH, conductivity (EC) and total dissolved solids (TDS) using a handheld Crison Portable Multimeter MM40+ meter with a 5059P probe.

- Air temperature using a handheld thermometer.
- Secchi depth.

6.2.3 Fish samples

Fish caught in the gill nets were sorted according to the mesh size in which they were caught, identified to species level and measured for fork and, or total length (to the nearest millimeter) depending on species. Smaller specimens (< 3 kg) were weighed using a Terraillon T800 scale with a maximum capacity of 3 kg (accuracy of 1 g), while larger specimens (> 3 kg) were weighed using an Ishida IPC 1356 scale with a maximum capacity of 15 kg and an accuracy of 5 g.

6.2.4 Establishment and population structure

Establishment success of the larger fish species with fisheries potential (i.e. *C. carpio, C. gariepinus, Ctenopharyngodon idella, L. aeneus, L. capensis, L. kimberleyensis, L. umbratus* and *Micropterus salmoides*) was based on an assessment of their population structure. To do this, length data were sorted into 100 mm fork length (FL) size classes. These size classes represent important periods in the life history of these large bodied fishes. Young of year are generally < 100 mm; immature fish with length ranging from 110 – 300 mm while maturity in the larger cyprinids is attained at lengths of > 300 mm (see Table 2.4, Chapter 2). Due to the larger size of *C. gariepinus* the catch data for this species were sorted within 200 mm size classes and was based on total length.

6.2.5 Jaccard's Index of Similarity

Similarity of fish assemblages in 20 selected impoundments was tested using Jaccard's Index of Similarity (Jaccard, 1912) which is based on the presence and absence of species, using the following equation:

$$S_J = \frac{a}{(a + b + c)}$$

where S_J is Jaccard's similarity coefficient;
a is the number of species shared between two sites;
b is the number of species unique to site 1, and
c is number of species unique to site 2.

S_J was expressed as a percentage of the complete similarity.

6.2.6 Environmental and morphometric drivers for fish distribution and abundance

Catch per unit effort (CPUE) for gill nets was determined as the total weight per fish species caught per gill net per netting night. Gill net catch data for the six main fishery species caught during the 2012/2013 and 2013/2014 summer seasons' fish surveys were combined which equates for the 2012/2013 surveys to: 11 impoundments x three gill net fleets x three netting nights = 99 gill net nights + 1 impoundment (Welbedacht Dam) x three gill net sets x one netting night = 3 gill net night; thus 102 gill net nights. For the 2013/2014 surveys it equated to: 18 impoundments x three gill net fleets x 2 netting nights = 108 gill net nights + 2 impoundments (Serfontein and Tierpoort Dams) x three gill net fleets x 1 netting nights = , 6 gill net nights = 114 gill net nights. For both surveys it equates to 216 gill net nights.

To determine the drivers of the distribution of fish species at the sampled impoundments, 13 quantitative and nine qualitative variables were originally identified for analyses. After an initial assessment, it was reduced to 12 quantitative and six qualitative variables. Using a Canonical Correspondence Analysis (CCA), the measured environmental and morphometric variables obtained for the 20 sampling sites (impoundments) were related to the species variation. Based on an inspection of the length of the gradients of the first four canonical axes, a decision was taken to use a unimodal based technique. This was based on the longest gradient length of 3.67 SD units (standard deviation of the species response curves), which was determined through the use of a detrended correspondence analysis. Bi-plot scaling was chosen as the preferred scaling type, which in unimodal methods allows species and sample points to be projected onto quantitative environmental variables.

To reduce the number of variables, standard methods and procedures developed for this purpose were applied, specifically the use of forward selection and removal of the collinear variables. After removal of the collinear and statistically non-significant variables, a slight decrease in the Eigen values from 0.361 to 0.32 was observed, indicating that some explanatory ability was lost, which was deemed as acceptable. The remainders of the variables were also tested for statistical significance with the $p < 0.05$, indicating statistical significance in explaining species distribution. The first two axes of CCA analysis were projected using CanoDraw software to create an ordination diagram.

6.2.7 Historical data sources

In order to compare the current results with historic fisheries data that are kept in hard copy in the library of the Free State Department of Economic, Small Business Development, Tourism and Environmental Affairs (FS DESTEA) in Bloemfontein, a literature search was done to obtain these.

6.3 Results

6.3.1 Presence, absence and relative abundance of fish species

The presence and absence and relative abundance of fish species caught with all gear types (i.e. gill, seine and fyke nets) during the 2012/2013 and 2013/2014 fish surveys are summarised in Table 6.2.

Due to the locality of Metsi Matso Dam in the far upper reaches of the Metsi Matso River in the Drakensberg Mountain range at the highest altitude of all the selected impoundments and the fact that only eight *Oncorhynchus mykiss* were caught, which was artificially stocked in the impoundment, the results of the impoundment's fish survey will be excluded in the further discussions of this chapter.

Table 6.2: Presence, absence and relative abundance of fish species at the selected impoundments in the Orange-Senqu and Vaal River Systems.

Species	Total fish caught	A.sc. %	B.an. %	B.pa. %	C.au. %	C.ca. %	C.ga. %	C.id. %	G.af. %	L.ae. %	L.ca. %	L.ki. %	L.um. %	M.sa. %	P.ph. %	T.sp. %	Total number of species
Impoundments in VRS																	
Allemanskraal	**1 052**	0	0	0.9	0	45.2	0.5	0	1.8	2.7	11.2	1.0	36.8	0	0	0	8
Bloemhoek	**627**	0	0	0	0	51.7	3	0	0	0.2	30	0.5	12.3	0.6	0	0	7
Bloemhof	**1 256**	0	0	0.1	0	62.2	11.6	4.7	0.1	4.3	3.7	0	9.1	0	4.1	0.1	10
Erfenis	**3 530**	0	0	36.8	0	26.9	0.8	0	0	14.4	7.4	2.7	10.8	0.1	0	0	8
Kalkfontein	**3 392**	0	0	0	0	75.3	1.4	0	0	5.2	8.4	0.9	8.8	0	0	0	6
Koppies	**2 634**	0	0	11.9	0	25.6	9.3	0	0.1	22.5	4	4.2	21.3	0	1.1	0	9
Krugersdrift	**1 582**	0	0	6.9	0.7	36.7	6.4	0	0	3.7	8.7	0.1	26.2	0	10.6	0	9
Mockes	**779**	0	0.1	0	0	80.4	11.8	0	0	1.2	1.5	0.4	4.2	0	0.4	0	8
Moutloatsi Setlogelo	**731**	0	0.3	0	0	12	10.9	0	0	0	49	0	27.4	0.4	0	0	6
Rustfontein	**884**	0	0	0.1	0	17.9	5.2	0	0	17.1	31.8	0.9	19.5	0	7.6	0	8
Serfontein	**54**	0	0	0	0	31.5	42.6	0	0	1.9	14.8	0	9.3	0	0	0	5
Sol Plaatje	**116**	0	0	0.9	0	22.4	1.7	0	0	30.2	31	0	12.9	0.9	0	0	7
Sterkfontein	**528**	0.6	37.3	0	0	0.2	1.9	0	0	34.3	18.6	0.6	5.5	1.1	0	0	9
Tierpoort	**505**	0	0	0	0	48.7	12.2	0	0	16.4	2.4	1.6	18.8	0	0	0	6
Impoundments in ORS																	
Armenia	**655**	0	4.4	0	0	19.8	1.8	0	0	45.8	12.8	2.6	12.7	0	0	0	7
Egmont	**1 797**	0	0.6	0	0	56.1	0.7	0	0	4.6	3.1	0	34.9	0	0	0	6
Gariep	**2 297**	0	0	0	0	30.9	2.1	0	0	24.6	38.1	1	3.3	0	0	0	6
Jimmie Roos	**562**	0	2.5	0	0	36.3	2.5	0	0	0	0	0	58.7	0	0	0	4
Knellpoort	**669**	0	12.7	0	0	17.6	1.6	0	0	12.1	37.4	0	16.6	1.9	0	0	7
Welbedacht	**181**	0	47	0	0	43.6	3.9	0	0	1.7	2.2	0	1.7	0	0	0	6

Key: A.sc. – *Austroglanis sclateri;* B.an. – *Barbus anoplus;* B.pa. – *Barbus paludinosus;* C.au. – *Carassius auratus;* C.ca. – *Cyprinus carpio;* C.ga. – *Clarias gariepinus;* C.id. – *Ctenopharyngodon idella;* G.af. – *Gambusia affinis;* L.ae. – *Labeobarbus aeneus;* L.ca. – *Labeo capensis;* L.ki. – *Labeobarbus kimberleyensis;* L.um – *Labeo umbratus;* M.sa. – *Micropterus salmoides;* O.my. – *Oncorhynchus mykiss;* P.ph. – *Pseudocrenilabrus philander;* T.sp. – *Tilapia sparrmanii.* VRS – Vaal River System; ORS – Orange River System.

The mean number species recorded at impoundments in the Vaal River System was 7.6 ± 1.4 and for the Orange-Senqu River System 6 ± 1.1. Results of a t-test revealed that $p = 0.03$, indicating a significant difference in the species diversity between impoundments in the OSRS and VRS.

Three species, *C. carpio, L. umbratus* and *C. gariepinus* were sampled at all 20 impoundments, while *L. capensis* was sampled at 19 of the 20 impoundments, *L. aeneus* at 18 and *L. kimberleyensis* at 12 of the 20 impoundments respectively.

Other species were less common. The endemic *Austroglanis sclateri* for example was only recorded in Sterkfontein Dam where ample rocky areas with clear water, the preferred habitat of this species, are available throughout most of the littoral zone. Chubbyhead minnows *Barbus anoplus* were more abundant in impoundments within the OSRS, with this species only recorded in Moutloatsi Setlogelo and Mockes Dams in the VRS, possibly having entered the inflowing Modder River System via the Caledon-Modder inter-basin water transfer scheme. The distribution of *Barbus paludinosus* was restricted to impoundments within the VRS, being most abundant in Koppies, Erfenis and Krugersdrift Dams, while *Pseudocrenilabrus philander* was only recorded in five impoundments in the VRS of which three (Rustfontein, Mockes and Krugersdrift Dams) lie on the main stem of the Modder River. Only one *Tilapia sparrmanii* was recorded during the study period and only at Bloemhof Dam. Gold fish *Carassius auratus* was only recorded in Krugersdrift Dam and it is assumed the species has spread from ponds in the Bloemfontein Zoo of which the outflow enters tributaries of the Modder River which enters Krugersdrift Dam eventually. Although major parts of the main stem of the VRS have been invaded by grass carp *C. idella,* this species was only recorded in Bloemhof Dam, while mosquito fish *Gambusia affinis* was recorded in low numbers at only three impoundments (Allemanskraal, Bloemhof and Koppies Dams) in the VRS. At five impoundments in the VRS and one in the OSRS, largemouth black bass *Micropterus salmoides* was recorded. Four of these impoundments (Bloemhoek, Knellpoort, Sol Plaatje and Sterkfontein Dams) are part of inter-basin water transfer schemes of which the recorded Secchi depths (31, 30, 45 and > 200 cm respectively) were of the highest measured of the 20 impoundments.

6.3.2 Jaccard's Index of Similarity

The VRS with its tributaries which drains the central Highveld of South Africa and most parts of the FSP is the main tributary of the OSRS. Jaccard's Index of Similarity was applied to determine whether fish assemblages at impoundments situated in the OSRS and VRS respectively, were similar. The results of the application are presented in Table 6.3.

In the VRS, the fish assemblage in Bloemhof Dam is the most dissimilar to those in impoundments in the OSRS, while in the OSRS the fish assemblage in Jimmie Roos Dam is the most dissimilar to that of impoundments in the VRS. The fish assemblages in Kalkfontein, Mockes, Moutloatsi Setlogelo, Serfontein and Tierpoort Dams are to a certain extent similar to that in the OSRS's impoundments (with exception of Jimmie Roos Dam), with the fish assemblages in Kalkfontein and Tierpoort Dams 100% similar to that of Gariep Dam.

The fish assemblages at the different impoundments within the OSRS are dissimilar, with only the fish assemblages in Egmont and Welbedacht Dams that are the same. The fish assemblages in Egmont and Jimmie Roos Dams differs significantly from that of Gariep Dam, while at most other impoundments, the recorded index of similarity is 60% and higher.

The similarity index of fish assemblages amongst impoundments situated in the VRS ranges from 33% to 100%. The fish assemblage in Moutloatsi Setlogelo Dam is the most dissimilar compared to that of the other impoundments. In the VRS, only the fish assemblages of Kalkfontein and Tierpoort Dam are 100% the same, possibly due to the fact that Tierpoort Dam is situated within the main tributary of the Riet River which enters Kalkfontein Dam.

Although situated within the main stem of the same river system, the fish assemblages in the three impoundments in the Modder River System are not 100% the same, with Rustfontein and Krugersdrift Dam having the most similar fish assemblages at nearly 90%.

Table 6.3: Jaccard's Index of Similarity of the 20 selected impoundments (expressed as %).

	ALD	ARM	BHOEK	BHOF	EGM	ERF	GAR	JR	KALK	KNEL	KOP	KRUG	MOCK	MOUT	RUST	SERF	SOL	STER	TIER	WEL
ALD		67	67	64	56	78	75	33	75	50	89	70	60	40	78	63	67	55	75	56
ARM	67		75	42	86	67	86	57	86	75	60	60	88	63	67	71	56	78	86	86
BHOEK	67	75		42	63	88	86	38	86	75	60	60	67	63	67	71	75	78	86	63
BHOF	64	42	42		45	50	45	27	45	42	73	58	50	33	64	50	55	36	45	45
EGM	56	86	63	45		56	71	67	71	86	50	50	75	71	56	83	63	67	71	100
ERF	78	67	88	50	56		75	33	75	67	70	70	60	56	78	63	88	70	75	56
GAR	75	86	86	45	45	75		43	100	63	67	78	75	50	75	83	63	67	100	71
JR	33	57	38	27	67	33	43		43	57	30	30	50	67	33	50	38	44	43	67
KALK	75	86	86	45	71	75	100	43		63	67	67	75	50	75	83	63	67	100	71
KNEL	50	75	75	42	86	67	63	57	63		45	45	67	86	50	71	75	78	63	86
KOP	89	60	60	73	50	70	67	30	67	45		80	70	36	89	56	60	50	67	50
KRUG	70	60	60	58	50	70	67	30	67	45	80		70	36	89	56	60	50	67	50
MOCK	60	88	67	50	75	60	75	50	75	67	70	70		56	78	63	50	70	75	75
MOUT	40	63	63	33	71	56	50	67	50	86	36	36	56		40	57	63	67	50	71
RUST	78	67	67	64	56	78	75	33	75	50	89	89	78	40		63	67	55	75	56
SERF	63	71	71	50	83	63	83	50	83	71	56	56	63	57	63		71	56	83	83
SOL	67	56	75	55	63	88	63	38	63	75	60	60	50	63	67	71		60	63	63
STER	55	78	78	36	67	70	67	44	67	78	50	50	70	67	55	56	60		67	67
TIER	75	86	86	45	71	75	100	43	100	63	67	67	75	50	75	83	63	67		71
WEL	56	86	63	45	100	56	71	67	71	86	50	50	75	71	56	83	63	67	71	
Average	64	72	69	48	68	67	72	46	72	67	61	60	67	56	66	68	63	62	72	64

Yellow shaded cells – impoundments within the Orange-Senqu River System

Key for impoundments: ALD – Allemanskraal; ARM – Armenia; BHOEK – Bloemhoek; BHOF – Bloemhof; EGM – Egmont; ERF – Erfenis; GAR – Gariep; JR – Jimmie Roos; KALK – Kalkfontein; KNEL – Knellpoort; KOP – Koppies; KRUG – Krugersdrift; MOCK – Mockes; MOUT – Moutloatsi Setlogelo; RUST – Rustfontein; SERF – Serfontein; SOL – Sol Plaatje; STER – Sterkfontein; TIER – Tierpoort; WEL – Welbedacht.

The fish assemblages in the four main impoundments that are part of inter-basin water transfer schemes are more than 70% similar with only that of Sol Plaatje and Sterkfontein Dams that are 60% similar. Most of these impoundments can be viewed as "young" and with their clean and clear waters create suitable habitats for especially predatory species, i.e. *M. salmoides* which was recorded at all four impoundments.

On average, the fish assemblage in Bloemhof Dam is only 48% similar to those of the 19 other impoundments, while the fish assemblage in Jimmie Roos Dam was the most dissimilar at 46%. On average, the fish assemblage in Moutloatsi Setlogelo Dam is only 56% similar to the other 19 impoundments. For the rest (17 impoundments) averages of the index of similarity range from 60 – 72%, indicating that most fish assemblages amongst impoundments in the OSRS and VRS are not dissimilar.

6.3.3. Gill net versus seine net catches

During the recent fish surveys, gill nets were set offshore at a depth of 3 to 5 m, while seine nets were used in the shallower, inshore littoral zones. The differences in fish species composition between the littoral and off-shore areas, the total catch and total weight of the total catch for each species expressed as % based on gill and seine nets catches, are presented in Table 6.4.

Table 6.4: Total catch and total weight of the total catch for the six main and the other fish species caught during the 2012/2013 and 2013/2014 fish surveys with gill and seine nets (expressed as %).

	Gill nets		Seine nets	
	Number (n = 6 129 fish)	**Weight (n = 4 188.4 kg)**	**Number (n = 13 927fish)**	**Weight (n = 4 819.1 kg)**
Species	**% N of total catch**	**% W of total catch**	**% N of total catch**	**% W of total catch**
Cyprinus carpio	6.0	5.5	65.2	61.3
Clarias gariepinus	5.1	18.9	2.4	18.7
Labeobarbus aeneus	41.7	29.8	1.9	0.8
Labeo capensis	16.8	8.5	11.6	5.8
Labeobarbus kimberleyensis	4.4	6.1	0.2	0.1
Labeo umbratus	25.2	30.4	10.6	12.4
Austroglanis sclateri	<0.01	<0.01	0.0	0.0
Barbus anoplus	0.0	0.0	1.8	<0.01
Barbus paludinosus	0.1	<0.01	3.4	<0.01
Carassius auratus	0.0	0.0	0.1	0.1
Ctenopharyngodon idella	0.2	0.3	0.3	0.8
Gambusia affinis	0.0	0.0	0.2	<0.01
Micropterus salmoides	0.3	0.4	0.1	0.1
Pseudocrenilabrus philander	0.0	0.0	2.1	<0.01
Tilapia sparrmanii	0.0	0.0	<0.01	<0.01

Gill and seine net catches will differ as there were differences in effort in the use of the two gear types. However, it allowed for a comparison of the species composition between the littoral/inshore and off-shore areas within impoundments. In general, 10 species were sampled with gill nets in the off-shore areas, while 14 species were sampled with seine nets in the littoral zone. Of the total of 16 recorded species at all 21 impoundments, two species were sampled only with gill nets (*O. mykiss* at Metsi Matso Dam and *A. sclateri* at Sterkfontein Dam), while five species (*B. anoplus, C. auratus, G. affinis, P. philander* and *T. sparrmanii*) were only sampled with seine nets. The latter five species were recorded in very low numbers within the shallower littoral zones. The majority of *B. paludinosus* was sampled with seine nets, confirming that the two minnow and two cichlid species' preferred habitats are the shallower littoral zones.

Gills nets that were set within the off-shore areas mostly caught adult *L. aeneus*, *L. capensis* and *L. umbratus*. Seine nets used for sampling in the littoral/inshore areas mostly caught *C. carpio, L. capensis* and *L. umbratus*, of which catches consisted mostly of juveniles. These three species' juveniles make use of the shallower areas to forage and possibly find shelter. Very few adult *L. aeneus* and *L. kimberleyensis* were caught in the shallower littoral zones, indicating this species' preference for off-shore and open areas, while juvenile *L. aeneus* also made use of the shallower littoral zones to forage.

Results indicate that *C. gariepinus* does not have a specific preference for littoral or off-shore areas, as nearly the same numbers were sampled in both areas. These results thus imply that for future fisheries development, seine nets would be the gear of choice to harvest *C. carpio* and *C. gariepinus*, while adult *L. umbratus* and *L. capensis* can be harvested with gill nets within the off-shore areas. Unfortunately this is also the area where the protected *L. kimberleyensis* mostly occur, while *L. aeneus* is also deemed a protected species according to the FSP's Nature Conservation Ordinance and Regulations.

6.3.4 Population structure

Due to the large number of juveniles of *C. carpio* that were caught at most impoundments, the length structure was completely obscured and therefore a logarithmic scale was added to the y-axis indicating the number of *C. carpio* caught. Length analysis demonstrates that *C. carpio* is fully established at most of the selected impoundments and all size classes are well presented, except at Bloemhoek Dam (Figure 6.2).

Wide distribution of length classes in the population indicate that *C. gariepinus* is fully established in 12 of the 21 selected impoundments. However, juveniles were often absent and successful recruitment was only observed at Allemanskraal, Erfenis and Mockes Dams (Figure 6.3). At most of the other impoundments there was a total absence of fry and juveniles within the 0 to 200 mm size class, indicating failure in recruitment during this period.

At 14 of the 21 impoundments for which sufficient data were obtained, *L. aeneus* is fully established at 13. The population at Bloemhof Dam consisted mostly of individuals within the 201 to 300 mm size class, with an absence of specimens in all other size classes. At all impoundments, except Armenia, Bloemhof, Knellpoort, Sterkfontein and Tierpoort Dams, fry and juveniles were caught indicating successful recruitment of the species during the 2012/2013 and 2013/2014 summer seasons (Figure 6.4).

The Orange River mudfish *L. capensis* is fully established at 15 of the 21 impoundments. Successful recruitment during the 2012/2013 and 2013/2014 summer seasons was observed at 11 impoundments, except Bloemhoek, Knellpoort, Sol Plaatje and Sterkfontein Dams (Figure 6.5). The latter four impoundments are part of major inter-basin water transfer schemes and the artificial manipulation of water levels during the species' spawning season might be the reason for the failure in recruitment.

Although few specimens of *L. kimberleyensis* were caught at most impoundments due to the species' preference for lotic systems with clear water, results indicated that this species is established at five of the 21 selected impoundments (Figure 6.6). No fry or juveniles were caught, which may be attributed to the fact that this species spawns on gravel beds within lotic systems. The largest *L. kimberleyensis* populations were recorded at Erfenis, Koppies and Kalkfontein Dams with the majority of fish caught within the 201 to 300 mm size class.

A significant variation in the presence of different size classes was observed for *L. umbratus* populations at 17 of the 21 selected impoundments (Figure 6.7). At Bloemhof, Erfenis and Gariep Dams the populations consisted mostly of individuals within the 0 to 100 mm size class, with very few individuals within the 101 to 300 mm size classes at Erfenis Dam, with a complete absence of individuals within 101 to 300 mm size classes at Bloemhof and Gariep Dams. At Bloemhoek Dam only two specimens were caught within the 0 to 300 mm size classes, while at Sterkfontein and Knellpoort Dams, no individuals in the 0 to 200 mm size classes were recorded. At most of the other impoundments, the populations consisted mostly of individuals within the 301 to 400 and 401 to 500 mm size classes.

With the exception of *C. carpio*, the only two other alien and invasive species that are established at impoundments, are *M. salmoides* at Knellpoort Dam (Figure 6.8) and *C. idella* at Bloemhof Dam (Figure 6.9). Although the two alien species were recorded in relative low numbers, it may be assumed that given the right conditions, the two species' numbers may increase in future. Although *M. salmoides* was also sampled at five other impoundments, only a few specimens were recorded.

Cyprinus carpio

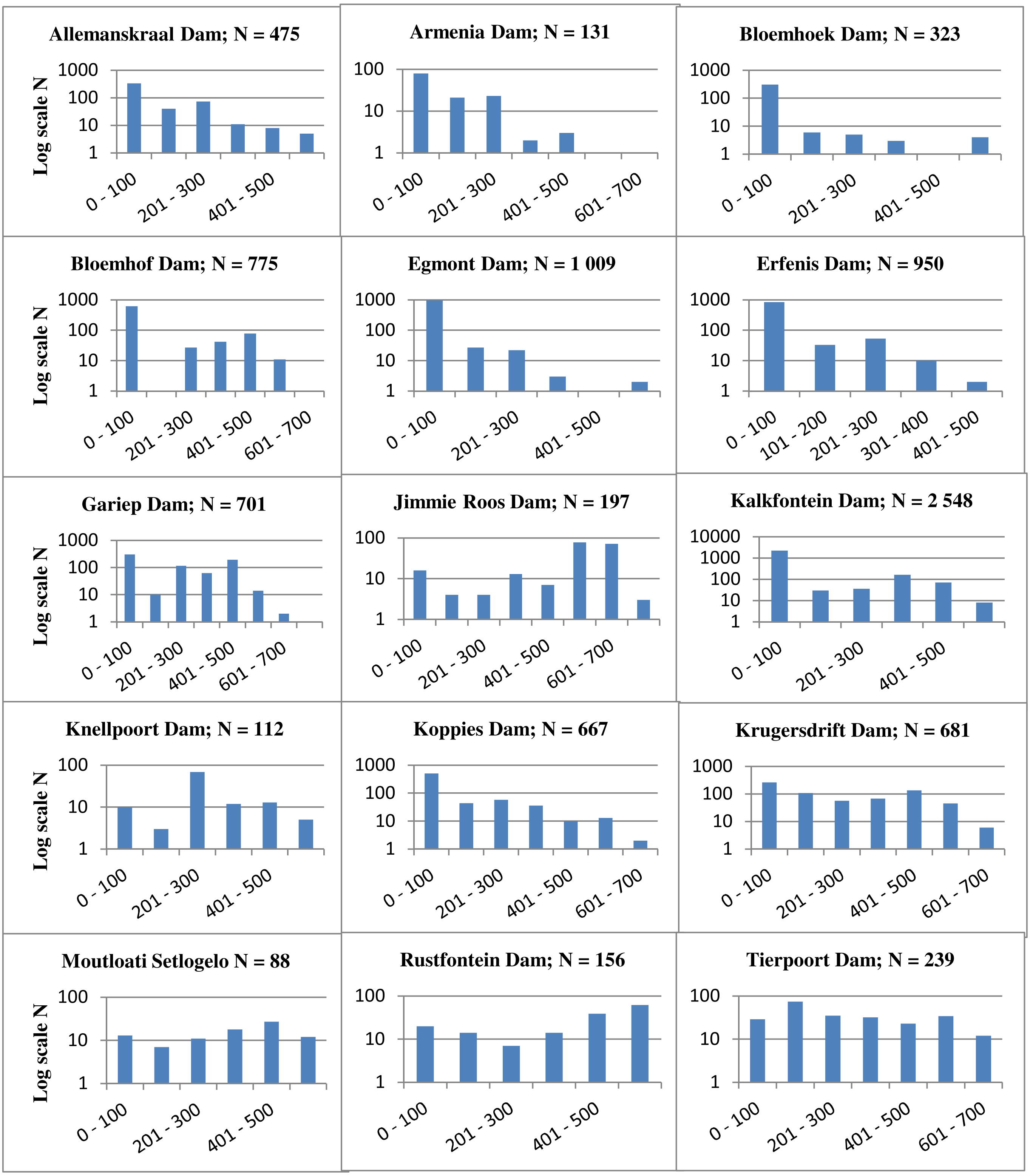


Figure 6.2: Length frequency distribution for *Cyprinus carpio*. X-axes indicate length frequency distribution within 100 mm size classes based on fork length (mm).

Clarias gariepinus

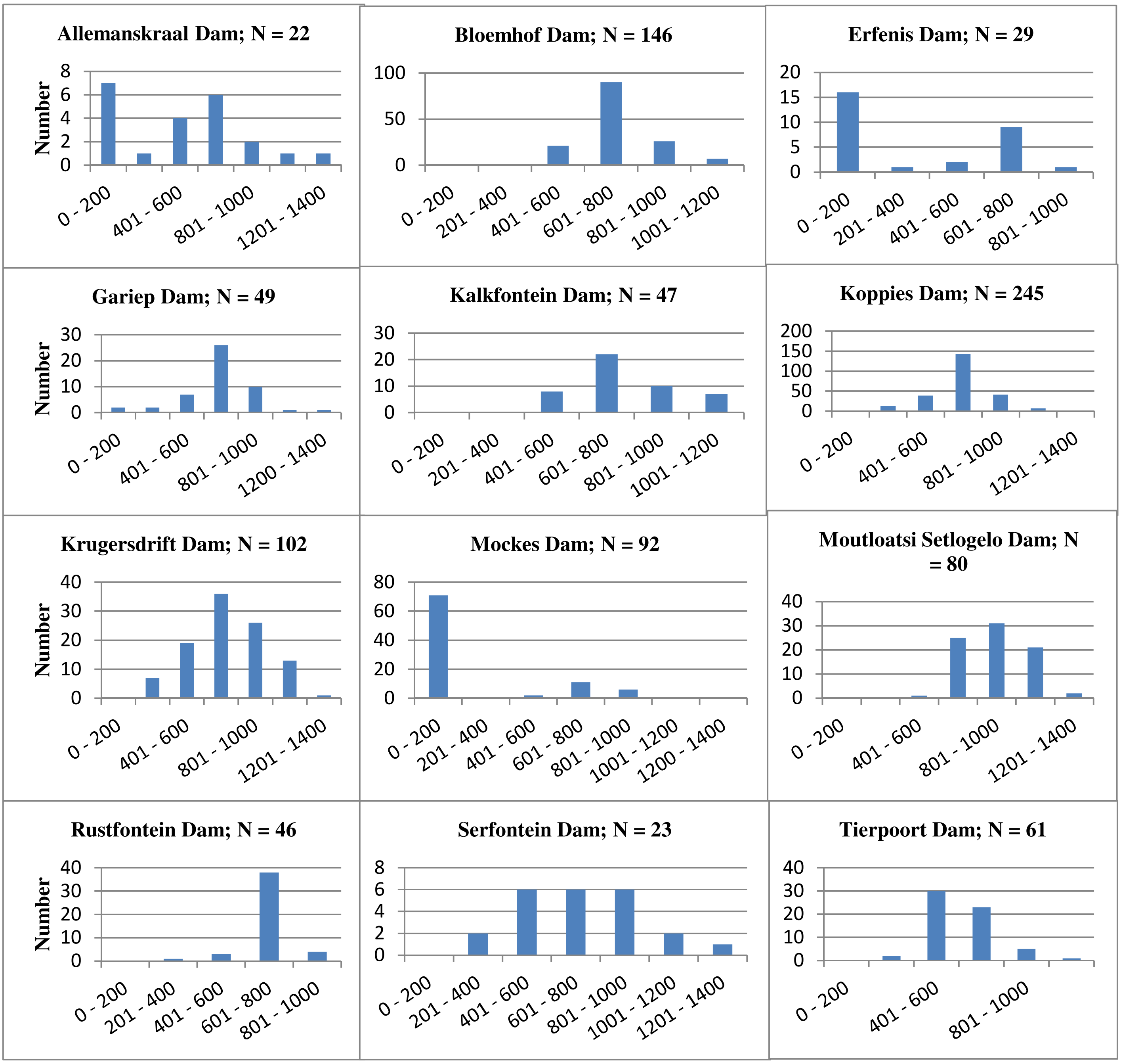


Figure 6.3: Length frequency distribution for *Clarias gariepinus*. X-axes indicate length frequency distribution within 200 mm size classes based on total length (mm).

Labeobarbus aeneus

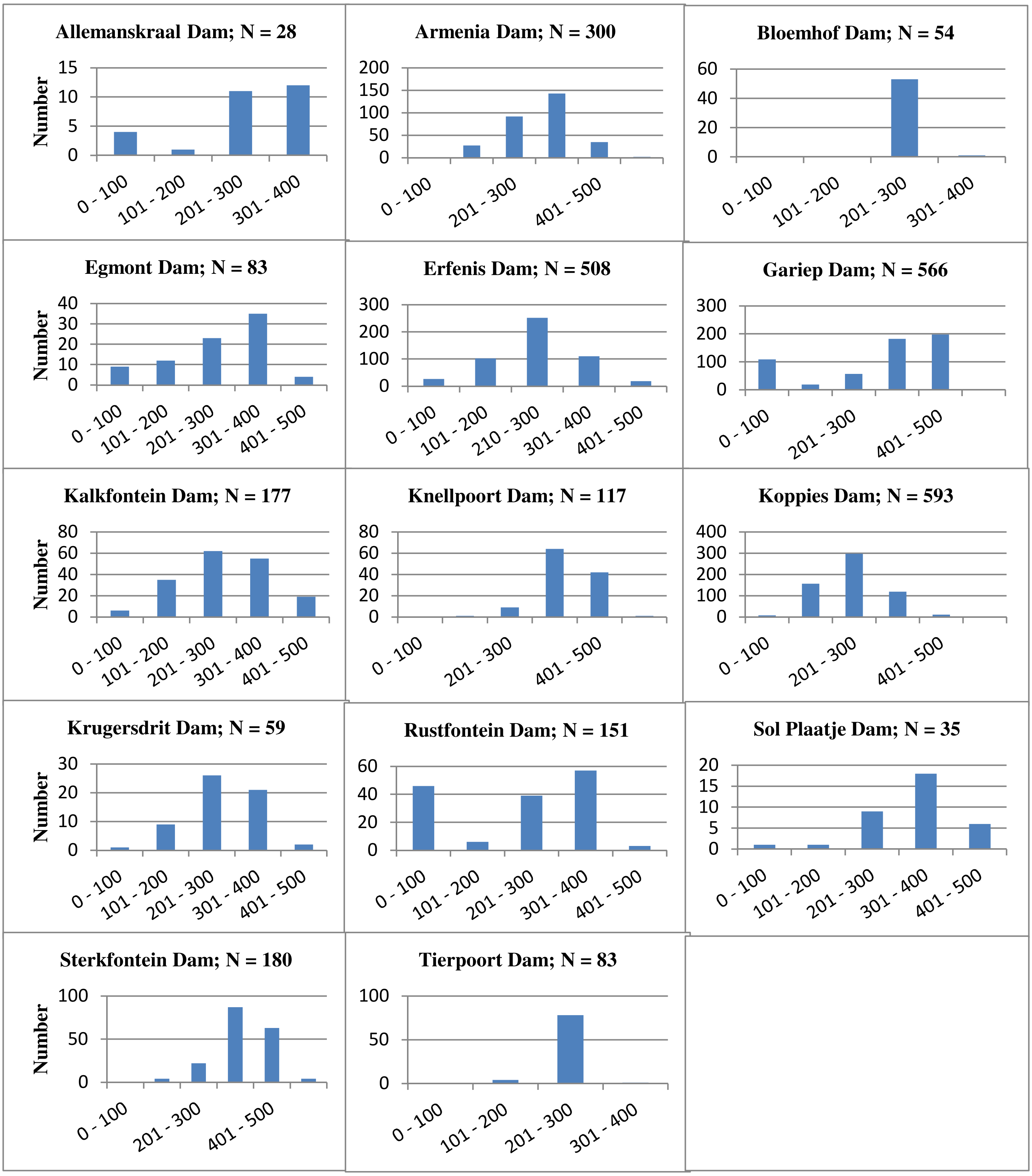


Figure 6.4: Length frequency distribution for *Labeobarbus aeneus*. X-axes indicate length frequency distribution within 100 mm size classes based on fork length (mm).

Labeo capensis

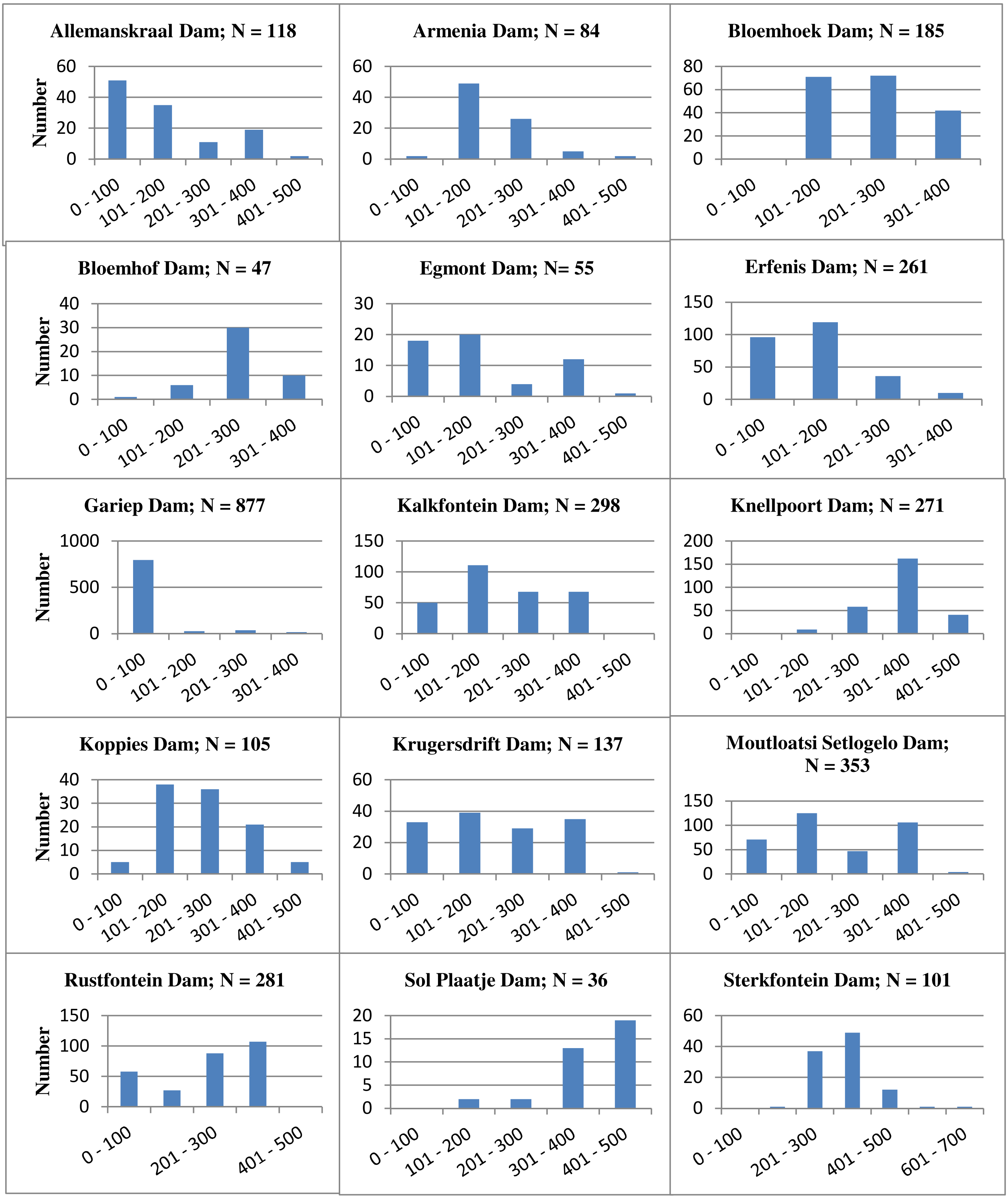


Figure 6.5: Length frequency distribution of *Labeo capensis*. X-axes indicate length frequency distribution within 100 mm size classes based on fork length (mm).

Labeobarbus kimberleyensis

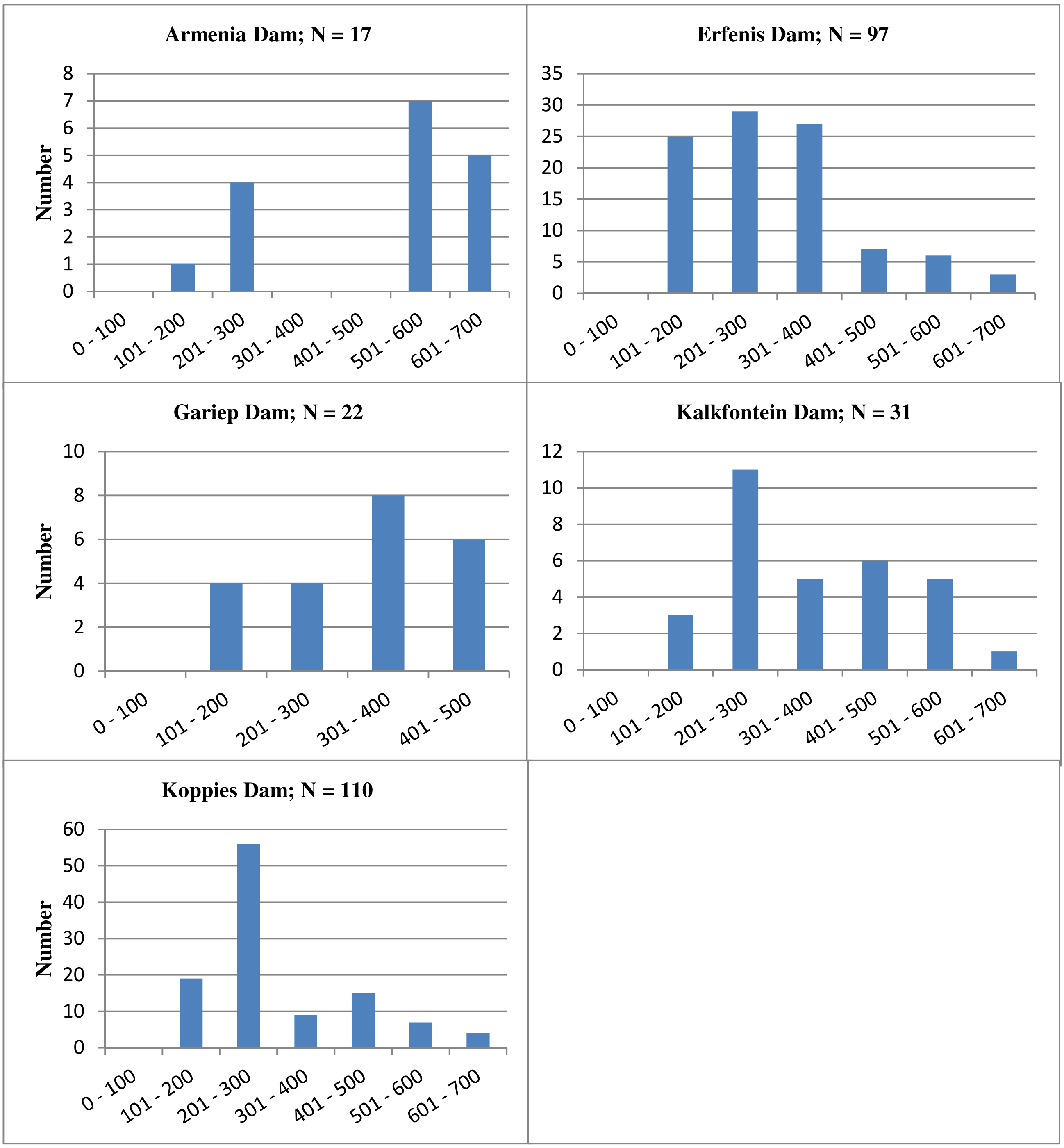


Figure 6.6: Length frequency distribution of *L. kimberleyensis*. X-axes indicate length frequency distribution within 100 mm size classes based on fork length (mm).

Labeo umbratus

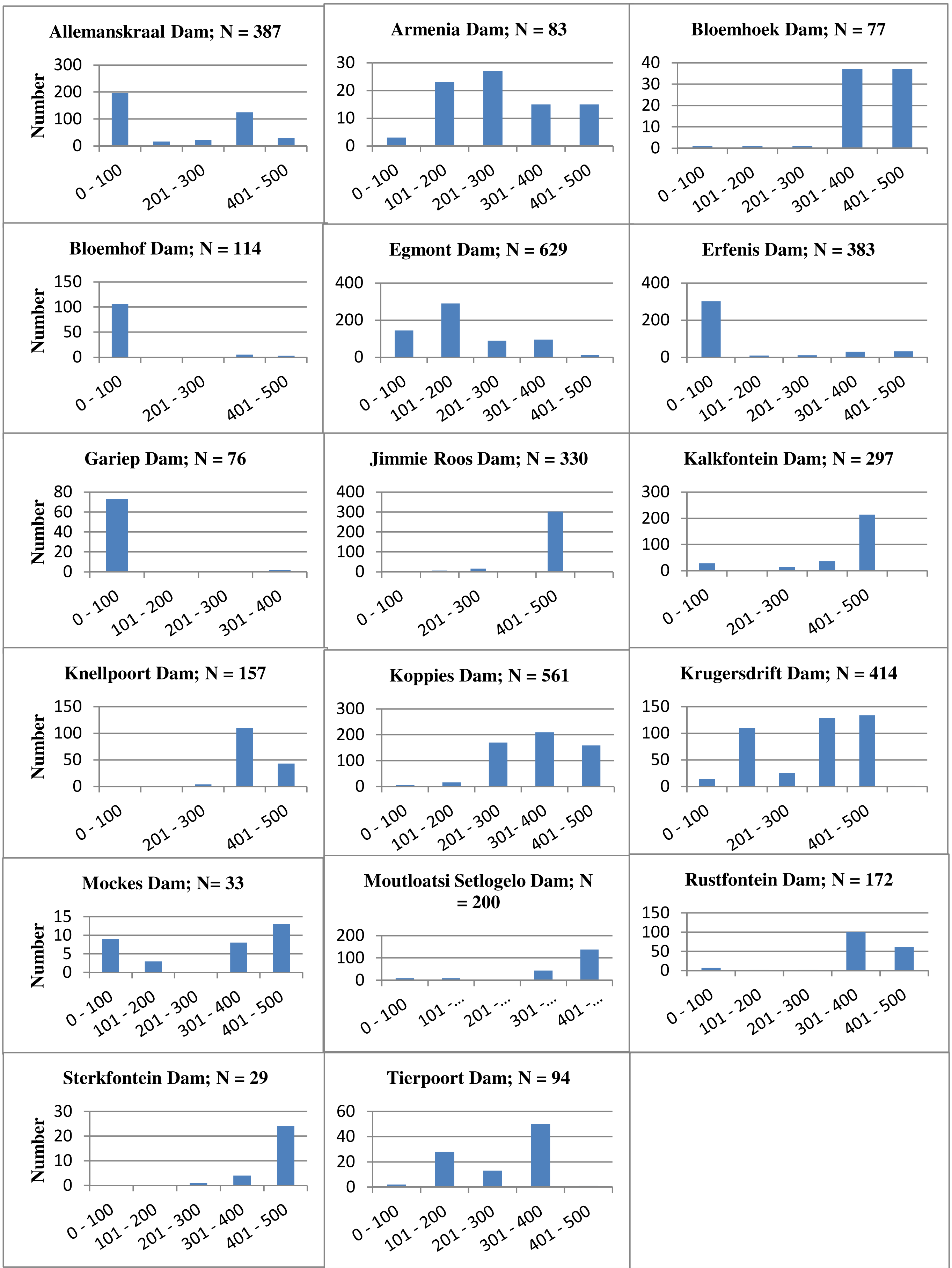


Figure 6.7: Length frequency distribution of *Labeo umbratus*. X-axes indicate length frequency distribution within 100 mm size classes based on fork length (mm).

Micropterus salmoides

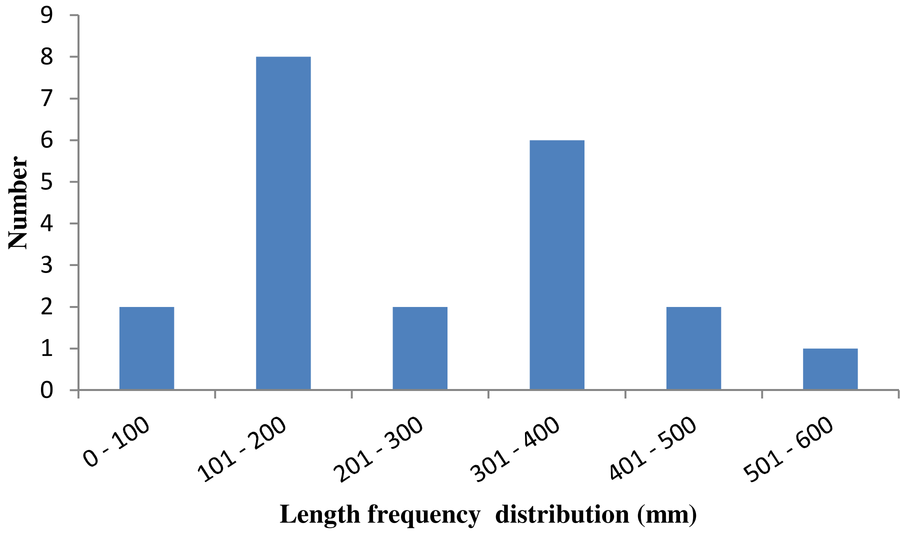


Figure 6.8: Length frequency distribution of *Micropterus salmoides* at Knellpoort Dam within 100 mm size classes. (N = 21).

Ctenopharyngodon idella

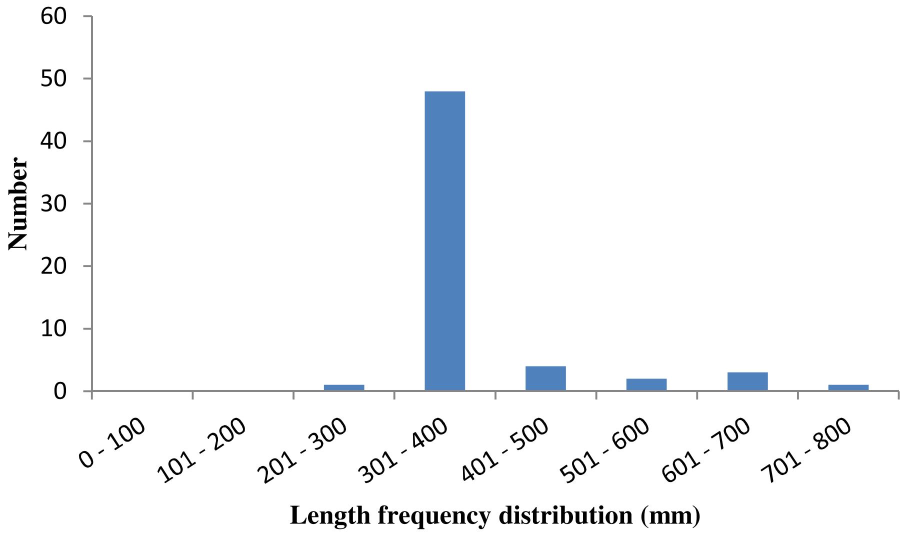


Figure 6.9: Length frequency distribution of *Ctenopharyngodon idella* at Bloemhof Dam based on 100 mm size classes based on fork length (mm). (N = 59).

6.3.5 Environmental and morphometric variables driving species distribution

The CPUE of gill net catches, based on the total weight per species for all sets of gill nets combined for all netting nights per impoundment for the six main fishery species (*C. carpio, C. gariepinus, L. aeneus, L. capensis, L. kimberleyensis* and *L. umbratus*), is summarised in Table 6.5. The CPUE per individual gill net set based on the total number and total weight of three species caught per gill net set per night, is presented in Appendix 51.

The main environmental and morphometric variables used in the multi-variate analysis were categorised as quantitative or qualitative variables. The quantitative variables were surface area, average depth, catchment area, latitude, altitude, mean annual air temperature, the average water level of the impoundment based on the water levels of the past six years, age, pH, Secchi depth, conductivity and total dissolved solids. Qualitative variables were major or minor fluctuations in water levels experienced at impoundment, part of an inter-basin water transfer scheme or not, impoundment situated on a major or seasonal river and impoundment part of VRS or OSRS. Although originally chosen as part of qualitative variables, the following variables were not used in the final CCA: open or closed access to impoundment, proximity to town or city, distance from town or city. The most important variables used in the CCA deemed to drive the distribution of fish species at impoundments in the FSP, are summarised in Table 6.6.

The first two axes of CCA analysis were projected using CanoDraw software to create an ordination diagram which is presented in Figure 6.10.

Table 6.5: Mean ± StDev catch per unit effort (CPUE) expressed as kg fish per net per night for the six main fisheries species.

Name of impoundment	CPUE C.ca.	CPUE C.ga.	CPUE L.ae.	CPUE L.ca.	CPUE L.ki.	CPUE L.um.
Allemanskraal (n=15)	0.33±0.84	1.80±4.10	0.62±0.88	0.63±0.82	0.78±1.43	1.70±1.54
Armenia (n = 6)	1.99±2.90	1.35±2.10	22.10±16.35	1.62±1.60	6.83±9.61	2.86±1.69
Bloemhoek (n = 6)	0.22±0.37	2.04±1.11	0.17±0.42	5.08±4.19	1.98±4.85	10.54±4.12
Bloemhof (n = 15)	4.92±6.27	5.26±4.98	0.88±1.24	0.45±0.74	0.30±0.49	0.40±0.50
Egmont (n=6)	0.05±0.09	1.04±2.12	2.66±2.14	0.42±0.37	0	1.05±1.45
Erfenis (n = 15)	0.66±0.92	1.93±3.11	9.83±11.17	0.99±0.82	4.13±4.60	1.91±2.16
Gariep (n = 15)	0	4.41±7.13	23.12±22.11	1.10±1.73	0.48±0.56	0.03±0.12
Jimmie Roos (n = 6)	0	3.55±4.34	0	0	0	25.62±19.06
Kalkfontein (n = 15)	0.84±1.17	3.16±3.24	5.61±13.39	2.80±2.53	2.18±2.61	16.02±18.16
Knellpoort (n = 15)	1.11±1.21	0.54±1.16	6.45±6.06	1.83±1.73	0	1.96±2.84
Koppies (n = 15)	0.63±0.62	7.63±8,22	10.23±7.61	1.70±1.30	4.58±4.64	15.39±12.22
Krugersdrift (n = 15)	1.87±1.76	6.11±5.91	1.51±1.55	1.93±2.31	0.04±0.14	17.61±16.32
Mockes (n = 6)	0	6.70±6.88)	0	0.45±1.11	0	1.17±1.19
Moutloatsi Setlogelo (n = 15)	0.27±0.66	1.65±2.50	0	2.54±4.46	0	1.43±2.10
Rustfontein (n=15)	1.72±4.51	6.06±6.18	3.02±2.27	1.14±0.77	0.79±1.17	7.47±7.25
Serfontein (n = 3)	0	3.51±4.99	0	0	0	0
Sol Plaatje (n = 6)	0	0.77±1.77	2.87±2.50	4.87±7.31	0	0.79±1.13
Sterkfontein (n = 15)	0.15±0.58	2.02±4.76	9.80±11.26	3.16±3.88	0.56±2.17	1.87±3.39
Tierpoort (n = 3)	9.52±2.36	21.87±4.96	4.90±4.50	0.60±0.39	0.34±0.58	10.45±8.95
Welbedacht (n = 3)	0.91±1.19	3.24±2.83	0.17±0.29	0.52±0.90	0	0.95±1.65

Abbreviations:

C.ca – *C. carpio;* C.ga. – *C. gariepinus;* L.ae. – *L. aeneus;* L.ca. – *L. capensis;* L.ki. –*L. kimberleyensis;* L.um. – *L. umbratus*

Table 6.6: Environmental and morphometric variables used in the Canonical Correspondence Analysis. For pH, total dissolved solids, conductivity and Secchi depth the mean and standard deviation are indicated.

Impoundment	Surface area (ha)	Av. depth at FSL (m)	Catchment area (km²)	Latitude	Altitude (m)	Mean annual air temp. (°C)	Av. water level past 6 years (%)	pH	TDS (mg/l)	Con (µS/m²)	SECCHI depth (cm)
Allemanskraal	2 667	6.7	3 628	28	1 361	18.3	56.3	8.25±0.22	150.1±22.4	226.5±30.7	13.4±4.3
Armenia	393	3.4	861	29	1 514	15.9	52.7	8.34±0.03	238.0±2.34	371.7±3.4	10.0±0
Bloemhoek	370	7.1	66	27	1 366	17.2	*50%**	8.44±0.02	213.0±0.5	332.7±1.0	36.3±1.4
Bloemhof	23 067	5.5	108 125	27	1 222	17.8	60	8.78±0.18	358.1±100.5	559.6±157	47.9±11.1
Egmont	244	4	310	30	1 475	15.8	67.5	8.03±0.05	151.0±0.8	236.0±0.9	8.7±0.5
Erfenis	3 291	6.5	4 724	28	1 326	18.3	58.4	8.33±0.11	166.67±20.2	260.6±31.7	23.4±6.2
Gariep	35 216	15.2	70 665	30	1 255	17.2	90	8.35±0.15	68.9±35.9	108.89±57.6	41.8±23.7
Jimmie Roos	115	3.1	*No data*	29	1 506	15.8	*50%**	8.74±0.07	272.7±1.4	425.7±2.1	21.7±2.6
Kalkfontein	3 769	6.9	10 264	29	1 221	16.3	37.6	8.76±0.13	381.7±62.9	598.6±96.3	35.6±9.1
Knellpoort	977	14	766	29	1 442	15.8	59.4	8.14±0.13	100.1±22.3	156.6±34.9	28.3±4.8
Koppies	1 439	2.8	2 142	27	1 396	15.4	84.9	8.5±0.13	323.3±37.9	504.9±59.1	25.5±4.7
Krugersdrift	1 853	3.6	6 331	28	1 241	16.6	54.4	8.63±0.15	388.9±27.0	607.5±42.2	33.0±10.5
Mockes	147	2.8	2 968	29	1 306	15.9	*50%**	7.8±0.15	138.8±3.9	217.0±6.3	10.0±0.0
Moutloatsi Setlogelo	250	5.6	116	29	1 484	15.9	44.3	8.27±0.09	178.8±20.6	278.8±31.7	19.1±3.6
Rustfontein	1 159	6.2	937	29	1 361	15.9	45.1	8.31±0.08	171.6±4.5	268.3±6.9	37.9±6.3
Serfontein	142	2.9	3 420	27	1 355	17.2	*50%**	7.82±0.26	80.3±4.1	125.5±6.4	10.0±0
Sol Plaatje	356	4.4	*No data*	28	1 673	14.3	101.9	8.15±0.21	57.6±1.4	90.0±2.2	50.7±3.6
Sterkfontein	6 937	37.7	195	28	1 705	15.1	98.8	8.09±0.06	36.2±17.8	56.5±27.8	200.0±0
Tierpoort	911	3.7	922	29	1 376	16.7	33.2	9.09±0.05	268.0±2.7	418.7±3.8	31.3±2.3
Welbedacht	1 018	1	15 270	29	1 402	15.8	84.9	8.15±0.09	195.4±1.7	305.3±2.9	16.0±1.7

* - No data was available, and was subsequently estimated at 50%; TDS – total dissolved solids; Con – conductivity.

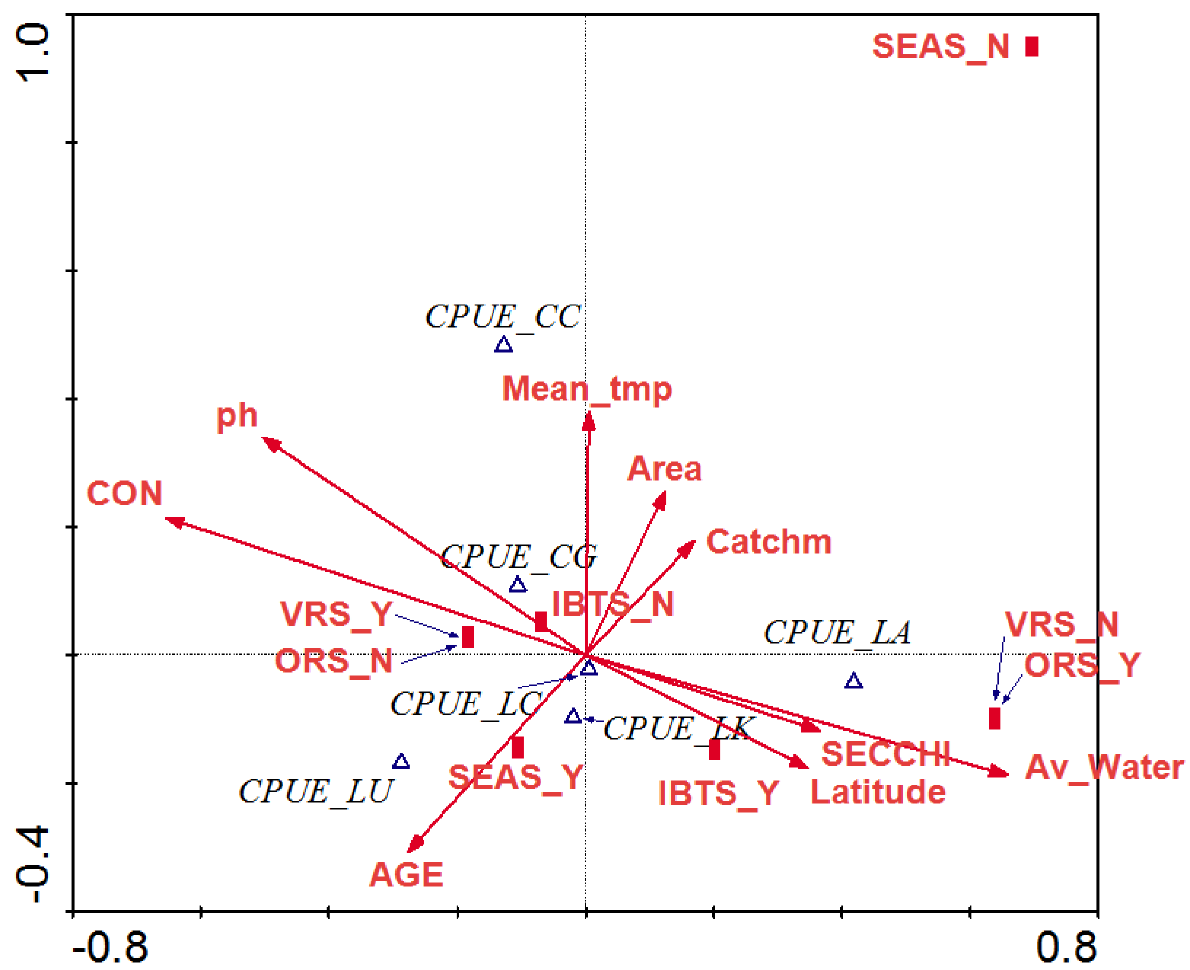


Figure 6.10: Ordination diagram obtained after the Canonical Correspondence Analysis was done, indicating the qualitative and quantitative variables driving the distribution of the main fisheries species in impoundments in the Orange-Senqu River and Vaal River Systems.

Key: CPUE_LA: Catch per unit effort (kg fish/net/night) for *L. aeneus;* CPUE_LK: Catch per unit effort (kg fish/net/night) for *L. kimberleyensis;* CPUE_LU: Catch per unit effort (kg fish/net/night) for *L. umbratus;* CPUE_LC: Catch per unit effort (kg fish/net/night) for *L. capensis;* CPUE_CG: Catch per unit effort (kg fish/net/night) for *C. gariepinus;* CPUE_CC: Catch per unit effort (kg fish/net/night) for *C. carpio.*

Key to quantitative variables: Av_Water: average water level of impoundments of past six years; Secchi: Secchi depth in cm; Age – age of impoundments in years as on 1 December 2014; CON: conductivity in µS m^{-2}; ph – pH; Mean_tmp: average annual air temperature in °C; Area: surface area of impoundments in ha; Catchm: catchment area in km^2.

Key to qualitative variables are: VRS_Y/N: impoundments situated in Vaal River System; ORS_Y/N: impoundments situated in Orange-Senqu River System; IBTS_Y/N: impoundments part of inter-basin water transfer scheme; SEAS_Y/N: impoundments situated in seasonal river.

The location of *L. capensis* close to the origin of the ordination diagram, suggests that the CPUE of this species is influenced the least by the measured environmental variables. Analysis did, however, indicate that the relative abundance (CPUE) of the other five species was influenced by a variety of environmental variables. The relative abundance of *L. umbratus* was generally higher in older "off-channel" impoundments characterised by lower conductivity, impoundments with a smaller catchment and surface area and higher turbidity (indicated by a lower Secchi depth). In the younger mainstream impoundments within large catchment areas situated in areas with a higher mean annual temperature, *C. carpio* were most abundant. In addition the relative abundance of *C. carpio* was also correlated with a higher pH. The opposite was applicable for especially *L. aeneus* which was most abundant in the less productive water bodies. The extent of the impact of environmental and morphometric variables on the distribution of the main fisheries species at impoundments is summarised in Table 6.7.

Table 6.7: Extent of the impact of environmental and morphometric variables on the distribution of the main fisheries species at impoundments in the Free State Province.

	Mean annual air temperature	**Conductivity**	**pH**	**Age**	**Catchment area**	**Secchi depth**
Species						
Cyprinus carpio	High	High	High	Low	High	Low
Clarias gariepinus	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Labeobarbus aeneus	Moderate	Low	Low	Low	High	High
Labeo capensis	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Labeobarbus kimberleyensis	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Labeo umbratus	Low	Moderate	Moderate	High	Low	Moderate

The outputs of Table 6.7 is further demonstrated in Figures 6.11 to 6.16 where the mean CPUE for each of the main fisheries species are compared with the six main environmental variables impacting on the species' distribution, namely catchment area (Figure 6.11), pH (Figure 6.12), average annual air temperature (Figure 6.13), conductivity (Figure 6.14), Secchi depth (Figure 6.15) and age of the impoundments (Figure 6.16). Scatter plots were compiled and a linear trendline added with the R^2 value included on the graphs. Although in some instances very poor relationships and correlations were found between the mean CPUE and environmental variables, in general the trends observed in Table 6.7 are confirmed by the different plots.

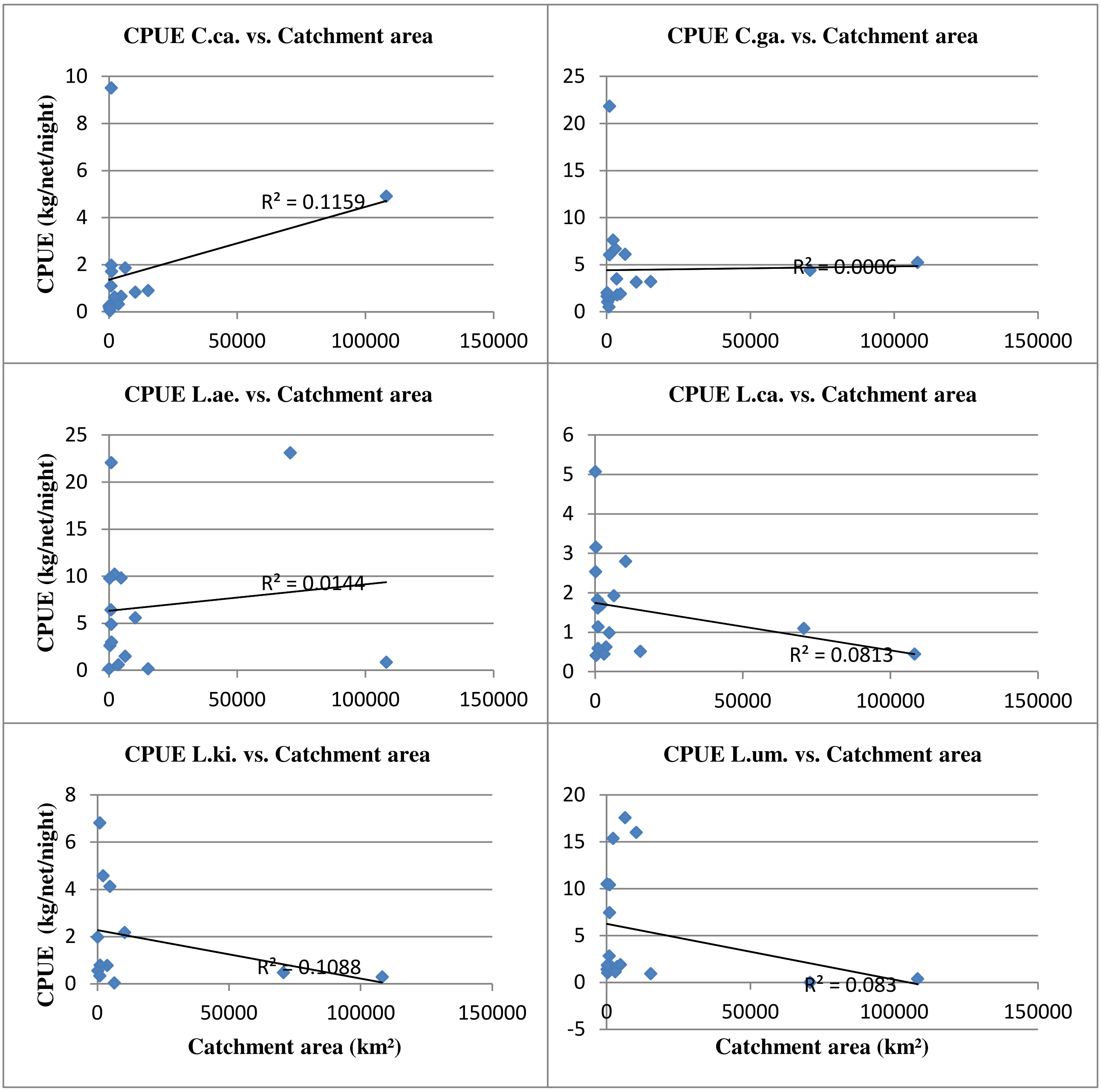


Figure 6.11: Catch per unit effort (kg fish/net/night) of the main fisheries species compared to catchment area (in km²). C.ca. – *Cyprinus carpio*; C.ga. – *Clarias gariepinus*; L.ae. – *Labeobarbus aeneus*; L.ca – *Labeo capensis*; L.ki. – *Labeobarbus kimberleyensis*; L.um. – *Labeo umbratus*.

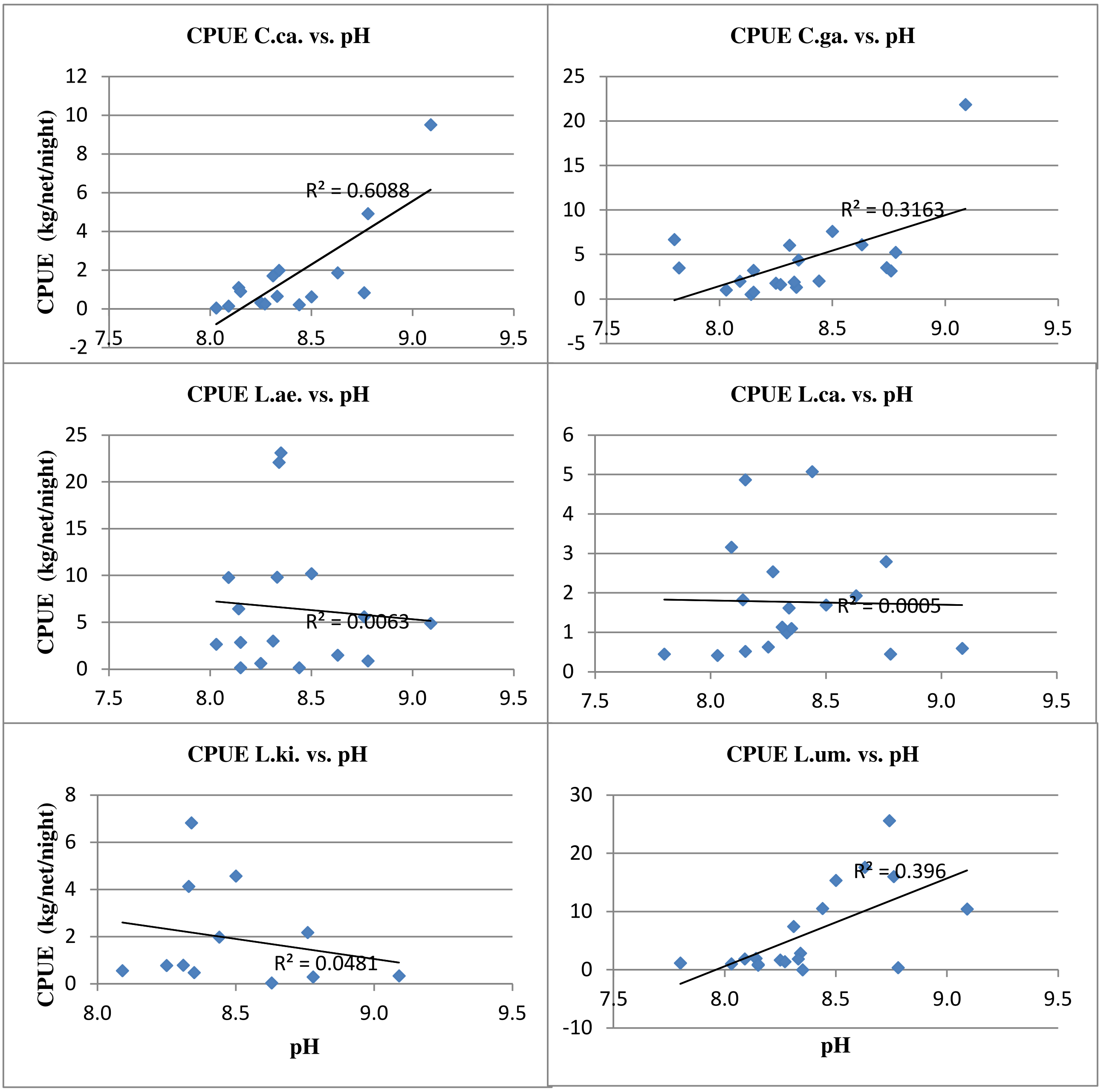


Figure 6.12: Catch per unit effort (kg fish/net/night) of the main fisheries species compared to pH. C.ca. – *Cyprinus carpio*; C.ga. – *Clarias gariepinus*; L.ae. – *Labeobarbus aeneus*; L.ca. – *Labeo capensis*; L.ki. – *Labeobarbus kimberleyensis*; L.um. – *Labeo umbratus*.

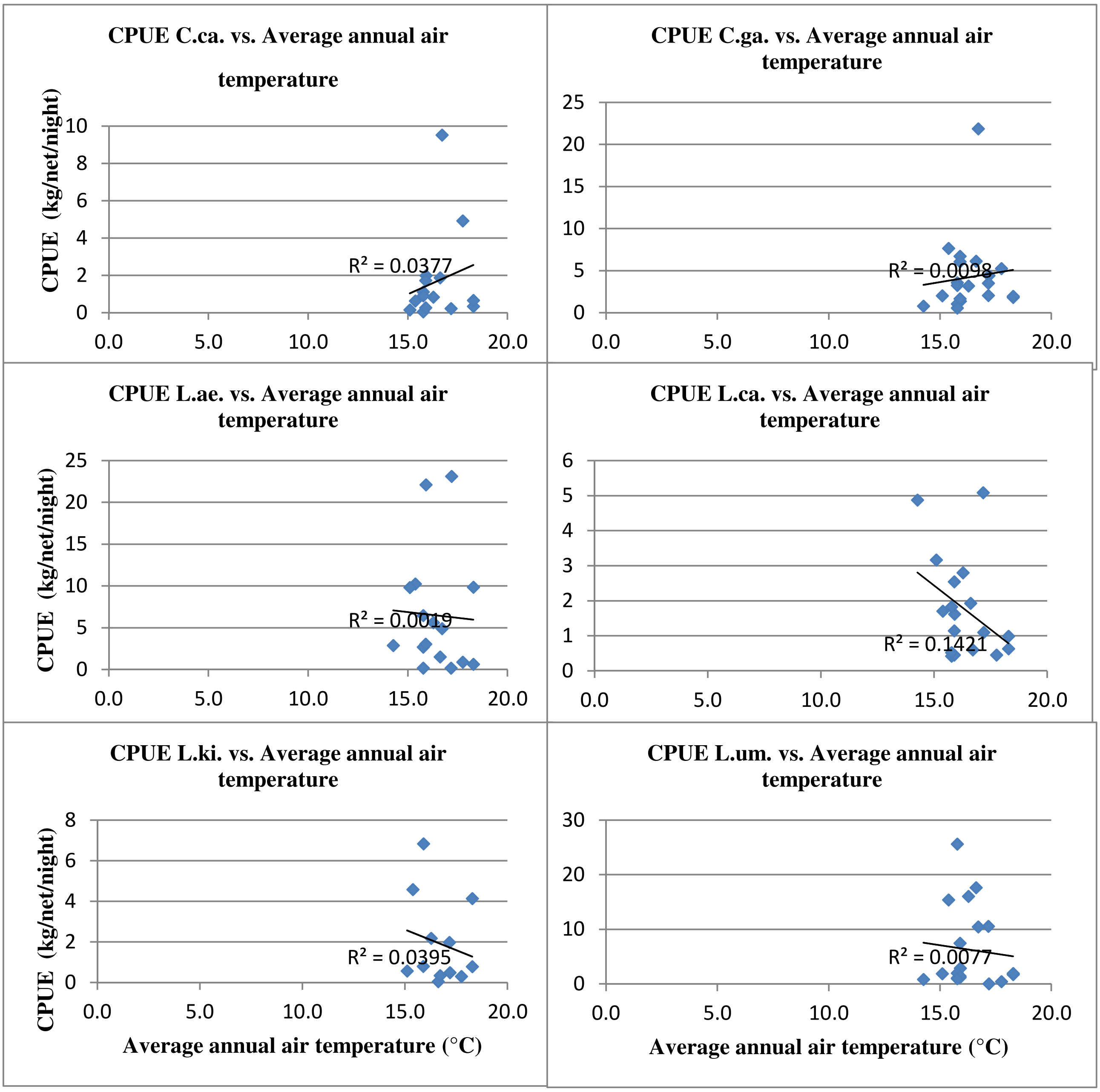


Figure 6.13: Catch per unit effort of the main fishery species compared to average annual air temperature (°C). C.ca. – *Cyprinus carpio*; C.ga. – *Clarias gariepinus*; L.ae. – *Labeobarbus aeneus*; L.ca. – *Labeo capensis*; L.ki. – *Labeobarbus kimberleyensis*; L.um. – *Labeo umbratus*.

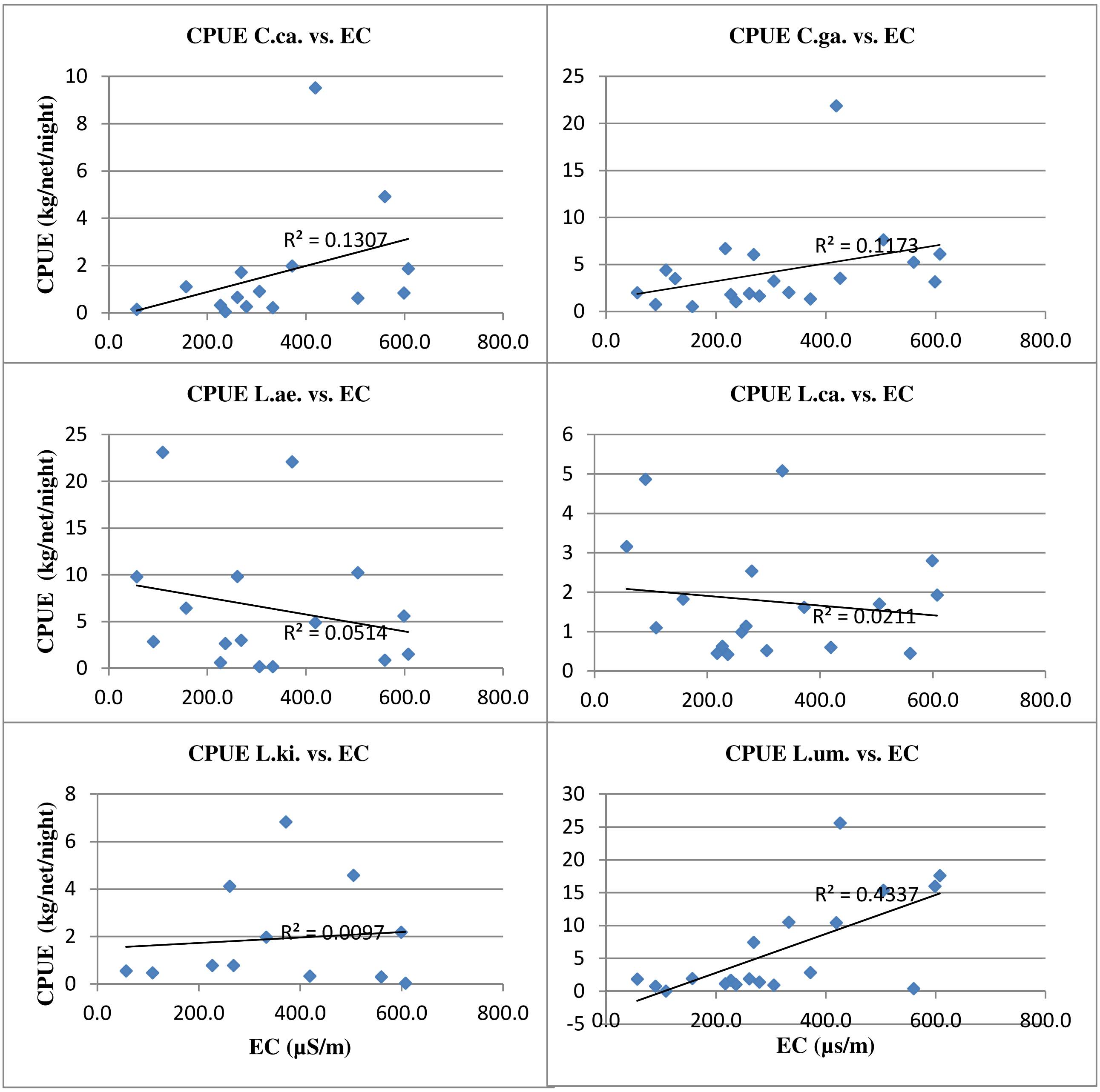


Figure 6.14: Catch per unit effort of the main fishery species compared to conductivity (in µS/m-²). C.ca – *Cyprinus carpio*; C.ga. – *Clarias gariepinus*; L.ae. – *Labeobarbus aeneus*; L.ca. – *Labeo capensis*; L.ki. – *Labeobarbus kimberleyensis*; L.um. – *Labeo umbratus*.

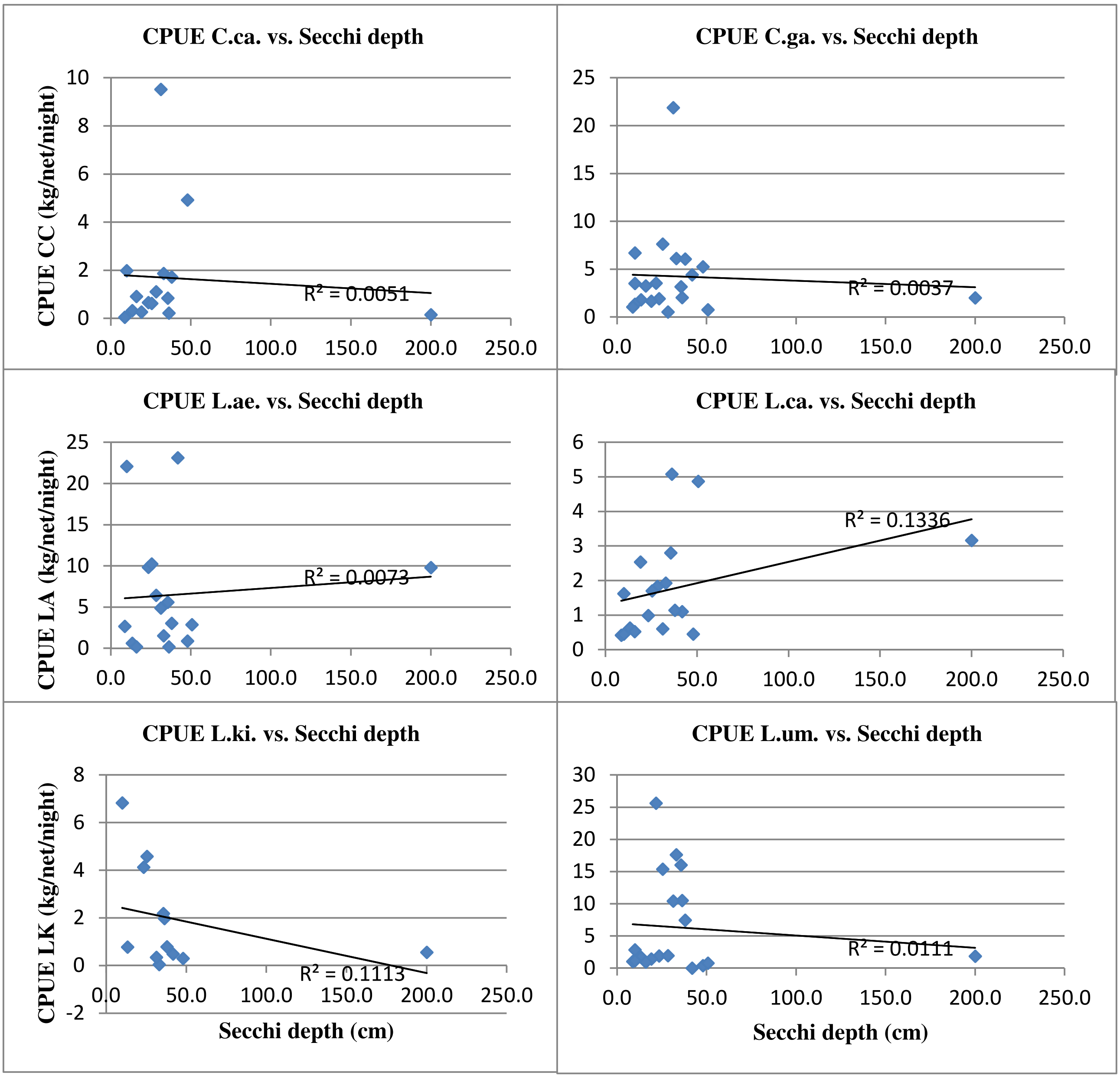


Figure 6.15: Catch per unit effort of the main fishery species compared to Secchi depth (cm). C.ca. – *Cyprinus carpio*; C.ga. – *Clarias gariepinus*; L.ae. – *Labeobarbus aeneus*; L.ca. – *Labeo capensis*; L.ki. – *Labeobarbus kimberleyensis*; L.um. – *Labeo umbratus*.

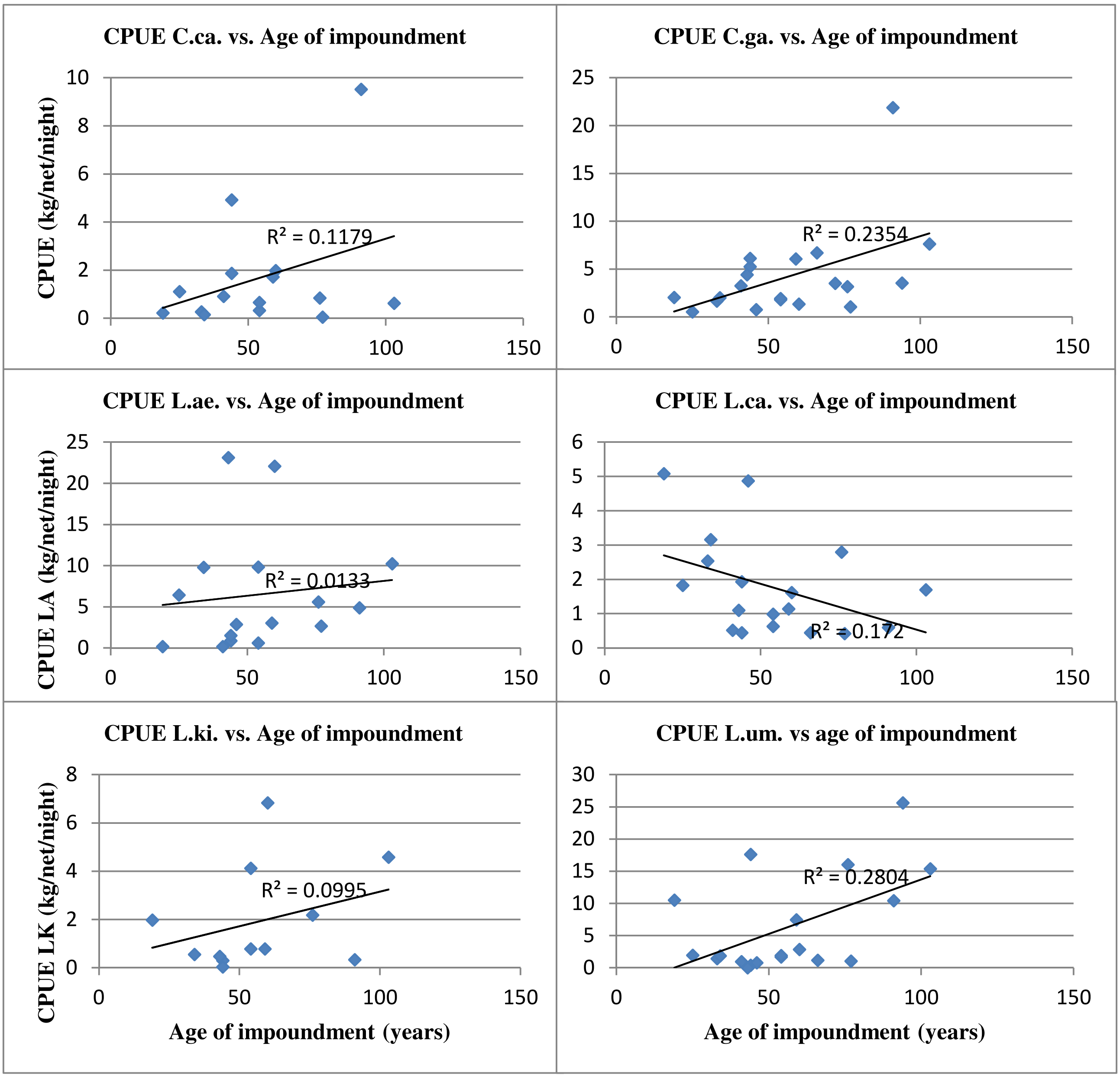


Figure 6.16: Catch per unit effort the main fishery species compared to age of impoundment (in years). C.ca. – *Cyprinus carpio*; C.ga. – *Clarias gariepinus*; L.ae. – *Labeobarbus aeneus*; L.ca. – *Labeo capensis*; L.ki. – *Labeobarbus kimberleyensis*; L.um. – *Labeo umbratus*.

6.3.6 Historical changes in fish species compositions

Limited research was done on freshwater fish populations at state impoundments in the FSP (see Table 6.8). The only impoundments that were surveyed were those that were surrounded by, or that lie in close proximity of provincial nature reserves managed by the former Orange Free State Directorate of Nature and Environmental Conservation. Except for the fish surveys done by Barkhuizen (1995; 1996) at 11 impoundments, the only other fish surveys done at impoundments for which historic records were found are:

(i) 1972 and 1976 at Allemanskraal Dam;
(ii) 1970's and early 1980's at Gariep Dam;
(iii) 1974 at Krugersdrift, Mockes and Rustfontein Dams;
(iv) 1975 at Sol Plaatje and Sterkfontein Dams;
(v) 1980's at Sterkfontein Dam.

Gariep and Sterkfontein Dams are the only two impoundments where long term fishery projects were implemented. During other projects to determine the occurrence and distribution of freshwater fish in river systems, only a few sites were sampled in impoundments. A summary of the historic records of fish surveys done at impoundments and river systems and the number of species that were recorded for the period 1971 until 2012, is provided in Table 6.8.

Table 6.8: Historic records (1971 – 2012) of fish surveys done at state impoundments and river systems within the borders of the Free State Province.

Impoundment	No. species recorded	Reference	River system	No. species recorded	Reference
Allemanskraal	4	Marshall, 1972	Sand	6	Janse van Vuren, 1976
	5	Janse van Vuuren, 1976		6	Dlomo and O'Brien, 2012
	6	Barkhuizen, 1993a			
	6	Barkhuizen, 1995			
	6	Barkhuizen, 1996			
Bloemhof	7	Barkhuizen, 1994a	Vaal	6	Mulder, 1971
	5	Barkhuizen, 1995		9	Dlomo and O'Brien, 2012
	5	Barkhuizen, 1996			
Erfenis	8	Barkhuizen, 1993b	Vet	6	Janse van Vuren, 1978
	6	Barkhuizen, 1995		10	Dlomo and O'Brien, 2012
	6	Barkhuizen, 1996			
Gariep	8	Hamman, 1974	Orange	8	Van Schoor, 1972
	9	Hamman, 1981		12	Avenant, 2012
	3	Barkhuizen, 1995			
	6	Barkhuizen, 1996			
	10	Ellender, 2008			
Kalkfontein	6	Barkhuizen, 1994b	Riet	6	Janse Van Vuren, 1978
	6	Barkhuizen, 1995		6	Avenant, 2012
	6	Barkhuizen, 1996			
Knellpoort	5	Barkhuizen, 1993c			
	4	Barkhuizen, 1996			
Koppies	7	Barkhuizen, 1993d	Renoster	9	Dlomo and O'Brien, 2012
	6	Barkhuizen, 1995			
	6	Barkhuizen, 1996			
Krugersdrift	7	Rossouw, 1974	Modder	9	Rossouw, 1974
	8	Barkhuizen, 1994c		8	Avenant, 2012
	6	Barkhuizen, 1995			
	6	Barkhuizen, 1996			
Metsi Matso	1	Barkhuizen, 1995			
Mockes	7	Rossouw, 1974	Modder	7	Rossouw, 1974
				8	Avenant, 2012
Rustfontein	7	Rossouw, 1974	Modder	7	Rossouw, 1974
	6	Barkhuizen, 1994d		8	Avenant, 2012
	6	Barkhuizen, 1995			
	6	Barkhuizen, 1996			
Sol Plaatje	6	Le Roux, 1975	Wilger	9	Le Roux, 1975
Sterkfontein	4	Le Roux, 1975			
	9	Dörgeloh, 1986			
	8	Barkhuizen, 1994e			
	5	Barkhuizen, 1995			
	5	Barkhuizen, 1996			
Tierpoort			Tierpoort	10	Marshall, 1972
Welbedacht	7	Barkhuizen, 1993c	Caledon	7	Marshall, 1970
	6	Barkhuizen, 1995		6	Baird, 1971
	4	Barkhuizen, 1996		5	Avenant, 2012

For more information on the historic records on the presence, absence and relative abundance of fish species compared to most recent records based on the 2012/2013 and 2013/2014 fish surveys, refer to appendixes 34 to 50. An overview of the number of fish surveys done at state impoundments in the FSP over the past 50 years, the number of fish species recorded within periods of ten year cycles, as well as the fish species and number of species recorded at state impoundments is presented in Table 6.9.

Table 6.9: Overview of fish surveys done at state impoundments in the Free State Province and number of species recorded. (For each 10 year period, the number next to the fish species in each column indicates during how many surveys the species was recorded). Species presence (%) is the percent of 20 sampled impoundments where the species was present between 2006 and 2015.

Period	**1966 – 1975**	**1976 – 1985**	**1986 – 1995**	**1996 – 2005**	**2006 – 2015**	**Species presence (%)**
Number of impoundments surveyed during 10 year period	7	2	11	11	20	
Fish species						
Austroglanis sclateri	1	1	1	0	2	10
Barbus anoplus	5	1	3	0	9	45
Barbus paludinosus	1	0	4	1	7	35
Carassius auratus	0	0	0	0	1	5
Cyprinus carpio	5	2	9	10	20	100
Clarias gariepinus	5	2	11	11	20	100
Ctenopharyngodon idella	0	0	0	0	1	5
Gambusia affinis	0	0	0	0	3	15
Labeobarbus aeneus	7	2	11	10	18	90
Labeo capensis	6	2	11	10	19	95
Labeobarbus kimberleyensis	5	1	9	8	12	60
Lepomis macrochirus	0		1	0	0	0
Labeo umbratus	7	2	11	11	20	100
Micropterus salmoides	0	0	1	1	6	30
Oncorhynchus mykiss	2	1	1	0	1	5
Pseudocrenilabrus philander	0	0	2	0	5	25
Tilapia sparrmanii	0	0	0	0	1	5
Total species recorded	**10**	**9**	**13**	**8**	**16**	

(The shaded areas indicate the six main fishery species that were caught during all surveys).

From 1975 until 2014 there has been an increase in the total number of fish species recorded at state impoundments in the FSP. New distribution records have been obtained for three alien and invasive species, namely *C. auratus, C. idella* and *G. affinis.* The distribution range of the alien and invasive *M. salmoides* has also expanded. During the most recent fish surveys this species was recorded in six impoundments within the OSRB in comparison to the only one impoundment where it was recorded during 1995. Most of the alien and invasive species were recorded in low numbers, except for the *M. salmoides* population that is established in Knellpoort Dam and *C. idella* that is established in Bloemhof Dam.

For the past 50 years, six fish species, namely *C. gariepinus, C. carpio, L. aeneus, L. capensis, L. kimberleyensis* and *L. umbratus* have dominated the catch composition (see Table 6.9).

Results also indicate that impoundments are not suitable habitats for *A. sclateri* and *T. sparrmanii,* while *P. philander* was only sampled at five impoundments. Of the smaller minnow species, *B. anoplus* is restricted to only a few impoundments in the OSRS, while *B. paludinosus* was recorded in seven impoundments in the VRS.

Although the results have indicated an increase in total number of species recorded at state impoundments in the FSP, during the 50 year period there has been no decline or decrease in the number of mostly riverine species which have seemed to successfully adapted to the more lentic conditions created after water was impounded. An exception is *A. sclateri* which is mostly a riverine species and which has seemingly disappeared from impoundments, except at Sterkfontein Dam where the species preferred habitat is present.

6.4 Discussion

Sixteen fish species were recorded at 21 impoundments during the current study period. Impoundments in the FSP are characterised by very low species diversity with a mean number of 7.6 ± 1.4 and 6 ± 1.1 different species recorded in the VRS and OSRS respectively. The lowest number of species (four) was recorded at Jimmie Roos Dam, with a maximum of ten species recorded at Bloemhof Dam, followed by Koppies, Krugersdrift and Sterkfontein Dams with nine species each. All four of these impoundments are situated within the VRS and the higher species richness can be attributed to higher alien species richness. Except for *C. carpio* and *C. idella* at Bloemhof Dam, four other alien and invasive species were recorded but in very low numbers.

Based on the use of Jaccard's Index of Similarity, the fish assemblages amongst impoundments situated within the VRS (range from 33% to 100%), those situated within the OSRS (range from 42% to 100%), and between impoundments of the VRS and OSRS (range from 33% to 100%), are to a certain extent similar. The fact that Rustfontein, Mockes and Krugersdrift Dams are all situated on the main stem of the Modder River allowed for comparison of fish assemblages within one system which indicated that there was a degree of similarity between the fish assemblages (range from 70% - 89%), but none were 100% similar. A relatively high similarity (> 70%) was observed for fish assemblages between impoundments that are part of inter-basin water transfer schemes which can amongst others be attributed to the presence of *M. salmoides* in all.

Historical records have indicated the paucity of information and limited research done on freshwater fish and fisheries at state impoundments in the FSP since 1966 (Janse van Vuren, 1978; Barkhuizen, 1995; 1996). Research reports that were compiled, however, were mostly inaccessible and difficult to obtain as indicated by McCafferty *et al.* (2012). The historical analysis of available records indicates an increase in fish species diversity at impoundments in the FSP from only 10 species recorded during the 1966 - 1975 period, to 16 species recorded during the 2006 - 2015 period. This observed increase is due to new distribution records been obtained for three alien and invasive species, while the distribution range of the alien and invasive *M. salmoides* has also expanded. At most impoundments the alien and invasive species were recorded in very low numbers indicating that these species have not established successfully, except for *C. idella* that has established successfully in Bloemhof Dam, while results indicated that *M. salmoides* has only established a viable population in Knellpoort Dam. The higher species diversity may also be attributed to the fact that for the first time in the history of the FSP, in depth and comprehensive fish surveys were done using a variety of gear types over an extended period of time.

Based on the historic and recent catch data, the bulk of the total fish catches at state impoundments for the past 50 years in the FSP consisted of six fish species, namely *C. gariepinus, C. carpio, L. aeneus, L. capensis, L. kimberleyensis* and *L. umbratus* of which the latter five species are large cyprinids. Three of these are endemic species (*L. aeneus, L. kimberleyensis* and *L. capensis*), two indigenous species (*L. umbratus* and *C. gariepinus*), and one alien and invasive species (*C. carpio*). Two of the endemic species (*L. aeneus* and *L. capensis*) and the indigenous *L. umbratus,* whose original habitats were riverine systems before the onset of the dam building era, have successfully adapted to the more lentic systems created by impoundments and these species were well sampled in gill nets during all fish surveys. At Gariep Dam for example, Winker *et al.* (2012) found that 40 years after impoundment, the ichthyofauna was dominated by *L. capensis* and based on comparative pre-impoundments studies, this species has maintained its lotic life history characteristics. The authors also noted that the availability of large flooded vegetated littoral zones played a major role in the successful establishment of this species in Gariep Dam. These conditions are also available during the rainy seasons at the other impoundments and could lead to the successful establishment of this species elsewhere.

The predatory largemouth yellowfish *L. kimberleyensis* which prefers lotic systems with clear water and gravel or sandy substrates (Mulder, 1973a; Skelton, 1993; Kotze, 2002; De Villiers, 2007b), was absent at a number of impoundments, but where it was sampled, it was recorded in low numbers as can be expected from a top predator. Impoundments are not deemed suitable habitats for this species due to the high silt load and turbidity and absence of suitable gravel beds for spawning. During experimental gill net sampling at Gariep Dam, Ellender *et al.* (2012) reported that only 2% of the total catch comprised of *L. kimberleyensis,* while it contributed only 8% to the total weight of the total catch. This also corresponds with the results of the current study where this species was recorded in very low numbers at most impoundments.

The alien and highly invasive *C. carpio* has been present in South Africa and the FSP since before the 1960's (Harrison, 1963; Jubb, 1972; Skelton, 1993). Harrison (1963) noted the first importation of *C. carpio* into South Africa during 1896 and that this species was bred at the Jonkershoek hatchery in the former Cape Province until 1921, when breeding of this species was stopped and stock destroyed as the damaging causing impacts of *C. carpio* became known. Unfortunately by then, *C. carpio* had already invaded large areas and spread throughout South Africa (Bruton and Merron, 1985; De Moor and Bruton, 1988) causing this species to become the most preferred and choice angling species for recreational anglers and upon which a multi million rand recreational fishery industry depends (see Chapter 5). This species has become naturalised in the aquatic systems in South Africa and has successfully adapted to co-exist with the indigenous fish fauna within the OSRS and VRS.

Being an omnivore and bottom feeder, the feeding behaviour of *C. carpio* can, however, significantly increase the silt load in lentic systems and can have a serious detrimental effect on aquatic systems and organisms (Le Roux and Steyn, 1968; Bruton *et al.,* 1982; De Moor and Bruton, 1988). The species is also known for the introduction of a large number of non-specific fish parasites which subsequently infected indigenous fish species (De Moor and Bruton, 1988).

Jackson *et al.* (2010) during a study in lakes in Iowa in the USA found that lakes with large populations of *C. carpio* were eutrophic, had an excessive phytoplankton biomass and high turbidity levels that impacted negatively on the catch of sport fishes. Results of their study found that *C. carpio* preferred shallower systems and that these systems may be more prone to the negative effects created by *C. carpio*. Koehn (2004) noted that *C. carpio* has in a short period of time since its first introduction spread to over 1 million km^2 in south east Australia and the author predicted the further spread of this alien and invasive species.

For the temperate regions in the world, Baxter (1977) noted that at new impoundments there is usually a decline in fish populations after a few years. Mol *et al.* (2007) working in the tropics in Suriname noted a drastic decline in the number fish species in the Brokopondo Dam from 172 species present in the Suriname River before impoundment, to only 41 species recorded during 2005. The main aging process at impoundments according to Miranda (2001) is an increase in siltation that decreases the storage capacity and average depth of impoundments which directly impacts on the productive littoral zones. On the long term the physical characteristics of impoundments and water quality parameters will change, while nutrients contained in the silt might become available for primary production (Miranda, 2001). For fish populations at impoundments in the FSP, this proposed impact seems to be limited as most fish populations have adapted to the lentic conditions.

Another important aspect associated with the aging of impoundments is the change of the shoreline habitats into barren homogenous mudflats (Miranda, 2001), which is evident at most impoundments for example Kalkfontein, Bloemhof, Tierpoort, Moutloatsi Setlogelo, Rustfontein and Krugersdrift Dams. This will ultimately impact directly on the natural recruitment of species as indicated for *C. gariepinus* populations at a number of impoundments. Liermann *et al.* (2012) noted that the change from lotic to lentic habitats in impoundments, usually favour the more generalist species, that might lead to biotic homogenisation.

Gill nets are passive gears, and catches depend on fish encountering the nets in the deeper lentic zones. With seine nets, catches depend on entrapping fish within the semi-circle created in the shallower littoral zones when the net is set and ultimately leading fish to the sack in the middle of the net as the net is pulled towards the shore. Results of this study have shown that riverine species, especially the pelagic *L. aeneus* and *L. kimberleyensis* were mostly caught in gill nets, while seine nets were most successful in catching *C. carpio.* Adults and heavier fish for all species were caught in gill nets except for *C. gariepinus* populations, while nearly no differences were found between the total catch and weight for *C. gariepinus* when using gill and seine nets. Jackson *et al.* (1983), who tested the efficiency of different fishing gear for commercial fishing as well as for scientific sampling also noted that different types of gear will influence what fish species as well as size class will be caught.

The highly fecund, adaptive and invasive nature of *C. carpio* is clearly demonstrated by the species' dominance within the 0 to 100 mm size class compared to indigenous species at most impoundments. Despite major fluctuations of impoundments' water levels (see Chapter 3), which impacted negatively on the recruitment of most endemic and indigenous species during the most recent spawning seasons, *C. carpio* was able to spawn successfully. Of the observed data, except for Bloemhoek Dam, this alien species is well established at all impoundments with all size classes present.

The absence of individuals of *C. gariepinus* within the 0 to 200 mm size class at eight of the 12 impoundments may also be attributed to the major fluctuation of water levels at impoundments. As indicated by Jubb (1967), Bruton *et al.* (1982) and Kotze (2002) this species requires flooded vegetation to spawn, but this is absent at impoundments which experience a continuous decline in water level and limited natural inflow during the spawning season.

A trend being observed for *L. aeneus, L. capensis* and *L. umbratus* populations in impoundments that are receiving water via inter-basin water transfer schemes is the total lack of, or limited number of specimens within the 0 to 100 mm and 101 to 200 mm size classes. The artificial manipulation and regulation of water levels at Bloemhoek, Knellpoort, Sol Plaatje and Sterkfontein Dams during these species' spawning seasons have a negative impact on the natural recruitment of these species. This trend was especially noted for these three fish species at Sterkfontein Dam. Dörgeloh (1986) noted that for a period of five years prior to surveys been done in Sterkfontein Dam, all indigenous species had a very low recruitment which was attributed to a lack of suitable spawning areas and all populations were dominated by adult fish. Nearly 81% of the *L. aeneus* catch comprised of individuals ranging from 280 to 550 mm; 87% of the total *L. capensis* catch comprised of individuals between 180 to 470 mm; more than 94% of the *L. umbratus* caught range from 320 to 470 mm, while just over 90% of the *C. gariepinus* catch comprised of adults between 400 and 1 010 mm. Because water is pumped from the Upper Tugela River System in Kwazulu Natal over the escarpment to Sterkfontein Dam in the VRS, Dörgeloh (1986) mentioned the possibility of the translocation of fish species between the two systems, but to date this seemingly has not happened.

Of the 21 impoundments surveyed, *L. kimberleyensis* populations are established in only five (Armenia, Erfenis, Gariep, Kalkfontein and Koppies Dams). No fry or juveniles within the 0 to 100 mm size class were caught. This may be attributed to the fact that impoundments do not have suitable spawning areas as this species that prefers lotic systems, requires gravel beds and flowing water to spawn. Various authors (Mulder, 1969; Cambray, 1984; Benade, 1993; Eccles, 1993) noted the difficulty in differentiating between juveniles of *L. aeneus* and *L. kimberleyensis* that are smaller than 100 mm. The author of the current study, however, is of the opinion that *L. kimberleyensis* do not breed within impoundments.

Results of the CCA have indicated that the main environmental and morphometric variables driving the distribution of the six main fishery species at impoundments in the FSP, are mean annual air temperature (which will ultimately influence the water temperature), conductivity (which impacts on the trophic state of an impoundment), pH, the age of impoundments, size of the catchment (impacts on the quality of water entering the impoundment and may impact on productivity) and Secchi depth (the larger the Secchi depth, the clearer the water, thus enhancing productivity). For *L. capensis* the CPUE is the least influenced by the measured environmental variables, while the other five main fisheries species' distribution was influenced to a varying extent by certain variables. For *C. carpio* and *L. aeneus* the results have confirmed the ecology and biology of the two species, as *C. carpio* tends to increase nutrient loading and prefer more eutrophic waters, while *L. aeneus* are an open water plankton feeder that requires clearer water. Suitable spawning areas, e.g. flooded vegetation for *L. umbratus* and inflowing streams and rivers for *L. capensis*, may further impact on the distribution of these two species.

6.5 Conclusion

Fish communities at impoundments situated in the OSRS and VRS within the borders of the FSP, that is situated in the southern temperate zone is characterised by very low species diversity, with the bulk of fish communities consisting of five large cyprinids and *C. gariepinus.* Impoundments in the VRS have a significantly higher species diversity which is a result of the presence of more alien and invasive species. Except for *C. carpio, M. salmoides* (at Knellpoort Dam) and *C. idella* (at Bloemhof Dam), most of these alien and invasive species are not established in impoundments as it was recorded in very low numbers. Based on the historic catch records of the past 50 years and most recent data, four of the five cyprinids (i.e. *L. aeneus, L. capensis, L. umbratus* and *C. carpio*) and *C. gariepinus* have successfully adapted to lentic conditions created by impoundments. At only five impoundments (Armenia, Erfenis, Gariep, Kalkfontein and Koppies Dams) established populations of *L. kimberleyensis* were found and due to the conservation status of this species, the establishment of any future commercial fisheries at these five impoundments should carefully be considered before it is allowed.

At impoundments situated within the same river system and amongst impoundments in the VRS and OSRS, variation in fish species assemblages was observed with only a small number of fish assemblages being 100% similar. One of the drivers of the dissimilarities is the presence of non-native species and the fragmentation of rivers caused through the building of impoundments.

The importance of the use and the inclusion of different gear types in sampling fish populations at impoundments in the FSP have been highlighted by the differences found in total catch, total number of species caught, as well as average weight and size classes when gill and seine net catches were compared. This will ultimately also determine which gear types to select once small-scale fishery projects are established in the future. To determine a more suitable gear type to be used in the future establishment of small-scale fisheries, an investigation was launched on the suitability of fyke nets for use in small-scale fisheries which will be discussed in the next chapter.

Chapter 7 Suitability of fyke nets for use in small-scale fisheries in the Free State Province

7.1 Introduction

There is limited information of the use of fyke nets in South African freshwater environments. Only five studies report on the use of fyke nets as sampling gear. Hamman (1974) used four fyke nets (1 m x 2 m) made from wire with funnel-shaped openings with a diameter of 100 mm during March and April 1973, set at depths of 1 to 4 m in Gariep Dam. Some fyke nets were baited, but Hamman (1974) reported on the poor performance of this type of sampling gear as only 27 fish, mostly *C. carpio* and *C. gariepinus* were caught. Batchelor (1974) used fish traps (assumed to be fyke nets), and reported that only two fish species that had no angling potential were caught and in general this gear was not effective. More recently, Potts (2003) and Booth and Potts (2006) used fyke nets as an alternative non-destructive sampling method to determine the selectivity of gill nets. Olds *et al.* (2011) used fyke nets in the Wilderness Lakes System in the Western Cape Province to determine the status of invasive species in this sensitive system.

Fyke nets are, however, used extensively in fisheries elsewhere. Berka (1990) noted that fyke nets and fish traps were commonly used in the USSR due to its simple design, low cost and because it could easily be made. Fyke nets and fish traps were most effective during spring as fish moved closer to the shoreline (Berka, 1990). In Sweden, Dutch type fyke nets are used extensively along the Swedish west coast in eel fisheries (Königson *et al.*, 2007). According to Colotelo *et al.* (2013) fyke nets are used extensively by commercial fishers in Canada to target a variety of species. Krueger *et al.* (1998) used two types of tandem-set fyke nets to evaluate its efficiency compared to gill nets and noted that bottom dwelling and species preferring habitats with cover, were more readily caught in the fyke nets while pelagic species were mostly caught in the gill nets. Apart from anecdotal reports on the use of fyke nets to attempt to establish eel fishery in the Eastern Cape Province (Booth and Potts, 2006) there is no information in the published literature on the use of fyke nets in small-scale or commercial inland fisheries in South Africa. Historically, gill nets (mesh size > 100 mm), seine nets (mesh size > 50 mm), long lines and electro-fishers were used by commercial fisheries to harvest fish in impoundments in the Free State Province (FSP) (see Chapter 4).

In South Africa there is increasing pressure to develop fisheries (see Chapters 2 and 4) and to develop avenues for increasing individual catch rates beyond that from angling. Fyke nets are potentially a low cost gear that might allow for increased harvest. It is a passive gear that can be set in shallow water. No boat is required as in the case when setting gill and seine nets, and there is no need for a skipper license of safety certificates for boats as required by the South African Maritime Safety Authority. Conflict with other user groups may be prevented as certain sections of the shorelines at impoundments can be zoned for exclusive use by small-scale fishermen using fyke nets. As fish caught in fyke nets are not entangled as in the case with gill nets, non-targeted and species of conservation concern can be released with limited injuries.

The purpose of this chapter was to assess the suitability of fyke nets as a potential harvesting method for impoundments in the Orange-Senqu River Basin, assessing catch rates, species composition and conducting a preliminary economic viability assessment.

7.2 Materials and Methods

Three double ended Dutch type fyke nets were used without otter-guards to allow for fish of all sizes to enter. The guiding (leader) net between the hoop nets had an average length of 9.7 ± 0.1 m with a depth of 1 m and the primary hoop was 1 m high x 1.5 m wide. The netting material in the guiding net and covering both sections had a stretched mesh size of 20 mm, while a section of the netting material at the entrances were made from stronger twine with a stretched mesh size of 25 mm. The end sections of the nets can be closed with strings attached. Anchors (5 liter paint tins filled with rocks and concrete) were tied to the end ropes of each section to secure the net in its position. A red marker was attached to the top of one of the entrances to mark the site where the net was set. The left sections of the fyke nets used during the study period are indicated in Figure 7.1.

Figure 7.1: Left sections of the three Dutch type fyke nets that were used.

All fyke nets were set at a depth of 1 to 1.5 m, and 100 to 200 meters apart. The nets were set by wading into the water and when the correct depth was reached, the entrances were set first and each section was pulled to its maximum to open the cone-shaped netting bags by moving backwards to ensure the bags and the guiding net between the two hoop nets were straight and tight before the anchors were released. All fyke nets were set parallel to the shoreline and none were baited.

At each net placement site, the following parameters were recorded:

(i) General observations: GPS coordinates and altitude were determined with a handheld Garmin GPSmap 62; date and time when net was set; type of substrate/bottom; interesting features nearby; weather conditions;
(ii) The impoundment's water level (in %) was obtained from the local office of the Department of Water and Sanitation;
(iii) Air temperature using a handheld thermometer;
(iv) Water temperature, pH, total dissolved solids and electrical conductivity using a hand held Crison MM40+ multi-meter;
(v) Turbidity using a portable Eutech TN-100/T-100 turbidity meter;
(vi) Secchi depth.

All fyke nets were left in the water for two nights (except for Tierpoort and Serfontein Dams). Fish caught in each fyke net were identified to species level and measured for fork and total length to the nearest mm. The weight was recorded using an Ishida IPC 1356 scale with maximum capacity of 15 kg and graduations of 5 g. Smaller specimens were weighed using a Terraillon T800 scale with a maximum capacity of 3 kg and graduations of 1 g. Specimens larger than 15 kg were weighed using a basic spring balance.

The length frequency distribution was determined only for the main fishery species. For *C. carpio, L. aeneus, L. capensis,* and *L. umbratus* the catch data were summarised and processed in MS EXCEL and were sorted within 100 mm size classes based on fork length. As indicated in Chapter 6, these size classes represent important periods in the life history of these large bodied fishes. Young of year are generally < 100 mm, immature fish vary from 110 to 300 mm in length, while maturity in the larger cyprinids is attained at lengths of > 300 mm. Due to the larger size of *C. gariepinus* the catch data for this species were sorted within 200 mm size classes and was based on total length. As the population structure of fish species at the study sites have already been discussed in detail in Chapter 6, only one length frequency distribution graph per species will be presented.

As indicated in Chapter 4, gill nets (mesh size > 100 mm), seine nets (mesh size > 50 mm), long lines and electro-fishers were used by commercial fisheries at state impoundments in the FSP. During the 2013/2014 summer season's fish surveys, three sets of gill nets, of which three 20 m panels had a mesh size of 100 mm and three 20 m panels had a mesh size of 144 mm, were used to sample fish. A 100 m x 3 m seine net with a mesh size of 75 mm was also used to sample fish. Recreational anglers' catches were discussed and summarised in Chapter 5. This allowed for a comparison of the species compositions and average weights of the major fishery species caught in fyke, gill and seine nets, as well as recreational anglers' tournament catches.

Catch per unit effort (CPUE) for the fyke nets were determined as the total weight per species caught per fyke net per night. For the 2013/2014 season's fish surveys, this was based on three fyke nets that were in the water for two nights per impoundment (i.e. 18 impoundments x three fyke nets x two nights = 108 + two impoundments x three fyke nets x one night = 6 fyke net nights; thus 114 fyke net nights). A multi-variate analysis was performed to establish whether significant relationships exist between the CPUE and environmental and morphometric variables that were recorded.

In order to determine the current monetary value of the freshwater fish that were caught using the fyke nets, the price of gutted fish per kilogram as sold by the Venterstad Community Fisheries Project at Gariep Dam, the only operational small-scale fishery in central South Africa as during March 2015, was used as a guideline which was ZAR17.50 per kilogram.

7.3 Results

7.3.1 Species composition of fyke net catches

The species composition of the total catch and total weight of the total catch of the three fyke nets combined for each impoundment expressed as a % are summarised in Tables 7.1 and 7.2 respectively. No fish were caught at Metsi Matso Dam and only river frogs, tadpoles, freshwater crabs and two Cape clawless otters *Aonyx capensis* (Schinz, 1821) that drowned in a net. At Sterkfontein Dam only two fish with a combined weight of 3 kg were caught. The most fish caught in a fyke net during the study period was at Koppies Dam as shown in Figure 7.2.

Figure 7.2: Fyke net filled to capacity with *Clarias gariepinus* at Koppies Dam.

Table 7.1: Species composition of the total catch of the three fyke nets combined for each impoundment, expressed as a percentage (%).

Impoundment	No. of species caught	Total number of fish caught	B.an (%)	B.pa. (%)	C.au. (%)	C.ca. (%)	C.ga. (%)	L.ae. (%)	L.ca. (%)	L.ki. (%)	L.um (%)	L.um. x L.ca. (%)	M.sa. (%)	P.ph. (%)
Allemanskraal	7	131	0	5.3	0	6.9	0.8	3.1	31.3	0.8	49.6	2.3	0	0
Armenia	7	136	13.3	0	0	14	0.7	5.1	24.3	3.7	39	0	0	0
Bloemhoek	5	130	0	0	0	15.4	5.4	0	76.2	0	1.5	0	1.5	0
Bloemhof	6	154	0	0.7	0	13.6	68.8	0	0.7	0	13.6	0	0	2.6
Egmont	5	527	1.3	0	0	2.7	0.4	4.9	4.4	0	86.3	0	0	0
Erfenis	6	1 257	0	79.9	0	2.1	0	3.7	10.9	1.2	2.2	0	0	0
Gariep	5	84	0	0	0	36.9	15.5	17.9	28.6	0	1.2	0	0	0
Jimmie Roos	4	98	4.08	0	0	12.24	2.04	0	0	0	81.63	0	0	0
Kalkfontein	4	112	0	0	0	7.1	1.8	0	53.6	0	37.5	0	0	0
Knellpoort	5	132	0	0	0	4.5	0	0.8	38.6	0	53.8	0	2.3	0
Koppies	7	499	0	46.7	0	2.6	38.1	0.8	1	0.2	10.6	0	0	0
Krugersdrift	6	249	0	0	0.4	36.55	5.22	0	22.1	0	32.13	0	0	3.61
Metsi Matso	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mockes	7	38	2.6	0	0	18.4	15.8	23.7	21.1	2.6	15.8	0	0	0
Moutloatsi Setlogelo	5	67	0	0	0	3	7.5	0	35.8	0	49.3	4.5	0	0
Rustfontein	5	43	0	0	0	20.9	0	16.3	32.6	0	14	0	0	16.3
Serfontein	5	47	0	0	0	36.2	38.3	2.1	17	0	6.4	0	0	0
Sol Plaatje	5	31	3.2	0	0	80.6	0	3.2	3.2	0	9.7	0	0	0
Sterkfontein	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Tierpoort	6	108	0	0	0	60.2	13	4.6	3.7	2.8	15.7	0	0	0
TOTAL		**3 845**												

Shaded areas: the preferred and most popular angling species in the Free State Province.

Key: B.an. – *Barbus anoplus*; B.pa. – *Barbus paludinosus*; C.au. – *Carassius auratus*; C.ca. – *Cyprinus carpio*; C.ga. – *Clarias gariepinus*; L.ae. – *Labeobarbus aeneus*; L.ca. – *Labeo capensis*; L.ki. – *Labeobarbus kimberleyensis*; L.um. – *Labeo umbratus*; L.um. x L.ca. – hybrids of *L. umbratus* and *L. capensis*; M.sa. – *Micropterus salmoides;* P.ph. – *Pseudocrenilabrus philander.*

Eleven fish species were caught in the fyke nets. Non-target species were an incidental component in catches (Table 7.1). One *C. auratus* was caught at Krugersdrift Dam, while the predatory *M. salmoides* was recorded in very low numbers at Bloemhoek and Knellpoort Dams. At Armenia, Egmont, Jimmie Roos, Mockes and Sol Plaatje Dams *B. anoplus* was recorded in low numbers, while *B. paludinosus,* which were caught in the netting material of the nets, dominated the total catch at nearly 80% and 47% at Erfenis and Koppies Dams respectively. At Allemanskraal, Armenia, Erfenis, Koppies, Mockes and Tierpoort Dams, *L. kimberleyensis* was recorded in very low numbers in the total catch but was absent from fyke net catches at most impoundments. At 12 impoundments *L. aeneus* were recorded in low numbers, being the dominant species of the catch at Mockes Dam.

Target species dominated catch composition but their relative contributions differed between impoundments. Moggel dominated the total catch of fyke nets at Egmont Dam (86%), Jimmie Roos Dam (81%), Knellpoort Dam (54%), Allemanskraal Dam (50%), Moutloatsi Setlogelo Dam (49%) and Armenia Dam (39%). Carp were caught in fyke nets at 18 of the 20 impoundments, and was the dominant species in catches at Sol Plaatje Dam (81%), Tierpoort Dam (60%), Gariep Dam (37%) and Serfontein Dam (36%), while *C. gariepinus* was caught at 14 of the 20 selected impoundments, being the dominant species in the total catch at Bloemhof Dam (69%) and Serfontein Dam (38%). At 17 of the 20 selected impoundments *L. capensis* were caught, being the dominant species of the total catch at Bloemhoek Dam (76%), Kalkfontein Dam (54%) and Rustfontein Dam (33%). When combining the total catch of *L. capensis* and *L. umbratus,* the combined total of the two *Labeo* spp. indicates that the two species dominated the total catch at Allemanskraal Dam (81%), Armenia Dam (63%), Kalkfontein Dam (92%), Knellpoort Dam (93%), Krugersdrift Dam (54%) and Moutloatsi Setlogelo Dam (85%).

Table 7.2: Species' contribution to the total weight of the total catch of all three fyke nets combined, expressed as a percentage (%).

Impoundment	Total weight of total catch (kg)	B.an. (%)	B.pa. (%)	C.au. (%)	C.ca. (%)	C.ga. (%)	L.ae. (%)	L.ca. (%)	L.ki. (%)	L.um. (%)	L.um. x L.ca. (%)	M.sa. (%)	P.ph. (%)
Allemanskraal	27	0	0.1	0	4.9	0.2	0.1	4.8	0.5	85.5	3.9	0	0
Armenia	20.3	0.1	0	0	2.4	8.2	16.6	11.9	2.8	58.1	0	0	0
Bloemhoek	52.6	0	0	0	30.6	40.1	0	22.8	0	2.1	0	4.4	0
Bloemhof	377.1	0	0.001	0	10.4	89.6	0	0.03	0	0.002	0	0	0.005
Egmont	94.7	0.02	0	0	1.6	3	8.1	6	0	81.4	0	0	0
Erfenis	42.1	0	10	0	6.2	0	18.4	13.8	5	46.7	0	0	0
Gariep	106.1	0	0	0	27.1	67	4.5	0.7	0	0.7	0	0	0
Jimmie Roos	143.6	0.01	0	0	17.15	13.42	0	0	0	69.42	0	0	0
Kalkfontein	39.3	0	0	0	3.1	19.4	0	20.9	0	56.7	0	0	0
Knellpoort	79.7	0	0	0	3.9	0	1.6	20.2	0	68.7	0	5.6	0
Koppies	610.9	0	0.1	0	4.5	87	0.3	0.7	0.02	7.4	0	0	0
Krugersdrift	126.1	0	0	0.03	27.15	60.69	0	5.99	0	6.11	0	0	0.02
Metsi Matso	0	0	0	0	0	0	0	0	0	0	0	0	0
Mockes	46.4	0.001	0	0	29.2	64.2	0.2	2.2	1	3.3	0	0	0
Moutloatsi Setlogelo	59.8	0	0	0	0.03	57.9	0	7.9	0	31.1	3.1	0	0
Rustfontein	5.3	0	0	0	11.8	0	2.2	34.1	0	51.4	0	0	0.5
Serfontein	115.4	0	0	0	27.7	71	0.03	1.2	0	0.1	0	0	0
Sol Plaatje	5.1	0.1	0	0	79.6	0	0.2	4.7	0	15.5	0	0	0
*** Sterkfontein**	3 *	0	0	0	0	0	0	0	0	0	0	0	0
Tierpoort	72.2	0	0	0	32.7	59.4	1.1	0.4	0.7	5.7	0	0	0

Shaded areas: the preferred and most popular angling species in the Free State Province; * only two fish were caught at Sterkfontein Dam.
Key: B.an. – *Barbus anoplus*; B.pa. – *Barbus paludinosus*; C.au. – *Carassius auratus*; C.ca. – *Cyprinus carpio*; C.ga. – *Clarias gariepinus*; L.ae. – *Labeobarbus aeneus*; L.ca. – *Labeo capensis*; L.ki. – *Labeobarbus kimberleyensis*; L.um. – *Labeo umbratus*; L.um. x L.ca. – hybrids of *L. umbratus* and *L. capensis*; M.sa. – *Micropterus salmoides;* P.ph. – *Pseudocrenilabrus philander.*

The total catch at Sol Plaatje Dam was dominated by carp fingerlings, while the total catch at Rustfontein Dam was dominated by fingerlings of *L. capensis* and *L. umbratus*. The 154 fish at Bloemhof Dam had a combined weight of 377.1 kg with *C. gariepinus* contributing 89% and *C. carpio* contributing 10% to total weight of the total catch. At Jimmie Roos Dam where 98 fish with a combined weight of 143.6 kg were caught, *L. umbratus* contributed 69% to the total weight of the total catch, *C. carpio* 17.2% and *C. gariepinus* 13.4%. The total catch of 249 fish at Krugersdrift Dam had a combined weight of 126.1 kg with *C. gariepinus* contributing 60.7% and *C. carpio,* 27.2% to the total weight of the catch. The total weight of 115.4 kg of the 47 fish caught at Serfontein Dam was dominated by *C. gariepinus* at 71%, followed by *C. carpio* at 28%, while at Gariep Dam, the total weight 106.1 kg of the 84 fish that were caught, was dominated by *C. gariepinus* at 67% and *C. carpio* at 27%. At Bloemhoek, Mockes and Tierpoort Dams the two species also contributed most to the total weight of the total catch.

Off all species caught in fyke nets, *L. umbratus* contributed the most to the total weight of the total catch, notably at Allemanskraal (86%), Egmont (81%), Jimmie Roos (69%), Knellpoort (69%), Armenia (58%), Kalkfontein (57%), Rustfontein (51%) and Erfenis Dams (47%).

The two small minnow species and *P. philander* did not contribute significantly to the total weight of the total catch, except at Erfenis Dam where *B. paludinosus* contributed 10% to the total weight. The contribution of the two predatory species *L. kimberleyensis* and *M. salmoides* to the total weight of the total catch at all impoundments was insignificant. This is also applicable to *L. aeneus* and only at Erfenis and Armenia Dams this species contributed a significant part to the total weight of the total catch at 18% and 17%, respectively.

7.3.2 Length frequency distribution of fish species

As the population structure of the different species has already been discussed in Chapter 6, only one representative length frequency distribution graph per species will be presented. These are presented for *C. carpio* in Figure 7.3, for *C. gariepinus* in Figure 7.4, for *L. aeneus* in Figure 7.5, for *L. capensis* in Figure 7.6, and for *L. umbratus* in Figure 7.7.

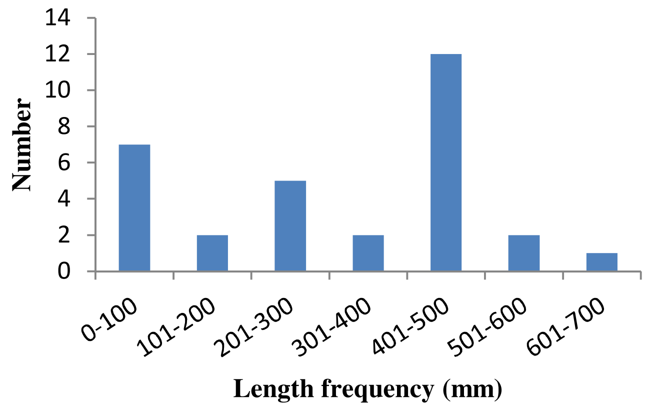


Figure 7.3: Length frequency distribution of *Cyprinus carpio* caught at Gariep Dam. (N = 31).

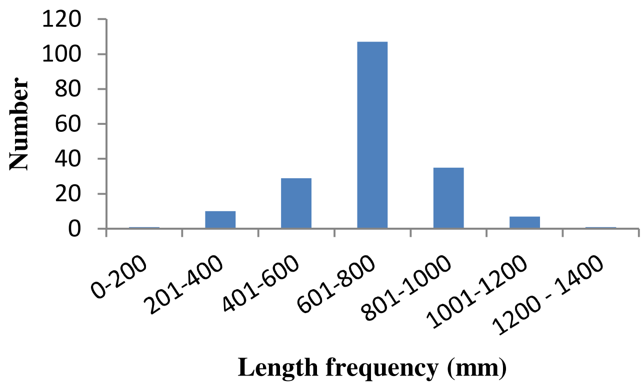


Figure 7.4: Length frequency distribution of *Clarias gariepinus* caught at Koppies Dam. (N = 190).

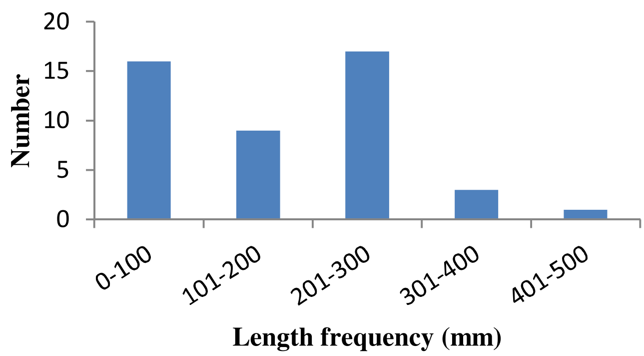


Figure 7.5: Length frequency distribution of *Labeobarbus aeneus* caught at Erfenis Dam. (N = 46).

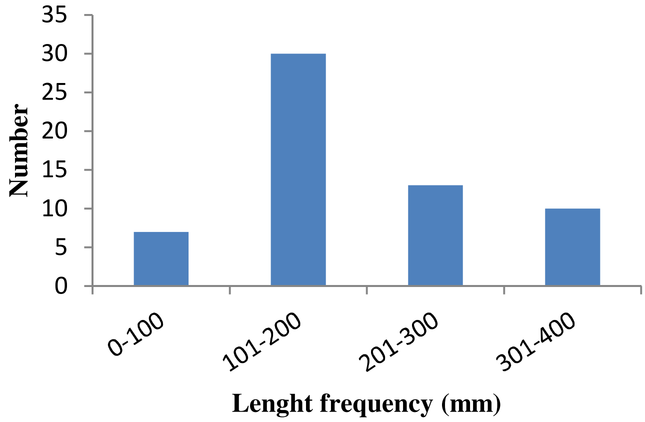


Figure 7.6: Length frequency distribution of *Labeo capensis* caught at Kalkfontein Dam. (N = 60).

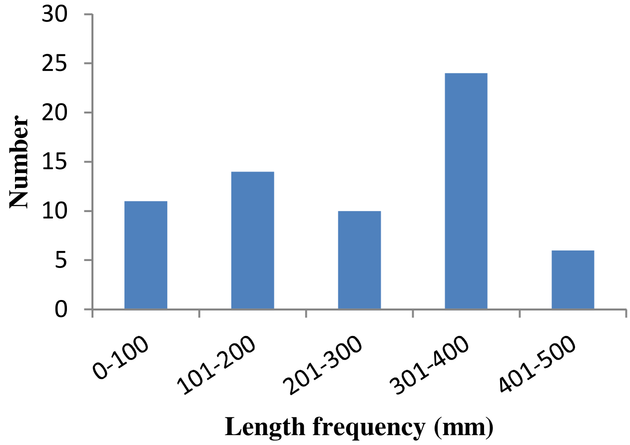


Figure 7.7: Length frequency distribution of *Labeo umbratus* caught at Allemanskraal Dam. (N = 65).

7.3.3 Catch composition of fyke nets compared to standard commercial gears used in commercial fisheries and tournament angling

A summary of the catch composition of fyke nets compared to the standard commercial gears used in commercial fisheries, and tournament angling records, is presented in Table 7.3.

Table 7.3: Comparison of fyke net, gill net (100 and 144 mm mesh) and seine net (75 mm mesh) and recreational tournament catches.

	Fyke nets			**Gill nets (100 mm and 144 mm mesh)**			**Seine net (75 mm mesh)**			**Tournament catches of recreational anglers**		
	N (%)	**W (%)**	**Av. W (kg)**	**N (%)**	**W (%)**	**Av. W (kg)**	**N (%)**	**W (%)**	**Av. W (kg)**	**N (%)**	**W (%)**	**Av. W (kg)**
Main species total (%)	**65.4**	**99.2**		**95.4**	**91.9**		**99.7**	**100.0**		**100.0**	**100.0**	
Cyprinus carpio	10.2	12.6	0.7	8.8	7.0	1.0	53.8	64.0	1.9	77.6	80.9	1.0
Clarias gariepinus	9.9	62.3	3.3	9.4	19.8	2.6	5.7	13.3	3.6	7.8	10.3	1.3
Labeobarbus aeneus	3.3	1.4	0.2	18.5	14.6	1.0	1.6	0.6	0.6	2.0	1.4	0.7
Labeo capensis	15.3	3.6	0.1	6.0	4.1	0.9	11.6	5.4	0.7	12.6	7.3	0.6
Labeo umbratus	26.6	19.3	0.4	52.7	46.4	1.1	27.0	16.6	1.0	0.1	0.1	0.8
Bycatch total (%)	**34.6**	**0.8**		**4.6**	**8.1**		**0.3**	**0.0**		**0.0**	**0.0**	
Labeobarbus kimberleyensis	0.7	0.2	0.2	3.9	7.5	2.4	0.2	0.0	0.2	0.0	0.0	0.0
Barbus anoplus	0.8	0.0	< 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Barbus paludinosus	32.5	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Carassius auratus	0.0	0.0	< 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Micropterus salmoides	0.1	0.3	1.4	0.6	0.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Oncorhynchus mykiss	0.0	0.0	0.0	0.1	0.1	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Pseudocrenilabrus philander	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sample size	**3 834**	**2 023.70**		**1 342**	**1 685.70**		**1 755**	**2 733.60**		**427 078**	**412 351.30**	

Key: N %: total number of fish caught expressed as %; W %: total weight of fish caught expressed as %; Av. W: average weight (kg).

The largest average fish weight for *C. carpio* was from seine net catches (1.9 kg), followed by gill nets (1.0 kg), tournament angling (also 1.0 kg) and fyke nets (0.7 kg). The highest average weight for *C. gariepinus* was recorded in seine nets (3.6 kg); followed by fyke nets (3.3 kg), gill nets (2.6 kg) and tournament angling catches (1.3 kg). The lowest average weight for the two Orange Vaal River yellowfish species combined was recorded in fyke nets (0.2 kg), with the highest average weight recorded in gill net catches (1.0 kg). Orange River mudfish *L. capensis* caught in fyke nets had the lowest average weight (0.1 kg) compared to the highest average weight of 0.9 kg of fish caught in gill nets. The highest average weight for *L. kimberleyensis* was recorded in gill net catches (2.4 kg), with the lowest average weight (0.1 kg) recorded in fyke nets. The highest average weight for *L. umbratus* (1.1 kg) was recorded from gill net catches with the lowest average weight of 0.4 kg recorded from fyke net catches. The bycatch in fyke nets was low except at Erfenis and Koppies Dams where large numbers of *B. paludinosus* were caught in the netting material.

In order to determine if there is any correlation between fyke and gill nets total CPUE, CPUE data were plotted on a scatter graph and a linear trendline added. A very weak relationship between fyke net CPUE and gill net CPUE were observed indicating no correlation (see Figure 7.8).

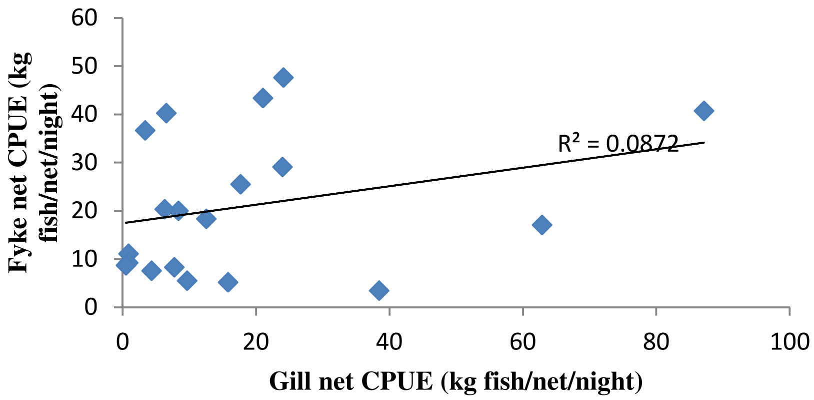


Figure 7.8: Fyke net catch per unit effort (CPUE) in relation to gill net catch per unit effort (CPUE) indicated as kg fish per net per night.

7.3.4 Comparison of CPUE between impoundments and possible drivers of fyke net catches

There was no correlation between environmental and morphometric variables and fyke net CPUE. The correlation matrix showed very low correlations (absolute values closer to zero than to one) between the predictor and response variables and it can be concluded that none of the environmental and morphometric variables impacted significantly on the CPUE of the five main fisheries species caught in the fyke nets. A summary of the environmental and morphometric variables measured each time a fyke net was set indicating the mean and standard deviation, is presented in Appendix 52. The mean CPUE for the main fisheries species caught based on the total weight per species in kilogram per fyke net per night, and the correlation matrix is presented in Table 7.4.

Table 7.4: Summary of the catch per unit effort (CPUE) for the main fishery species and the correlation matrix.

	Cyprinus carpio	*Clarias gariepinus*	*Labeobarbus aeneus*	*Labeo capensis*	*Labeo umbratus*
Mean CPUE (kg fish/net/night)	2.17	11.66	0.34	0.46	2.21
StDev	4.07	20.33	0.31	0.49	3.07
Correlation coefficients					
SufArea	0.26	0.29	0.19	-0.25	-0.22
Avwat6y	-0.22	0.12	0.08	-0.31	-0.2
Avdepth	-0.26	-0.19	-0.04	-0.02	-0.12
CatchA	0.36	0.46	0.06	-0.24	-0.22
Lat	-0.34	-0.52	0.42	-0.02	0.15
Alt	-0.42	-0.27	-0.11	-0.27	0.02
MeanAT	0.31	0.13	0.05	-0.09	-0.11
MeanWT	0.56	0.31	0.12	0.15	-0.06
AvWlevel during survey	0.1	0.06	-0.15	-0.36	-0.21
AGE	0.33	0.38	0.15	-0.34	0.36
pH	0.22	0.35	0.19	0.03	0.27
TDS	0.16	0.49	-0.11	0.2	0.26
EC	0.28	0.5	-0.1	0.15	0.24
Secchi	-0.25	-0.16	-0.26	-0.24	-0.21
TUR	-0.06	-0.1	0.53	-0.06	-0.09

Quantitative variables: SufArea – surface area in ha; Avwat6y – average water for past six years as %; Avdepth – average depth at full supply level; CatchA – catchment area in km²; Lat – latitude; Alt – altitude in m; MeanAT – mean annual air temperature in °C; MeanWT – mean water temperature °C; AvWlevel during survey – water level of impoundment at time of survey in %; AGE – age of impoundment in years as on 1 December 2014; pH; TDS – total dissolved solids in mg/l; EC – conductivity in µS/m; Secchi – Secchi depth in m; TUR – turbidity in NTU.

7.4 Discussion

As indicated in Chapter 4, gill nets were the gear of choice mostly used by commercial fisheries in South Africa and the FSP as it was readily available and caught a variety of species. However, in some parts of South Africa the use of gill nets is controversial as it is not species specific and may also catch scarce and threatened species. To use gill nets in any fisheries require much higher technical training, while skippers of boats and vessels must be compliant to, and be registered with the South African Maritime Safety Authority (SAMSA). As indicated by Weyl *et al.* (2007) and Ellender *et al.* (2010a; 2010b) subsistence fisheries based on angling have developed at several impoundments. Whilst these might be productive, subsistence angling requires the presence of a person all the time that sometimes needs to spend a substantial amount of time per day until enough fish are caught. Fyke nets can therefore provide an opportunity to allow for livelihood diversification at an intermediate level and do not require small-scale fishers to obtain a skipper license, or incur expenses to obtain a boat, vehicle and trailer as well as the required safety certificates.

A total of 11 fish species have been caught in fyke nets at 19 impoundments. The catch was dominated by bottom dwelling species (*C. gariepinus, C. carpio, L. capensis* and *L. umbratus*) with the pelagic species (*L. aeneus* and *M. salmoides*) caught in very low numbers. Bycatch of non-fisheries species (i.e. *B. anoplus, B. paludinosus, C. auratus* and *P. philander*) and the protected *L. kimberleyensis* in fyke nets was relatively low. In Eastern Africa where large quantities of *B. paludinosus* are caught, it is a main food source for local communities (Kotze, 2002; Bills *et al.,* 2010). Results have indicated that in waters with a very high silt load (Secchi depth < 20 cm), more fish were caught (Erfenis and Egmont Dams), while at dams with clean and clear water with a high Secchi depth (> 200 cm), the least number of fish were caught, as in the case of Sterkfontein and Metsi Matso Dams.

The total weight of the total catch at most impoundments was dominated by *C. carpio, C. gariepinus, L. capensis* and *L. umbratus.* At seven impoundments the bulk weight of the catches consisted of a combination of *C. carpio* and *C. gariepinus,* while at seven other impoundments, the bulk weight consisted of a combination of *L. capensis* and *L. umbratus.* This indicated the adults of these species' preference for similar habitats within the shallow littoral zones where most species forage and where spawning sites are available, except for *L. capensis* that prefers lotic systems to spawn. The contribution of the bycatch to the total weight of the total catch at all impoundments was insignificant.

As indicated in the results of Chapter 4, *L. umbratus* dominated commercial fisheries' catches when gill nets were used, and as only seine nets were allowed as fishing gear from 2005, the catch of this species decreased significantly. Results of Chapter 5 have indicated that *L. umbratus* has no value as an angling species and it is very seldom caught with hook and line. The main driving force behind early attempts to establish inland commercial fisheries was to decrease the numbers of *L. umbratus* in impoundments as earlier research has indicated that this species largely dominated fish communities, possibly out-competing the more suitable angling species like *L. capensis* and *C. carpio* (Jordaan, 1982; Mitchell and Jordaan, 1985; Fouchè, 1988). Marshall (1972) noted that with the increase in *L. umbratus* populations there was a decline in other fish species and attributed this to possible interspecies competition for food and spawning sites. Potts (2003) also observed that *L. umbratus* populations, due to their faster growth rate were a more suitable species to be harvested, possibly able to sustain inland fisheries. Fyke nets therefore might be a more suitable gear to harvest *L. umbratus* in the absence of gill nets.

The length frequency distribution of the main fishery species indicates that all size classes, from fry and juveniles to adults are well sampled in fyke nets. The main target of any fisheries is to catch large specimens, and therefore bycatch of fry and juveniles can be prevented by covering fyke nets with netting material with a larger mesh size that will enable smaller specimens to escape.

Recreational anglers' catches, as demonstrated in Chapter 5, were dominated by *C. carpio, L. capensis* and *C. gariepinus.* Seine net catches during the 2013/2014 season's fish surveys were also dominated by *C. carpio* followed by *L. umbratus* and *L. capensis.* Gill net catches within the 100 mm and 144 mm mesh sizes were dominated by adult *L. umbratus, C. gariepinus* and the pelagic *L. aeneus.* Fyke net catches were dominated by *L. umbratus, L. capensis* and *C. carpio.* The linear regression of the CPUE of fyke nets compared to the CPUE of gill nets also indicated a very weak, insignificant relationship. Therefore, to ensure limited bycatch of the protected yellowfish species in the OSRB, the gear of choice recommended for small-scale fisheries is fyke nets as adults of *L. aeneus* and *L. kimberleyensis* are not readily caught.

Based on the results of the present study, the highest mean CPUE (kg fish per net per night) was obtained for *C. gariepinus*, followed by *L. umbratus* and *C. carpio.* Based on the combined mean CPUE for all five species, an average yield of 16.84 kg fish per net per night was achieved, which, if the catch is sold at ZAR17.50, equates to a possible income of ZAR294.70 per night (based on the whole fish, not gutted).

Despite the advantages of fyke nets as a gear of choice for future small-scale inland fisheries, this gear type pose a threat to the Cape clawless otter *A. capensis* that occurs throughout most of South Africa (Nel and Somers, 2007) as fish is usually part of the species' diet (Ligthart *et al.,* 1994; Watson and Lang, 2003). Once trapped within the fyke nets, otters cannot escape and subsequently drown. Fyke nets, if made of soft netting material may also be torn and damaged by otters in their quest to get to the fish inside. A study by Königson *et al.* (2007) in Sweden where Dutch type fyke nets were used extensively in eel fisheries, has shown that by using stronger materials in fyke nets and by regularly checking the nets, may significantly decrease the damage to nets. In America where high turtle bycatches were recorded, Fratto *et al.* (2008) noted that by including bycatch reduction devices can significantly decrease the numbers of turtles caught.

One of the main advantages of fyke nets is that bycatch and non-targeted species may be released after catch. This is demonstrated by Booth and Potts (2006) during which no mortalities were observed when 204 *L. umbratus* were released after been caught in fyke nets. Krueger *et al.* (1998) also noted that mortalities and injuries to fish caught in fyke nets were very rare.

The advantages and disadvantages of using fyke nets as a gear of choice for the establishment of small-scale inland fisheries are summarised in Table 7.5.

Table 7.5: Advantages and disadvantages of using fyke nets in the Free State Province.

Advantages	**Disadvantages**
Small-scale fishers do not need expensive gear, a boat and required licenses and certificates as required by the South African Maritime Safety Authority.	Possible threat to otters and other wildlife. Can be mitigated when exclusion devices are included in the design.
Fish are kept alive in fyke nets and none targeted species and species of conservation concern, for example *L. aeneus* and *L. kimberleyensis* can with ease be returned to the water with limited harm, compared to damage caused by gill nets.	As fyke nets are set in shallow water, possible theft of nets and fish may occur. Threat can be limited if part of the shoreline at impoundments are zoned for exclusive use for small-scale fishers using fyke nets.
Fyke nets are suitable gear to harvest *L. umbratus* which is not an angling species and which occurs in large numbers at certain impoundments.	Not effective at impoundments with clear water and where bentic zones are covered with aquatic plants and other obstacles.
Fyke nets can be used in shallow water with a depth of 1 to 2 m.	During spawning seasons the spawner biomass may be reduced due to fish entering littoral zones to spawn where fyke nets will be encountered.
As fish are caught alive, smaller size classes can be returned to the water and only large specimens can be kept.	

7.5 Conclusion

Results of this study have shown that fyke nets have the potential to be a suitable gear type for the establishment of small-scale fisheries at certain impoundments, but at impoundments situated at higher altitudes and with clear water, it might not be effective. The only major expense to be incurred by potential small-scale fisheries will be to obtain fyke nets. There will be no need to obtain the different licenses and certificates as required by SAMSA when more technology advanced gears and vessels are used. Fyke nets were shown to target species preferring the shallower littoral zones, while few pelagic species were caught. The current study has also shown that fyke nets mostly caught the preferred fisheries species, namely *C. gariepinus* and *C. carpio*, which is also the preferred table fish in the FSP. As *L. umbratus* is very seldom caught by recreational anglers, but readily caught in fyke nets, and because this species occurs in large numbers at impoundments, fyke nets might be the suitable gear to target this species in future. The current study has also shown the potential monetary value of fyke net catches, and although it was based on the total catch of all species, further research is needed to determine the actual catches of the preferred fisheries species, especially during the cooler and colder autumn and winter months experienced in the central Highveld in South Africa.

The study to determine the suitability of fyke nets for use in small-scale fisheries was done during one summer season at 20 impoundments and further research is recommended to include amongst others a seasonal study comparing catches during the different seasons, the development of "otter-friendly" fyke nets that will also decrease bycatch, and the sustainability and economical viability of small-scale fisheries based on the use of fyke nets.

Based on the results of this study, the following recommendations for future research are proposed:

(i) Design a more suitable and effective type of fyke net with more durable material, covered with netting material with a larger mesh size and that will be "otter-friendly", and test its efficacy;

(ii) Conduct seasonal surveys at Rustfontein and Krugersdrift Dams for a period of one year to determine the influence of water temperature and seasonal changes on catches;

(iii) Experiment with baited and non-baited fyke nets;

(iv) Determine the economical viability and sustainability of small-scale fisheries based on the results of the seasonal surveys;

(v) Investigate the possible effect of fluctuating water levels on fyke net catches;

(vi) Determine how many fyke nets will be needed per individual small-scale fishery to make it economical viable and sustainable.

Once these research questions have been answered, it is envisaged that fyke nets could be useful in the development of small-scale fisheries in the FSP and possibly South Africa.

Chapter 8 General discussion and conclusion, recommendations and future research

8.1 General discussion

The importance of inland fisheries in the lives and livelihoods of millions of people in the developing world has been highlighted by a number of authors (see Henderson and Welcomme, 1974; De Silva, 1988; Crul, 1992; Marshall and Maes, 1994; Sarch and Allison, 2000; Allan *et al.,* 2005; NEPAD, 2014). Béné (2003) noted that subsistence fishermen were the poorest of rural communities and that small-scale fisheries in the developing world were characterised by poverty and dispossession. The low levels of development of fisheries in South Africa therefore provide a unique opportunity to develop fisheries that are appropriate for the conditions in impoundments and thus avoid the social and economic costs of overexploitation. This requires an understanding not only of the fish populations but also of the harvesting fisheries and the environmental, morphometric and general characteristics of the impoundments.

Unfortunately, fish and fisheries in South African impoundments are poorly understood because of a lack of directed research and poor monitoring and reporting of catch data. This is partly due to a lack of capacity at departmental level with the author being the only ichthyologist in the Free State Provincial Government and Free State Province (FSP). The responsible department for inland fisheries development in the FSP, the Department of Agriculture and Rural Development, has no personnel and annual budget, and no sections within the department with prior knowledge, experience or skills to implement inland fisheries. This situation severely constrains decision making, especially now that there is an increasing demand to develop fisheries. The need for guidance with regard to provincial fishery policy and the severe paucity of historical data necessitated the broad scale assessment approach used in this thesis. In this regard, this thesis presents the first consolidation of catch data from commercial and recreational fisheries data in South Africa and is also the first broad scale fish survey of provincial impoundments using standardised gears and approaches. As a result this thesis contributes towards the development of a provincial fishery policy by contextualising some of the realities that will affect fisheries.

As custodians of all water resources in South Africa, the National Department of Water and Sanitation (DWS) has the mandate for the management and protection of all water resources and most recently has started with the development of Resource Management Plans (RMP) for impoundments. The main aims of RMPs are to provide guidance on the management, control, protection and conservation, development, and utilisation of water resources for recreational purposes which are based on principles of sustainability and equity (DWA, 2006). As from 2009 the Department the Agriculture, Forestry and Fisheries (DAFF) carries the mandate for inland fisheries (McCafferty *et al.,* 2012; Britz *et al.,* 2015). This was historically the responsibility of provincial nature conservation and environmental agencies which never had a developmental focus.

All matters pertaining to the conservation and protection of indigenous biodiversity in South Africa are guided by the National Environmental Management: Biodiversity Act of 2004 (NEM: BA, 2004). Emanating from this act, the Threatened or Protected Species regulations (TOPS, 2007) and the most recently promulgated Alien and Invasive Species regulations (AIS, 2014) provide regulations that guide and manage the use of indigenous biodiversity and provide control measures for alien and invasive species. Concurrently, each province in South Africa has its own provincial nature conservation ordinance and regulations. In the FSP since the promulgation of the Orange Free State Nature Conservation Ordinance in 1969 (NCO, 1969) and Nature Conservation Regulations in 1983 (NCR, 1983) all matters pertaining to recreational and commercial fisheries were controlled and managed according to these. During 2012, due to an increase interest in the development of inland fisheries, the Free State Department of Economic, Small Business Development, Tourism and Environmental Affairs (FS DESTEA), compiled Operational Guidelines for commercial fisheries. Since then this has been used to guide the development of this sector in the Province. Although the responsibility for inland fisheries development at a provincial level lie with the Free State Department of Agriculture and Rural Development, it is foreseen that inland fishery development will therefore in future still be managed by the FS DESTEA.

The literature review and discussion in Chapter 2 has indicated the importance of inland fisheries in the lives and livelihoods of millions of people in the developing world. Recently the African Union has identified inland fisheries as one of the most important sectors for future investment (NEPAD, 2005). The Partnership for African Fisheries (PAF) under NEPAD therefore aims to enhance sustainability of and strengthen inland fisheries in Africa (NEPAD, 2014). With the new interest in the promotion and development of inland fisheries in South Africa to address government's economical and social developmental goals, a number of authors (see Weyl *et al.,* 2007; McCafferty *et al.,* 2012; Hara & Backeberg, 2014; Britz *et al.,* 2015) noted the need for a national inland fishery policy to guide and provide management guidelines for this sector. Although no mention on the development of such a policy was found in the DAFF Strategic Plan for the period 2013/2014 until 2017/2018, during February 2015 at the China South Africa Agricultural Technology and Demonstration Centre at Gariep Dam, the first national consultative process took place to set in motion the development of a national inland fishery policy for South Africa.

Although a national inland fisheries policy may provide policy guidelines and the necessary national authority as well as backing for the development of this sector, the reality is that management issues at a local level are much more complex. As indicated in Chapter 3, 81% of the 412 registered impoundments in the FSP are categorised as small, mostly situated on farm land with no value for inland fisheries. Of the 412 registered impoundments, only 8% are managed and controlled by the DWS, while 14 % are owned by local municipalities. Most of the impoundments managed by DWS are situated within the borders, or adjacent to provincial nature reserves which is managed by the FS DESTEA. At these impoundments, limited sections of the total shoreline were and are available for recreational anglers while commercial fishing was and is only allowed to operate at certain sections of the shoreline as zoned for that purpose by reserve managers. Access to the water surface, depending on the season, was and is currently restricted from 06:00 until 18:30, while commercial fisheries were only allowed entrance to fishing grounds within reserves from 07:00 until 17:30. In some cases certain sections of impoundments are only accessible via private farm land but due to security and safety concerns, most farmers do not allow fishermen or commercial fishery enterprises entry to their land. Access to impoundments via private land and safety concerns need to be addressed, because it can impact negatively on future inland fisheries development.

The main motivation and renewed interest in the promotion and development of inland fisheries in South Africa is driven by the fact that many people, and particularly politicians, see it as a means of addressing the major social and economic problems of poverty, unemployment and lack of economic development in rural areas in South Africa. As indicated by Statistics South Africa (StatsSA, 2014), 25% of people in South Africa are unemployed. The FSP, with the largest inland water surface water in South Africa, has the highest unemployment rate of 35%. For South Africa, Marshall and Maes (1994) estimated a potential inland fish yield of 2 300 tons per year, while Weyl (2012) and Britz *et al.* (2015) proposed an optimistic annual yield of 15 000 tons per year based on a global estimate of 50 kg per hectare and a utilisation potential of 3 000 km^2 of South African impoundments. Should this be related to a monetary value based on the selling price of gutted fish per kilogram in the FSP as during January 2015 (ZAR17.50/kg), it implies a possible gross lakeshore value of ZAR263 million y^{-1}. It is, however, also evident that this is actually a very small value when compared for example, to South Africa's marine fisheries.

Impoundments in the FSP are situated at altitudes >1 200 m in the largest inland water basin in southern Africa within the southern temperate zone, with the Orange-Senqu River System (OSRS) and Vaal River System (VRS) and their tributaries draining the basin. The FSP's climate is characterised by cold to extreme cold winters, with mild to warm summers with erratic rainfall. The inland waters carry a high silt load and the Orange-Senqu River System are regarded as one of the most turbid systems in the world as indicated in Chapter 3. At a local context, every impoundment is unique based on the combination of, and interaction of the various environmental and morphometric characteristics. A characteristic shared between most impoundments, except those that are part of inter-basin water transfer schemes, is the highly fluctuating and regulated nature of the water levels as indicated in Chapter 3.

The water levels as on 8 June 2015 of the impoundments that were part of the current study area is presented in Table 8.1. The water levels of Moutloatsi Setlogelo and Tierpoort Dams are estimated at 0.03% and 0.04%, respectively and it is expected these impoundments will dry up within the next few months. During a recent site inspection at Moutloatsi Setlogelo Dam, officials from the DWS have expressed their concern with the continuous decline of water levels of other impoundments (Allemanskraal, Erfenis, Kalkfontein, Rustfontein, Armenia, Knellpoort and Krugersdrift Dams), especially with no forecast of rain during the next months. Should these impoundments eventually reach critical low levels, major fish deaths, as already been recorded at Moutloatsi Setlogelo Dam (personal observation based on site inspection on 3 June 2015), can be expected. Fluctuating water levels are therefore one of the most important variables to consider in future inland fisheries development, especially for impoundments in the FSP.

Table 8.1: Water levels of selected impoundments as recorded on 8 June 2015.

Impoundment	Water level first week of June 2015 (%)	Water level during corresponding period 2014 (%)
Allemanskraal	19.6	47.3
Armenia	34.1	36.9
Bloemhoek	*No data*	
Bloemhof	48.8	97.2
Egmont	73.1	93.1
Erfenis	24.7	46.3
Gariep	78.6	92
Jimmie Roos	*No data*	
Kalkfontein	15.9	31.5
Knellpoort	43.3	50.6
Koppies	81.6	89.9
Krugersdrift	57.1	63.6
Metsi Matso	*No data*	
Mockes	*No data*	
Moutloatsi Setlogelo	0 *(estimated at 0.03)*	2.7
Rustfontein	25.3	21.3
Serfontein	*No data*	
Sol Plaatjie	102.7	101.5
Sterkfontein	98.5	99.1
Tierpoort	0 *(estimated at 0.04)*	5.4
Welbedacht	72.2	103.7

(Based on information from http://dwa.gov.za/Hydrology/Weekly/ProvinceWeek.aspx?region=FS)

In the absence of historic reports and data on how the original fishing quotas that were allocated to commercial fisheries in the FSP were determined, and to provide a first time estimate of the potential fish yield of impoundments, various Morphoedaphic Indices (MEI) and models were applied. All of these are based on the mean depth of impoundments at full supply level. Ryder (1982) noted that the average depth seemed to be the variable that is directly linked to production processes within impoundments. As impoundments' water levels fluctuate significantly, the mean depth will vary accordingly and results of the application of MEI and models where average depth is used, should therefore be considered as estimates and must not be used as a definite figure of an impoundment's potential fish yield. Based on the results of Chapter 3, it is proposed that the MEI and models as developed for the northern temperate zone by Ryder (1965) and Schlesinger and Regier (1982) are more applicable to conditions in the FSP. These models are more conservative than those developed for African fisheries (e.g. the MEI of Marshall and Maes, 1994) and are more appropriate than the global optimistic yield of 50 kg ha^{-1} y^{-1} at maximum water level used as first estimate by Britz *et al.* (2015).

Despite the optimism on inland fisheries in broad scale assessments and by the South African government, the assessment of commercial fisheries data (Chapter 4) suggests otherwise. Between 1979 and 2014, only 9 036 tons of fish were harvested in the FSP, which equates to only 258 tons per year. Most of this catch (73%) was from Bloemhof and Kalkfontein Dams (23%), with all other impoundments contributing only 4% to the total yield. This implies that only commercial fishery enterprises that were able to harvest more than 100 tons per annum were able to sustain their businesses. During inspections done at the fisheries as part of this study, it was clear that they all faced major financial challenges, hardly making any profit and in some cases workers were not been paid for months. Smaller initiatives also appear to have failed. During the former Apartheid regime, freshwater fish and aquaculture were seen as a means of creating employment and providing the rural poor with a source of protein and food in the former homelands areas (Batchelor, 1988; Andrew *et al.,* 2000; Britz *et al.,* 2015). Despite this, no information could be found if fishery projects were established, but if so, if it were sustainable. Similar initiatives have also failed, as demonstrated by the results of the study on the economic sustainability of the community based poverty alleviation projects at Gariep Dam (see Chapter 4). That case study clearly demonstrated the unrealistic goals that were set and lack of planning, as out of 50 original beneficiaries that were to profit from the fishery, only eight were left after a year with an income of less than ZAR80 per person per month. Doing pre-feasibility studies on the economical viability of fishery projects is therefore essential and critical.

In the South African context, recreational and subsistence angling is often ignored by development initiatives that consider the lack of "commercial" ventures an under-utilisation of the fishery. Weyl *et al.* (2007) and Ellender *et al.* (2009; 2010a; 2010b) reported on an increase in subsistence fishermen at impoundments. Britz *et al.* (2015) noted that small-scale fishing was done by poor, unemployed people who use it as an adaptive strategy in response to deteriorating economic conditions. During the study period, the author also noted the presence of subsistence fishermen at 12 impoundments where fish surveys were done during the 2012/2013 and 2013/2014 seasons.

In contrast to the informal subsistence fishery sector, the recreational fishery sector in South Africa and the FSP is highly organised and structured. This sector has historically been the most important inland fisheries sector in South Africa (Marshall and Maes, 1994; Weyl *et al.,* 2007; Welcomme, 2011a; 2011b; McCafferty *et al.,* 2012). Cooke and Cowx (2004) estimated that on a global scale 700 million people are involved. As indicated in Chapter 5, the participants in the recreational fishery sector in the FSP during 2014 comprised of 6 962 anglers that were not affiliated with any formal structure, while 748 sport anglers were affiliated to 30 angling clubs under the Free State Freshwater Bank Angling Association and the South African Freshwater Bank Angling Federation. The historic review of recreational angling in the FSP has indicated a 76% decline in the number of recreational anglers since 1971. A similar trend has also been observed for the number of angling tournaments held during recent years. The reason for this decline is not clear but it is assumed to be caused by the deteriorating economic conditions in the country.

The main social and economical aspects addressed by the different fishery sectors in the FSP by subsistence fishermen are "survival and sustaining livelihoods", for recreational anglers, "leisure and sport" and for commercial fisheries the focus is on "profit and running a business". As these three fishery sectors in the FSP targeted the same fishery species (*Cyprinus carpio, Labeo capensis* and *Clarias gariepinus*) and to a lesser extent *Labeobarbus aeneus*, it inevitably lead to conflict.

At Koppies Dam, one of the most popular angling venues in the FSP, declining catches of *C. carpio* was attributed to the actions of the commercial fishery, to an extent that on demand of recreational anglers the former Directorate Nature and Environmental Conservation during 1987 released 25 000 *C. carpio* fingerlings. Results of 377 angling tournaments for the period 1982 until 1993 at Koppies Dam, however, showed that 69% of participating anglers were successful in catching fish, mostly *C. carpio*. For the period 1982 until 1985, the commercial fishery mostly used seine nets to harvest fish, while from 1986 until 1989 mostly gill nets were used. As *C. carpio* is not readily caught in gill nets, the recreational anglers' accusations that the commercial fishery has depleted the targeted angling species, was unfounded. The commercial fishery eventually closed down during 1993 as it was no more economical viable.

Major conflict occurred between recreational and subsistence anglers and a community based fishery project at Gariep Dam. On a regular basis recreational and subsistence anglers had to vacate their fishing spots as the commercial fishery chased them away to enable the fishery to set their seine net. This conflict was resolved after a number of meetings during which it was agreed to zone the shoreline at Gariep Dam within the Oviston Nature Reserve and each user group was allocated a certain area for their exclusive use.

Bloemhof Dam is known as one of the best and most popular angling venues in South Africa to catch *C. carpio* and on an annual basis a large number of provincial, national and international angling tournaments are held. This is also the only impoundment in South Africa where two commercial fishing enterprises operated on a continuous basis for 32 years, and one would have expected major conflict between the different user groups. This was, however, prevented as commercial fishing was only allowed in a section of Sandveld Nature Reserve bordering the impoundment which was zoned for exclusive use and entry for the fisheries. Anecdotal reports indicated that the commercial fisheries were supported by the formal angling sector, as it was believed that the fisheries contributed to *C. carpio* reaching larger sizes.

Conflict, however, was not limited between the different user groups. Most of the community based poverty alleviation fishery projects at Gariep Dam were flawed with interpersonal conflicts which regularly lead to small groups breaking away from the main group. Equipment and nets were stolen, and in one instance one of the project members were murdered after a dispute. This indicates the necessity of capacity building and continuous support on all levels, from administrative and financial to conflict resolution, for fishery projects' beneficiaries by implementers of fishery projects.

Results of Chapter 4 indicated that the main fish species that were caught by commercial fisheries were *L. capensis, C. carpio, C. gariepinus* and *Labeo umbratus,* while *L. aeneus* and *Labeobarbus kimberleyensis* were viewed as protected species in the FSP and targeting and catching these species were prohibited. As indicated by Barkhuizen (1994b), at Kalkfontein Dam the commercial fishery was stopped once, due to large numbers of yellowfish that was caught. Due to conservation status of *L. kimberleyensis* and concerns about the threat gill nets holds for this species, from 2005 gill nets were prohibited for use in commercial fisheries and only seine nets with a stretched mesh size of 50 mm and larger were allowed. Definite differences in the total catch and species composition of the catches were observed when different gears were used. Gill nets mostly caught the indigenous cyprinids (*L. capensis, L. umbratus* and *L. aeneus*), while seine nets catches were dominated by *C. carpio* and *C. gariepinus.* Since 2005 with only seine nets been allowed as fishing gear, indigenous cyprinids have gradually disappeared from catches to a point that only *C. carpio, Ctenopharyngodon idella* and *C. gariepinus* were caught at Bloemhof Dam.

As indicated in Chapter 3, recreational anglers' catches based on results of angling tournaments held since 1974 until 2014, have been dominated by the alien and invasive *C. carpio.* Of the total catch, this species contributed 88% to the total weight and by number, 77%, while the rest of the catch consisted mostly of *C. gariepinus* and *L. capensis.* Catch rates and catch per unit effort (CPUE) of recreational anglers catches were driven by that of *C. carpio.* The extent of the impact of provincial environmental legislation on recreational angling is clearly demonstrated by the lack of catches of *L. aeneus* and *L. kimberleyensis*, as these species were deemed as protected species in the FSP with bag and size limits been enforced.

Fish surveys demonstrate that long-lived, slow growing cyprinids dominate fish faunas in impoundments in the FSP. A total of 16 fish species were sampled in impoundments during the study period, confirming the low species diversity for fish in the OSRS as previous been reported on by Jubb (1972), Skelton (1986) and Benade (1993). Three new distribution records have been recorded for alien and invasive species, namely *C. idella, Carassius auratus* and *Gambusia affinis*. Survey data and a review of historical distribution records demonstrate that the bulk of biomass is comprised of four large cyprinids (*L. capensis, L. umbratus, C. carpio* and *L. aeneus*) and *C. gariepinus* which appear to be well adapted to the more lentic habitats created by impoundments. The alien *C. carpio* has successfully invaded all impoundments surveyed, but data suggest that native species co-exist with this invader. This is similar to the finding of the study of Winker (2010) who theorised that the different species used different niches.

A review of the ecology and biology of the main fisheries species indicate that those with the following life strategies have the potential to be harvested in fisheries: a fast to rapid growth rate, high fecundity, early maturation, adaptability to a wide range of aquatic environments, omnivorous diet, preference for lentic systems, readily available spawning areas within impoundments and eggs that hatch within a short period of time. These strategies are characteristic only for the alien *C. carpio* and *C. idella*, and the native *C. gariepinus.* The native large cyprinids are slow growing and late maturing with intermediate fecundity and a preference for more lotic and pelagic habitats. While these life history traits imply relatively stable population structures (Adams, 1980), it takes a long time for populations of these fish to recover after overfishing. As a result, fisheries on these species will need to be developed with consideration of their life histories and will require guidance from proper stock assessments.

8.2 General conclusion

This thesis provides the first ever comprehensive provincial level assessment of freshwater fish and inland fisheries at impoundments in South Africa. For the first time ever, historic and most recent catch data of inland commercial fisheries that operated at 11 impoundments in the FSP since 1979, have been assessed. The results obtained indicated the high rate of failure and management complexities of most enterprises. Experience, knowledge, extensive skills and most importantly a fixed market, have shown to be the indicators of success as only one enterprise was able to operate commercial fisheries since 1979.

The first qualitative and quantative analysis of freshwater angling in the FSP, indicating the level of participation and number of anglers involved in the more formal sport and informal recreational sectors, have been presented in this thesis. For the first time in South Africa, angling tournament catch data for 17 impoundments dating back from 1974 to 2014 have been investigated and assessed, indicating that the freshwater bank angling sector in the FSP revolves around and depends mostly on the alien and invasive *C. carpio*.

The last provincial level assessment of freshwater fishes at impoundments was done 20 years ago. Most fish surveys done during the 1970's and 1980's focused on river systems, with very few studies done at impoundments. This thesis provides the most recent and updated records on the occurrence, distribution, population and community structure and relative abundance of freshwater fish species at impoundments in the FSP, based on 41 comprehensive and in depth fish surveys done at 21 impoundments during the study period.

The first assessment of the suitability of fyke nets for use in small-scale fisheries in the FSP has been done during the study period. Results of the preliminary feasibility study have shown that fyke nets may be suitable gear for use in future small-scale fisheries. The study, however, has revealed a number of research questions which first needs to be addressed as indicated in Chapter 7 to ensure the successful use of fyke nets in future fisheries.

With the new interest in the development and promotion of inland fisheries in South Africa to address government's policy objectives of job creation and poverty alleviation, this thesis contribute to the knowledge base as for the first time in South Africa, such a comprehensive study on the assessment of fish and fisheries within impoundments has been done. This thesis provides baseline information which support and inform the policy development process for inland fisheries in South Africa, which was initiated during February 2015 by the National Department of Agriculture, Forestry and Fisheries.

8.3 Management recommendations

The findings of this thesis conclude that there is no single solution for the development of fisheries in the FSP. This research contributes to better understand the frame conditions that will be needed to guide the future decision making processes. It strongly suggests that before attempting to increase commercialisation of fisheries, all social, economical, political, management as well as bio-physical aspects at each individual impoundment should be investigated and considered. This will ensure the sustainability of fisheries and set realistic goals. Through this study, the author is able to make overall recommendations for initiating a management process for impoundments.

As fisheries development will require considerable inputs in terms of research and monitoring, and because the state does not have the resources to be able to support this process at multiple impoundments, prioritisation is important. By ranking impoundments by their potential productivity based on the application of and results of various Morphoedaphic Indices (MEI) and models can provide baseline information on impoundments' suitability for fisheries development. It is therefore recommended that this be used as a first step in feasibility studies for future fishery projects. Based on MEI and water level fluctuations the top three impoundments that are suitable are Bloemhof, Gariep and Kalkfontein Dams.

Large-scale commercial fishing enterprises which are owned and managed by private individuals with no or limited benefit for local and surrounding communities at impoundment, should be discouraged. Data demonstrates that such enterprises contribute little to the FSP's revenue, as the concession fee payable during the 2014/2015 financial year, was only ZAR0.45 kg^{-1}. However, the failure of all previous fishery projects that were intended to provide poverty alleviation in rural area necessitates a more structured approach than the current "there is a need for such projects". Realistic goals and objectives for such projects should be set, including the potential harvest, the level of technological intervention that is appropriate, the number of beneficiaries that such a project could realistically support and information on the processes that have determined the success and failure in small-scale fisheries development globally.

As recreational fisheries and angling have been the largest and most important fishery sector at impoundments in South Africa for the past 100 years, government and management authorities should take note of this sector's direct and indirect contribution to local and regional economies. While the full extent of the economic impacts of this sector is not entirely understood, data from case studies (see Du Plessis and Le Roux, 1965; Cadieux, 1980; Leibold and Van Zyl, 2008; Brand *et al.*, 2009; Du Preez and Lee, 2010) demonstrate that this is considerable. Expenditure by anglers includes amongst others accommodation, food and beverage, fuel for boats and vehicles, equipment, bait, license and entry fees. It is important that this contribution to employment in rural areas be recognised as a fishery benefit. As a result, this sector should be included in all public participation processes as part of fishery development initiatives. In addition, government and management authorities should work in close cooperation with the recreational fishery sectors in all provinces, also to improve access to and provide improved facilities for anglers at impoundments at protected areas and resorts.

The relevance of requiring from recreational anglers to obtain angling licenses should be addressed. The revenue from license sales is miniscule, and sport and recreational anglers are questioning why they should obtain angling licenses, while conservation and environmental management agencies are turning a blind eye to the hundreds of unlicensed subsistence anglers, who due to their social and economic status, cannot afford the ZAR40 per year angling license. However, licensing provides formal rights to resource users. As a result, using existing recreational licenses could be used to ensure that the rights of "subsistence" anglers are recognised. As a result, the state could consider a license subsidisation scheme which could include license fee waivers for bona fide subsistence anglers and reduced fees for local residents. These subsistence anglers would then operate under the same regulations as the recreational anglers.

As *C. carpio* is the most important and targeted angling species at impoundments in the FSP, and due to the listing of this species in the most recent Alien and Invasive Species Regulations in South Africa, an alien and invasive species management plan should be drafted for this species (NEM: BA, 2004; AIS, 2014). A major part of current legislation is centred on areas that are already invaded. The research presented in this thesis has demonstrated that this species already occurs in all impoundments. As a result management plans should investigate ways in which to use this resource for maximum benefit and apply exemptions to cater for the needs of the different fishery sectors where necessary. This is especially relevant as the most important impoundments for recreational angling in the FSP are surrounded by or lie in close proximity to formal protected areas, where the focus is on conserving indigenous biodiversity. This will need to be contextualised with the consideration that although impoundments are man-made environments, they could act as invasion sources into upstream areas.

One species, *L. kimberleyensis,* was present in 12 impoundments. While relatively widespread, nowhere is it abundant. In addition, this species has been developed as a conservation icon in central South Africa and is used to derive environmental management programmes on rivers. Its current IUCN status is "Near threatened" (IUCN, 2014). At the moment we do not understand whether impoundments are population sinks for this species or refugia for riverine populations. The presence of mostly adult *L. kimberleyensis* in survey catches indicates that impoundments may be important refugia for adult fishes which might spawn in rivers and contribute to recruitment in the habitats as found by Tomasson *et al.* (1983). As this is South Africa's largest cyprinid which is long lived and late maturing (Ellender *et al.,* 2012), *L. kimberleyensis* has special conservation standing. As a result, its harvest is likely to cause considerable conflicts between sectors. For this reason, it is highly recommended that the no-take policy be maintained. As a result of considerable bycatch in gill nets, this gear appears unsuitable for harvest.

Smallmouth yellowfish appear to be highly abundant in almost all impoundments and as this species have been caught in gill nets, this gear should not be considered for use in future small-scale fishery developments, especially where *L. kimberleyensis* populations are established. As a result of their abundance and in conjunction with the relatively small size of fishes in impoundments, it is recommended that the strict regulations pertaining to the catch and keep of *L. aeneus* by recreational anglers as enforced in the FSP (all fish smaller than 45 cm to be returned to the water immediately and anglers may only catch and keep 10 individuals larger than 45 cm per day) be reviewed. A major point of contention from the recreational fishery sector is that the regulations pertaining to the catch and keep of *L. aeneus* differs significantly amongst all the provinces bordering the FSP, with the FSP having the strictest regulations. This species has considerable potential for harvest by subsistence anglers and new regulations should also take into consideration the prevalent population structure and potential yield of this species. As a result, research into appropriate harvest methods is highly recommended.

Given the failure of commercial fisheries, the potential of bycatch in gill nets and potential conflicts with recreational and subsistence anglers, there is a need to identify alternative gears for small-scale fishery developments. The results of the current study have indicated that fyke nets might have the potential as suitable gears in future small-scale fisheries in the FSP. It is recommended that the research questions and needs for further research as indicated in Chapter 7 be addressed and investigated as soon as possible, as this can possibly change the small-scale inland fishery sector in South Africa in future.

8.4 Recommendations for future research

A monitoring system should be developed to ensure all fishery data are sent to a central office where it must be filed to ensure easy and open access for researchers.

Stock assessments need to be done for the main fisheries species to ensure realistic goals and objectives are set for future small-scale fishery development.

There is a need to investigate the most suitable harvest strategies for *L. aeneus*, especially for populations in impoundments with clear water (e.g. at Sterkfontein and Sol Plaatje Dams) and the more turbid impoundments.

The possible inclusion of subsistence angling in a generalised “fishing” license that will give rights to subsistence anglers, rather than the “blind eye policy”, should be investigated.

An in-depth social and economic assessment of why the various poverty alleviation fishery projects have failed, especially with an assessment of recent initiatives that were implemented in the North West Province, should be implemented.

The reasons for the presence of *L. kimberleyensis* in impoundments should be investigated, i.e. do they use impoundments as forage areas, have the species adapted to the lentic environment and use inflowing rivers as spawning areas, what will the impact be of future fishery development and harvesting on this species?

Angling license sales may not provide a true reflection of anglers' catches and therefore it is recommended that angling effort at impoundments where both subsistence and recreational anglers fish, be evaluated.

Anecdotal reports from bank anglers and the increase in catches of the highly invasive *C. idella* have indicated that this species is steadily invading more parts of the Vaal River System and lower reaches of the Wilger River in the eastern Free State. The extent of invasion should be investigated, as well as possible control measures.

The invasion of Sterkfontein Dam, the most important fly fishing venue for *L. aeneus* in South Africa, by *Micropterus salmoides* and the impact of this alien and invasive species on the indigenous biodiversity and especially *L. aeneus,* requires urgent attention.

Additional research questions, that do not emanate from the results of this thesis, but which should be investigated, are the impact of alien and invasive fish parasites on indigenous fish species; to which extent will climate change and global warming impact on fish communities and inland fisheries in the future; what will the impact be of increased water abstraction to satisfy the needs of an ever increasing population, on fish and inland fisheries.

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Afrikaanse opsomming

Suid-Afrika is ‘n ariede land wat as gevolg van die behoefte vir water vir huishoudelike, industriële en landbougebruik, heelwat belê het in die bou van damme wat tans ‘n geskatte 3 000 km^2 beslaan. As gevolg van hoë vlakke van armoede en werkloosheid, word daar tans in Suid-Afrika op die ontwikkeling van visserye in binnelandse waters gefokus om ekonomiese geleenthede en voedselsekuriteit in plattelandse gebiede te skep. Om effektief te wees moet sulke ontwikkelings deur inligting oor die huidige gebruikspatrone, gemeenskapstruktuur en voorkoms van visse en potensiële oes metodes gelei word. Ongelukkig het binnelandse visserye baie min aandag in ‘n land met ‘n groot mariene vis-industrie en ‘n geskiedenis van onvermoë om binnelandse visserye te ontwikkel, gekry. As gevolg daarvan is daar ‘n algehele gebrek aan basiese inligting oor visgemeenskappe in damme en hoe diè bronne benut kan word. Hierdie proefskrif poog om die gebrek aan inligting in die Vrystaat Provinsie aan te spreek deur ‘n assessering van die visserypotensiaal van damme deur die gebruik van empiriese benaderings; die samevatting van data van hengelkompetisie-vangste en kommersiële visserye oor ‘n periode van 40 jaar; die uitvoering van visopnames by 21 damme om die spesiesamestelling te bepaal en die toets van ‘n nuwe metode en toerusting om vis te oes.

Die Vrystaat Provinsie (VP) het die grootste (145 677 ha) binnelandse wateroppervlak in Suid-Afrika en is sentraal in die Oranje-Senqurivier wateropvanggebied geleë wat deur die Oranje-Senqu en Vaalriviersisteme gedreineer word. As gevolg van ‘n algehele gebrek aan data oor binnelandse visserye in die VP, is ‘n punte-sisteem (gebaseer op empiriese skattings van potensiële visopbrengs en wisselings in watervlakke) ontwikkel om inligting oor die potensiaal van damme vir die ontwikkeling van kommersiële visserye te verskaf. Die toepassing van modelle deur die gebruik van morfo-edafiese data het die eerste skattings van visopbrengste verskaf wat van baie konserwatief tot hoogs opportunisties gevarieer het (bv. vir Gariepdam van 5.0 tot 58.5 kg ha^{-1} j^{-1}). Soos voorspel deur die meeste morfo-edafies gebaseerde modelle, het damme met die hoogste ligging bo seevlak, die grootste gemiddelde diepte en met die minste wisseling in watervlakke, die laagste potensiaal vir die ontwikkeling van visserye.

Data van kommersiële visserye vanaf verskeie natuurreservate is saamgestel en verwerk. Dit verskaf die eerste volledige databasis van kommersiële visserye in Suid-Afrika. Tussen 1979 en 2014 is 'n totaal van 9 036 ton vis deur kommersiële visserye, wat sporadies by sewe damme vis geoes het, gevang. Kommersiële visopbrengste by Bloemhofdam (73%), gevolg deur Kalkfonteindam (23%) het die totale visopbrengs gedomineer met sporadiese pogings om kommersiële visserye in vyf ander damme te ontwikkel wat slegs 4% tot die totale visopbrengs oor 'n 35 jaar-periode bygedra het. Die toerusting wat gebruik is om visse te oes, het bepaal watter spesies gevang is met die inheemse Oranjerivier moddervis *Labeo capensis,* moggel *Labeo umbratus* en kleinbekgeelvis *Labeobarbus aeneus* wat vangste gedomineer het terwyl kiefnette gebruik is, terwyl gewone karp *Cyprinus carpio* vangste gedomineer het waar sleepnette gebruik is. Slegs twee kommersiële visvangoperateurs het by een dam (Bloemhofdam) op 'n aaneenlopende basis vir 32 jaar vis geoes. Vorige kennis, vaardighede en ondervinding en die belangrikste, 'n reeds bestaande en self ontwikkelde mark, is as die bepalende faktore of visserye suksesvol was, geïdentifiseer.

Data van die verkoop van hengellisensies toon dat die ontspanningsvissery sektor in die VP uit 7 710 gelisensieerde hengelaars bestaan. 'n Analise van die historiese data dui aan dat daar 'n 76% afname was in die getal van hengelaars in die provinsie sedert 1971 (gebaseer op hengellisensie verkope). Van die 7 710 hengelaars, was 748 by 30 hengelklubs geaffilieerd. Beskikbare data toon dat vanaf 1974 tot 2014, 4 817 hengelkompetisies by 17 damme plaasgevind het. 'n Historiese analise van deelname toon ook 'n afname in deelname tydens hengelkompetisies. Die tendens was in ooreenstemming soos gesien met die van lisensie-verkope. Die totale aangetekende visopbrengs van die kompetisies was 414 ton. Die ontspanningsvisserye se vangste is deur *C. carpio* gedomineer, wat 81% tot die totale gewig en 77% tot die totale getal van vis wat gevang is, bygedra het. Pogings om die hengelkompetisiedata deur die gebruik van multi-variasie analises te interpreteer, het geen noemenswaardige korrelasie tussen omgewings- en morfometriese veranderlikes en kompetisies se vangs per eenheidspoging aangedui nie.

Tydens eksperimentele visopnames wat tydens die studie gedoen is, is 23 831 visse by 21 damme versamel. Sestien spesies is versamel waarvan die grootste deel van vangste uit vier groot Cyprinidae spesies (*L. capensis, L. umbratus, L. aeneus* en *C. carpio*), en die skerptandbaber *Clarias gariepinus* bestaan het. Gemiddeld is 7.6 ± 1.4 en 6.0 ± 1.1 spesies onderskeidelik in damme in die Vaalrivier- en Oranje-Senqustelsels versamel. Visgemeenskappe in die verskillende damme was tot ‘n mate dieselfde (Jaccard se Indeks van Eenvormigheid) met ‘n gemiddelde eenvormigheidindeks van 64.2%. Ondersoeke van die bevolkingstruktuur (deur die gebruik van lengtefrekwensie-verspreidings) het aangedui dat die meeste spesies wat versamel is, gevestig is met bewyse van verskeie jaargroepe, bestaande uit volwassenes en jaarlinge.

‘n Assessering van fuiknette as ‘n potensiële vangtoerusting het aangedui dat hierdie tipe toerusting moontlik ‘n meer geskikte passiewe visvangmetode vir kleinskaalvisserye kan wees. Elf visspesies is in fuiknette gevang waarvan die vangste deur vier groot spesies van die Cyprinidae (*L. capensis, L. umbratus, L. aeneus* en *C. carpio*), en *C. gariepinus* gedomineer is, waarvan almal, behalwe *L. umbratus,* belangrike hengelspesies en voorkeur eetvis is. Die voorlopige assessering oor die geskiktheid van fuiknette as toerusting vir kleinskaalvisserye het verdere navorsingsvrae opgelewer en sodra dit beantwoord is, kan fuiknette moontlik die gekose toerusting in die verdere ontwikkeling van binnelandse visserye in sentraal Suid-Afrika word.

Met die nuwe belangstelling in die ontwikkeling en bevordering van binnelandse visserye in Suid-Afrika om die regering se doelwitte van werkskepping en armoedeverligting aan te spreek, sal hierdie proefskrif tot die huidige kennisvlak bydra aangesien dit die eerste keer in Suid-Afrika is dat so ‘n omvattende en volledige assessering van visse en binnelandse visserye gedoen is. Navorsingsresultate van hierdie proefskrif kan die basis vorm wat die proses vir die ontwikkeling van ‘n nasionale binnelandse visseryebeleid kan ondersteun wat tydens Februarie 2015 deur die Nasionale Departement van Landbou, Bosbou en Visserye geïnissieer is.

List of Appendixes

Appendix 1: Permit conditions for commercial fishing in the Free State Province.

Appendix to the Permit for Commercial Fishing at State Dams and Provincial Nature Reserves in the Free State Province

Permit number	
Date issued	
Expiry date	
Approved by	

The permit holder should take note that this permit may be withdrawn at any time by the Free State Department of Economic, Small Business Development, Tourism and Environmental Affairs (FS DESTEA) should the control measures and conditions listed herewith are not abide by or in the case where Provincial policy regarding Commercial Fishing may change.

Name of the dam and nature reserve	
Reserve office's telephone number	
Name of Reserve Manager	
Official responsible for inspections	
Contact details	

1. Control measures regarding fish

(i) Only the following fish species may be caught and kept:

Common name	**Scientific name**
Indigenous species	
Moggel	*Labeo umbratus*
Orange River mudfish	*Labeo capensis*
Sharptooth catfish	*Clarias gariepinus*
Alien species	
Carp	*Cyprinus carpio*
Grass carp	*Ctenopharyngodon idella*
All Black bass species	*Micropterus* species
All trout species	*Oncorhynchus* and *Salmo* species
All other alien fish species e.g. goldfish	*Carassius* species

(ii) No largemouth (*Labeobarbus kimberleyensis*) or smallmouth yellowfish (*Labeobarbus aeneus*) may be caught and kept. If any yellowfish are caught, it must be returned unharmed to the water as soon as possible.

(iii) If any yellowfish are hurt or found dead in the net it may be kept but it needs to be recorded on the **Daily Record** form.

(iv) If a large number of fish are caught on any day it may not be left in the nets in the water overnight but all fish must be removed from the reserve before the end of the day.

(v) Fish spawning during the warmer months may not be disturbed or caught.

(vi) No live fish may leave the nature reserve and no live fish may be sold without a valid approved permit from the FS DESTEA.

(vii) No fish that has been caught may be released into any other water system in the Free State Province without an approved permit from the FS DESTEA.

2. Documents to be completed

(i) Daily catches as well as a monthly summary of all the catches must be recorded on the forms (**Daily Record** and **Monthly Record** forms) provided by the FS DESTEA.

(ii) All the fish must be counted and weighed immediately after it has been caught, and the number of fish and their weight must be recorded on the **Daily Record** forms. If this is not possible to do at the dam, the number of fish as well as the weight must be recorded in an organized register that must at all times be available for inspection by the officials of the FS DESTEA. Once at the fish processing plant the information must be recorded on the applicable official forms.

(iii) No estimates of the number of fish caught or their weight may be made.

(iv) If no fishing took place during a month, a zero return must be filled in on the **Monthly Record** form which must be handed in at the nature reserve's office before or on the 10th of the following month.

(v) Officials of the FS DESTEA must at all times have access to all records and documents pertaining to the commercial fishing operations at the dam and nature reserve.

3. Payments to be made

(i) A fee of 40c (forty cents) per kilogram live weight is charged for the fish caught during the Financial Year 2013/2014.

(ii) The payment must be done at the nature reserve's office where the commercial fishing takes place or at the nearest Provincial Nature Reserve. All communication in connection with the payments must be done through the relevant Reserve Manager.

(iii) All completed **Daily Record** and **Monthly Record** forms must be submitted with payment to the relevant nature reserve's office before or on the 10th of every month.

(iv) No further commercial fishing will be allowed until the necessary payments have been made.

4. Equipment and licenses

(i) Only trawl nets with a stretched mesh size of 50 millimeters and bigger may be used to catch fish. No other types of nets, long lines or gear which has not been approved by the FS DESTEA may be used.

(ii) The trawl net must be in a good condition and no empty plastic bottles or containers may be used as floats on the net.

(iii) The commercial fishing operator is responsible to acquire a SABS approved scale, which at all times must be in a good working condition, to weigh the fish.

(iv) The Skipper/s of all vessels/boats that are used during the commercial fisheries, must have a valid Certificate of Competence (Skipper License) as required by the South African Maritime Safety Authority (SAMSA) and it must be carried on the boat at all times.

(v) All vessels/boats to be used during the commercial fisheries must have a valid Local General Safety Certificate (including Buoyancy Certificate) as issued by SAMSA and this must be renewed annually.

(vi) Vehicles and trailers must be in a good condition, road worthy and properly licensed and only people with a valid driver's license may drive a vehicle in the nature reserve.

(vii) A copy of the driver's license must be handed in at the relevant nature reserve's office.

5. Control measures relating to the entrance and access to the nature reserve, and management of the commercial fishing operations within the borders of the nature reserve

(i) All the basic rules and regulations applicable to the relevant nature reserve must be adhered to. Copies of this can be obtained at the nature reserve's office or entrance gate.

(ii) According to the Environmental Management Plan and subsequent zoning of the nature reserve, the Reserve Manager has the authority to designate the areas where commercial fishing may take place.

(iii) If the designated zone results in the targeting of scarce or threatened species like yellowfish, the area may be closed and commercial fishing operations will be relocated to another area.

(iv) The local Reserve Manager or official responsible must be notified before 09:00 every Monday on which days in the week and in which areas in the nature reserve commercial fishing is going to take place.

(v) Only designated roads may be used within the nature reserve and at no stage may anyone drive in an area where no roads exist except in the area below the high water mark of the dam.

(vi) Commercial fishing operations may only take place between 06:30 and 17:30 and all people and vehicles need to be out of the nature reserve at 18:00. Should any unforeseen event happen that prevent people to be out of the nature reserve at 18:00, the Reserve Manager or responsible official must be contacted immediately.

(vii) No commercial fishing is allowed after 17:30, public holidays or weekends.

(viii) All boats, nets and equipment must be removed from the nature reserve on Friday afternoons and nothing may be left in the nature reserve during weekends.

(ix) Permission should be obtained from the Reserve Manager to put locks on the approved entrance gates to fishing areas within the nature reserve. No locks may be put on a gate that is not approved by the Reserve Manager. The Reserve Manager must be supplied with a key to the lock/s and under no conditions may keys be hidden (e.g. under stones near the gate).

(Scrap which is not applicable to this permit)

(x) At Bloemhof Dam and Sandveld Nature Reserve commercial fishing may only take place on the Free State Province side of the dam at Lake Warden and within the approved areas designated by the Reserve Manager.

(xi) At Oviston and Gariep Dam commercial fishing may only take place on the Eastern Cape side of the dam and within the approved areas within Oviston Nature Reserve as designated by the Reserve Manager.

(xii) At Bethulie and Gariep Dam commercial fishing may only take place on the Free State Province side of the dam and on the local municipality's land and within the approved areas within the Gariep Nature Reserve as designated by the Reserve Manager.

(xiii) Should entrance and access to any dam be through private gates and through private land, written permission need to be obtained from the land owner and all arrangements regarding the use of gates or roads must be made with the land owner. This is not the responsibility of the FS DESTEA to arrange.

(xiv) A list of the names of the people working for the commercial fishing permit holder as well as copies of their identity documents or proof if identification need to be send to the FS DESTEA and also given to the Reserve Manager.

(xv) People that have nothing to do with the commercial fishing activity are not allowed to enter the nature reserve.

(xvi) People working for the commercial fishing permit holder should all be issued with identity cards or some type of identification tag that will identify them as members of the fishing team. These cards or tags must be worn at all times when working within the nature reserve.

(xvii) The area where fishing takes place must at all times be clean and no littering is allowed.

(xviii) After each day's fishing, all boats, nets, ropes and other equipment must be removed from the shore line and stored at a safe place at least 20 meters away from the water's edge. All boats, nets, ropes and equipment should be covered to ensure no animal can get entangled in especially the nets and ropes.

(xix) All dead fish must be removed from the fishing areas and care must be taken that dead fish do not fall off vehicles when transported to the fish processing plant.

(xx) No fish may be cleaned and processed on the nature reserve.

(xxi) Under no condition may any fires be made within the nature reserve and people that smoke should take care where they throw their cigarette buds.

6. General

(i) This permit is only valid for the period as stated on the cover page and only the fishing quota as specified on this permit may be caught. Care must be taken that the quota is not completed before the end of the term.

(ii) The commercial fishing permit holder and all the people working for him/her enter and work within the nature reserve, and use their own boats and equipment on the dam completely at their own risk. Government and its officials will not be held responsible or liable for any injuries to and death of any person; or damages to, theft of or loss of belongings that may result from working and catching fish within the borders of the nature reserve.

(iii) Under no circumstances may recreational and subsistence anglers be disturbed and commercial fishing may not take place in the areas designated for these anglers.

(iv) If unknown fish species are caught, it must be frozen and the Ichthyologist of the FS DESTEA must be notified immediately at 051 400 4787.

(v) Any outbreaks of fish diseases, fish parasites, fish deaths and any unlawful fishing activities should be reported immediately to the Reserve Manager and the FS DESTEA's Ichthyologist at 051 400 4787.

Appendix 2: Record form for daily catches.

Please complete in duplicate / Voltooi asseblief in tweevoud

Date: *Datum:*	Permit holder: *Permit houer:*
Permit no.	Equipment used: *Toerusting gebruik:*

Fish species / *Vissoort*		Number / *Getal*	Mass / *Massa (in kg)*
Carp *Karp*			
Orange River Mudfish *Onderbek*			
Mud mullet *Moggel*			
Sharptooth Catfish *Skerptandbaber*			
Grass carp *Graskarp*			
Yellowfish ★ *Geelvis*			
Other (specify): *Ander (spesifiseer):*			
TOTAL *TOTAAL*			

★ **All live Yellowfish should be returned to the water immediately and may not be kept.**

Alle lewende Geelvisse moet onmiddellik in die water teruggeplaas word en mag nie gehou word nie

For official use / *Vir amptelike gebruik* Date stamp / *Datum stempel*	Signature of permit holder: *Handtekening van permithouer:*
	Signature of controlling official: *Handtekening van kontrolerende beampte:*
Remarks / *Opmerkings:*	

Appendix 3: Record form for monthly catches.

Month: *Maand:*		Permit number: *Permit nommer:*	
Name of permit holder *Naam van permithouer*			
Contact numbers *Kontak nommer*	(home) *(tuis)*	(cell) *(selfoon)*	
Address *Adres*			
	Code / *Kode:*		

Fish species / *Vissoort*		**Number / *Getal***	**Mass / *Massa (in kg)***
Carp / *Karp*			
Orange River Mudfish / *Onderbek*			
Mud mullet / *Moggel*			
Sharptooth Catfish / *Skerptandbaber*			
Grass carp /*Graskarp*			
Yellowfish / *Geelvis*			
Other (specify): *Ander (spesifiseer):*			
TOTAL / *TOTAAL*			

Amount payable: *Bedrag betaalbaar:*	Receipt number: *Kwitansie nommer:*
For official use / *Vir amptelike gebruik* Date stamp / *Datum stempel*	Signature of permit holder: *Handtekening van permithouer:*
	Signature of controlling official: *Handtekening van kontrolerende beampte:*
Remarks / *Opmerkings:*	

Appendix 4: Commercial fishing data for Kalkfontein Dam.

Yearly summaries of the commercial fisheries at **Kalkfontein Dam** indicating the type of gear used, the total number of fish and weight per species caught per year and the total catch and weight of all species per year, CPUE as well as the total concession fee paid.

YEAR	GN	SN	N CC	W CC (kg)	N LC	W LC (kg)	N LU	W LU (kg)	N CG	W CG (kg)	N LAK	W LAK (kg)	TOTAL FISH	TOTAL W (kg)	CPUE (kg fish day^{-1} year^{-1})	ADMIN. FEE (ZAR)
1979	X	X	75	123	0	0	3 714	2 735	3	17	0	0	3 792	2 875	193.571	135.50
1982		X	30 760	39 470	18 940	19 055	215 138	218 213	988	4 559	11	17	265 837	281 314	-	19 691.98
1983		X	7 922	10 157	6 425	6 328	451 715	453 084	188	1 551	657	134	466 907	471 254	-	32 987.78
1984	X	X	3 343	6 598	29 448	26 478	91 184	93 018.5	452	2 083	98	147	124 525	128 325	-	8 982.72
1985	X	X	3 963	8 257	34 857	27 262	108 996	107 643	197	614	204	319	148 217	144 095	-	10 086.65
1986	X		5 292	11 658	20 510	16 421	38 853	36 823	489	2 093	445	383	65 589	67 378	518.292	4 716.46
1987	X	X	5 489	6 082	21 261	15 640	65 392	58 334	752	2 387	1 235	1 113	94 129	83 556	525.509	5 848.92
1988	X		786	495	1 144	899	6 216	6 150	94	129	110	101	8 350	7 774	310.960	544.18
1989	X		3 087	1 975	9 598	6 676	30 911	20 585	466	998	249	291	44 311	30 525	381.563	2 136.75
1993	X	X	11 263	11 155	7 560	5 064	50 621	35 682	263	1 114	100	70	69 807	53 085	547.268	13 271.25
1994	X	X	84 360	107 724	14 574	11 963	110 369	102 420	651	3 770	293	264	210 247	226 141	1 000.624	56 535.25
1997		X	24 208	30 389	7 450	9 106	38 216	40 543	365	1 298	47	86	70 286	81 422	409.156	20 355.50
1998	X		2 731	3 928	10 778	12 414	117 216	124 612	106	317	10	15	130 841	141 286	831.094	35 321.50
1999		X	8 922	10 944	8 335	9 019	52 503	56 240	163	566	0	0	69 923	76 769	959.613	19 192.25

Appendix 4 (cont.): Commercial fishing data for Kalkfontein Dam.

YEAR	GN	SN	N CC	W CC (kg)	N LC	W LC (kg)	N LU	W LU (kg)	N CG	W CG (kg)	N LAK	W LAK (kg)	TOTAL FISH	TOTAL W (kg)	CPUE (kg fish day^{-1} year^{-1})	ADMIN. FEE (ZAR)
2005		X	4 025	8 176	32	32	149 043	144 014	207	672	0	0	153 307	152 894	6 370.583	53 512.90
2009		X	11 002	14 872	3 933	4 802	67 341	72 454	784	2 309	3	3	83 063	94 440	1 967.500	33 054.00
TOT.			**207 228**	**272 003**	**194 845**	**171 159**	**1 597 428**	**1 572 551**	**6 168**	**24 477**	**3 462**	**2 943**	**2 009 131**	**2 043 133**		**316 373.59**

GN: Gill net
N CC: Total *C. carpio*
N LC: Total *L. capensis*
N LU: Total *L. umbratus*
N CG: Total *C. gariepinus*
N LAK: Total for *L. aeneus* and *L. kimberleyensis* combined

SN: Seine net
W CC: Total weight for *C. carpio*
W LC: Total weight for *L. capensis*
W LU: Total weight for *L. umbratus*
W CG: Total weight for *C. gariepinus*
W LAK: Total weight for *L. aeneus* and *L. kimberleyensis* combined

CPUE: Determined by dividing the total weight of all species caught per year by the number of days that actual fishing was done. The number of days the commercial fishery operated during 1982 till 1985 could not be found on the historic records.

Appendix 5: Species' contribution to the total catch and total weight of the commercial fishery at Kalkfontein Dam.

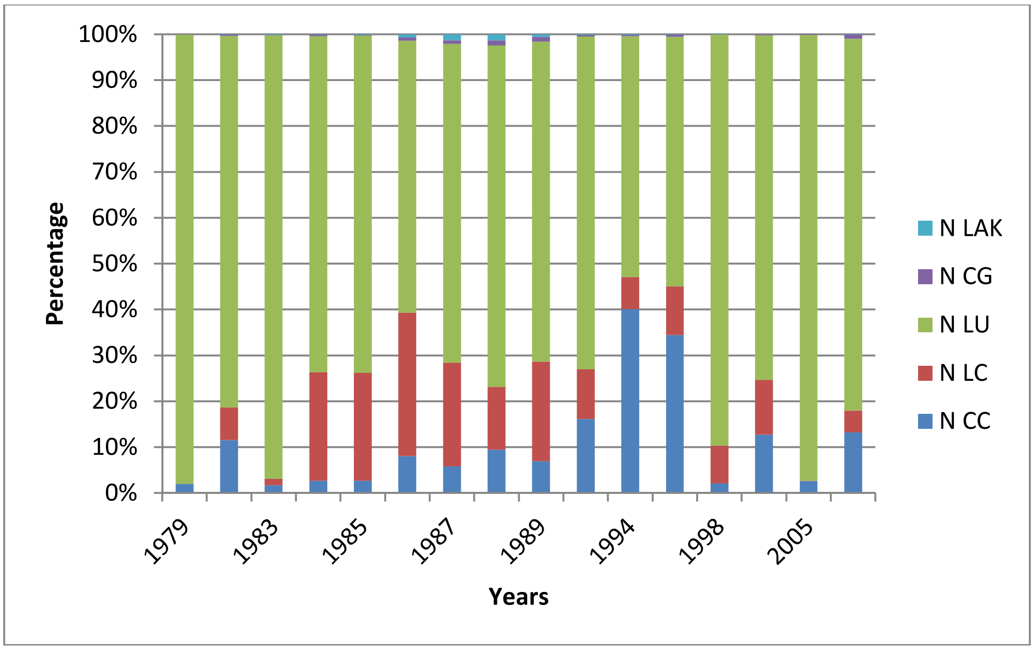

Figure 5.1: Total number of fish per species caught per year (%) at **Kalkfontein Dam**.

N CC: Total *C. carpio* N LC: Total *L. capensis*
N LU: Total *L. umbratus* N CG: Total *C. gariepinus*
N LAK: Total *L. aeneus* and *L. kimberleyensis* combined

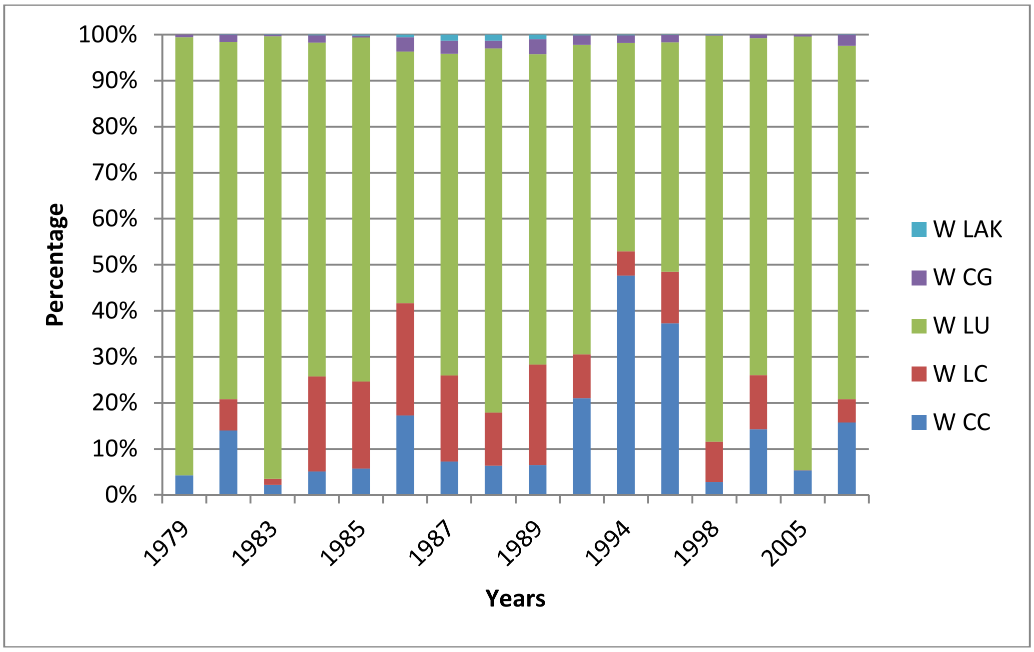

Figure 5.2: Total weight of fish per species caught per year (%) at **Kalkfontein Dam.**

W CC: Total weight for *C. carpio* W LC: Total weight for *L. capensis*
W LU: Total weight for *L. umbratus* W CG: Total weight *C. gariepinus*
W LAK: Total weight for *L. aeneus* and *L. kimberleyensis* combined

Appendix 6: Commercial fishing data for Bloemhof Dam.

Yearly summaries of the commercial fisheries at **Bloemhof Dam** for the period 1982 till January 2014 indicating the type of gear that was used, the total number of fish and weight per species and total catch and weight of all species caught per year.

YEAR	GN	SN	N CC	W CC (kg)	N LC	W LC (kg)	N LU	W LU (kg)	N CG	W CG (kg)	N LAK	W LAK (kg)	N CI	W CI (kg)	TOTAL FISH	TOTAL W (kg)
1982	-	-	2 275	3106	222	305	910	1 121	245	1 241.5	36	61	0	0	3 688	5 834.5
1983	-	-	15 089	18 953	69 016	82 556	138 371	158 727	1 548	5 575	14 313	16 707	0	0	238 337	282 518
1984	-	-	19 576	25 208	58 725	70 129	124 021	146 154	2078	6 942	1 768	2170	0	0	206 168	250 603
1985	-	-	127 137	251 808	46121	54 171	200 260	224 159.5	6443	24866	931	1 145	0	0	380 892	556 149.5
1986	-	-	78 931	182 668	43 225	44 979	176 891	190 019	3 588	25 124	44	105	0	0	302 679	442 895
1987	-	-	39 595	99 512	23 244	22 652	76 240	91 696	3 983	27 251	38	258	0	0	143 100	241 369
1988	-	-	47 673	62 591	2 766	2 844	18 325	22 404	1 854	9 366	72	99	0	0	70 690	97 304
1989	-	-	2 571	4 019	0	0	718	775	283	1 907	0	0	0	0	3 572	6 701
1990	-	-	42 416	65 335	3 852	4 207	34 940	35 618	6 783	16 563	384	645	0	0	88 375	122 368
1991	-	-	35 903	50 819	10 988	11 598	75 209	74 391	11 495	30 866	174	181	0	0	133 769	167 855
1992	-	-	36 811	60 333.5	1 060	1 171	37 509	40 577	4 949	15 638	67	98.5	0	0	8 0396	117 818
1993	X		49 591	83 919	319	329	50 934	51 874	1 460	5 843	46	55	0	0	102 359	142 020
1994	X		46 062	78 440	21 350	21 608	55 493	57 156	5 550	19 169	162	306	0	0	128 617	176 679
1995	X	x	58 830	105 226	22 797	20 804	109 999	111 572	6 891	18 187	282	267	0	0	198 799	256 056
1996	X	x	28 081	54 300	6 344	5 233	85 072	85 590	2 643	9 012	554	826	0	0	122 694	154 961
1997	X	x	7 6730	161 572	4 513	4 186	54 776	57 175	4 488	12 994	671	1 585	0	0	141 178	237 512
1998		X	107 068	214 714	336	336	47 177	49 267	4 927	15 718	0	0	0	0	159 508	280 035
1999	x	X	79 796	209 004	0	0	37 436	39 338	7 848	32 090	0	0	0	0	125 080	280 432
2000		X	21 142	44 615	0	0	13 021	14498	1 582	6 181	0	0	0	0	35 745	65 294
2001		X	70 213	160 872	0	0	32 113	32 919	5 695	22 373	0	0	0	0	108 021	216 164
2002	x	X	108 722	245 663	0	0	40 283	43 637	7 409	29 603	0	0	4 076	5 431	160 490	324 334
2003		X	159 451	347 708	733	748	47 151	51 109	21 322	61 534	57	101	13 899	20 016	242 613	481 216

Appendix 6 (cont): Commercial fishing data for Bloemhof Dam.

YEAR	GN	SN	N CC	W CC (kg)	N LC	W LC (kg)	N LU	W LU (kg)	N CG	W CG (kg)	N LAK	W LAK (kg)	N CI	W CI (kg)	TOTAL FISH	TOTAL W (kg)
2004		X	161 424	355 671	0	0	54 601	58 792	855	3 909	0	0	2 529	4 601	219 409	422 973
2005	x	X	38 964	74 311	523	482	41 357	42 813	2 613	7 108	0	0	0	0	83 457	124 714
2006		X	53 432	102 497	19	43	28 012	42 270	3 364	18 742	12	25	111	237	84 950	163 814
2007		X	186 231	380 098	0	0	28	45	5 764	61 337	0	0	538	632	192 561	442 112
2008		X	34 839	74 579	0	0	0	0	1 223	6 034	0	0	0	0	36 062	80 613
2009		X	21 541	40 367	0	0	0	0	1 745	5 637	0	0	941	2 462	24 227	48 466
2010		X	27 511	50 031	0	0	36	49	1 780	7 133	0	0	3 175	6 790	32 502	64 003
2011		X	27 481	47 687	5	2	8	11	3 621	12 008	0	0	222	1 136	31 337	60 844
2012		X	46 454	91 156	0	0	12	12	8 008	23 204	0	0	64	224	54 538	114 596
2013		X	67 956	148 747	1	1	51	129	10 158	36 503	0	0	649	1 535	78 815	186 915
2014		X	7 256	16 691	0	0	0	0	613	1 998	0	0	69	233	7 938	18 922
TOTAL			**1 926 752**	**3 912 221**	**316 159**	**348 384**	**1 580 954**	**1 723 898**	**152 808**	**581 657**	**19 611**	**24 635**	**26 273**	**43 297**	**4 022 566**	**6 634 090**

X: Main gear type used
x: Gear type also used but not main method to catch fish
GN: Gill net
SN: Seine net
N CC: Total *C. carpio*
W CC: Total weight for *C. carpio*
N LC: Total *L. capensis*
W LC: Total weight for *L. capensis*
N LU: Total *L. umbratus*
W LU: Total weight for *L. umbratus*
N CG: Total *C. gariepinus*
W CG: Total weight for *C. gariepinus*
N LAK: Total for *L. aeneus* and *L. kimberleyensis* combined
W LAK: Total weight for *L. aeneus* and *L. kimberleyensis* combined
N CI: Total *C. idella*
W CI: Total weight for *C. idella*

Appendix 7: Yearly summaries of commercial fisheries at Bloemhof Dam.

Yearly summaries of the commercial fisheries at **Bloemhof Dam** for the period 1982 till January 2014 indicating the number of days that were fished, CPUE and concession fee paid to government.

Year	TOTAL W (KG)	TOTAL DAYS FISHED BY BOTH FISHERIES	CPUE	CONCESSION FEE (ZAR)
1982	5 834.5	-	-	408.42
1983	282 518	-	-	19 776.26
1984	250 603	-	-	17 542.21
1985	556 149.5	-	-	38 930.47
1986	442 895	-	-	31 002.65
1987	241 369	-	-	16 895.83
1988	97 304	-	-	2 500.96
1989	6 701	-	-	1 683.29
1990	122 368	-	-	8 565.76
1991	167 855	-	-	11 749.85
1992	117 818	-	-	8 247.26
1993	142 020	139	1 021.727	35 508.55
1994	176 679	210	841.329	44 485.75
1995	256 056	290	882.952	64 129.00
1996	154 961	284	545.637	39 577.24
1997	237 512	332	715.398	59 378.50
1998	280 035	220	1 272.886	70 120.25
1999	280 432	223	1 257.543	70 107.50
2000	65 294	137	476.599	19 404.90
2001	216 164	198	1 091.737	64 858.30
2002	324 334	223	1 454.413	101 942.85
2003	481 216	290	1 659.366	146 167.90
2004	422 973	270	1 566.567	129 327.35
2005	124 714	128	974.328	41 519.50
2006	163 814	102	1 606.020	57 331.40
2007	417 566	132	3 163.379	133 415.70
2008	80 613	74	1 089.365	28 214.55
2009	48 466	70	692.371	16 986.20
2010	64 003	133	481.226	20 805.75
2011	60 844	113	538.442	21 094.85
2012	114 596	211	543.109	40 149.55
2013	186 915	253	738.794	70 814.55
2014	18 922	14	1 351.571	7 568.80
TOTAL				**1 440 211.90**

Appendix 8: Species' contribution to the total catch of commercial fisheries at Bloemhof Dam.

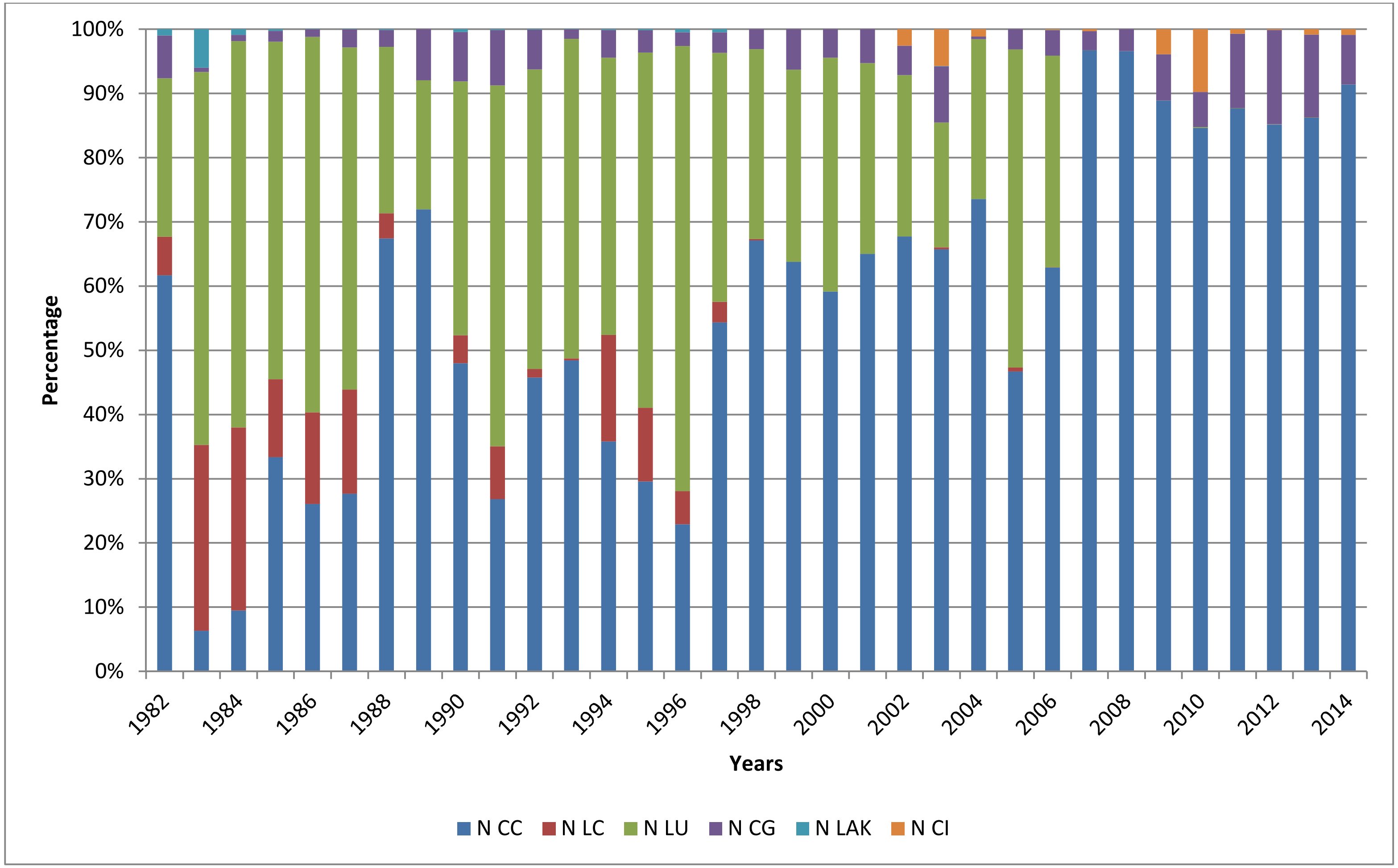

Figure 8.1: Total number of fish per species caught per year at **Bloemhof Dam** (%).

Appendix 9: Species' contribution to the total weight of commercial fisheries' catches at Bloemhof Dam.

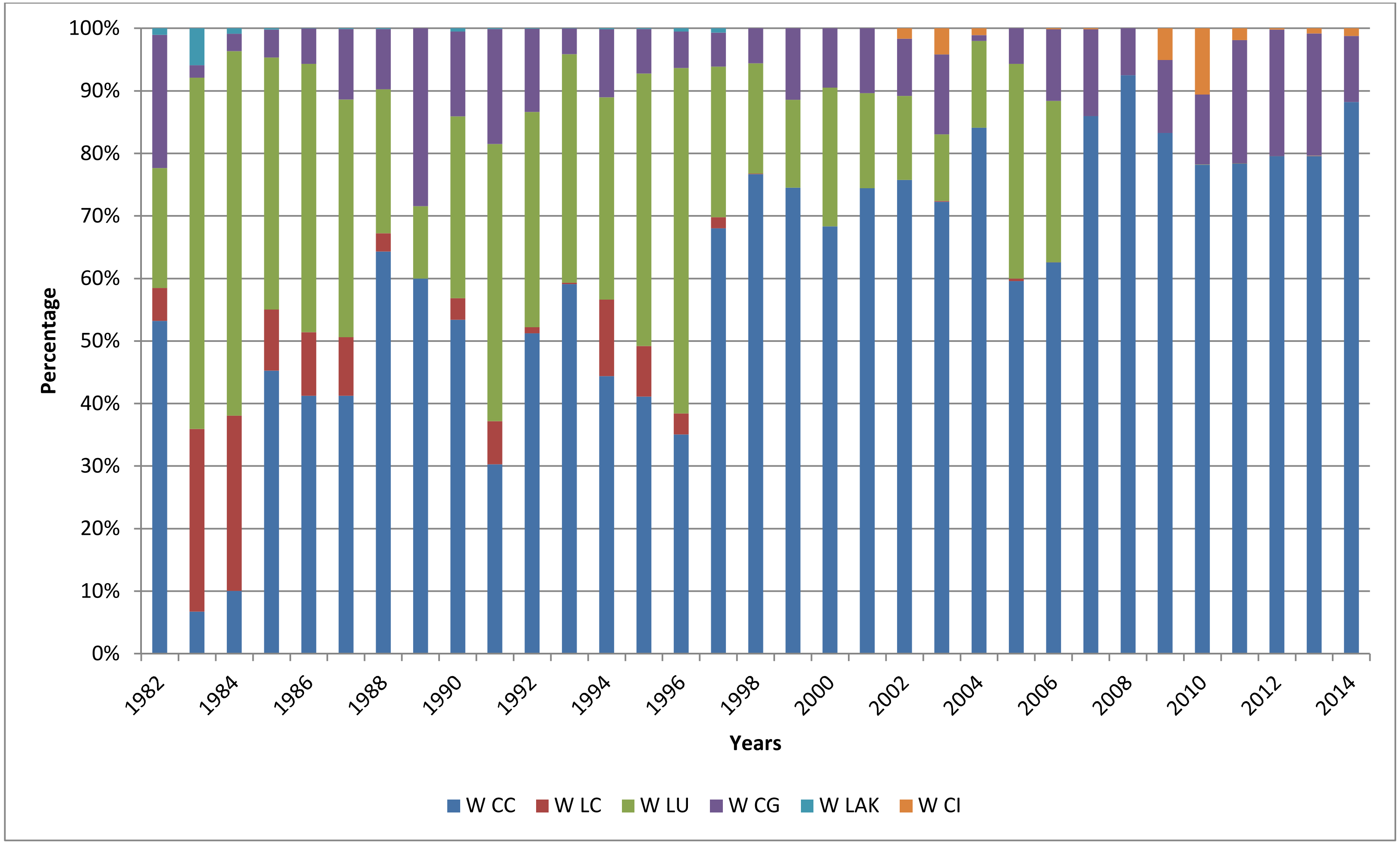

Figure 9.1: Total weight of fish per species caught per year (%) at **Bloemhof Dam**.

Appendix 10: Commercial fishing data for Koppies Dam.

Yearly summaries of the commercial fisheries at **Koppies Dam** for the period 1982 till 1993 indicating the type of gear that was used, the total number of fish and weight per species, and total catch and weight of all species caught per year.

YEAR	GN	SN	N CC	W CC	N LC	W LC	N LU	W LU	N CG	W CG	N LAK	W LAK	TOTAL FISH	TOTAL W
1982	X	X	1 082	1 622	574	641.8	1 988	2 132.3	618	1 882	0	0	4 262	6 278.1
1983		X	2 867	4 851	2 268	2 829	9 562	10 613	1 041	2 907	0	0	15 738	21 200
1984	X	X	486	1 132	2 905	3 585	13 426	15 055	1 080	2 571	0	0	17 897	22 343
1985		X	747	1 305	2 708	3 247	14 579	16 077	532	1041	28	41	18 594	21 711
1986	X	x	181	327	2 686	2 821	18 332	17 405	88	322	59	76	21 346	20 951.7
1987	X	x	41	66	2 458	2 725	17 633	17 886	571	2 498	27	32	20 730	23 207
1988	X	x	0	0	1 405	1 564	10 183	10 649	1 290	5 857	1	1	12 879	18 071
1989	X	x	0	0	451	497	6 882	7 312	1 380	3 643	0	0	8 713	11 452
1990	X		0	0	0	0	12 484	13 268	1 580	4 041	0	0	14 064	17 309
1991	X		0	0	0	0	10 005	11 100	1 417	3 550	0	0	11 422	14 650
1992	X		3	3	69	71	8 603	9 404	2 105	4 405	14	11.5	10 794	13 894
1993	X		0	0	4	2.7	622	634	359	959	1	0.5	986	1 596.2
TOTAL			**5 407**	**9 306**	**15 528**	**17 984**	**124 299**	**131 535**	**12 061**	**33 676**	**130**	**162**	**157 425**	**192 663**

X – indicating that this was the main gear used.

x – indicating that this type of gear was used only a few times during the year

GN: Gill net
N CC: Total *C. carpio*
N LC: Total *L. capensis*
N LU: Total *L. umbratus*
N CG: Total *C. gariepinus*
N LAK: Total for *L. aeneus* and *L. kimberleyensis* combined

SN: Seine net
W CC: Total weight for *C. carpio*
W LC: Total weight for *L. capensis*
W LU: Total weight for *L. umbratus*
W CG: Total weight for *C. gariepinus*
W LAK: Total weight for *L. aeneus* and *L. kimberleyensis* combined

Appendix 11: Species' contribution to the total catch and total weight of the commercial fishery at Koppies Dam.

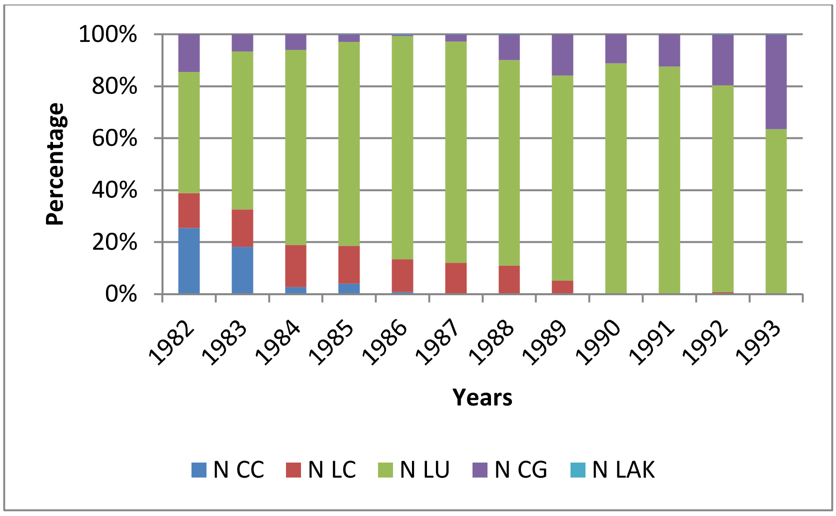

Figure 11.1: Total number of fish per species caught per year at **Koppies Dam** (%).

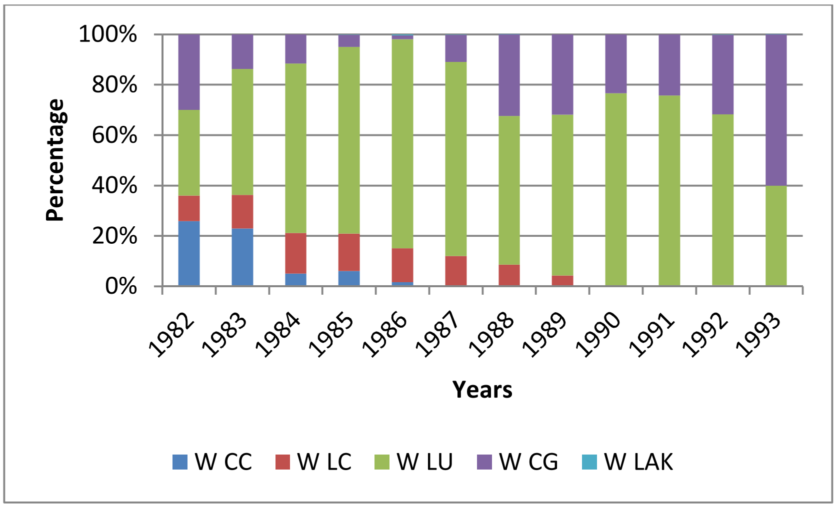

Figure 11.2: Total weight of fish per species caught per year at **Koppies Dam** (%).

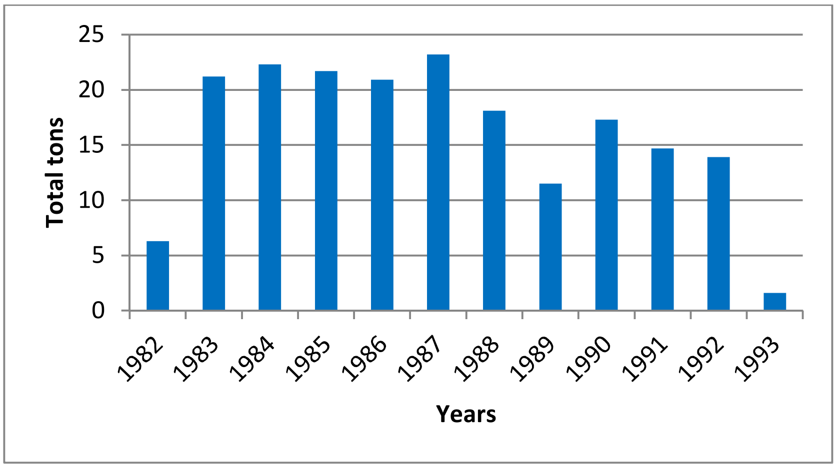

Figure 11.3: Total tons of fish caught per year at **Koppies Dam**.

Appendix 12: Commercial fishing data for Rustfontein Dam.

Yearly summaries of the commercial fisheries at **Rustfontein Dam** for the period 1983 till 1987, and 2000 indicating the type of gear that was used, the total number of fish and weight per species, and total catch and weight of all species caught per year.

YEAR	GN	SN	N CC	W CC	N LC	W LC	N LU	W LU	N CG	W CG	N LAK	W LAK	TOTAL FISH	TOTAL W
1983	X	X	1 978	2 561	1 568	1 728	8 099	8 939	638	2 086	190	255	12 473	15 569
1984	X	X	401	364	278	297	1 759	1 812	69	313	9	14	2 516	2 800
1985	X	X	474	506	456	442	2 168	1 928	355	774	73	96	3 526	3 746
1986	X	X	2 183	3 884	2 855	2 636	22 571	1 6761	438	2 249	299	355	28 346	25 885
1987	X	X	118	188	1 456	1 238	1 193	1 061	41	90	44	58	2 852	2 635
2000	X		1	1.2	55	41.25	168	142.8	11	29	7	4.2	242	218.45
TOT.			**5 155**	**7 504.2**	**6 668**	**6 382.3**	**35 958**	**30 644**	**1 552**	**5 541**	**622**	**782.2**	**49 955**	**50 853.7**

GN: Gill net
SN: Seine net
N CC: Total *C. carpio*
W CC: Total weight for *C. carpio*
N LC: Total *L. capensis*
W LC: Total weight for *L. capensis*
N LU: Total *L. umbratus*
W LU: Total weight for *L. umbratus*
N CG: Total *C. gariepinus*
W CG: Total weight for *C. gariepinus*
N LAK: Total for *L. aeneus* and *L. kimberleyensis* combined
W LAK: Total weight for *L. aeneus* and *L. kimberleyensis* combined

Appendix 13: Species' contribution to the total catch and total weight of the commercial fishery at Rustfontein Dam.

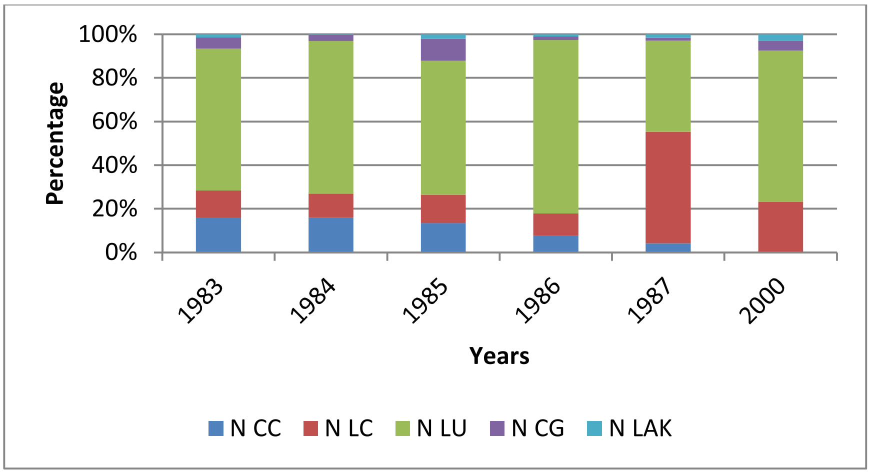

Figure 13.1: Total number of fish per species caught per year (%) at **Rustfontein Dam**.

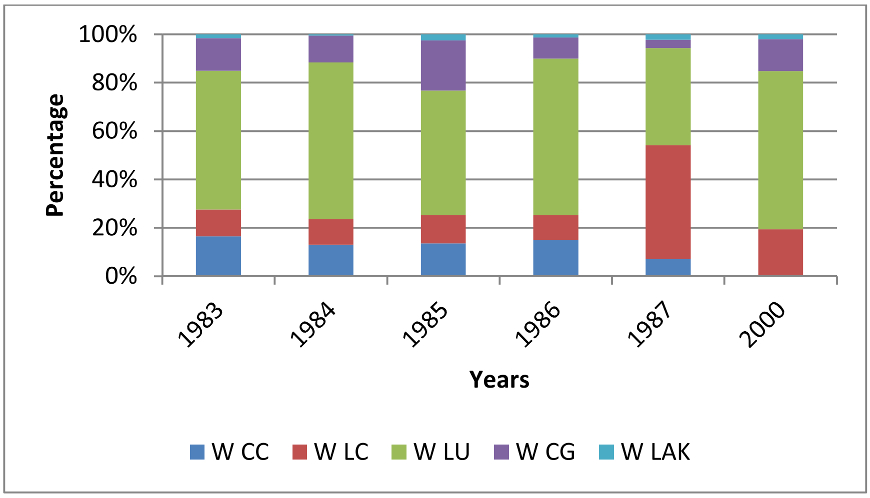

Figure 13.2: Total weight of fish per species caught per year at **Rustfontein Dam** (%).

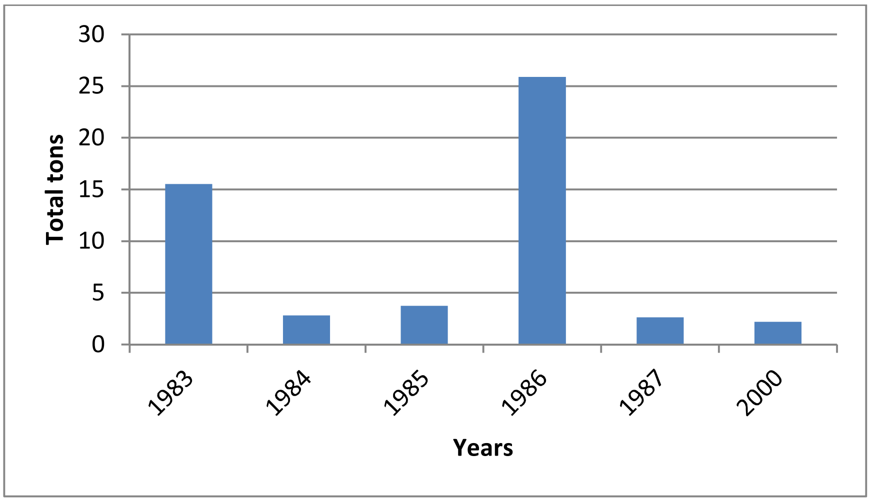

Figure 13.3: Total tons of fish caught per year at **Rustfontein Dam.**

Appendix 14: Record form for angling tournaments.

Summary of the results of an angling tournament *Opsomming van die uitslae van 'n hengelkompetisie*

Permit number *Permitnommer*					
Name of club *Naam van klub*					
Permit holder *Permithouer*					
Contact person *Kontakpersoon*			**Email** *Epos*		
Telephone number *Telefoonnommer*			**Cell.no.** *Selfoon*		
Date held *Datum gehou*			**Place/Dam** *Plek/Dam*		
Time started *Tyd begin*			**Time ended** *Tyd geëindig*		
Number of anglers *Getal hengelaars*		**Anglers that did catch a fish/fish** *Hengelaars wat wel 'n vis/visse gevang het*			
Other angling clubs participating *Ander klubs wat deelgeneem het*					

Fish species / *Vissoort*	**Number** *Getal*	**Total weight** *Totale gewig (kg)*	**Lightest fish** *Ligste vis (kg)*	**Heaviest fish** *Swaarste vis (kg)*
Largemouth Yellowfish *Grootbekgeelvis*				
Smallmouth Yellowfish *Kleinbekgeelvis*				
Orange River Mudfish *Onderbek*				
Sharptooth catfish (Barbel) *Skerptandbaber (Baber)*				
Carp *Karp*				
Moggel *Moggel*				
Grass carp *Graskarp*				
Other – specify name *Ander – spesifiseer naam*				
TOTAL *TOTAAL*				

Certified as correct *Gesertifiseer korrek*		**Portfolio in club** *Portefeulje in klub*		**Date** *Datum*	

Appendix 15: Key to abbreviations and acronyms used in Appendixes 16 to 32.

N LAK: Total number of *Labeobarbus aeneus* and *Labeobarbus kimberleyensis* caught combined

W LAK: Total weight of the total catch of *Labeobarbus aeneus* and *Labeobarbus kimberleyensis* combined in kilogram

N LU: Total number of *Labeo umbratus* caught

W LU: Total weight of the total catch of *Labeo umbratus* in kilogram

N LC: Total number of *Labeo capensis* caught

W LC: Total weight of the total catch of *Labeo capensis* in kilogram

N CG: Total number of *Clarias gariepinus* caught

W CG: Total weight of the total catch of *Clarias gariepinus* in kilogram

N CC: Total number of *Cyprinus carpio* caught

W CC: Total weight of the total catch of *Cyprinus carpio* caught in kilogram

N CI: Total number of *Ctenopharyngodon idella* caught

W CI: Total weight of the total catch of *Ctenopharyngodon idella* caught in kilogram

Total N fish: Total number for all different species caught

Total W: Total weight of the total catch of all species in kilogram

Total N anglers: The total number of anglers that took part in angling tournaments during that year at the impoundments

Total N anglers successful: Number of anglers that did catch a fish of fish during an angling tournament

% success: % anglers that were successful and that did catch fish in that year during an angling tournament

N Comp: Total number of angling tournaments held in that year at impoundment

Av. H of comp: The average number of hours/durations of angling tournaments

CPUE 1: Catch per unit effort based on the kilogram fish caught per successful angler per hour

CPUE 2: Catch per unit effort based on the kilogram fish caught per successful angler per angling tournament

Appendix 16: Allemanskraal Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL N FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESSFUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1977	38	22.0	0	0.0	4	2.0	26	39.3	15	26.5	83	89.8	30	22	73.3	1	0	-	-
1978	1	1.2	0	0.0	92	33.9	46	25.2	153	80.6	292	140.8	107	74	69.2	4	0	-	-
1979	19	23.9	0	0.0	20	18.4	14	59.1	281	167.8	334	269.2	95	78	82.1	3	0	-	-
1980	4	1.8	0	0.0	29	19.2	7	4.6	226	117.4	266	143.0	148	102	68.0	8	0	-	-
1981	2	0.8	0	0.0	0	0.0	55	164.4	100	108.7	157	273.9	54	32	59.3	3	0	-	-
1982	65	44.4	0	0.0	21	14.4	21	13.7	339	220.5	446	292.9	177	152	85.9	11	0	-	-
1983	69	36.4	1	0.8	18	9.3	33	51.1	502	358.1	623	455.6	302	169	56.0	19	0	-	-
1984	28	18.1	3	1.5	2	2.0	42	39.7	33	25.7	108	86.9	247	71	28.7	11	0	-	-
1985	40	25.1	0	0.0	30	13.1	5	10.0	34	17.9	109	66.1	68	41	60.3	4	0	-	-
1986	7	5.6	0	0.0	112	74.4	5	8.3	4	3.8	128	91.9	48	41	85.4	3	0	-	-
1987	4	2.6	0	0.0	3	1.5	9	13.4	6	8.3	22	25.7	74	14	18.9	2	0	-	-
1988	5	4.6	1	0.7	0	0.0	388	243.5	4	3.5	398	252.3	226	160	70.8	5	0	-	-
1989	4	5.6	0	0.0	15	8.2	162	66.6	0	0.0	181	80.4	103	68	66.0	4	0	-	-
1990	62	50.6	0	0.0	67	41.5	148	47.6	35	45.5	312	185.1	220	153	69.6	5	0	-	-
1991	62	45.4	13	8.7	42	16.9	976	356.8	249	230.6	1342	658.3	443	343	77.4	12	0	-	-
1992	119	58.0	0	0.0	178	60.1	397	711.2	385	664.6	1079	1493.9	358	278	77.7	16	0	-	-
1993	86	54.4	0	0.0	470	153.0	280	390.3	359	679.9	1195	1277.5	283	194	68.6	11	0	-	-
1994	0	0.0	0	0.0	4	2.5	2	0.6	20	23.9	26	27.0	20	13	65.0	1	8	0.3	0.104
1995	5	7.0	0	0.0	19	9.1	177	421.2	87	198.4	288	635.7	71	52	73.2	3	7	1.7	0.172
1996	14	18.7	0	0.0	105	71.4	372	822.5	234	304.5	725	1217.1	945	281	29.7	26	7	0.7	0.005
1997	5	7.4	0	0.0	180	68.1	143	68.8	86	142.3	414	286.5	305	126	41.3	15	6	0.4	0.007
1998	0	0.0	0	0.0	41	14.7	121	64.7	120	102.7	282	182.1	337	153	45.4	10	6	0.2	0.004
1999	1	1.1	0	0.0	357	178.5	317	96.7	807	884.0	1482	1160.4	377	289	76.7	16	6	0.6	0.011
2000	0	0.0	0	0.0	7	3.5	34	19.9	15	10.1	56	33.5	20	20	100.0	1	5	0.3	0.084
2001	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-

Appendix 16 (cont.): Allemanskraal Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL N FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESSFUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
2002	16	7.4	0	0.0	451	149.8	488	164.0	2763	1710.7	3718	2031.9	825	799	96.8	18	8	0.3	0.0031
2003	71	27.9	0	0.0	180	110.7	82	52.9	959	730.2	1292	921.8	190	156	82.1	9	8	0.7	0.0311
2004	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2005	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2006	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2007	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2008	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2009	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2010	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2011	0	0.0	0	0.0	0	0.0	7	27.6	448	508.6	455	536.3	41	41	100.0	3	8	1.6	0.319
2012	0	0.0	0	0.0	0	0.0	2	0.8	10	9.6	12	10.4	23	11	47.8	2	8	0.1	0.0411
2013	45	23.4	1	0.7	81	41.2	51	30.8	463	395.0	641	491.1	189	165	87.3	14	8	0.4	0.0157
2014	0	0.0	16	9.6	22	10.8	318	909.3	623	520.9	979	1450.7	165	154	93.3	12	8	1.2	0.0571
TOTAL	772	493.2	35	22.0	2550	1127.9	4728	4924.5	9360	8300.2	17445	14867.7	6491	4252	65.5	252			

Appendix 17: Bloemhoek Dam angling tournament data.

YEAR	N LAK	W LAK	N MG	W MG	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1996	0	0.0	0	0.0	89	22.9	10	5.8	232	115.8	331	144.4	424	178	42.0	20	7	0.12	0.04
1997	1	1.2	0	0.0	95	23.2	19	8.7	313	163.0	428	196.2	362	166	45.9	18	7	0.16	0.07
1998	0	0.0	0	0.0	138	32.6	7	1.9	236	137.2	381	171.6	402	145	36.1	19	7	0.17	0.06
1999	0	0.0	0	0.0	332	110.8	6	8.4	195	142.9	533	262.1	210	110	52.4	9	7	0.32	0.26
2013	0	0.0	1	0.9	36	12.9	6	5.3	265	188.7	308	207.8	196	113	57.7	10	8	0.23	0.18
2014	0	0.0	0	0.0	44	16.7	1	2.0	263	100.9	308	119.6	80	58	72.5	4	8	0.26	0.52
TOTAL	**1**	**1.2**	**1**	**0.9**	**734**	**219.0**	**49**	**32.1**	**1504**	**848.6**	**2289**	**1101.7**	**1674**	**770**	**46.0**	**80**	**7**	**0.19**	**0.02**

Appendix 18: Bloemhof Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	N CI	W CI	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1974	0	0.0	0	0.0	0	0.0	0	0.0	2	1.8	0	0.0	2	1.8	8	2	25	1	-	-	-
1975	60	50.7	32	20.8	142	106.3	319	1023.7	7755	8540.6	0	0.0	8308	9742.0	1035	982	94.88	20	-	-	-
1976	4	3.6	0	0.0	33	19.0	318	280.9	3391	2622.1	0	0.0	3746	2925.7	386	302	78.24	17	-	-	-
1977	10	6.1	0	0.0	45	31.8	64	58.7	373	358.7	0	0.0	492	455.2	180	139	77.22	8	-	-	-
1978	24	24.6	2	0.8	84	99.4	182	215.9	3459	3622.0	0	0.0	3751	3962.7	1217	867	71.24	40	-	-	-
1979	17	16.8	0	0.0	15	8.8	62	167.7	2254	1637.7	0	0.0	2348	1831.0	455	362	79.56	29	-	-	-
1980	127	81.9	0	0.0	5	3.0	23	45.9	2146	1451.8	0	0.0	2301	1582.5	356	336	94.38	22	-	-	-
1981	30	21.2	0	0.0	26	24.0	31	106.2	3182	2617.0	0	0.0	3269	2768.3	823	677	82.26	28	-	-	-
1982	52	52.5	1	1.3	120	122.6	49	301.1	10850	8041.5	0	0.0	11072	8519.0	1356	1240	91.45	54	-	-	-
1983	22	21.7	2	1.8	9	6.3	109	166.9	9363	8209.1	0	0.0	9505	8405.7	936	847	90.49	40	-	-	-
1984	3	3.9	1	0.7	26	16.8	86	220.5	3528	3749.2	0	0.0	3644	3991.1	467	434	92.93	19	-	-	-
1985	2	2.7	0	0.0	80	52.5	26	31.5	667	928.0	0	0.0	775	1014.8	244	176	72.13	9	-	-	-
1986	3	3.2	0	0.0	183	109.7	125	208.3	458	862.5	0	0.0	769	1183.6	353	236	66.86	14	-	-	-
1987	9	4.5	0	0.0	71	57.0	45	124.8	255	196.2	0	0.0	380	382.6	233	149	63.95	10	-	-	-
1988	5	2.6	1	1.0	37	16.0	476	479.8	3406	6602.8	0	0.0	3925	7102.2	1264	848	67.09	42	-	-	-
1989	10	9.9	0	0.0	19	9.4	1280	561.3	2868	3381.4	0	0.0	4177	3962.0	1004	802	79.88	31	-	-	-
1990	23	12.8	0	0.0	17	8.4	301	491.2	3347	4415.3	0	0.0	3688	4927.7	607	453	74.63	21	-	-	-
1991	8	5.8	0	0.0	30	10.8	259	408.2	3532	4840.6	0	0.0	3829	5265.4	556	479	86.15	26	-	-	-
1992	74	35.0	0	0.0	86	24.3	524	922.5	11430	11806.2	0	0.0	12114	12788.0	1186	1140	96.12	47	-	-	-
1993	41	16.5	1	1.1	1	1.0	202	412.1	3754	5814.7	0	0.0	3999	6245.3	594	542	91.25	27	-	-	-
1994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.00	0	-	-	-
1995	0	0.0	0	0.0	13	6.8	204	379.7	1116	2667.5	0	0.0	1333	3054.0	364	332	91.21	3	6	1.5	3.1
1996	3	3.5	0	0.0	201	121.1	402	801.9	1369	4079.1	0	0.0	1975	5005.6	1550	748	48.26	36	7	0.9	0.2

Appendix 18 (cont.): Bloemhof Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	N CI	W CI	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1997	0	0.0	0	0.0	186	90.3	729	411.8	2438	2687.0	0	0.0	3353	3189.1	910	685	75.27	26	7	0.7	0.2
1998	0	0.0	0	0.0	616	280.6	749	1282.8	14568	14991.4	0	0.0	15933	16554.8	2373	2083	87.78	47	8	1.1	0.2
1999	0	0.0	0	0.0	227	84.6	370	706.8	8734	10391.5	0	0.0	9331	11182.9	1170	1050	89.74	38	7	1.5	0.3
2000	0	0.0	0	0.0	14	4.6	4	3.3	318	258.8	0	0.0	336	266.7	40	39	97.50	2	8	0.9	3.4
2001	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.00	0	-	-	-
2002	0	0.0	0	0.0	14	4.3	8	22.1	123	94.9	0	0.0	145	121.3	10	10	100.00	1	8	1.5	12.1
2003	48	25.1	0	0.0	96	43.4	498	512.8	10729	14023.8	426	236.3	11797	14841.4	1594	1500	94.10	36	8	1.2	0.3
2004	0	0.0	0	0.0	1	0.5	108	170.2	5895	6003.8	0	0.0	6004	6174.5	257	257	100.00	7	8	3.0	3.4
2005	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.00	0	-	-	-
2006	0	0.0	0	0.0	0	0.0	0	0.0	26	42.8	0	0.0	26	42.8	18	12	66.67	1	8	0.4	3.6
2007	0	0.0	0	0.0	0	0.0	26	18.0	142	156.7	0	0.0	168	174.7	24	22	91.67	1	8	1.0	7.9
2008	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.00	0	-	-	-
2009	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.00	0	-	-	-
2010	0	0.0	0	0.0	2	0.9	23	54.3	153	169.1	0	0.0	178	224.3	19	19	100	1	8	1.5	11.8
2011	0	0.0	0	0.0	0	0.0	31	27.6	471	541.3	0	0.0	502	568.9	56	54	96.43	3	8	1.3	3.5
2012	0	0.0	0	0.0	0	0.0	0	0.0	9	7.1	0	0.0	9	7.1	8	3	37.50	1	8	0.3	2.4
2013	1	0.5	0	0.0	1	0.3	143	314.6	2934	3055.0	263	179.8	3342	3550.2	339	302	89.09	21	8	1.5	0.6
2014	2	0.7	0	0.0	8	3.8	169	854.8	3791	5157.0	43	36.8	4013	6053.2	405	362	89.38	20	9	2.0	0.8
TOTAL	578	405.7	40	27.3	2408	1368.3	7945	11787.5	128836	144026.1	732	453.0	140539	158067.8	22397	18491		749			

Appendix 19: Erfenis Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1982	3	2.0	0	0	12	10.0	33	15.3	15	32.7	63	60.1	92	27	29.4	3	-	-	-
1984	0	0.0	0	0	0	0.0	95	248.7	0	0.0	95	248.7	18	15	83.3	1	-	-	-
1985	6	5.1	0	0	4	1.9	265	559.8	7	5.9	282	572.7	125	60	48.0	4	-	-	-
1986	0	0.0	0	0	0	0.0	119	183.8	0	0.0	119	183.8	76	28	36.8	3	-	-	-
1987	5	2.7	0	0	18	9.0	16	14.4	0	0.0	39	26.0	152	39	25.7	5	-	-	-
1988	0	0.0	0	0	0	0.0	16	20.3	5	23.0	21	43.3	14	10	71.4	1	-	-	-
1989	0	0.0	0	0	0	0.0	21	13.5	2	4.8	23	18.3	30	12	40.0	1	-	-	-
1990	0	0.0	0	0	0	0.0	113	24.1	40	83.8	153	107.9	37	31	83.8	2	-	-	-
1991	0	0.0	0	0	0	0.0	271	360.6	74	138.1	345	498.7	158	76	48.1	6	-	-	-
1992	0	0.0	0	0	1	0.4	30	49.2	258	611.2	289	660.8	102	60	58.8	4	-	-	-
1993	40	19.6	0	0	40	11.4	32	30.2	140	250.6	252	311.7	100	73	73.0	5	-	-	-
1994	0	0.0	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
1995	0	0.0	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
1996	0	0.0	0	0	0	0.0	50	129.1	8	16.0	58	145.1	60	20	33.3	3	8	0.9	2.4
1997	0	0.0	0	0	1	0.5	35	11.6	10	24.6	46	36.8	93	31	33.3	5	7.5	0.2	0.2
1998	0	0.0	0	0	3	0.5	7	2.8	6	1.2	16	4.4	22	11	50.0	1	8	0.0	0.4
1999	0	0.0	0	0	1	0.7	97	202.1	2	10.1	100	213.0	34	27	79.4	1	9	0.9	7.9
2000	0	0.0	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2001	0	0.0	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2002	3	1.0	0	0	0	0.0	0	0.0	2	5.5	5	6.5	12	5	41.7	1	8	0.2	1.3
2003	15	9.6	0	0	6	4.1	3	2.2	12	15.1	36	30.9	17	8	47.1	1	8	0.5	3.9
2004	0	0.0	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2005	0	0.0	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2006	0	0.0	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-

Appendix 19 (cont.): Erfenis Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
2007	0	0.0	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2008	0	0.0	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2009	0	0.0	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2010	0	0.0	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2011	0	0.0	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2012	8	5.7	0	0	40	19.6	0	0.0	102	79.9	150	105.1	21	17	81.0	2	8	0.8	3.1
2013	76	59.7	0	0	17	11.8	11	8.1	406	299.1	510	378.6	127	113	89.0	7	17	0.2	0.5
2014	12	6.7	0	0	15	11.0	211	928.6	414	584.7	652	1531.0	188	113	60.1	8	10	1.4	1.7
TOTAL	**168**	**112.0**	**0**	**0**	**158**	**80.7**	**1425**	**2804.3**	**1503**	**2186.2**	**3254**	**5183.2**	**1478**	**776**	**52.5**	**64**			

Appendix 20: Gariep Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1993	0	0.0	0	0.0	3	2.0	12	15.6	33	37.3	48	54.9	15	15	100.0	1	8	0.5	3.7
1994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
1995	1	0.8	0	0.0	7	6.5	21	33.6	36	26.6	65	67.5	137	37	27.0	3	8	0.2	0.6
1996	0	0.0	0	0.0	0	0.0	35	10.5	34	15.6	69	26.1	54	21	38.9	7	7	0.2	0.2
1997	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
1998	2	0.7	0	0.0	2	1.7	26	38.9	83	76.8	113	118.2	55	48	87.3	6	8	0.3	0.4
1999	1	1.4	0	0.0	18	8.1	15	5.4	24	31.8	58	46.7	11	11	100.0	1	8	0.5	4.2
2000	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2001	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2002	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2003	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2004	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2005	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2006	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2007	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2008	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2009	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2010	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0		-
2011	3	1.8	1	0.7	0	0.0	2	1.6	37	21.6	43	25.6	17	15	88.2	1	8	0.2	1.7
2012	7	11.2	0	0.0	2	2.4	58	62.7	640	775.2	707	851.5	100	87	87.0	7	8	1.2	1.4
2013	26	49.5	0	0.0	4	4.7	11	59.3	903	1166.3	944	1279.9	256	185	72.3	12	8	0.9	0.6
2014	13	12.3	0	0.0	5	7.8	37	201.0	433	598.0	488	819.1	109	98	89.9	11	10	0.9	0.8
TOTAL	**53**	**77.8**	**1**	**0.7**	**41**	**33.2**	**217**	**428.5**	**2223**	**2749.3**	**2535**	**3289.4**	**754**	**517**	**68.6**	**49**			**0.1298**

Appendix 21: Jimmie Roos Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1993	0	0	0	0.0	0	0.0	0	0.0	70	180.7	70	180.7	33	21	63.6	2	9	1.0	4.3
1994	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
1995	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
1996	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
1997	0	0	0	0.0	0	0.0	1	0.2	2	2.4	3	2.6	14	3	21.4	1	8	0.1	0.9
1998	0	0	0	0.0	0	0.0	0	0.0	73	68.2	73	68.2	32	20	62.5	2	8	0.4	1.7
1999	0	0	4	1.8	0	0.0	26	10.4	225	153.3	255	165.6	34	32	94.1	2	8	0.6	2.6
2000	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2001	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2002	0	0	4	1.6	0	0.0	6	1.9	126	78.4	136	81.9	49	44	89.8	3	8	0.2	0.6
2003	0	0	10	5.2	19	7.4	1	0.3	536	702.5	566	715.4	200	162	81.0	8	8	0.6	0.6
2004	0	0	0	0.0	0	0.0	0	0.0	137	64.5	137	64.5	7	7	100.0	1	8	1.2	9.2
2005	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2006	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2007	0	0	2	0.9	0	0.0	0	0.0	215	85.0	217	86.0	12	12	100.0	1	8	0.9	7.2
2008	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2009	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2010	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2011	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2012	0	0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2013	0	0	0	0.0	0	0.0	0	0.0	5	14.2	5	14.2	22	5	22.7	2	9	0.3	1.4
2014	0	0	0	0.0	0	0.0	0	0.0	5	2.7	5	2.7	19	4	21.1	1	8	0.1	0.7
TOT.	**0**	**0**	**20**	**9.6**	**19**	**7.4**	**34**	**12.7**	**1394**	**1351.9**	**1467**	**1381.7**	**422**	**310**	**73.5**	**23**			

Appendix 22: Kalkfontein Dam angling tournament data.

Year	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1975	19	11.5	0	0.0	89	59.2	70	53.7	147	180.0	325	304.4	235	109	46.4	3	-	-	0.9
1976	3	3.6	1	1.0	0	0.0	4	2.1	14	17.9	22	24.6	14	9	64.3	1	-	-	2.7
1977	6	2.8	0	0.0	7	4.7	0	0.0	2	1.6	15	9.1	12	8	66.7	1	-	-	1.1
1978	3	4.0	0	0.0	0	0.0	0	0.0	16	14.0	19	18.0	18	6	33.3	1	-	-	3.0
1979	131	171.4	0	0.0	39	62.7	2	1.2	63	132.5	235	367.9	112	71	63.4	7	-	-	0.7
1980	21	15.5	2	3.2	2	1.1	0	0.0	39	55.0	64	74.8	58	30	51.7	2	-	-	1.2
1981	19	14.8	0	0.0	0	0.0	0	0.0	30	58.0	49	72.8	61	33	54.1	2	-	-	1.1
1982	20	21.0	0	0.0	15	3.5	10	82.1	202	311.6	247	418.2	73	61	83.6	5	-	-	1.4
1983	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
1984	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
1985	2	0.8	0	0.0	19	15.5	0	0.0	1	3.7	22	20.0	12	6	50.0	1	-	-	3.3
1986	6	2.5	1	1.5	8	5.6	29	92.6	102	213.0	146	315.2	76	44	57.9	3	-	-	2.4
1987	61	29.9	1	1.0	5	4.2	25	55.8	250	274.5	342	365.4	146	104	71.2	11	-	-	0.3
1988	10	8.6	0	0.0	10	7.0	38	46.1	187	152.9	245	214.5	228	113	49.6	9	-	-	0.2
1989	14	14.9	0	0.0	8	6.6	9	14.3	294	258.1	325	293.8	135	77	57.0	10	-	-	0.4
1990	10	13.8	6	3.5	0	0.0	117	2.0	658	916.9	791	936.2	322	153	47.5	10	-	-	0.6
1991	5	2.4	0	0.0	0	0.0	0	0.0	66	77.2	71	79.6	35	15	42.9	3	-	-	1.8
1992	7	3.0	0	0.0	1	0.4	9	36.2	752	639.1	769	678.7	124	112	90.3	11	-	-	0.6
1993	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
1994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
1995	14	7.7	0	0.0	0	0.0	0	0.0	60	40.5	74	48.2	16	16	100.0	1	8	0.4	3.0
1996	0	0.0	0	0.0	0	0.0	4	1.8	202	205.8	206	207.6	67	38	56.7	3	8	0.7	1.8
1997	0	0.0	0	0.0	0	0.0	0	0.0	450	390.6	450	390.6	74	73	98.6	4	8	0.7	1.3
1998	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-

Appendix 22 (cont.): Kalkfontein Dam angling tournament data.

Year	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1999	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2000	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2001	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2002	1	1.9	0	0.0	0	0.0	0	0.0	307	366.4	308	368.3	59	52	88.1	2	8	-	3.5
2003	0	0.0	0	0.0	11	4.0	7	2.4	100	96.3	118	102.6	40	35	87.5	2	8	-	1.5
2004	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2005	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2006	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2007	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2008	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2009	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2010	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2011	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2012	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2013	2	0.8	0	0.0	2	0.6	3	30.5	74	99.1	81	131.0	21	19	90.5	3	15	0.5	2.3
2014	1	0.3	0	0.0	1	0.7	4	2.1	664	454.0	670	457.1	117	74	63.2	3	8	0.8	2.1
TOTAL	355	331.1	11	10.2	217	175.7	331	422.9	4680	4958.5	5594	5898.4	2055	1258	61.2	98			

Appendix 23: Knellpoort Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP	AV. H OF COMP.	CPUE 1	CPUE 2
1996	0	0.0	0	0	0	0.0	0	0.0	1	2.0	1	2.0	12	1	8.3	1	8	0.3	2.0
1998	3	2.0	0	0	1	0.7	1	1.0	7	12.4	12	16.0	14	8	57.1	1	8	0.2	2.0
2013	0	0.0	0	0	40	15.7	22	21.3	669	279.4	731	316.4	34	31	91.2	2	16	0.6	5.1
2014	0	0.0	0	0	57	20.2	8	2.4	346	147.1	411	169.7	13	13	100.0	1	26	0.5	13.1
TOTAL	**3**	**2.0**	**0**	**0**	**98**	**36.5**	**31**	**24.6**	**1023**	**440.9**	**1155**	**504.0**	**73**	**53**	**72.6**	**5**			

Appendix 24: Koppies Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1975	6	4.4	0	0.0	30	20.0	24	24.9	38	42.9	98	92.1	50	33	66.0	1	-	-	2.8
1976	2	0.7	0	0.0	37	15.1	11	5.4	8	8.7	58	29.9	77	33	42.9	2	-	-	0.5
1977	57	27.9	0	0.0	442	225.6	30	56.9	110	124.1	639	434.5	180	128	71.1	4	-	-	0.8
1978	80	51.0	0	0.0	82	48.5	83	156.6	453	358.1	698	614.2	235	176	74.9	10	-	-	0.3
1979	173	102.3	0	0.0	405	227.5	46	80.8	540	429.9	1164	840.5	603	446	74.0	17	-	-	0.1
1980	31	22.3	0	0.0	408	322.0	9	6.6	165	152.9	613	503.9	250	182	72.8	10	-	-	0.3
1981	30	18.6	0	0.0	367	178.0	174	296.6	55	81.5	626	574.6	418	203	48.6	10	-	-	0.3
1982	300	198.3	1	1.4	1408	881.1	179	383.9	897	659.0	2785	2123.7	547	493	90.1	35	-	-	0.1
1983	644	509.7	14	12.2	3888	3318.0	643	1806.5	1289	1287.9	6478	6934.2	2842	1977	69.6	71	-	-	0.0
1984	171	93.1	1	1.3	751	525.5	230	509.8	170	164.2	1323	1293.9	724	391	54.0	33	-	-	0.1
1985	524	436.7	6	4.6	1989	1234.0	373	595.9	668	506.6	3560	2777.9	1549	1117	72.1	54	-	-	0.0
1986	64	49.3	0	0.0	3304	2383.7	209	322.1	805	584.9	4382	3340.0	2134	1485	69.6	38	-	-	0.1
1987	133	83.5	1	0.8	486	294.4	470	458.1	517	295.6	1607	1132.3	758	430	56.7	41	-	-	0.1
1988	14	7.8	1	0.8	22	10.4	170	307.0	70	87.4	277	413.4	193	108	56.0	25	-	-	0.2
1989	11	8.6	0	0.0	36	22.9	101	43.4	181	141.4	329	216.3	168	89	53.0	17	-	-	0.1
1990	93	52.8	0	0.0	183	97.8	139	60.5	357	317.5	772	528.5	428	284	66.4	26	-	-	0.1
1991	60	29.4	0	0.0	13	2.8	200	115.2	1863	777.2	2136	924.6	270	201	74.4	17	-	-	0.3
1992	250	110.0	0	0.0	12	7.8	161	87.3	580	351.3	1003	556.3	172	150	87.2	13	-	-	0.3
1993	77	40.9	0	0.0	82	30.3	37	29.8	124	135.1	320	236.1	110	77	70.0	7	-	-	0.4
1994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
1995	0	0.0	0	0.0	14	8.2	30	60.7	28	45.4	72	114.3	41	23	56.1	2	8	0.6	2.5
1996	1	2.4	0	0.0	33	19.4	23	34.2	254	349.6	311	405.5	522	179	34.3	20	8	0.3	0.1
1997	5	6.2	0	0.0	323	185.2	483	525.7	2219	2051.3	3030	2768.4	1282	754	58.8	37	9	0.4	0.1

Appendix 24 (cont.): Koppies Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1998	1	2.0	0	0.0	205	132.9	270	209.6	2757	1886.4	3233	2230.9	986	651	66.0	33	8	0.4	0.1
1999	0	0.0	2	2.2	675	310.5	183	129.2	2980	2245.1	3840	2687.1	1247	869	69.7	44	9	0.3	0.1
2000	0	0.0	0	0.0	42	11.7	8	7.3	66	47.6	116	66.6	68	40	58.8	2	8	0.2	0.8
2001	0	0.0	0	0.0	8	2.3	3	1.2	7	5.4	18	8.9	20	11	55.0	1	8	0.1	0.8
2002	43	19.3	0	0.0	293	132.7	49	24.5	384	320.8	769	497.3	264	206	78.0	10	8	0.3	0.2
2003	20	11.5	1	0.8	118	70.5	32	16.0	206	231.9	377	330.7	158	113	71.5	8	8	0.4	0.4
2004	10	4.4	0	0.0	33	17.1	3	1.0	87	97.1	133	119.6	40	37	92.5	2	8	0.4	1.6
2005	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2006	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2007	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2008	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2009	0	0.0	0	0.0	10	3.1	5	2.5	37	27.4	52	33.0	16	14	87.5	1	8	0.3	2.4
2010	4	1.9	0	0.0	42	26.2	2	0.7	41	43.7	89	72.5	35	21	60.0	2	8	0.4	1.7
2011	84	74.4	0	0.0	246	129.6	57	37.0	254	273.1	641	514.0	178	122	68.5	13	9	0.5	0.3
2012	119	54.9	0	0.0	125	58.8	71	58.1	309	339.1	624	510.8	234	170	72.6	11	8	0.4	0.3
2013	133	75.8	3	3.3	121	86.4	72	104.1	2012	1620.7	2341	1890.3	731	537	73.5	21	8	0.4	0.2
2014	12	15.1	0	0.0	127	87.0	48	118.9	1177	955.6	1364	1176.6	212	178	84.0	17	8	0.8	0.4
TOTAL	**3152**	**2114.9**	**30**	**27.4**	**16360**	**11127.0**	**4628**	**6677.9**	**21708**	**17046.0**	**45878**	**36993.1**	**17742**	**11928**	**67.2**	**655**			

Appendix 25: Krugersdrift Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTA L FISH	TOTA L W	TOTAL N ANGLER S	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP .	AV. H OF COMP.	CPUE 1	CPUE 2
1974	0	0.0	0	0.0	0	0.0	0	0.0	6	5.0	6	5.0	31	4	12.9	2	-	-	0.6
1975	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
1976	1	0.5	0	0.0	0	0.0	0	0.0	21	24.5	22	25.0	38	17	44.7	3	-	-	0.5
1977	13	16.8	0	0.0	0	0.0	32	22.1	156	160.9	201	199.8	186	96	51.6	12	-	-	0.2
1978	19	10.9	0	0.0	0	0.0	90	182.9	253	317.1	362	510.9	154	101	65.6	9	-	-	0.6
1979	39	21.4	0	0.0	4	2.1	202	285.4	349	353.6	594	662.5	131	108	82.4	9	-	-	0.7
1980	0	0.0	0	0.0	0	0.0	3	4.0	31	56.0	34	60.0	35	19	54.3	3	-	-	1.1
1981	3	3.5	0	0.0	1	0.3	9	9.9	39	76.0	52	89.6	35	17	48.6	3	-	-	1.8
1982	8	7.1	0	0.0	0	0.0	85	83.4	225	218.9	318	309.3	199	118	59.3	15	-	-	0.2
1983	11	11.4	13	16.1	25	18.6	498	723.2	5995	6080.3	6542	6849.6	1307	1134	86.8	90	-	-	0.1
1984	13	5.7	9	14.0	31	16.1	203	639.1	2290	3126.7	2546	3801.6	1144	822	71.9	81	-	-	0.1
1985	1	0.5	1	0.8	123	70.1	186	565.2	311	407.1	622	1043.7	452	269	59.5	31	-	-	0.1
1986	2	2.0	0	0.0	232	119.5	191	440.6	172	323.0	597	885.1	416	211	50.7	28	-	-	0.1
1987	18	10.3	0	0.0	47	26.3	137	381.9	146	312.4	348	730.9	449	181	40.3	33	-	-	0.1
1988	23	16.5	0	0.0	76	48.1	66	156.1	180	403.4	345	624.1	280	126	45.0	17	-	-	0.3
1989	19	11.9	0	0.0	54	37.6	371	353.0	1499	1878.4	1943	2281.0	627	405	64.6	33	-	-	0.2
1990	10	5.1	0	0.0	7	2.3	193	140.8	3745	3066.3	3955	3214.5	1323	943	71.3	42	-	-	0.1
1991	34	17.7	0	0.0	17	18.8	193	180.6	2924	2347.6	3168	2564.6	1307	872	66.7	59	-	-	0.0
1992	111	47.4	2	1.0	37	15.3	337	337.2	4886	5338.0	5373	5738.9	1400	1092	78.0	67	-	-	0.1
1993	56	26.5	15	7.1	10	5.5	341	755.3	6163	8030.3	6585	8824.6	1227	1060	86.4	56	-	-	0.1
1994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
1995	0	0.0	1	0.9	25	20.0	35	136.8	557	1321.6	618	1479.1	97	81	83.5	6	24	0.8	3.0
1996	8	17.3	0	0.0	80	37.5	88	382.0	668	1164.9	844	1601.7	829	415	50.1	43	12	0.3	0.1
1997	13	10.6	1	0.3	108	48.4	190	284.7	2872	2630.0	3184	2974.1	877	643	73.3	39	12	0.4	0.1
1998	3	3.6	0	0.0	60	37.4	214	357.2	3056	2973.2	3333	3371.4	967	691	71.5	41	14	0.4	0.1

Appendix 25 (cont.): Krugersdrift Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1999	0	0.0	0	0.0	133	59.9	189	286.8	7784	7052.6	8106	7399.3	1162	1071	92.2	42	11	0.6	0.2
2000	0	0.0	0	0.0	24	6.6	3	3.8	450	1065.0	477	1075.4	49	49	100.0	2	91	0.2	11.0
2001	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2002	4	1.8	0	0.0	117	47.1	28	80.5	449	627.9	598	757.2	445	287	64.5	12	8	0.3	0.2
2003	31	18.4	0	0.0	109	49.5	35	26.8	2547	2057.1	2722	2151.9	677	542	80.1	20	9	0.5	0.2
2004	0	0.0	1	0.3	24	8.9	4	13.2	684	534.6	713	556.9	78	71	91.0	5	8	1.0	1.6
2005	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2006	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
2007	0	0.0	0	0.0	0	0.0	1	5.2	116	106.6	117	111.8	46	28	60.9	2	7	0.6	2.0
2008	0	0.0	0	0.0	57	20.6	5	5.8	642	431.8	704	458.3	76	76	100.0	5	7	0.8	1.2
2009	1	1.2	0	0.0	0	0.0	5	26.2	77	140.7	83	168.1	46	26	56.5	3	24	0.3	2.2
2010	1	0.9	0	0.0	0	0.0	24	177.2	349	317.5	374	495.5	117	73	62.4	6	20	0.3	1.1
2011	0	0.0	0	0.0	2	1.1	7	10.4	531	506.0	540	517.5	388	170	43.8	9	10	0.3	0.3
2012	1	0.7	0	0.0	2	0.6	14	11.4	674	727.7	691	740.4	247	185	74.9	10	10	0.4	0.4
2013	1	0.3	0	0.0	7	4.4	8	22.1	3214	3239.6	3230	3266.4	747	560	75.0	32	8	0.7	0.2
2014	12	4.7	0	0.0	3	1.5	22	77.7	3845	2909.3	3882	2993.1	471	394	83.5	21	8	0.9	0.4
TOT.	**456**	**274.5**	**43**	**40.5**	**1415**	**723.7**	**4009**	**7168.5**	**57906**	**60331.5**	**63829**	**68538.6**	**18060**	**12957**	**71.7**	**891**			

Appendix 26: Moutloatsi Setlogelo Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
2007	0	0	0	0	287	81.7	10	3.7	357	259.2	654	344.5	46	45	97.8	3	8	1.0	2.6
2010	0	0	0	0	6	1.3	31	9.6	28	15.3	65	26.2	16	16	100.0	1	6	0.3	1.6
2011	0	0	0	0	75	20.4	10	52.7	132	131.0	217	204.1	148	70	47.3	3	7	0.4	1.0
2012	0	0	0	0	0	0.0	13	31.4	177	361.8	190	393.3	42	37	88.1	4	8	1.3	2.7
2013	0	0	0	0	115	51.2	22	132.2	189	317.0	326	500.4	90	80	88.9	9	8	0.8	0.7
TOTAL	**0**	**0**	**0**	**0**	**483**	**154.6**	**86**	**229.6**	**883**	**1084.3**	**1452**	**1468.5**	**342**	**248**	**72.5**				

Appendix 27: Rustfontein Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1974	24	21.6	0	0.0	23	16.1	38	114.2	125	117.6	210	269.5	271	112	41.3	7	-	-	0.3
1975	64	49.1	7	4.8	289	181.8	32	41.4	511	576.7	903	853.8	572	325	56.8	17	-	-	0.2
1976	93	53.6	2	2.0	264	112.2	251	188.9	659	841.5	1269	1198.2	689	416	60.4	34	-	-	0.1
1977	315	246.6	5	6.8	1106	599.8	245	243.0	1306	1765.2	2977	2861.4	1207	778	64.5	50	-	-	0.1
1978	170	148.8	3	2.7	857	681.3	216	240.6	4415	3699.6	5661	4773.0	1470	1108	75.4	47	-	-	0.1
1979	101	91.7	5	7.0	1672	1234.7	98	96.7	2009	1634.0	3885	3064.0	1053	751	71.3	29	-	-	0.1
1980	32	16.3	0	0.0	733	502.8	32	34.0	1659	1036.6	2456	1589.7	734	612	83.4	18	-	-	0.1
1981	13	7.5	3	1.9	22	13.8	116	154.6	363	408.4	517	586.2	386	201	52.1	22	-	-	0.1
1982	38	19.0	0	0.0	375	272.1	29	37.1	1379	1439.3	1821	1767.5	693	477	68.8	37	-	-	0.1
1983	38	21.2	1	0.5	214	170.5	16	22.5	530	581.9	799	796.7	377	292	77.5	24	-	-	0.1
1984	45	18.9	0	0.0	20	7.7	28	12.6	201	129.5	294	168.7	75	69	92.0	6	-	-	0.4
1985	174	65.4	0	0.0	3	1.1	21	53.1	254	190.0	452	309.6	187	126	67.4	15	-	-	0.2
1986	142	54.5	1	0.9	318	206.5	76	153.2	480	487.6	1017	902.7	658	368	55.9	32	-	-	0.1
1987	99	48.9	0	0.0	79	41.2	140	161.2	481	488.1	799	739.5	627	318	50.7	29	-	-	0.1
1988	122	71.8	2	1.5	92	49.0	141	202.8	1300	1515.8	1657	1840.7	1056	513	48.6	53	-	-	0.1
1989	132	80.0	2	1.8	166	87.2	615	400.9	4793	4283.0	5708	4853.0	1374	961	69.9	59	-	-	0.1
1990	25	23.3	1	1.3	303	195.5	238	163.4	1899	1841.5	2466	2225.0	600	455	75.8	31	-	-	0.2
1991	20	23.3	0	0.0	318	210.1	133	115.3	3349	2738.5	3820	3087.2	775	592	76.4	38	-	-	0.1
1992	24	13.7	0	0.0	490	258.1	256	207.5	5975	5477.4	6745	5956.7	1081	887	82.1	41	-	-	0.2
1993	8	5.0	0	0.0	304	178.4	29	38.5	1273	1530.6	1614	1752.5	515	362	70.3	23	-	-	0.2
1994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
1995	0	0.0	0	0.0	164	87.7	0	0.0	222	196.6	386	284.3	43	43	100.0	2	9	0.8	3.3
1996	1	0.5	12	4.0	632	275.4	99	164.2	3516	4061.7	4260	4505.9	1396	1019	73.0	44	9	0.5	0.1

Appendix 27 (cont.): Rustfontein Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1997	3	3.7	6	4.2	479	245.5	110	76.0	3149	3040.8	3747	3370.3	995	848	85.2	42	9	0.5	0.1
1998	6	7.6	1	1.1	844	416.8	32	70.0	2299	2351.8	3182	2847.2	1129	787	69.7	44	7	0.5	0.1
1999	1	1.2	1	0.5	766	418.2	21	62.7	2109	2505.0	2898	2987.6	820	669	81.6	27	8	0.6	0.2
2000	1	1.3	0	0.0	108	22.7	1	0.3	140	220.8	250	245.1	60	47	78.3	2	9	0.6	2.6
2001	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2002	69	30.8	0	0.0	123	45.9	23	26.7	774	847.6	989	951.0	575	345	60.0	19	8	0.3	0.1
2003	68	40.8	2	2.3	341	134.9	19	7.7	3818	2686.5	4248	2872.2	1108	832	75.1	41	8	0.4	0.1
2004	32	15.7	0	0.0	27	11.2	14	16.3	703	482.6	776	525.8	109	103	94.5	6	8	0.6	0.9
2005	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2006	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2007	11	5.4	0	0.0	45	22.0	0	0.0	362	316.4	418	343.9	82	71	86.6	5	8	0.6	1.0
2008	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2009	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2010	5	2.1	0	0.0	0	0.0	3	21.7	13	18.0	21	41.8	32	12	0.4	2	19	0.2	1.7
2011	6	3.6	0	0.0	332	100.1	33	9.2	398	277.7	769	390.7	155	111	0.7	6	10	0.4	0.6
2012	0	0.0	0	0.0	52	22.3	1	3.1	110	93.1	163	118.5	23	23	100.0	2	8	0.6	2.6
2013	11	6.4	1	1.1	33	11.8	71	35.4	253	224.6	369	279.3	113	87	77.0	6	8	0.4	0.5
2014	0	0.0	0	0.0	106	46.6	38	11.7	185	181.5	329	239.8	111	72	64.9	5	8	0.4	0.7
TOTAL	**1893**	**1199.3**	**55**	**44.4**	**11700**	**6881.1**	**3215**	**3186.5**	**51012**	**48287.7**	**67875**	**59599.0**	**21151**	**14792**	**69.9**	**865**			

Appendix 28: Sol Plaatje Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1996	6	10.3	0	0	217	160.0	25	43.4	210	210.0	458	423.6	602	195	32.4	22	8	0.3	0.1
1997	0	0.0	0	0	161	92.7	91	30.5	303	206.9	555	330.0	350	190	54.3	20	8	0.2	0.1
1998	2	3.0	0	0	61	27.0	68	52.8	137	143.3	268	226.1	245	93	38.0	15	8	0.3	0.2
1999	1	1.9	0	0	60	21.9	88	92.5	159	165.8	308	282.1	273	137	50.2	17	8	0.3	0.1
2000	0	0.0	0	0	20	6.8	12	4.6	25	17.7	57	29.1	29	28	96.6	2	8	0.1	0.5
2001	0	0.0	0	0	1	0.2	3	1.1	9	2.4	13	3.8	12	6	50.0	1	8	0.1	0.6
2002	0	0.0	0	0	33	12.1	12	3.9	4	2.2	49	18.2	17	11	64.7	1	8	0.2	1.7
2003	6	2.7	0	0	50	24.1	17	22.6	68	70.6	141	120.0	19	18	94.7	6	8	0.8	1.1
TOTAL	**15**	**17.9**	**0**	**0**	**603**	**344.8**	**316**	**251.4**	**915**	**818.9**	**1849**	**1433.0**	**1547**	**678**	**43.8**	**84**			

Appendix 29: Sterkfontein Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1982 - 1993	86	124.0	11	11.9	140	110.7	62	127.0	18	40.6	317	414.2	1107	307	27.7	20	?	-	-
1995	74	91.9	11	9.7	466	338.7	13	8.8	88	139.6	652	588.7	236	139	58.9	10	8	0.5	0.4
1996	5	8.3	1	0.7	357	179.0	9	11.5	21	22.2	393	221.7	104	57	54.8	5	8	0.5	0.8
1997	15	20.7	8	6.3	2155	874.7	47	40.3	245	262.9	2470	1205.0	331	247	74.6	17	9	0.6	0.3
1998	7	10.1	10	7.4	1966	824.7	10	8.3	194	243.9	2187	1094.3	320	218	68.1	13	8	0.7	0.4
1999	5	8.4	1	0.8	362	126.1	1	0.3	34	52.3	403	188.0	102	79	77.5	4	8	0.3	0.6
2000	1	1.0	0	0.0	35	18.2	0	0.0	6	8.6	42	27.8	16	10	62.5	1	5	0.6	2.8
2002	3	5.4	0	0.0	7	4.6	1	0.1	2	3.9	13	14.0	26	9	34.6	1	7	0.2	1.6
2003	21	18.5	13	11.6	22	26.6	3	4.1	13	37.2	72	98.0	151	42	27.8	9	6	0.4	0.3
2004	12	13.4	1	1.1	64	42.8	1	0.1	2	4.0	80	61.3	40	21	52.5	3	6	0.5	1.0
TOTAL	**229**	**301.7**	**56**	**49.6**	**5574**	**2546.1**	**147**	**200.4**	**623**	**815.4**	**6629**	**3913.1**	**2433**	**1129**	**46.4**	**83**			

Appendix 30: Tierpoort Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1996	0	0.0	0	0	0	0.0	0	0.0	29	26.3	29	26.3	10	6	60.0	1	8	0.5	4.4
1997	0	0.0	0	0	1	0.1	2	0.2	9	8.7	12	9.0	39	8	20.5	1	9	0.1	1.1
2012	0	0.0	0	0	0	0.0	0	0.0	73	168.2	73	168.2	26	18	69.2	1	8	1.2	9.3
2014	2	0.5	0	0	0	0.0	6	27.2	756	979.3	764	1007.1	92	86	93.5	6	13	0.9	2.0
TOTAL	**2**	**0.5**	**0**	**0**	**1**	**0.1**	**8**	**27.4**	**867**	**1182.6**	**878**	**1210.6**	**167**	**118**	**70.7**	**9**	**9**		

Appendix 31: Welbedacht Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV H OF COMP.	CPUE 1	CPUE 2
1978	0	0.0	0	0	0	0.0	0	0.0	1	0.8	1	0.8	22	1	4.6	1	-	-	0.8
1979	0	0.0	0	0	0	0.0	0	0.0	2	6.7	2	6.7	17	2	11.8	1	-	-	3.4
1989	0	0.0	0	0	0	0.0	167	221.9	8	57.2	175	279.1	314	82	25.1	12	-	-	0.3
1990	2	0.9	0	0	0	0.0	185	148.9	5	43.3	192	193.1	199	106	53.3	9	-	-	0.2
1991	0	0.0	0	0	1	0.6	31	32.6	10	89.3	42	122.5	109	25	23.9	4	-	-	1.2
1992	7	3.1	0	0	2	1.9	45	23.7	5	26.5	59	55.2	69	33	47.8	2	-	-	0.8
TOTAL	**9**	**4.0**	**0**	**0**	**3**	**2.5**	**428**	**427.0**	**31**	**223.9**	**471**	**657.3**	**730**	**249**	**34.1**	**29**			

Appendix 32: Vaal Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	N CI	W CI	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1974	0	0.0	0	0.0	0	0.0	8	7.9	33	22.4	0	0.0	41	30.3	25	16	64.0	1	-	-	1.9
1975	0	0.0	0	0.0	19	7.2	5	3.4	11	16.7	0	0.0	35	27.4	56	20	35.7	2	-	-	0.7
1976	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
1977	1	1.1	0	0.0	13	9.2	3	6.7	11	14.4	0	0.0	28	31.4	34	13	38.2	4	-	-	0.6
1978	14	8.1	0	0.0	303	161.1	76	48.6	117	129.0	0	0.0	510	346.7	177	114	64.4	9	-	-	0.3
1979	3	1.7	0	0.0	30	20.0	2	1.0	287	185.5	0	0.0	322	208.1	167	98	58.7	6	-	-	0.4
1980	7	4.2	0	0.0	6	3.6	19	18.5	421	235.9	0	0.0	453	262.2	283	127	44.9	9	-	-	0.2
1981	6	4.3	0	0.0	47	25.0	44	48.5	1236	698.1	0	0.0	1333	775.9	520	346	66.5	18	-	-	0.1
1982	13	11.9	0	0.0	243	124.7	128	202.8	1996	1653.9	0	0.0	2380	1993.2	1087	662	60.9	39	-	-	0.1
1983	7	4.5	1	0.9	27	14.9	48	31.0	282	226.1	0	0.0	365	277.4	156	90	57.7	12	-	-	0.3
1984	47	34.9	1	0.5	127	114.3	79	72.7	1768	1540.6	0	0.0	2022	1763.0	878	521	59.3	36	-	-	0.1
1985	22	19.3	0	0.0	28	17.0	26	54.3	164	189.4	0	0.0	240	280.0	212	116	54.7	13	-	-	0.2
1986	50	44.4	1	1.7	211	116.4	101	140.6	306	465.9	0	0.0	669	768.9	434	215	49.5	19	-	-	0.2
1987	2	1.2	0	0.0	89	48.3	4	14.1	20	33.0	0	0.0	115	96.6	192	73	38.0	12	-	-	0.1
1988	1	0.8	0	0.0	208	132.9	80	43.4	235	282.4	0	0.0	524	459.4	144	118	81.9	13	-	-	0.3
1989	39	50.6	0	0.0	132	83.6	441	162.6	648	459.6	0	0.0	1260	756.5	614	400	65.2	33	-	-	0.1
1990	135	98.5	0	0.0	369	249.7	517	284.3	4260	2712.0	0	0.0	5281	3344.5	1305	906	69.4	50	-	-	0.1
1991	78	33.7	0	0.0	379	200.5	229	299.0	2543	2271.3	0	0.0	3229	2804.4	1283	703	54.8	36	-	-	0.1
1992	99	65.6	0	0.0	497	190.6	379	445.5	6189	4998.3	0	0.0	7164	5699.9	1503	1137	75.7	79	-	-	0.1
1993	41	24.0	1	0.6	200	109.9	189	224.0	3205	3203.2	0	0.0	3636	3561.6	969	669	69.0	34	-	-	0.2
1994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	-	-	-
1995	1	2.4	0	0.0	162	49.9	49	73.4	259	360.5	0	0.0	471	486.2	268	168	62.7	9	10	0.3	0.3
1996	13	17.9	0	0.0	621	278.4	415	266.7	902	1516.4	0	0.0	1951	2079.4	1597	797	49.9	65	12	0.2	0.0
1997	11	18.6	0	0.0	893	373.8	754	245.4	1934	1006.7	0	0.0	3592	1644.5	1084	704	64.9	45	11	0.2	0.1

Appendix 32 (cont.): Vaal Dam angling tournament data.

YEAR	N LAK	W LAK	N LU	W LU	N LC	W LC	N CG	W CG	N CC	W CC	N CI	W CI	TOTAL FISH	TOTAL W	TOTAL N ANGLERS	N ANGLERS SUCCESS-FUL	% SUCCESS	N COMP.	AV. H OF COMP.	CPUE 1	CPUE 2
1998	2	5.4	0	0.0	730	462.2	822	274.8	5609	3878.5	0	0.0	7163	4620.9	1666	1252	75.2	70	11	0.3	0.1
1999	17	13.2	0	0.0	719	286.9	228	89.5	2686	1869.3	19	12.4	3669	2271.4	1309	891	68.1	56	9	0.3	0.0
2000	0	0.0	0	0.0	3	1.2	3	1.4	18	16.7	0	0.0	24	19.2	10	9	90.0	1	8	0.3	2.1
2001	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2002	25	13.9	0	0.0	351	132.1	62	35.2	672	564.4	1	1.0	1111	746.6	433	338	78.1	14	8	0.3	0.2
2003	98	63.5	9	3.9	1178	521.7	554	321.5	2998	2489.0	0	0.0	4837	3399.5	1291	995	77.1	46	8	0.4	0.1
2004	11	5.0	1	0.6	140	63.5	78	38.9	505	806.7	0	0.0	735	914.7	224	183	81.7	6	8	0.6	0.8
2005	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2006	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2007	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2008	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0	-	-
2009	0	0.0	0	0.0	770	371.0	10	9.5	268	153.0	0	0.0	1048	533.5	71	70	98.6	3	8	1.0	2.5
2010	0	0.0	0	0.0	420	182.0	33	24.7	2168	1604.7	367	232.6	2988	2043.9	366	338	92.3	18	8	0.8	0.3
2011	13	5.9	0	0.0	276	119.9	74	34.5	784	651.2	239	174.9	1386	986.4	325	235	72.3	17	10	0.4	0.2
2012	21	9.6	0	0.0	971	342.3	93	37.2	1101	831.0	214	217.5	2400	1437.6	314	286	91.1	16	8	0.6	0.3
2013	0	0.0	0	0.0	339	167.1	81	92.6	1313	1634.0	282	335.9	2015	2229.6	510	384	76.2	28	8	0.7	0.2
2014	5	1.8	7	5.6	830	484.5	64	118.5	1890	2160.4	329	346.6	3125	3117.3	846	656	77.5	42	8	0.6	0.1
TOTAL	**782**	**565.6**	**21**	**13.7**	**11331**	**5465.2**	**5698**	**3772.5**	**46839**	**38880.1**	**1451**	**1320.9**	**66122**	**50018.1**	**20353**	**13650**	**67.1**	**861**			

Appendix 33: Mean CPUE (kg fish/angler/day) and environmental and morphometric variables of impoundments.

	Mean CPUE (kg fish /angler/day)	Av. Depth at FSL (m)	Mean annual air temp. (°C)	EC (µS/m)	Secchi depth (cm)	TDS (mg/l)	MEI TDS (kg/ha/year)	Altitude (m)	Latitude	Surface area (ha)	Catchment area (km²)
Impoundment											
Allemanskraal	2.8	6.7	18.3	238.3	16.3	154.0	8.4	1 361	28	2 667	3 628
Bloemhoek	0.9	7.1	17.2	333.3	31.1	213.3	12.4	1 366	27	370	66
Bloemhof	7.2	5.5	17.8	589.9	28.7	458.3	25.8	1 222	27	23 067	108 125
Erfenis	3.7	6.5	18.3	266.3	15.6	170.4	9.3	1 326	28	3 291	4 724
Gariep	3.7	15.2	17.2	119.4	27.2	76.2	4.4	1 255	30	35 216	70 665
Jimmie Roos	3.5	3.1	15.8	421.9	21.1	270.1	17.1	1 506	29	115	*Data unknown*
Kalkfontein	3.0	6.9	16.3	591.0	33.1	377.5	23.2	1 221	29	3 769	10 264
Knellpoort	5.9	14	15.8	165.2	30.4	105.7	6.7	1 442	29	977	766
Koppies	2.1	2.8	15.4	481.3	20.4	308.0	20.0	1 396	27	1 439	2 142
Krugersdrift	4.1	3.6	16.6	597.9	33.2	383.7	23.1	1 241	28	1 853	6 331
Moutloatsi Setlogelo	5.1	5.6	15.9	279.4	19.6	179.2	11.3	1 484	29	250	116
Rustfontein	2.9	6.2	15.9	265.1	29.1	169.7	10.7	1 361	29	1 159	937
Sol Plaatje	1.5	4.4	14.3	91.4	44.6	58.5	4.1	1 673	28	356	*Data unknown*
Sterkfontein	2.0	37.7	15.1	58.6	200	37.5	2.5	1 705	28	6 937	195
Tierpoort	5.1	3.7	16.7	418.3	24.5	267.8	16.0	1 376	29	911	922
Vaal	2.4	7.9	15.4	204.0	27	139.6	9.1	1 532	26	32 275	38 638
Welbedacht	0.7	1	15.8	297.5	10	190.4	12.1	1 402	29	1 018	15 270

Appendix 34: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Allemanskraal Dam and the Sand River based on historic and most recent catch data.

References	Marshall, 1972	Janse van Vuren, 1976[1]	Janse van Vuren, 1976[1] (Sand River System)	Barkhuizen, 1993a[2] (dam @ 38%)	Barkhuizen, 1995[3] (dam @ 21%)	Barkhuizen, 1996[4] (dam @ 15%)	Barkhuizen, 2013 (dam @ 39%)	Barkhuizen, 2013 (dam @ 17%)
Total fish caught				**600**	**89**	**68**	**799**	**273**
Fish species		(%)	(%)	(%)	(%)	(%)	(%)	(%)
Labeobarbus aeneus	X	8.6	12.5	11.2	56.2	27.9	1.9	4.8
Labeobarbus kimberleyensis	0	0	0	0	3.4	5.9	0.1	3.7
Barbus paludinosus	0	0	0	75.3	0	0	0.1	2.9
Barbus pallidus	0	0	*	0	0	0	0	0
Labeo capensis	X	24.7	13.3	6.5	6.7	20.6	6.8	23.8
Labeo umbratus	X	44.3	62.7	4.8	25.8	13.2	32.4	49.1
L. umbratus X L. capensis	0	0	0	0	0	0	0	1.1
Cyprinus carpio	0	12.4	6.1	0.3	1.1	4.4	57	11
Clarias gariepinus	X	10.2	5.3	1.8	6.7	27.9	0	1.8
Gambusia affinis	0	0	0	0	0	0	1.8	1.8
Total species	**4**	**5**	**6**	**6**	**6**	**6**	**7**	**8**

X: Indicates that species was recorded

*: *B. pallidus* not included in determination of percentage of total catch.

[1]: Depending on the sampling site, a 100 m x 3 m seine net with 30 mm stretched mesh size, a 50 m x 3 m seine net with a stretched mesh size of 10 mm, and one gill net of 41 m x 2.3 m with a stretched mesh size of 100 mm were used

[2]: Two sets of gill nets with mesh sizes 140, 110, 100, 90, 70, 65, 60 and 55mm; two cast nets; two seine nets: one of 50 m with stretched mesh size of 10 mm and one of 10 m with stretched mesh size of 5 mm; two baited fyke nets of 1 x 0.5 x 0.5 m; two long lines; one with 20 hooks and the other with 10 hooks.

[3]: Three sets of gill nets used as sampling gear: first set 110 m x 2.75 m with 10 m panels with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120, 140 mm, and one 20 m panel with 180 mm mesh size; second set 100 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 and 180 mm; the third set 90 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 mm. Nets in water for 24 h.

[4]: Two sets of gill nets used as sampling gear. First set 190 m x 2m with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120 and 140 mm; second set 120 m x 2.5 m with stretched mesh size of 28, 44, 60, 75, 100 and 144 mm. Nets in water for 24 h.

Appendix 35: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Bloemhof Dam and the Vaal and Vet Rivers.

References	VRS Main stem (Mulder, 1971)[1]	Barkhuizen, 1994a[2] (dam @ 18%)	Barkhuizen, 1995[3] (Dam @ 8%)	Barkhuizen, 1996[4] (Dam @ 98%)	Barkhuizen, 2013 (Dam @ 48%)	Barkhuizen, 2014 (Dam @ 36%)
Total fish caught		**671**	**134**	**72**	**227**	**1 029**
Fish species	(%)	(%)	(%)	(%)	(%)	(%)
Labeobarbus aeneus	10.5	1.5	0.8	8.3	1.8	4.9
Labeobarbus kimberleyensis	3	0.5	0	0	0	0
Barbus paludinosus	0	0	0	0	0	0.1
Labeo capensis	61.5	33.3	14.9	37.5	9.3	2.5
Labeo umbratus	5.7	52.2	63.4	26.4	1.8	10.7
Cyprinus carpio	2.2	5.8	9.7	12.5%	40.1	67.1
Ctenopharyngodon idella	0	0	0	0	21.6	1
Clarias gariepinus	17.1	1.3	12.6	15.3	13.2	11.3
Tilapia sparrmanii	0	0	0	0	0	0.1
Pseudocrenilabrus philander	0	5.2	0	0	11.8	2.4
Gambusia affinis	0	0	0	0	0.4	0
Total species	**6**	**7**	**5**	**5**	**8**	**9**

[1]: Percentage of total catch based on gill net catches at various sites in main stem of VRS.

[2]: Two sets of gill nets with mesh sizes 140, 110, 100, 90, 70, 65, 60 and 55mm; two cast nets; two seine nets: one of 50 m with stretched mesh size of 10 mm and one of 10 m with stretched mesh size of 5 mm; three baited fyke nets of 1 x 0.5 x 0.5 m; two long lines with 20 hooks each. Gill and fyke nets and long lines set for 44 h.

[3]: Three sets of gill nets used as sampling gear: first set 110 m x 2.75 m with 10 m panels with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120, 140 mm, and one 20 m panel with 180 mm mesh size; second set 100 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 and 180 mm; the third set 90 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 mm. Nets in water for 24 h.

[4]: Two sets of gill nets used as sampling gear. First set 190 m x 2m with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120 and 140 mm; second set 120 m x 2.5 m with stretched mesh size of 28, 44, 60, 75, 100 and 144 mm. Nets in water for 24 h.

Appendix 36: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Erfenis Dam and the Vet River.

References	Janse van Vuren, 1978 (Vet River System)	Barkhuizen, 1993b[1] (Dam @ 38%)	Barkhuizen, 1995[2] (Dam @ 18%)	Barkhuizen, 1996[3] (Dam @ 19%)	Barkhuizen, 2013 (Dam @ 48%)	Barkhuizen, 2013 (Dam @ 23%)
Total fish caught		**334**	**79**	**55**	**1 626**	**1 904**
Fish species	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Labeobarbus aeneus	9.9	12.6	44.3	41.8	15.2	13.7
Labeobarbus kimberleyensis	0	3.3	18.9	12.7	3.6	2
Barbus paludinosus	0	6.9	0	0	0.3	68
Labeo capensis	17.4	59.6	7.6	5.5	3.3	10.9
Labeo umbratus	50.3	3.6	17.7	7.3	20	3
Cyprinus carpio	16.1	9.6	7.6	3.6	56	2
Clarias gariepinus	6.2	4.2	3.8	29.1	1.5	0.2
Tilapia sparrmanii	<1	0	0	0	0	0
Micropterus salmoides	0	0.5	0	0	0.1	0.1
Total species	**6**	**8**	**6**	**6**	**8**	**8**

[1]: Fish survey done November 1993 with dam level at 38%. Two sets of gill nets with mesh sizes 140, 110, 100, 90, 70, 65, 60 and 55mm; two cast nets; two seine nets: one of 50 m with stretched mesh size of 10 mm and one of 10 m with stretched mesh size of 5 mm; three baited fyke nets of 1 x 0.5 x 0.5 m; three long lines, two with 20 hooks and one with 15 hooks. Gill and fyke nets and long lines set for 44 h.

[2]: Three sets of gill nets used as sampling gear: first set 110 m x 2.75 m with 10 m panels with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120, 140 mm, and one 20 m panel with 180 mm mesh size; second set 100 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 and 180 mm; the third set 90 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 mm. Nets in water for 24 h.

[3]: Two sets of gill nets used as sampling gear. First set 190 m x 2m with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120 and 140 mm; second set 120 m x 2.5 m with stretched mesh size of 28, 44, 60, 75, 100 and 144 mm. Nets in water for 24 h.

Appendix 37: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Gariep Dam and the Orange River.

References	Van Schoor, 1972[1] (Upper Orange River)	Hamman, 1974[2]	Hamman, 1981	Barkhuizen, 1995[3] (Dam @ 50%)	Barkhuizen, 1996[4] (Dam @ 58%)	Ellender, 2008[5]	Barkhuizen, 2013 (Dam @ 97%)	Barkhuizen, 2014 (Dam @ 78%)
Total fish caught				**14**	**152**		**1 417**	**880**
Fish species	(%)	(%)		(%)	(%)	(%)	(%)	(%)
Labeobarbus aeneus	59.2	X (22.8)	X	50	75	38	25.5	23.2
Labeobarbus kimberleyensis	2.3	X (2)	X	0	4.6	8	1.3	0.5
Barbus anoplus	0	0	X	0	0	X	0	0
Labeo capensis	33.5	X (18.6)	X	35.7	9.2	41	57	7.8
Labeo umbratus	1.3	X (18.3)	X	0	0.7	1	0.1	8.4
Cyprinus carpio	0.4	X (29.3)	X	0	5.3	5	14	58
Austroglanis sclateri	0.9	X	X	0	0	X	0	0
Clarias gariepinus	2.3	X (9.1)	X	14.3	5.3	7	2.1	2.2
Oncorhynchus mykiss	0.2	X	X	0	0	X	0	0
Micropterus salmoides	0	0	0	0	0	X	0	0
Total species	**8**	**8**	**9**	**3**	**6**	**10**	**6**	**6**

X: Indicates that species was recorded

[1]: Based on fish surveys from 1969 till 1972 using gill nets in Upper OSRS at three sampling points in OSR above wall of Gariep Dam

[2]: Percentages indicate contribution to total catch using gill nets with mesh sizes 44, 63, 76, 89, 102, 114 and 146 mm.

[3]: Three sets of gill nets used as sampling gear: first set 110 m x 2.75 m with 10 m panels with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120, 140 mm, and one 20 m panel with 180 mm mesh size; second set 100 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 and 180 mm; the third set 90 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 mm. Nets in water for 24 h.

[4]: Two sets of gill nets used as sampling gear. First set 190 m x 2m with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120 and 140 mm; second set 120 m x 2.5 m with stretched mesh size of 28, 44, 60, 75, 100 and 144 mm. Nets in water for 24 h.

[5]: Percentage of total catch based on gill net catches.

[6]: Fish species recorded by Ellender (2008) in Gariep Dam.

Appendix 38: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Kalkfontein Dam and the Riet River.

References	Janse van Vuren, 1978 (Riet River System)	Barkhuizen, 1994b[1] (Dam @ 31%)	Barkhuizen, 1995[2] (Dam @ 68%)	Barkhuizen, 1996[3] (Dam @ 36%)	Barkhuizen, 2012 (Dam @ 66%)	Barkhuizen, 2013 (Dam @ 38%)
Total fish		**509**	**127**	**167**	**2 624**	**768**
Fish species	(%)	(%)	(%)	(%)	(%)	(%)
Labeobarbus aeneus	7.7	19.5	22.8	40.1	6.1	2.2
Labeobarbus kimberleyensis	1.1	5.3	9.5	1.2	1	0.7
Labeo capensis	20.3	21.2	43.3	28.1	3.7	24.5
Labeo umbratus	69	32.6	8.7	25.8	1.9	32
Cyprinus carpio	1.1	20.2	12.6	4.2	86.7	36.6
Clarias gariepinus	0.9	1.2	3.2	0.6	0.6	4
Total species	**6**	**6**	**6**	**6**	**6**	**6**

[1]: Fish survey done January 1994 with dam level at 31%. Two sets of gill nets with mesh sizes 140, 110, 100, 90, 70, 65, 60 and 55mm; two cast nets; two seine nets: one of 50 m with stretched mesh size of 10 mm and one of 10 m with stretched mesh size of 5 mm; three baited fyke nets of 1 x 0.5 x 0.5 m; two long lines with 20 hooks each. Gill and fyke nets and long lines set for 48 h.

[2]: Three sets of gill nets used as sampling gear: first set 110 m x 2.75 m with 10 m panels with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120, 140 mm, and one 20 m panel with 180 mm mesh size; second set 100 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 and 180 mm; the third set 90 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 mm. Nets in water for 24 h.

[3]: Two sets of gill nets used as sampling gear. First set 190 m x 2m with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120 and 140 mm; second set 120 m x 2.5 m with stretched mesh size of 28, 44, 60, 75, 100 and 144 mm. Nets in water for 24 h.

Appendix 39: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Knellpoort Dam and the Riet Spruit.

References	Barkhuizen, 1993c[1]	Barkhuizen, 1996[2] (Dam @ 34%)	Barkhuizen, 2013 (Dam @ 40%)	Barkhuizen 2013 (Dam @ 43%)
Total fish caught		**21**	**181**	**488**
Species	(%)	(%)	(%)	(%)
Labeobarbus aeneus	18.2	52.4	1.7	16
Barbus anoplus	39.4	0	47	0
Labeo capensis	27.3	23.8	2.2	50.4
Labeo umbratus	9.1	19.1	1.7	22.1
Cyprinus carpio	0	0	43.6	8
Clarias gariepinus	6.1	4.8	3.9	0.8
Micropterus salmoides	0	0	0	2.7
Total species	**5**	**4**	**6**	**6**

[1]: Four gill nets with stretched mesh size of 110, 70, 60 and 55 mm and two seine nets: one of 50 m with stretched mesh size of 10 mm and one of 10 m with stretched mesh size of 5 mm.

[2]: Two sets of gill nets used as sampling gear. First set 190 m x 2m with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120 and 140 mm; second set 120 m x 2.5 m with stretched mesh size of 28, 44, 60, 75, 100 and 144 mm. Nets in water for 24 h.

Appendix 40: Presence and abundance of freshwater fish in Koppies Dam and the Renoster River.

References	Barkhuizen, 1993d[1] (Dam @ 36%)	Barkhuizen, 1995[2] (Dam @ 55%)	Barkhuizen, 1996[3] (Dam @ 68%)	Barkhuizen, 2012[3] (Dam @ 70%)	Barkhuizen, 2013[3] (Dam 58 %)
Total fish caught	**495**	**101**	**76**	**1 498**	**1 136**
Species	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Labeobarbus aeneus	17.9	16.8	35.5	24.3	20.2
Labeobarbus kimberleyensis	1.0	5.9	3.9	4	4.4
Barbus paludinosus	2.4	0	0	3.4	23.2
Labeo capensis	24.4	41.6	10.5	4.1	3.8
Labeo umbratus	47.7	29.7	40.8	19.4	23.9
Cyprinus carpio	4.5	1.9	5.3	40.1	6.4
Clarias gariepinus	2.0	3.9	3.9	2.7	18
Pseudocrenilabrus philander	0	0	0	1.8	0.3
Gambusia affinis	0	0	0	0.1	0
Total species	**7**	**6**	**6**	**9**	**8**

[1]: Two sets of gill nets with mesh sizes 140, 110, 100, 90, 70, 65, 60 and 55mm; one cast nets; two seine nets: one of 50 m with stretched mesh size of 10 mm and one of 10 m with stretched mesh size of 5 mm; three baited fyke nets of 1 x 0.5 x 0.5 m; two long lines with 20 hooks each. Gill and fyke nets and long lines set for 48 h.

[2]: Three sets of gill nets used as sampling gear: first set 110 m x 2.75 m with 10 m panels with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120, 140 mm, and one 20 m panel with 180 mm mesh size; second set 100 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 and 180 mm; the third set 90 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 mm. Nets in water for 24 h.

[3]: Two sets of gill nets used as sampling gear. First set 190 m x 2m with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120 and 140 mm; second set 120 m x 2.5 m with stretched mesh size of 28, 44, 60, 75, 100 and 144 mm. Nets in water for 24 h.

Appendix 41: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Krugersdrift Dam and the Modder River.

References	Rossouw, 1974[1]	Rossouw, 1974 (Modder River)	Barkhuizen, 1994c[2] (Dam @ 95%)	Barkhuizen, 1995[3] (Dam @ 49%)	Barkhuizen, 1996[4] (Dam @ 8%)	Barkhuizen, 2012 (Dam @ 39%)	Barkhuizen, 2013 (Dam @ 30%)
Total fish caught			**1 157**	**98**	**163**	**984**	**705**
Species	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Labeobarbus aeneus	12.9	17.9	0.3	6.1	43.6	3.8	3.1
Labeobarbus kimberleyensis	0.6	0.5	0.3	4.1	9.2	0.2	0
Barbus paludinosus	0	*	0.3	0	0	11.1	0
Barbus anoplus	*	*	0	0	0	0	0
Labeo capensis	10.7	17.7	13.4	4.1	4.3	5.3	12.1
Labeo umbratus	71.5	59.6	52.2	48.9	34.9	7.7	47.9
Cyprinus carpio	1.8	2.6	1.6	14.3	2.5	54.7	21.3
Carassius auratus	0	0	0	0	0	1	0.1
Austroglanis sclateri	0	0.1	0	0	0	0	0
Clarias gariepinus	2.3	1.6	1.9	22.5	5.5	6.1	6
Pseudocrenilabrus philander	0	0	30.1	0	0	10.2	9.5
Total species	**7**	**9**	**8**	**6**	**6**	**9**	**7**

*: Present but not used in determining % of total catch

[1]: Sampling done with: gill net, 41.6 m x 2.3 m with 100 mm stretched mesh size; seine net 61 m x 6 m with stretched mesh size of 10 mm.

[2]: Two sets of gill nets with mesh sizes 140, 110, 100, 90, 70, 65, 60 and 55mm; two cast nets; two seine nets: one of 50 m with stretched mesh size of 10 mm and one of 10 m with stretched mesh size of 5 mm; three baited fyke nets of 1 x 0.5 x 0.5 m; three long lines with 20 hooks each. Gear set for 44 h.

[3]: Three sets of gill nets used as sampling gear: first set 110 m x 2.75 m with 10 m panels with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120, 140 mm, and one 20 m panel with 180 mm mesh size; second set 100 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 and 180 mm; the third set 90 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 mm. Nets in water for 24 h.

[4]: Two sets of gill nets used as sampling gear. First set 190 m x 2m with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120 and 140 mm; second set 120 m x 2.5 m with stretched mesh size of 28, 44, 60, 75, 100 and 144 mm. Nets in water for 24 h.

Appendix 42: Presence and relative abundance of freshwater fish in Metsi Matso Dam.

Reference	Barkhuizen, 1995[1]	Barkhuizen, 2014 (Dam @ 100%)
Species	**Number**	**Number**
Oncorhynchus mykiss	17	8

[1]: Two sets of gill nets used as sampling gear, each 120 m x 2.75 m with 20 m panels with stretched mesh size of 55, 63, 73, 85, 98 and 110 mm. Gill nets in water for only 3 h.

Appendix 43: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Mockes Dam.

Reference	Rossouw, 1974[1]	Barkhuizen, 2014 (Dam @ 100%)
Total fish caught		**779**
Species	(%)	(%)
Labeobarbus aeneus	37.2	1.2
Labeobarbus kimberleyensis	0.7	0.4
Barbus anoplus	*	0.1
Labeo capensis	14.8	1.5
Labeo umbratus	45.5	4.2
Cyprinus carpio	1.4	80.4
Clarias gariepinus	0.4	11.8
Pseudocrenilabrus philander	0	0.4
Total species	**7**	**8**

*: Present but not used in determining % of total catch

[1]: Sampling done with: gill net, 41.6 m x 2.3 m with 100 mm stretched mesh size; seine net 61 m x 6 m with stretched mesh size of 10 mm.

Appendix 44: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Moutloatsi Setlogelo Dam.

Reference	Barkhuizen, 2012 (Dam @ 40%)	Barkhuizen, 2013 (Dam @ 10%)
Total fish	**388**	**346**
Species	(%)	(%)
Barbus anoplus	0	0.6
Labeo capensis	63.4	32.4
Labeo umbratus	3.1	54.3
L. umbratus x *L. capensis*	0	0.9
Cyprinus carpio	16.8	6.6
Clarias gariepinus	16	5.2
Micropterus salmoides	0.8	0
Total species	**5**	**5**

Appendix 45: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Rustfontein Dam.

Reference	Rossouw, 1974[1]	Rossouw, 1974[2]	Barkhuizen, 1994d[3] (Dam @ 100%)	Barkhuizen, 1995[4] (Dam @ 80%)	Barkhuizen, 1996[5] (Dam @ 55%)	Barkhuizen, 2012 (Dam @ 51%)	Barkhuizen, 2013 (Dam @ 27%)
Total fish caught			**548**	**86**	**147**	**642**	**242**
Species	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Labeobarbus aeneus	2.6	5.6	40.9	54.7	84.4	12.8	28.5
Labeobarbus kimberleyensis	0.9	0.1	3.5	12.8	2.7	0.8	1.2
Barbus paludinosus	0	0	0	0	0	0.2	0
Barbus anoplus	*	*	0	0	0	0	0
Labeo capensis	5.7	24.1	2.9	9.3	3.4	36.8	18.6
Labeo umbratus	89.4	68.7	27.2	17.4	4.8	21.7	13.6
Cyprinus carpio	0.9	0.7	23.4	4.7	1.4	20.6	10.7
Clarias gariepinus	0.4	0.4	2.2	1.2	3.4	4	8.3
Pseudocrenilabrus philander	0	0	0	0	0	3.3	19
Total species	**7**	**7**	**6**	**6**	**6**	**8**	**7**

***:** Was caught but excluded in percentage determination.

[1]: Sampling done with: gill net, 41.6 m x 2.3 m with 100 mm stretched mesh size; seine net 61 m x 6 m with stretched mesh Size of 10 mm.

[2]: Sampling done with seine net 61 m x 6 m with stretched mesh size of 10 mm.

[3]: Two sets of gill nets with mesh sizes 140, 110, 100, 90, 70, 65, 60 and 55mm; two cast nets; two seine nets: one of 50 m with stretched mesh size of 10 mm and one of 10 m with stretched mesh size of 5 mm; three baited fyke nets of 1 x 0.5 x 0.5 m; two long lines with 20 hooks each. Gill and fyke nets and long lines set for 48 h.

[4]: Three sets of gill nets used as sampling gear: first set 110 m x 2.75 m with 10 m panels with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120, 140 mm, and one 20 m panel with 180 mm mesh size; second set 100 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 and 180 mm; the third set 90 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 mm. Nets in water for 24 h.

[5]: Two sets of gill nets used as sampling gear. First set 190 m x 2m with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120 and 140 mm; second set 120 m x 2.5 m with stretched mesh size of 28, 44, 60, 75, 100 and 144 mm. Nets in water for 24 h.

Appendix 46: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Sol Plaatje Dam.

References	Le Roux, 1975 (Wilger River System)	Le Roux, 1975[1]	Barkhuizen, 2014 (Dam @ 100%)
Total fish caught			**116**
Species	(%)	(%)	(%)
Labeobarbus aeneus	7.8	9.6	30.2
Labeobarbus kimberleyensis	0.6	0.7	0
Barbus paludinosus	*	*	0.9
Barbus pallidus	*	0	0
Barbus anoplus	*	0	0
Labeo capensis	13.4	1.5	31
Labeo umbratus	60.4	72.6	12.9
Cyprinus carpio	15.7	15.6	22.4
Clarias gariepinus	4.8	0	1.7
Micropterus salmoides	0	0	0.9
Total species	**9**	**6**	**7**

[1]: Sampling was done near dam wall, main lake area and where Ash River enters dam with a seine net.

*: Was collected but not used in determining % of total catch.

Appendix 47: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Sterkfontein Dam.

References	Le Roux, 1975	Dörgeloh, 1986	Barkhuizen, 1994e[1] (Dam @ 70%)	Barkhuizen, 1995[2] (Dam @ 76%)	Barkhuizen, 1996[3] (Dam @ 44%)	Barkhuizen, 2012 (Dam @ 100%)	Barkhuizen, 2013 (Dam @ 100%)
Total fish caught			**174**	**71**	**94**	**267**	**261**
Species	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Labeobarbus aeneus	X (5.5)	X	35.8	11.3	22.3	58.8	9.2
Labeobarbus kimberleyensis	0	0	0.6	0	0	1.1	0
Barbus pallidus	0	X	0	0	0	0	0
Barbus anoplus	*	X	4.1	0	0	0	75.5
Labeo capensis	0	X	28.9	47.9	55.3	31.5	5.4
Labeo umbratus	X (77)	X	13.3	15.5	19.2	4.5	6.5
Cyprinus carpio	0	0	1.2	1.4	1.1	0.4	0
Austroglanis sclateri	0	X	0	0	0	1.1	0
Clarias gariepinus	0	X	15.6	23.9	2.1	1.9	1.9
Oncorhynchus mykiss	X (16.7)	X	0.6	0	0	0	0
Micropterus salmoides	0	0	0	0	0	0.7	1.5
Lepomis machrochirus	0	X	0	0	0	0	0
Total species	**4**	**9**	**8**	**5**	**5**	**8**	**6**

X: Indicates that species was recorded

*: Mention is made of large numbers of minnows that were caught, but no species name provided. It is assumed to be *B. anoplus.*

[1]: Two sets of gill nets with mesh sizes 180, 140, 110, 100, 90, 70, 65, 60 and 55 mm; two cast nets; seine net of 10 m with stretched mesh size of 5 mm; three baited fyke nets of 1 x 0.5 x 0.5 m; two long lines with 20 hooks each. Gill and fyke nets and long lines set for 48 h.

[2]: Three sets of gill nets used as sampling gear: first set 110 m x 2.75 m with 10 m panels with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120, 140 mm, and one 20 m panel with 180 mm mesh size; second set 100 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 and 180 mm; the third set 90 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 mm. Nets in water for 24 h.

[3]: Two sets of gill nets used as sampling gear. First set 190 m x 2m with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120 and 140 mm; second set 120 m x 2.5 m with stretched mesh size of 28, 44, 60, 75, 100 and 144 mm. Nets in water for 24 h.

Appendix 48: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Tierpoort Dam.

Reference	Marshall, 1972 (Tierpoort Dam and River)	Barkhuizen, 2013 (Dam @ 12%)
Total fish caught		**505**
Fish species		**(%)**
Labeobarbus aeneus	X	16.4
Labeobarbus kimberleyensis	X	1.6
Barbus paludinosus		0
Barbus pallidus	X	0
Barbus anoplus	X	0
Labeo capensis	X	2.4
Labeo umbratus	X	18.8
Cyprinus carpio		48.7
Carassius auratus	X	0
Austroglanis sclateri	X	0
Clarias gariepinus	X	12.2
Anguilla. mossambica	X	
Total species	**10**	**6**

X: Indicates that species was recorded

Appendix 49: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Welbedacht Dam and Caledon River.

References	Marshall, 1970[1] (Caledon River System)	Baird, 1971 (Caledon River)	Barkhuizen, 1993c[2] (Dam @ 100%)	Barkhuizen, 1995[3] (Dam at 3%)	Barkhuizen, 1996[4] (Dam at 98%)	Barkhuizen, 2013 (Dam at 100%)
Total fish caught			**182**	**119**	**17**	**181**
Species	(%)	(%)	(%)	(%)	(%)	(%)
Labeobarbus aeneus	30.3	42.5	4.9	30.3	0	1.7
Labeobarbus kimberleyensis	0.1	0	0.5	5	0	0
Barbus anoplus	0	0	1.6	0	0	47
Labeo capensis	32.8	40.5	32.9	5	58.8	2.2
Labeo umbratus	21.9	5	48.1	47.1	23.5	1.7
Cyprinus carpio	8.5	1	0.5	7.6	11.8	43.6
Austroglanis sclateri	0.5	1.5	0	0	0	0
Clarias gariepinus	6.1	8.3	11.4	5	5.9	3.9
Total species	**7**	**6**	**7**	**6**	**4**	**6**

[1]: Sampling done at 13 sites in Caledon River with 79 x 6 m seine net with mesh size 28 mm; 61 x 6 m seine net with mesh size 10 mm; 15.25 m x 0.91 m seine net with mesh size 2.5 mm.

[2]: Two sets of gill nets with mesh sizes 140, 110, 90, 65, 60 and 55 mm; two cast nets; seine net of 10 m with stretched mesh size of 5 mm; three baited fyke nets of 1 x 0.5 x 0.5 m; three long lines with 20 hooks each. Gill and fyke nets and long lines set for 36 h.

[3]: Three sets of gill nets used as sampling gear: first set 110 m x 2.75 m with 10 m panels with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120, 140 mm, and one 20 m panel with 180 mm mesh size; second set 100 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 and 180 mm; the third set 90 m x 2.75 m with stretched mesh size 35, 50, 63, 73, 85, 98, 110, 120, 140 mm. Nets in water for 24 h.

[4]: Two sets of gill nets used as sampling gear. First set 190 m x 2m with stretched mesh size of 35, 50, 63, 73, 85, 98, 110, 120 and 140 mm; second set 120 m x 2.5 m with stretched mesh size of 28, 44, 60, 75, 100 and 144 mm. Nets in water for 24 h.

Appendix 50: Presence and relative abundance (expressed as % of the total catch) of freshwater fish in Armenia, Bloemhoek, Egmont, Jimmie Roos and Serfontein Dams.

Impoundment	Total fish caught	B.an. (%)	C.ga. (%)	C.ca. (%)	L.ca. (%)	L.um. (%)	L.um. x L.ca. (%)	L.ae. (%)	L.ki. (%)	M.sa. (%)	Total species
Armenia	655	4.4	1.8	19.8	12.8	12.7	0	45.8	2.6	0	**7**
Bloemhoek	627	0	3	51.7	30.0	12.3	1.4	0.2	0.5	0.6	**7**
Egmont	1 797	0.6	0.7	56.1	3.1	34.9	0	4.6	0	0	**6**
Jimmie Roos	562	2.5	2.5	36.3	0	58.7	0	0	0	0	**4**
Serfontein	54	0	42.6	31.5	14.8	9.3	0	1.9	0	0	**5**

Key: B.an. – *Barbus anoplus*; C.ga. – *Clarias gariepinus*; C.ca. – *Cyprinus carpio*; L.ca. – *Labeo capensis*; L.um. – *Labeo umbratus*; L.um. x L.ca. – possible hybrids of L. *capensis* and *L. umbratus*; L.ae. – *Labeobarbus aeneus*; L.ki. – *Labeobarbus kimberleyensis*; M.sa. – *Micropterus salmoides*.

Appendix 51: CPUE per gill net set based on the total number (N) and total weight (W in kg) of fish caught per gill net set per night for *Labeobarbus aeneus* (L.ae.), *Labeo capensis* (L.ca.) and *Labeo umbratus* (L.um.).

Name of impoundment	GILL NET NUMBER	CPUE N L.ae.	CPUE W L.ae.	CPUE N L.ca.	CPUE W L.ca.	CPUE N L.um.	CPUE W L.um.
Allemanskraal	G1	4	1.39	2	0.12	2	0.95
Allemanskraal	G2	9	2.52	1	0.19	2	1.59
Allemanskraal	G3	1	0.34	0	0.00	0	0.00
Allemanskraal	G4	0	0.00	2	0.72	2	1.13
Allemanskraal	G5	0	0.00	0	0.00	0	0.00
Allemanskraal	G6	0	0.00	2	1.33	9	5.08
Allemanskraal	G7	0	0.00	2	1.49	1	0.82
Allemanskraal	G8	0	0.00	8	1.64	1	1.10
Allemanskraal	G9	1	0.45	4	2.71	3	3.24
Allemanskraal	G10	0	0.00	0	0.00	6	2.73
Allemanskraal	G11	0	0.00	1	0.39	6	4.33
Allemanskraal	G12	1	0.27	1	0.07	4	1.10
Allemanskraal	G13	3	1.26	6	0.78	2	1.24
Allemanskraal	G14	1	0.66	0	0.00	0	0.00
Allemanskraal	G15	4	2.42	1	0.08	3	2.21
Armenia	G1	15	4.70	4	0.39	8	5.23
Armenia	G2	19	6.68	12	2.10	8	3.37
Armenia	G3	75	44.00	5	4.61	3	3.18
Armenia	G4	57	39.25	3	0.37	0	0.00
Armenia	G5	74	20.25	12	1.35	5	2.83
Armenia	G6	52	17.72	8	0.93	3	2.56
Bloemhoek	G1	1	1.02	4	1.15	12	11.32
Bloemhoek	G2	0	0.00	3	1.67	7	6.45
Bloemhoek	G3	0	0.00	20	4.14	13	11.64
Bloemhoek	G4	0	0.00	16	3.19	22	16.82
Bloemhoek	G5	0	0.00	19	8.66	6	5.47
Bloemhoek	G6	0	0.00	29	11.68	14	11.54
Bloemhof	G1	1	0.46	0	0.00	1	0.58
Bloemhof	G2	0	0.00	0	0.00	2	1.02
Bloemhof	G3	2	1.08	1	0.16	1	0.45
Bloemhof	G4	1	0.45	3	0.40	0	0.00
Bloemhof	G5	1	0.47	0	0.00	0	0.00
Bloemhof	G6	0	0.00	0	0.00	0	0.00
Bloemhof	G7	0	0.00	0	0.00	0	0.00
Bloemhof	G8	0	0.00	0	0.00	0	0.00
Bloemhof	G9	0	0.00	0	0.00	0	0.00
Bloemhof	G10	2	0.40	2	0.54	1	1.36
Bloemhof	G11	3	0.60	1	0.07	1	0.97
Bloemhof	G12	14	2.74	4	0.79	0	0.00

Appendix 51 (cont.): Main fishery species.							
Bloemhof	G13	4	0.82	7	1.27	0	0.00
Bloemhof	G14	19	4.44	3	0.79	1	0.52
Bloemhof	G15	8	1.76	8	2.71	1	1.18
Egmont	G1	4	1.91	2	0.82	0	0.00
Egmont	G2	3	1.63	1	0.60	0	0.00
Egmont	G3	4	1.38	1	0.33	0	0.00
Egmont	G4	2	1.28	0	0.00	4	3.68
Egmont	G5	8	2.91	0	0.00	1	0.98
Egmont	G6	16	6.86	2	0.76	3	1.64
Erfenis	G1	4	1.70	12	3.07	4	1.17
Erfenis	G2	12	3.72	4	0.78	2	0.57
Erfenis	G3	8	1.88	5	1.67	8	6.13
Erfenis	G4	11	5.39	3	0.66	0	0.00
Erfenis	G5	92	20.50	10	2.07	2	1.73
Erfenis	G6	67	29.86	3	0.81	0	0.00
Erfenis	G7	11	4.15	1	0.38	7	3.75
Erfenis	G8	15	4.94	2	0.47	1	0.60
Erfenis	G9	13	3.81	2	0.58	3	1.45
Erfenis	G10	28	13.67	2	0.98	9	6.87
Erfenis	G11	8	1.80	5	0.89	0	0.00
Erfenis	G12	89	33.78	0	0.00	5	2.18
Erfenis	G13	2	0.02	3	0.23	1	0.13
Erfenis	G14	77	21.16	8	1.73	4	2.74
Erfenis	G15	5	1.08	6	0.53	2	1.29
Gariep	G1	8	6.22	3	1.60	0	0.00
Gariep	G2	32	10.06	14	5.60	0	0.00
Gariep	G3	31	13.38	23	3.95	0	0.00
Gariep	G4	47	59.39	0	0.00	0	0.00
Gariep	G5	91	79.71	10	2.97	0	0.00
Gariep	G6	30	31.38	1	0.59	0	0.00
Gariep	G7	3	3.53	1	0.15	0	0.00
Gariep	G8	3	2.86	1	0.51	1	0.47
Gariep	G9	2	1.46	0	0.00	0	0.00
Gariep	G10	24	18.89	0	0.00	0	0.00
Gariep	G11	15	12.12	0	0.00	0	0.00
Gariep	G12	35	23.96	1	0.20	0	0.00
Gariep	G13	34	26.73	5	1.00	0	0.00
Gariep	G14	47	39.31	0	0.00	0	0.00
Gariep	G15	21	17.89	0	0.00	0	0.00
Jimmie Roos	G1	0	0.00	0	0.00	30	36.98
Jimmie Roos	G2	0	0.00	0	0.00	37	50.94
Jimmie Roos	G3	0	0.00	0	0.00	4	4.61
Jimmie Roos	G4	0	0.00	0	0.00	29	36.17

Appendix 51 (cont.): main fishery species.							
Jimmie Roos	G5	0	0.00	0	0.00	8	3.83
Jimmie Roos	G6	0	0.00	0	0.00	28	21.18
Kalkfontein	G1	20	11.48	4	1.43	0	0.00
Kalkfontein	G2	1	0.12	0	0.00	5	6.46
Kalkfontein	G3	9	1.53	19	8.48	11	13.60
Kalkfontein	G4	91	52.54	6	1.92	1	0.93
Kalkfontein	G5	4	0.84	5	0.31	4	4.72
Kalkfontein	G6	2	0.21	12	4.21	9	14.01
Kalkfontein	G7	16	5.41	9	3.95	2	2.87
Kalkfontein	G8	11	7.05	2	0.63	4	2.95
Kalkfontein	G9	0	0.00	1	0.43	11	14.46
Kalkfontein	G10	0	0.00	8	3.53	64	70.39
Kalkfontein	G11	3	0.89	9	3.55	13	15.35
Kalkfontein	G12	0	0.00	0	0.00	23	31.52
Kalkfontein	G13	0	0.00	6	2.14	18	22.39
Kalkfontein	G14	5	1.55	49	5.28	32	32.22
Kalkfontein	G15	5	2.63	33	6.14	7	8.51
Knellpoort	G1	1	0.80	6	3.58	5	4.26
Knellpoort	G2	4	2.82	1	0.26	0	0.00
Knellpoort	G3	1	0.95	0	0.00	0	0.00
Knellpoort	G4	7	1.84	5	1.21	0	0.00
Knellpoort	G5	12	13.25	1	0.43	0	0.00
Knellpoort	G6	5	2.75	5	2.32	12	9.87
Knellpoort	G7	5	4.46	3	0.45	2	1.30
Knellpoort	G8	4	4.23	2	0.27	1	0.87
Knellpoort	G9	0	0.00	0	0.00	0	0.00
Knellpoort	G10	4	3.76	4	2.58	2	1.95
Knellpoort	G11	20	17.61	8	3.39	7	6.32
Knellpoort	G12	12	7.71	11	5.91	1	0.74
Knellpoort	G13	13	11.62	8	3.00	3	2.44
Knellpoort	G14	7	6.48	7	2.91	2	1.72
Knellpoort	G15	21	18.56	5	1.19	0	0.00
Koppies	G1	36	10.71	6	1.00	34	8.24
Koppies	G2	59	12.72	11	2.12	10	3.58
Koppies	G3	55	15.14	9	1.96	10	1.66
Koppies	G4	100	29.07	5	1.42	14	1.67
Koppies	G5	53	12.70	9	1.38	24	10.50
Koppies	G6	11	3.03	0	0.00	17	17.52
Koppies	G7	3	1.67	5	2.15	21	9.11
Koppies	G8	4	0.32	4	1.83	33	23.28
Koppies	G9	16	1.99	6	1.73	59	20.48
Koppies	G10	9	1.95	1	0.15	48	33.69
Koppies	G11	46	13.33	10	2.72	13	4.15
Koppies	G12	36	13.11	10	5.30	23	20.43

Appendix 51 (cont.): CPUE main fishery species.							
Koppies	G13	15	8.64	10	2.32	34	18.70
Koppies	G14	72	15.72	0	0.00	55	44.77
Koppies	G15	43	13.30	7	1.43	20	13.12
Krugersdrift	G1	6	1.99	3	1.22	9	3.90
Krugersdrift	G2	12	4.65	6	2.68	4	2.84
Krugersdrift	G3	8	4.18	5	1.84	1	0.09
Krugersdrift	G4	2	0.48	4	1.79	2	1.19
Krugersdrift	G5	1	0.16	6	2.79	15	10.04
Krugersdrift	G6	5	1.57	15	9.74	15	14.47
Krugersdrift	G7	1	0.13	4	0.63	1	0.08
Krugersdrift	G8	0	0.00	7	1.41	16	11.47
Krugersdrift	G9	1	0.94	1	2.00	9	9.32
Krugersdrift	G10	9	3.68	1	0.15	31	42.48
Krugersdrift	G11	4	1.25	7	1.48	21	24.05
Krugersdrift	G12	0	0.00	2	1.44	18	27.12
Krugersdrift	G13	4	1.25	3	1.44	26	29.70
Krugersdrift	G14	1	0.22	0	0.00	47	41.90
Krugersdrift	G15	3	2.14	1	0.39	52	45.50
Mockes	G1	0	0.00	3	2.72	2	1.74
Mockes	G2	0	0.00	0	0.00	1	1.08
Mockes	G3	0	0.00	0	0.00	3	3.17
Mockes	G4	0	0.00	0	0.00	0	0.00
Mockes	G5	0	0.00	0	0.00	1	1.04
Mockes	G6	0	0.00	0	0.00	0	0.00
Moutloatsi Setlogelo	G1	0	0.00	0	0.00	2	1.87
Moutloatsi Setlogelo	G2	0	0.00	1	0.02	1	0.88
Moutloatsi Setlogelo	G3	0	0.00	1	0.02	1	0.88
Moutloatsi Setlogelo	G4	0	0.00	0	0.00	0	0.00
Moutloatsi Setlogelo	G5	0	0.00	3	0.83	0	0.00
Moutloatsi Setlogelo	G6	0	0.00	6	1.95	0	0.00
Moutloatsi Setlogelo	G7	0	0.00	38	16.35	0	0.00
Moutloatsi Setlogelo	G8	0	0.00	22	8.63	0	0.00
Moutloatsi Setlogelo	G9	0	0.00	7	3.93	0	0.00
Moutloatsi Setlogelo	G10	0	0.00	1	0.76	2	1.97
Moutloatsi Setlogelo	G11	0	0.00	3	0.67	4	3.52

Appendix 51 (cont.): CPUE main fishery species.

Moutloatsi Setlogelo	G12	0	0.00	1	0.09	0	0.00
Moutloatsi Setlogelo	G13	0	0.00	0	0.00	2	1.02
Moutloatsi Setlogelo	G14	0	0.00	6	3.12	5	3.84
Moutloatsi Setlogelo	G15	0	0.00	5	1.73	8	7.44
Rustfontein	G1	3	1.86	3	1.76	18	16.34
Rustfontein	G2	9	4.58	2	0.44	30	25.27
Rustfontein	G3	12	6.27	5	1.32	9	7.65
Rustfontein	G4	14	7.01	6	1.24	16	12.88
Rustfontein	G5	3	1.89	3	0.57	11	9.35
Rustfontein	G6	5	2.68	11	2.31	2	1.86
Rustfontein	G7	9	4.57	9	2.02	8	7.20
Rustfontein	G8	9	5.93	5	1.54	12	10.64
Rustfontein	G9	4	1.00	10	2.65	16	13.04
Rustfontein	G10	0	0.00	1	0.77	3	2.64
Rustfontein	G11	8	3.35	2	0.44	2	1.39
Rustfontein	G12	0	0.00	1	0.63	1	0.75
Rustfontein	G13	6	3.09	2	0.73	5	2.74
Rustfontein	G14	2	0.29	1	0.41	0	0.00
Rustfontein	G15	6	2.85	2	0.22	1	0.36
Serfontein	G1	0	0.00	0	0.00	0	0.00
Serfontein	G2	0	0.00	0	0.00	0	0.00
Serfontein	G3	0	0.00	0	0.00	0	0.00
Sol Plaatje	G1	12	4.91	2	0.54	0	0.00
Sol Plaatje	G2	1	0.10	0	0.00	0	0.00
Sol Plaatje	G3	4	1.40	3	1.67	0	0.00
Sol Plaatje	G4	3	0.42	0	0.00	2	0.27
Sol Plaatje	G5	7	4.79	20	18.09	5	2.17
Sol Plaatje	G6	7	5.61	10	8.91	5	2.32
Sterkfontein	G1	2	2.85	7	1.50	0	0.00
Sterkfontein	G2	6	7.73	2	0.92	0	0.00
Sterkfontein	G3	2	2.17	1	0.59	0	0.00
Sterkfontein	G4	36	32.10	9	6.97	1	0.65
Sterkfontein	G5	7	8.43	30	10.53	0	0.00
Sterkfontein	G6	8	7.07	2	1.55	0	0.00
Sterkfontein	G7	12	6.82	5	2.88	0	0.00
Sterkfontein	G8	27	24.10	2	1.25	0	0.00
Sterkfontein	G9	55	35.83	25	12.55	11	10.63
Sterkfontein	G10	2	2.65	3	2.50	1	1.07
Sterkfontein	G11	6	3.64	1	0.15	2	2.04
Sterkfontein	G12	2	1.04	2	1.06	5	6.01

Appendix 51 (cont.): CPUE main fishery species.							
Sterkfontein	G13	2	2.28	6	4.47	8	7.68
Sterkfontein	G14	5	6.01	1	0.18	0	0.00
Sterkfontein	G15	6	4.36	1	0.27	0	0.00
Tierpoort	G1	55	10.09	5	0.81	41	18.53
Tierpoort	G2	14	2.44	1	0.15	4	0.84
Tierpoort	G3	9	2.16	2	0.83	27	11.99
Welbedacht	G1	0	0.00	3	1.57	0	0.00
Welbedacht	G2	2	0.50	0	0.00	0	0.00
Welbedacht	G3	0	0.00	0	0.00	3	2.86

Appendix 52: Summary of the general information and water parameters, and total number of fish and total weight of the total catch of the three fyke nets over a two night netting period, as well as the monetary value of the total catch.

Impoundment	Surface area (ha)	Av. Depth (m)	Catchment area (km²)	Latitude	Water level (%)	Altitude (m)	Mean air temp. (°C)	Mean water temp. (°C)	Mean pH	Mean EC (µs/cm)	Mean TDS (mg/l)	Mean turbidity (NTU)	Mean Secchi depth (cm)	Total number fish	Total weight fish (kg)	Monetary value (ZAR)
Allemanskraal	2667	6.7	3628	28	17.3	1 359	20±0	20.7±0.1	8.4±0.02	277.3±1.2	178.1±0.1	183.7±46.2	20±0	131	26.98	472.17
Armenia	393	3.4	861	29	15.9	1 512	26.0±0	23.8±0.5	8.3±0.04	374.0±1.7	239.3±1.2	293.7±9.2	9.0±0	136	20.29	355.11
Bloemhoek	370	7.1	66	27	20	1 365	29.0±0	26.2±0.8	8.4±0.02	334.0±1.7	213.3±1.2	47.4±7.7	31.0±3.5	130	52.55	919.63
Bloemhof	23 067	5.5	108 125	27	36	1 221	29.0±0	27.8±0.2	9.08±0.1	748.0±1.7	478.3±1.5	84.4±5.6	34.2±0.6	154	377.14	6599.92
Egmont	244	4	310	30	54.5	1 472	29.0±0	26.9±0.9	8.6±0.1	237.3±2.3	152.3±1.2	366.7±19.6	7.3±0.6	527	94.72	1657.60
Erfenis	3 291	6.5	4 724	28	23.1	1 324	21.0±0	20.7±0.3	8.3±0.02	299.7±1.5	191.6±1.1	113.3±12.7	14.0±1.7	1257	42.07	736.23
Gariep	35 216	15.2	70 665	30	78	1 252	24.0±0.9	27.0±0.6	8.5±0.02	174.4±0.6	111.6±0.4	43.9±1.9	29.7±1.2	84	106.15	1857.56
Jimmie Roos	115	3.1	*No data*	29	50	1 507	24.0±0	24.1±0.2	8.7±0.1	426.3±3.8	272.7±2.3	72.9±26.9	21.7±1.5	98	143.59	2512.83
Kalkfontein	3 769	6.9	10 264	29	37.9	1 218	29.0±0	25.7±0.8	8.6±0.01	648.7±2.3	415.0±1.7	46.1±8.5	30.0±0	112	39.26	687.10
Knellpoort	977	14	766	29	42.9	1 439	22.3±1.2	24.5±1.2	8.2±0.01	203.3±0.6	130.1±0.6	46.3±0.4	33.7±2.3	132	79.65	1393.88
Koppies	1 439	2.8	2 142	27	58.3	1 397	21.0±0	23.0±0.5	8.7±0.01	576.7±1.5	369.0±1	49.8±0.9	20.0±0	499	610.87	10690.23
Krugersdrift	1 853	3.6	6 331	28	29.7	1 238	25.0±0	21.9±0.3	8.5±0.01	562.0±1.7	360±1	33.7±4.9	40.0±0	249	126.12	2207.10
Metsi Matso	66	6.6	15	28	100	1 870	23.0±0	24.1±0.7	7.5±0.1	21.8±0.1	13.9±0.1	2.5±0.3	200±0	0	0.00	0.00
Mockes	147	2.8	2 968	29	100	1 305	29.0±0	26.6±1.0	8.0±0.2	233.3±3.1	149.3±1.9	179.3±16.8	10.0±0	38	46.38	811.69
Moutloatsi Setlogelo	250	5.6	116	29	10.2	1 485	27.0±0.0	20.8±0.8	8.2±0.1	289.0±3.6	185.7±1.2	119.4±32.4	19.3±1.2	67	59.82	1046.85
Rustfontein	1 159	6.2	937	29	27.3	1 362	30.0±0.0	19.0±0.2	8.1±0.03	260.3±0.6	166.6±0.2	53.2±3.8	25.0±0.0	43	5.43	95.08
Serfontein	142	2.9	3 420	27	100	1 349	31.0±0.0	29.63±1.4	7.5±0.1	122.1±1.1	78.1±0.6	173.7±4.5	10.0±0.0	47	115.38	2019.20
Sol Plaatje	356	4.4	*No data*	28	100	1 636	15.0±0.0	17.9±0.3	7.9±0.1	92.9±0.9	59.5±0.6	41.9±16.9	36.7±10.4	31	5.11	89.46
Sterkfontein	6 937	37.7	195	28	100	1 702	19.0±0.0	19.6±0.3	8.2±0.03	85.5±0.3	54.7±0.3	3.3±1.1	200.0±0	2	3.01	52.68
Tierpoort	911	3.7	922	29	12.4	1 376	26.0±0	24.5±0.7	9.1±0.1	421.0±4.0	269.3±2.5	100.1±25.3	28.0±5.2	108	72.22	1263.92