AN ASSESSMENT OF INLAND FISHERIES IN SOUTH AFRICA USING FISHERIES-DEPENDENT AND FISHERIES-INDEPENDENT DATA SOURCES

A thesis submitted in fulfilment of the requirements for the degree of

MASTER OF SCIENCE

of

RHODES UNIVERSITY

by

James Ross McCafferty

February 2012

Abstract

The role of inland fisheries as contributors to local and national economies in developing African countries is well documented. In South Africa, there is increasing interest in inland fisheries as vehicles for achieving national policy objectives including food security, livelihoods provision, poverty alleviation and economic development but there is surprisingly little literature on the history, current status, and potential of inland fishery resources. This lack of knowledge constrains the development of management strategies for ensuring the biological sustainability of these resources and the economic and social sustainability of the people that are dependent on them.

In order to contribute to the knowledge base of inland fisheries in South Africa this thesis: (1) presents an exhaustive review of the available literature on inland fisheries in South Africa; (2) describes the organisation of recreational anglers (the primary users of the resource); (3) compiles recreational angling catch records and scientific gill net survey data, and assesses the applicability of these data for providing estimates of fish abundance (catch-per-unit effort [*CPUE*]), and finally, (4) determines the potential for models of fish abundance using morphometric, edaphic, and climatic factors.

The literature review highlighted the data-poor nature of South African inland fisheries. In particular information on harvest rates was lacking. A lack of knowledge regarding different inland fishery sectors, governance systems, and potential user conflicts was also found. Recreational anglers were identified as the dominant user group and catch data from this sector were identified as potential sources of fish abundance and harvest information.

Formal freshwater recreational angling in South Africa is a highly organised, multi-faceted activity which is based primarily on angling for non-native species, particularly common carp *Cyprinus carpio* and largemouth bass *Micropterus salmoides*. Bank anglers constituted the largest number of formal participants (5 309 anglers affiliated to formal angling organisations) followed by bass anglers (1 184 anglers affiliated to formal angling organisations). The highly structured nature of organised recreational angling and dominant utilisation of inland fisheries resources by this sector illustrated not only the vested interest of anglers in the management and development of inland fisheries but also the role that anglers may play in future decision-making and monitoring through the dissemination of catch data from organised angling events.

Generalised linear models (GLMs) and generalised additive models (GAMs) were used to standardise *CPUE* estimates from bass- and bank angling catch records, which provided the most suitable data, and to determine environmental variables which most influenced capture probabilities and *CPUE*. Capture probabilities and *CPUE* for bass were influenced primarily by altitude and conductivity and multiple regression analysis revealed that predictive models incorporating altitude, conductivity, surface area and capacity explained significant ($p < 0.05$) amounts of variability in *CPUE* (53%), probability of capture (49%) and probability of limit bag (74%). Bank angling *CPUE* was influenced by conductivity, surface area and rainfall although an insignificant ($p > 0.05$) amount of variability (63%) was explained by a predictive model incorporating these variables as investigations were constrained by small sample sizes and aggregated catch information.

Scientific survey data provided multi-species information and highlighted the high proportion of non-native fish species in Eastern Cape impoundments. Gillnet catches were influenced primarily by species composition and were less subject to fluctuations induced by environmental factors. Overall standardised gillnet *CPUE* was influenced by surface area, conductivity and age of impoundment. Although the model fit was not significant at the $p<0.05$ level, 23% of the variability in the data was explained by a predictive model incorporating these variables. The presence of species which could be effectively targeted by gillnets was hypothesised to represent the most important factor influencing catch rates. Investigation of factors influencing *CPUE* in impoundments dominated by *Clarias gariepinus* and native cyprinids indicated that warmer, younger impoundments and smaller, colder impoundments produced higher catches of *C. gariepinus* and native cyprinids respectively. A predictive model for *C. gariepinus* abundance explained a significant amount of variability (77%) in *CPUE* although the small sample size of impoundments suggests that predictions from this model may not be robust. *CPUE* of native cyprinids was influenced primarily by the presence of *Labeo umbratus* and constrained by small sample size of impoundments and the model did not adequately explain the variability in the data ($r^2 = 0.31$, $p>0.05$).

These results indicate that angling catch- and scientific survey data can be useful in providing predictions of fish abundance that are biologically realistic. However, more data over a greater spatial scale would allow for more robust predictions of catch rates. This could be achieved through increased monitoring of existing resource users, the creation of a

centralised database for catch records from angling competitions, and increased scientific surveys of South African impoundments conducted by a dedicated governmental function.

Acknowledgements

Firstly, I would like to thank my supervisor, Dr Olaf Weyl, for providing me with immeasurable insight and advice throughout the course of this thesis. Your unerring dedication and drive, as well as your passion for freshwater fishes, have contributed in so many ways to the completion of this thesis (including pulling all-nighters to mark chapter drafts!). Your assistance with data collection, in providing me with contacts for angling representatives and colleagues all over South Africa, has proved invaluable to the outcomes of this study, and I thank you sincerely for your input.

To Dr Henning Winker, it is difficult to express my level of gratitude for the help that you so willingly gave me concerning the most complex and crucial aspects of this thesis. Your enthusiasm and approachable nature, coupled with immense know-how of a challenging (and daunting!) field, are in my experience unsurpassed and hugely appreciated. The knowledge that you imparted in only three short days has not only shaped a large part of this thesis, but has also sparked my interest in ecological modelling and statistics. Thank you.

To Dr Ernst Swartz, thank you for providing me with important information and insight into the NEM:BA process, as well as the maps from the survey process, and much needed company and advice on conference trips.

I would like to thank the following angling officials and representatives who contributed large amounts of their time and effort into providing contacts, data, and other information for the project: Mr John Pledger, Mr Fred Visagie, Mr Andre Nortje; Mr Trevor Spencer; Mrs Wendy Watson; Mr Bernard Venter; Mr Cyril Schwarz; Mr Louwtjie Louwens; Mr Eugene Kruger; Mr Jaco Janse van Rensburg; Mrs Sue Babich; Mr Barry Kurten; Mr Tim Mundy; Mr Knop van der Merwe; Mr Richard Prinsloo; Mr Albert Olivier; Mr Dawie Jacobs; Mr Louis Erasmus; Mr Hennie Zeelie; Mr Corrie Barnard; Ms Meisie Schneider; Mr Piet Rall.

Without your input this project would not have been possible and for this I sincerely thank you.

Thanks are also due to colleagues within the Department of Icthyology and Fisheries Science, in particular Dr, Warren Potts, Tim Richardson, Bruce Ellender, Geraldine Taylor, Qurban Rouhani, who provided me with their gillnet data and additional input on the project. I would also like to thank Taryn Murray, Matthew Parkinson, Richard Peel, and Reece Wartenberg for their continued friendship, support and advice throughout my time at DIFS and particularly during the completion of this thesis. I would also like to thank Jeremy Baxter foIt is much appreciated. Thanks are also due to Jeremy Baxter for his statistical insights and useful advice.

I would also like to acknowledge the Water Research Commission (WRC) for providing funding for this project, as well as the South Africa Netherlands Research Programme on Alternatives in Development (SANPAD) for funding gillnet surveys in the Eastern Cape used in this thesis.

Lastly to my family, Dad, Mom, and Richard. Mom and Dad, your unwavering support and belief in me throughout my life has been a source of constant inspiration .Rich, late night/early morning phone calls from the office always spurred me on and you have always been the first person I go to for guidance and encouragement. Thank you.

Table of Contents

List of figures

List of tables

List of acronyms

AIC	Akaike‟s Information Criterion
CIPS	Confédération Internationale de la Peche Sportive
CPUE	Catch per unit effort
DAFF	Department of Agriculture, Forestry and Fisheries
DEAET	Department of Economic Affairs, Environment and Tourism (Free State)
DIFS	Department of Ichthyology and Fisheries Science
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
ECA	Environmental Conservation Act
EPLTBAA	Eastern Province Light Tackle Boat Angling Association
FAO	Food and Agriculture Organization
MEI	Morpho-edaphic index
FIPS-ed	International Freshwater Sport Fishing Federation
FIPS-Mouche	International Fly Sport Fishing Federation
GAM	Generalised additive model
GLM	Generalised linear model
NEM:BA	National Environmental Management: Biodiversity Act
NEMA	National Environmental Management Act
NEPAD	New Partnership for Africa's Development
NWA	National Water Act
PC	Probability of capture
PCA	Principal Component Analysis
PLIM	Probability of limit
RFP	Rural Fisheries Programme
SAALAA	South Africa Deep Sea Angling Association
SABAA	South African Bass Angling Association
SAFALFA	The South African Federation of Artificial Lure and Fly Angling
SAFBAF	South African Freshwater Bank Angling Federation
SAFFA	South African Fly Fishing Association
SAIAB	South African Institute for Aquatic Biodiversity
SASACC	South African Sport Anglers and Casting Confederation
TAG	Trout Action Group
VCFP	Venterstad Community Fisheries Project
WRC	Water Research Commission
WTA	Wild Trout Association

CHAPTER 1:

General introduction and thesis outline

The importance of inland fisheries in African countries is well documented, both for their contribution to national economies and in the provision of food security (Kapetsky and Petr, 1984; Marshall and Maes, 1994; Van der Knaap, 1994; Weyl et al., 2007). In contrast, South Africa has poorly developed inland fisheries despite significant water resources including over 4 000 storage dams (Weyl et al., 2007; DWAF (Department of Water Affairs and Forestry), 2009). A number of reasons have been postulated for the lack of development in South African inland fisheries. Amongst these are a lack of historic involvement in fishing activities, cultural beliefs, and limited knowledge regarding the potential of the fisheries resource (Andrew, 2001; Weyl et al., 2007). Furthermore, South Africa has no form of policy or governance measures legislating inland fisheries, and there is no formal monitoring of inland fishing activities in the country. As a result decisions regarding the future development and management of these resources are difficult (Weyl et al., 2007).

The recent transferral of the South African fisheries function to the Department of Agriculture, Forestry and Fisheries (DAFF), has resulted in renewed interest in the development of inland fisheries for the purposes of achieving national policy objectives including poverty alleviation, the provision of food security, job creation and tourism development. This renewed interest has given rise to projects such as the Water Research Commission (WRC) project entitled: “Baseline and scoping study on the development and sustainable use of storage dams for inland fisheries and their contribution to rural livelihoods” which funds the research outlined in this thesis. Comprehensive information regarding the current status of South African inland fisheries is lacking. What is known, is that fisheries are dominated by recreational angling, and some ad hoc monitoring data are available, i.e., while inland fisheries are data-poor, they are not data-less. Recreational angling data have been used for assessment of inland fisheries in many other developed countries (Sigler and Sigler, 1990). The existence of a large recreational angling sector in South Africa suggests that angler catches from competition events may provide the best source of information in a largely data-poor environment. A comprehensive description of the recreational angling sector, in terms of spatial and temporal patterns and participation, is also required in order to contextualise the extent of resource utilisation. Furthermore, data compiled through scientific surveys of South African impoundments may also represent an important source of fisheries-independent information. In recognition of the concerns and gaps in information, the purpose of this thesis is therefore to contribute to the state of knowledge on South Africa"s inland fisheries.

Thesis outline

The aims of this thesis are to derive standardised estimates of abundance for impoundments using freshwater recreational angling catch data and scientific survey data; to identify key predictors in catch rates of popular recreational angling target species in impoundments; and to incorporate predictors in an empirical model to assess the potential for a predictive model of abundance.

The thesis is divided into six chapters. Chapter 2 is an introductory chapter in the form of a comprehensive literature review which compiles all the historical information regarding inland fisheries in South Africa, summarises their present status, and identifies knowledge gaps and areas of concern for future development of this resource. Chapter 3 is a description of the organised freshwater recreational angling sector in South Africa, documenting the administrative structure, participation, target species and inland fisheries of high priority to recreational anglers. Chapter 4 represents the first attempt at compiling fisheries-dependent recreational angling catch data in South Africa, assessing its applicability for deriving abundance estimates using generalised linear and generalised additive models, and using predictors outlined in the modelling process to determine the potential for a predictive model of angling quality and abundance using recreational angling catch data. Fisheries-independent data from scientific surveys are compiled and analysed in Chapter 5, including an assessment of species composition in the Eastern Cape and North West provinces, followed by an assessment of the potential for a predictive model of abundance in the absence of species information. Chapter 6 is a synopsis of the main research findings, highlighting the main outcomes in the research, followed by management recommendations for inland fisheries in South Africa.

CHAPTER 2:

Literature review on the use of water resources for inland fisheries in South Africa[1]

2.1 INTRODUCTION

The latest comprehensive assessment of global inland fisheries in 2003 estimated the total harvest at 8.7 million tons, which accounted for 6% of global fish production (FAO 2003). While the inland fisheries contribution on a global scale is relatively small, Neiland et al. (2005) caution that simple comparisons of gross production can be misleading because inland fisheries in many developing countries and regions generate a wide variety of benefits for millions of people. Such benefits include food security, the provision of livelihoods, and contributions to wealth and well-being of communities engaged in a variety of fisheries linked activities that collectively contribute significantly to both rural and national economies (Kapetsky and Petr, 1984; Van der Knaap, 1994; Geheb and Binns, 1997; Sarch and Allison, 2000; Allison et al., 2002; Allison, 2005).

In Africa, the role of inland fisheries as vehicles for rural development, poverty reduction, food security, livelihoods provision and regional economic development are being increasingly recognised (Marshall and Maes, 1994; FAO, 2003), and fisheries have been identified as a priority investment area by the African Union (NEPAD (New Partnership for Africa's Development), 2005).

[1] MCCAFFERTY JR, ELLENDER BR, WEYL OLF, BRITZ PJ (2012) Literature review on the use of water resources for inland fisheries in South Africa. *WaterSA* **38**(2) 1-18.

In South Africa, there is also an increasing interest in developing the economic and social opportunities offered by inland capture fisheries. Such development will, however, need to take into consideration the dynamic nature of the current users of the fish resources, which are mainly subsistence and recreational anglers (Weyl et al., 2007; Ellender et al., 2009; 2010b). Commercial fisheries remain poorly developed despite several attempts to develop these fisheries dating back to the 1970s (Jackson, 1980; Koch and Schoonbee, 1980; Allanson and Jackson, 1983; Cochrane, 1987; Andrew, 2001). Possible reasons for the lack of inland fisheries development are cited as: a paucity of natural water bodies where a culture of fishing may have developed; a lack of access to fishing gear; market resistance to freshwater fish; availability of relatively cheap marine fish products; and a lack of knowledge of the potential of the resource (Andrew, 2001; Weyl et al., 2007). Significantly, South Africa has never had an inland fisheries policy, and the potential socio-economic value of fisheries has not been recognised in South Africa"s water resource management policies (Weyl et al., 2007). As a result, the responsibility for access to dams and their fishery resources is currently fragmented between government departments and is not directed by a coherent policy. This lack of a national policy was, and remains, a major bottleneck in the development of inland fisheries (Weyl et al., 2007).

Historically therefore, fishery management was mandated to the provincial nature conservation authorities, who managed the resource primarily for recreational purposes in terms of South Africa"s environmental legislation (Hey, 1977). As the conservation departments did not have a development mandate, there was not much capacity to support the development of livelihoods based on fisheries, although a number of projects were promoted in some provinces. This, coupled with a low direct value of freshwater fish (ZAR 6/kg, Ellender et al., 2010b), and in some cases with apartheid exclusion of people from accessing resources, has resulted in South African inland fisheries being utilised primarily by recreational anglers (Weyl et al., 2007). More recently, however, there is evidence of increasing utilisation of inland fisheries by subsistence anglers (van der Waal et al., 2000; Ellender et al., 2009). While subsistence anglers from local communities are generally regarded as having a legitimate claim to fish, in the absence of a supporting governance framework, their activities are in many cases illegal. This has led to conflicts between water users on a number of impoundments (Weyl et al., 2007; OLF Weyl et al., 2010).

South Africa"s national policy objectives in respect of natural resource use include: food security; economic empowerment; tourism development; optimal economic benefit from water;poverty eradication; sustainability; and conservation (ECA (Environmental Conservation Act), 1989; NEMA (National Environmental Management Act), 1998; NWA (National Water Act), 1998). Given these objectives, the formulation of an inland fishery policy needs to take into account the potential of the different fisheries sectors (recreational, subsistence and commercial), the long-term sustainable use of fish resources, and the promotion of the economic and social well being of the fishers (Charles, 2001). Consequently, the development of fisheries must be guided by policy, management protocols and institutional arrangements that ensure equitable resource access, biological sustainability and optimisation of economic benefits for both local communities and the national economy.

Policy and planning thus need to be well informed on the potential of the resource, the nature of existing fisheries, and the social, environmental and economic issues that shape resource use. Unfortunately, there is almost no information on current harvest rates or the value of various fisheries, and very little on indigenous knowledge and traditional governance arrangements with respect to fish. The data that are available are often either not collated, or, if collated, are in grey literature that is not easily accessible and, because inland fisheries has never been defined as an economic sector in policy, there are several constraints to the usefulness of much of the existing data. Firstly, inland fisheries research has never been well funded in South Africa, and most studies that were undertaken on the fisheries potential of impoundments date back to the 1980s, which marked the period just after some of the largest impoundments were constructed, stimulating a brief interest in developing inland fisheries (Cadieux, 1980a; Hamman, 1980; Cochrane, 1987; Jackson et al., 1983). In addition, the fresh water fish research focus has changed over the years from suitability assessments for stocking non-native fishes, through dam building and fisheries development, to a more recent era of biodiversity impact studies.

This literature review, undertaken as part of a larger Water Research Commission (WRC) solicited "baseline and scoping study on the development and sustainable use of storage dams for inland fisheries and their contribution to rural livelihoods" (WRC Project No. K5/1957//4, Water Research Commission, 2011), is the first comprehensive synthesis of existing peer-reviewed and grey literature on inland fisheries in South Africa and is an important step towards contextualising the resource as it: (1) summarises the state of knowledge on South African inland fisheries; (2) identifies potential data sources; (3) identifies important knowledge and (4) highlights knowledge gaps.

2.2 CATEGORISATION OF INLAND FISHERIES LITERATURE

In the planning process for South African impoundments, the recreational or commercial benefits from associated fisheries development were never considered. As a result, secondary uses of these impoundments for recreational and economic gain are incidental, primarily due to the lack of the incorporation of their potential social and economic importance in the planning process (Du Plessis and Le Roux, 1965). Nonetheless, in subsequent years, a number of studies have been undertaken on a variety of topics related to inland fisheries, including: fish biological production in different water bodies; rural fisheries development potential; recreational fisheries; traditional fisheries; and valuation studies. A comprehensive literature search from May to October of 2010 using the electronic databases *Fish and Fisheries Worldwide* and *EBSCOHost*, as well as grey data available from fisheries projects and reprints housed in the South African Institute for Aquatic Biodiversity (SAIAB), revealed 173 publications dealing directly with South African inland fisheries. The nature of these publications is summarised in Figures 2.1, 2.2 and 2.3, and in Table 2.1.

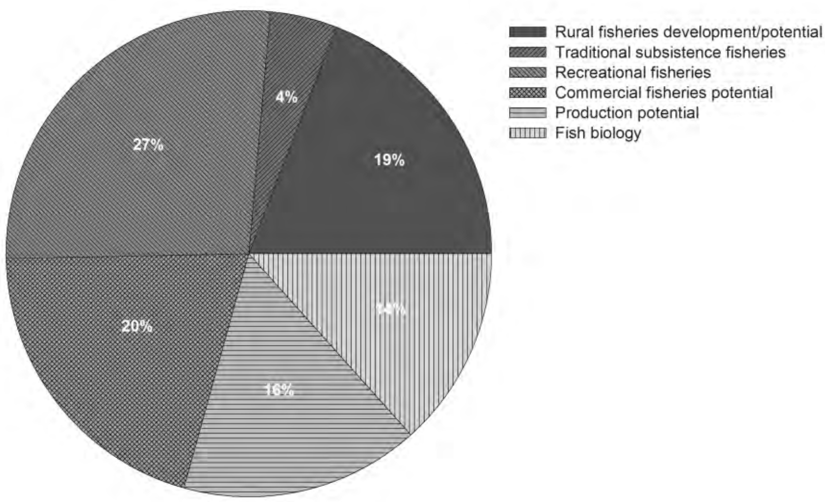


Figure 2.1 Proportion of published literature concerned with major research topics

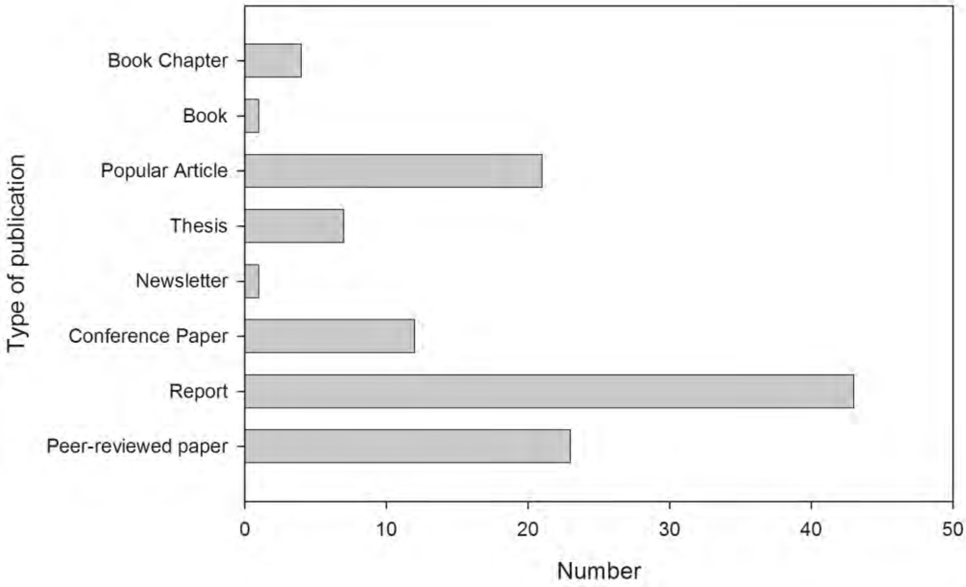


Figure 2.2 Number and type of publications relating to inland fisheries in South Africa.

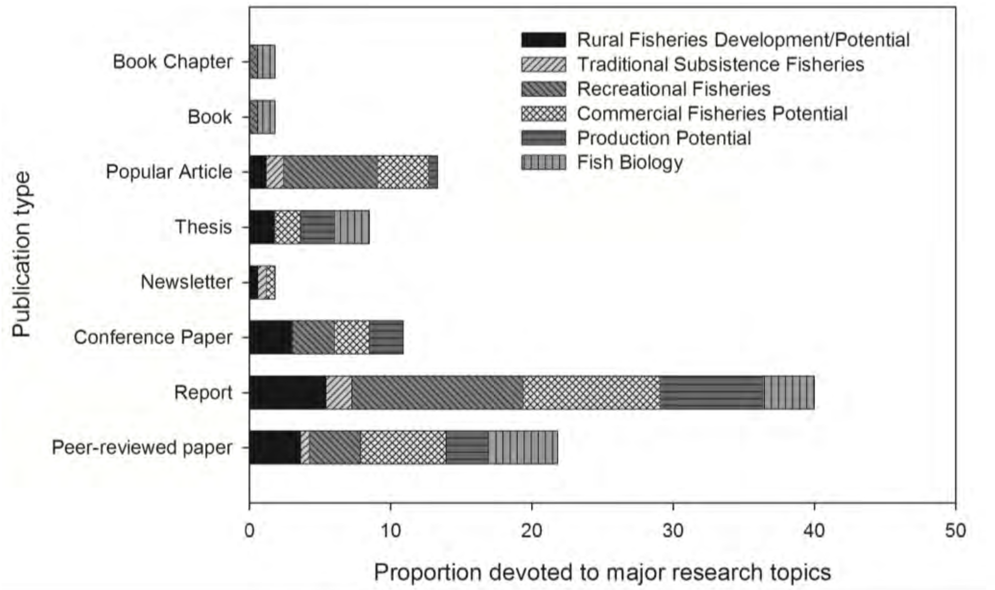


Figure 2.3 Proportion of different publication types devoted to major research topics in South African inland fisheries

Table 2.1 Summary of publications by topic with regards to inland fisheries

Rural fisheries development/potential
Andrew et al., 2000; Andrew, 2001; Burton et al., 2002; de Satge, 1978; Duncan–Brown, 1980; Roode, 1978; Rouhani and Andrew, 1998; Rouhani, 2001, 2003, 2004; Rouhani and Davies, 2003; Schramm, 1993; Seti, 2002; van den Berg et al., 1975; van der Waal, 1978a;b, 2000; Weyl et al., 2007.
Traditional subsistence fisheries
Coke and Pott, 1973; Heeg and Breen, 1982; Jubb, 1973; La Hausse de la Louvière, 1987; Merron et al., 1993; Merron and Weldrick, 1995; Tinley, 1964; van der Waal, 1978a;b.
Recreational fisheries
Alletson et al., 2004; Anon, 1970; Ashton et al., 1986; Bruwer, 1982; Cadieux, 1979, 1980a, 1980b; Clark, 2004; Cochrane, 1987; de Villiers, 1998; du Plessis and le Roux, 1965; Eccles et al., 1983; Ellender et al., 2009, 2010a, 2010b; Granek et al., 2008; Hey, 1926a, 1926b, 1941; Jackson 1976, 1989; le Roux, 1965; Leibold and van Zyl, 2008; McVeigh, 1978; Nel, 1988; Pott, 1973; Rouhani, 2003, 2004; Rouhani and Davies, 2003; Rouhani et al., 2010; Winker, 2007; Weyl et al., 2010.
Commercial fisheries potential
Allanson and Jackson, 1983; Anon, 1948; Eccles et al., 1983; Ellender et al., 2009, 2010a;b; Hamman, 1981; Jackson, 1973, 1974, 1976, 1981a, 1981b; Jubb, 1962; Koekemoer and Steyn, 2005; Nel, 1988; Richardson et al., 2009; Tómasson et al., 1983; Tómasson et al., 1985; van Senus et al., 1992; Weyl et al., 2007, 2010; Whitehead, 1978.
Production potential
Allanson and Jackson, 1983; Andrew et al., 2000; Andrew, 2001; Cochrane, 1987; Ellender et al., 2010a; Potts, 2003; Richardson et al., 2009; Rouhani, 2004; OLF Weyl et al., 2010.

2.3 CHRONOLOGICAL OVERVIEW OF INLAND FISHERIES LITERATURE

In this section we categorise the inland fishery literature themes chronologically and track the changing research interests which tend to mirror societal priorities of the time (Table 2.2).

Table 2.2 Research focus by period on inland fisheries related topics.

Period	Research Focus
<1940	Focus on inventory surveys of inland waters and the suitability for the introduction of edible and sport fish
1940-1960	The establishment and maintenance of freshwater fish
1961-1970	Sport fisheries and quantifying recreational angling. Developing eel fisheries
1971-1980	Prospects for inland fisheries exploitation and utilising inland waters for rural development in homeland areas
1981-1990	Continued emphasis on fisheries potential, although some focus is placed on population dynamics of the target species. Also increased research on management of inland water bodies. Quantifying angling also emerges
1991-2000	Fish population assessments and fisheries potential. Increased emphasis on the management on inland waters
2001-2010	Focus on fish as a vehicle for rural development and poverty alleviation. Valuation studies. Quantifying inland fisheries utilisation and in depth studies on fish population dynamics.

Colonial era fish introductions for recreational fisheries

Inland fisheries development began with the importation and spread of non-native fishes in South Africa during the 19th century colonial period. The details of the fish introductions are described in de Moor and Bruton (1988), and more recently discussed in van Rensburg et al. (2011). Early introductions of alien fishes primarily focused on providing opportunities for recreational angling.

The common carp, *Cyprinus carpio,* was the first of the popular non-native recreational angling species to be introduced into South Africa (de Moor and Bruton, 1988). It was initially introduced in the 1700s by British colonists for ornamental purposes, and for its believed potential to provide food from South Africa‟s apparently "barren" rivers (Anon, 1959; Bruton and Merron, 1985; Bruton and van As, 1986; de Moor and Bruton, 1988; Skelton, 2001; van Rensburg et al., 2011). Reports produced by the Inland Fisheries

Department, under the Cape Provincial Administration, document that the first official introduction took place in 1896 when *C. carpio* were imported from England to the Jonkershoek hatchery in the Cape and, in the same year, to the Pirie hatchery in King Williams Town from Scotland (Anon, 1944; Anon, 1950b). However, de Moor and Bruton (1988) noted that numerous other introductions of *C. carpio* probably occurred during the 19th century. An example of such is the"unofficial" introduction described in an article published in *The Cape Argus* in 1859, which documents the introduction of six *C. carpio* into the Botanical Gardens reservoir in Cape Town by Mr C A Fairbridge, a member of the Cape Legislative Assembly (Anon, 1959b). In addition, an article in *The South African Advertiser and Mail* refers to the introduction of three *C. carpio* from England by a Mr Ekstein into the pond on his estate (Harrison, 1966). Following their official introduction to the Cape, *C. carpio* were distributed to farm dams across South Africa in 1900 (Anon, 1944). After the realisation of their impacts on natural ecosystems, including the introduction of parasites as well as their ability to drastically alter habitats, stocking activities were ceased and legislation was created in the 1920s in order to halt the further spread of *C. carpio* (Harrison, 1959; de Moor and Bruton, 1988).

The successful introduction of non-native salmonids into South Africa occurred in the latter part of the 19th century. Brown trout, *Salmo trutta*, a European species, were imported to the Boschfontein Hatchery in Natal in 1890 (Pike, 1980a), and rainbow trout, *Oncorhynchus mykiss* native to the Pacific coast of North America, were introduced to the Jonkershoek Hatchery in the Cape in 1897 (Manning, 1908; Anon, 1944; Skelton, 2001). Their introduction was a consequence of British colonists" dissatisfaction with the lack of "suitable" indigenous angling fishes, and the realisation that many of the streams draining mountainous areas in the Cape and Natal would provide suitable trout habitat (Skelton, 2001).

Following several importations from European countries, the first hatcheries to successfully produce trout were established at Jonkershoek near Stellenbosch (Anon, 1944) and Pirie near King Williams Town in the Cape Province, in the late 1890s (Harrison, 1954b). Just over thirty years later, several other hatcheries had been installed in different parts of South Africa, including Tetworth and Lydenburg hatcheries in Natal and Transvaal, respectively (du Plessis, 1961; Pike, 1980a).

A large proportion of literature on trout fisheries from the colonial period is contained within the *Piscator*, the journal of the Cape Piscatorial Society (established in 1931), which was first published in 1947 (www.piscator.co.za). Articles within the journal, as well as other popular publications, include accounts of the first introductions of trout into the country as well as attempts to acclimate and introduce them into various parts of the country (Day, 1932; Harrison, 1940; 1948; 1951; 1953c; 1972/1973; 1975; Anon, 1950a; 1961/1962; Donnelly, 1965).

Four centrarchid species, fishes native to North America, were introduced into the country for angling purposes: the largemouth bass, *Micropterus salmoides*; the smallmouth bass, *Micropterus dolomieu*; the spotted bass, *Micropterus punctulatus* and the Florida bass, *Micropterus floridanus* (de Moor and Bruton, 1988; Skelton and Weyl, 2011). *Micropterus salmoides* was first introduced in 1928 at the Jonkershoek hatchery in the Cape (Anon, 1944), and was followed by *M. dolomieu* in 1937 (Anon, 1944; Harrison, 1953a; b; c). These two species were introduced into various localities in the province, and in 1952 they were stocked in the newly established Umgeni hatchery in Natal, which undertook responsibility for stocking in that province thereafter (Pike, 1980). *Micropterus punctulatus* was introduced in

1939 into various localities in Natal and the Cape Province (Harrison, 1965/1966), but failed to establish successfully, and its distribution is now limited to only a few localities (Crass, 1964; Smith, 1984; de Moor and Bruton, 1988; Skelton, 2001). In 1980, *M. floridanus* was introduced to the Umgeni hatchery in Natal for experimental purposes (de Moor and Bruton, 1988) and is now present throughout the province (Skelton, 2001). Both *M. salmoides* and *M. dolomieu* were introduced widely around the country through the efforts of both anglers and conservation authorities and, as with trout, a large amount of literature on these introductions is available in the *Piscator* journal, as well as in other popular publications (Harrison, 1936; 1948; 1951; Harrison, 1952a; 1952b; 1953a; 1953b; 1954a; 1962/1963; 1964/1965; 1965/1966; 1967/1968; Anon, 1952a; 1980; 1981;Coetzee, 1977; McVeigh, 1979; Joubert, 1984; de Moor and Bruton, 1988). Unlike trout fisheries in South Africa – especially those located on reservoirs – which generally require continual stocking as populations cannot reproduce due to adverse ecological conditions, bass fisheries have thrived as a result of these fishes having far wider ecological tolerance limits and the concomitant ability to reproduce in a variety of habitats (Skelton, 2001; Cooke and Philipp, 2009). These predatory fishes prompted many subsequent introductions of non-native fishes as fodder fish and for additional sport angling (de Moor and Bruton, 1988; Skelton, 2001; van Rensburg et al., 2011).

Early research (pre-1940) therefore concentrated on surveying South African impoundments in order to assess their suitability for stocking a variety of non-native fishes. The earliest reportage on such suitability is by Hey (1926a; b), while subsequent introductions of non-native fishes are comprehensively reviewed by de Moor and Bruton (1988). This focus on suitability of water for sport fishes, and the subsequent importation of a variety of fishes for recreational angling, dominated fisheries development and national stocking programmes until the mid-20th century (van Rensburg et al., 2011). As a result, inland fisheries were primarily developed for recreational angling (Hey, 1926a; b; McVeigh, 1978; Andrew et al., 2000; Weyl et al., 2007).

Interest in fish as food: 1960s onwards

An increasing realisation that fisheries could be utilised for commercial purposes, rural development and food security began in the 1960s, and this focus has continued to the present. Several studies investigated the fisheries potential of dams for the establishment of capture fisheries (Jackson, 1973; 1974; 1976; 1981a; b; Bruwer and Claasen, 1978; Whitehead, 1978; Koch and Schoonbee, 1980; Hamman, 1981; Bruwer, 1982; Eccles et al., 1983; Allanson and Jackson, 1983; Tómasson, 1983; Tómasson et al., 1983; 1985; Cochrane, 1987; van Senus, 1992; Schramm, 1993; Marshall and Maes, 1994; de Villiers, 1998; 2003; Rouhani and Andrew, 1998; Andrew, 2001; Rouhani, 2001; 2003; 2004; Burton et al., 2002; Potts, 2003; Rouhani and Davies, 2003; Potts et al., 2004; Ellender et al., 2009; 2010a; b; Richardson et al., 2009; OLF Weyl et al., 2010). Research was focused largely on estimating production potential and on the biology of potential fisheries species (de Villiers, 1998; 2003). The role of inland fisheries in potentially providing food received attention as part of South Africa‟s apartheid homeland development policies of the late 1970s and 1980s (van den Berg et al., 1975; Roode, 1978; van der Waal, 1978a; b; 2000; Mabitsela, 1981; Saayman et al., 1983; Schoonbee et al., 1995), as well as from development practitioners (de Satge, 1978; Duncan-Brown, 1980; Taylor and van Der Walt, 1985; Seti, 2002; Allison, 2005). In addition, wider human-ecosystem interaction and livelihood studies have highlighted the role of fisheries in traditional livelihoods. A number of authors have described the floodplain fisheries of the Tshonga people in Maputaland, and analysed the resource governance issues associated with the building of the Pongolapoort Dam, which disrupted the annual flood and associated fishing activities (Tinley, 1964; Coke and Pott, 1971; Jubb, 1973; Heeg and Breen, 1982; La Hausse de la Louvière, 1987; Merron et al., 1993; Merron and Weldrick, 1995; Jaganyi et al., 2008). Van der Waal (2000) and Dederen et al. (2001) undertook socio-biological studies of the aquatic resources and their utilisation in an underdeveloped rural region, the Mutshindudi River catchment in Limpopo Province.

From the late 1990s to the present, literature has increasingly focused on using inland fisheries as vehicles for food security and rural development (Andrew et al., 2000; van der Waal, 2000; Andrew, 2001), and is more recently moving towards assessing the need for policy (Weyl et al., 2007) and qualifying and quantifying resource use (van der Waal, 2000; Ellender et al., 2009; 2010a; b). It must however be noted that, apart from these very preliminary analyses and site specific descriptions on resource use, there is no recent literature available which contextualises inland fisheries with respect to rural development, livelihoods and policy development in South Africa.

Biodiversity concerns

Growing concerns about the impacts of non-native fish species on freshwater ecosystems began to surface in the 1960s and 1970s (Gabie, 1965; Gaigher, 1973; Hey, 1977), and in the 1980s the provincial nature conservation departments ceased breeding and stocking fish into impoundments and streams for recreational angling purposes (Skelton and Davies, 1986; Rouhani and Britz, 2004). A number of studies have documented the impacts of non-native fish introductions, which include predation on native biota, competition for food and space, hybridisation, and introduction of parasites and disease (Bruton and Merron, 1985; Bruton and van As, 1986; Ashton et al., 1986; de Moor and Bruton, 1988; Impson et al., 2007; Lowe et al., 2008; Swartz, 2009; PSR Weyl et al., 2010; Ellender et al., 2011; Olds et al., 2011; Stadtlander et al., 2011; van Rensburg et al., 2011; Wassermann et al., 2011). As a result of such impacts, removals of non-native fishes from some invaded areas have been planned in the Western Cape (Enviro-Fish Africa (Pty) Ltd., 2009). The National Environmental Management: Biodiversity Act (NEM:BA) of 2007 has provided a framework for managing the impacts and beneficial uses of non-native fish species. The primary management tool is the development of a zoning approach whereby permitted uses of non-native species are specified (Swartz, 2009). This legislation will also facilitate and legitimise the formal management of non-native fishes for fisheries.

Overall, there has been little research into inland fisheries related topics, and the research that is available is often outdated and no longer relevant. Of particular concern is the paucity of recent quantitative data on fisheries yields, participation and catch rates, as described in papers by van der Waal (2000) and Ellender et al. (2009; 2010a; b).

2.4 LITERATURE ON LEGISLATION GOVERNING INLAND WATER RESOURCES

As the research focus and published literature has shifted, from the introduction and propagation of non-native fishes, to fisheries development and, more recently, the impacts of non-native fishes in South Africa, so too has the legislation regarding the utilisation of inland waters and their resources. Hey (1977) described the history and evolution of nature conservation and associated legislation in South Africa noting that, after the promulgation of the Union of South Africa Act of 1909, which devolved responsibilities for the preservation of fish to the provinces, regulation of fishing activities was largely an administrative function enforced by the South African Police. In the case of the Cape Province, the importation of non-native species for the purposes of angling was encouraged and permitted in legislature in Act No. 10 of 1867 (Davies, 1986; Ness, 1991), and subsequently provincial governments largely provided financial support for the development and protection of non-native species fisheries (Anon, 1936; Day, 1936; Harrison, 1949; 1957). The formation of the Inland Fisheries Division (which was later expanded to become the Cape Nature Conservation Department) in the Cape Province in 1942 preceded the first piece of legislation, the Inland Fisheries Ordinance, No. 12 of 1947, which enacted measures pertaining specifically to the protection of aquatic fauna in inland waters, most notably from water pollution (Hey, 1977). As outlined in Harrison (1949), this protection was in the form of proclaimed areas for non-native trout, black bass, perch *Perca fluviatilis* Linnaeus 1758, and bluegill *Lepomis macrochirus* Rafinesque 1819, fishing for which required an inland fishing licence; no measures enforced the protection of carp, the sale and transportation of which was illegal. This ordinance expanded into the Nature Conservation Ordinance, No. 19 of 1974, which prohibited the transport of non-native fish species, while still allowing for the protection of species such as trout, through closed seasons, bag and size limits, and tackle restrictions (Hamman, 1986). The ordinance also allowed for the use of nets, subject to the possession of a licence issued by the Director of Nature and Environmental Conservation. In Natal, the establishment of the Freshwater Fish Protection Ordinance, No. 9 of 1955 and legislation thereof is discussed in Anon (1968) with specific reference made to proclaimed trout and non-trout areas, fishing seasons and licence requirements. This was followed by the declaration of the Natal Nature Conservation Ordinance, No. 15 of 1974, which made no distinction between native and non-native fishes and rendered the use of nets, other than those used for landing fish, illegal. In the Orange Free State, inland fisheries legislation that was first outlined in the Nature Conservation Ordinance, No. 8 of 1969, stipulated regulations including the enforcement of closed seasons, requirement of a licence for angling or netting, permitted fishing areas, and the importation of live fish. Anon (1970) describes fisheries management and legislation in the Transvaal: the Nature Conservation Division at this time was responsible for implementing fishing licence regulations and using these and other funding sources acquired to develop inland waters for public recreational angling through stocking programmes of native and non-native fishes. The proclamation of the Transvaal Nature Conservation Ordinance, No. 12 of 1983, amalgamated legislation regarding fisheries similar to that implemented in the Orange Free State.

Skelton and Davies (1986) documented the changing attitude of conservation authorities regarding legislation that protected non-native fishes; more specifically, the proposed removal of protective rights assigned to non-native angling species such as trout and bass by the Cape Department of Nature and Environmental Conservation. Hamman (1986) referred to the need for a change in legislation, to afford protection to native species while no longer actively propagating non-native species at state hatcheries for distribution into inland waters. Walmsley and Pike (1989) outlined the legislation surrounding non-native fishes and stressed the need for a revision of policy; this was accompanied by a document describing future guidelines for the promulgation of legislation that regulated non-native species importations (Anon, 1989). These changes led to cessation of non-native fish production and stocking by the provincial governments and the subsequent closure, mothballing or leasing of most provincial hatcheries, the consequences of which are documented in Rouhani and Britz (2004).

The proclamation of the National Water Act (NWA, 1998) and the National Environmental Management Act (NEMA, 1998) in post-apartheid South Africa, and the resultant governance measures introduced regarding inland fisheries, are discussed in Weyl et al. (2007). The authors note that access rights to all water is administered by the Department of Water Affairs and Forestry (DWAF), while resources, such as fish, are controlled by provincial governments as stipulated in the NEMA, which promotes sustainability, biodiversity, and equitable allocation of resources. Provincial governments reserve the right to administer licences for recreational, subsistence and commercial fishing; however, the paper illustrates the lack of cohesion between government departments and that there is no national lead agent enforcing an overall policy regarding access rights to particular dams and their resources.

NEM:BA was gazetted in 2004 within the fabric outlined in the NEMA. The regulations pertaining to non-native fishes within the NEM:BA, and the contentions of recreational anglers regarding these regulations, have led to official "position papers" published by various angling bodies such as the Federation of South African Flyfishers (Bainbridge et al., 2005) and the Trout Action Group (TAG), in coordination with the Eastern Cape Flyfishers Club (Fick, 2009). These publications largely object to the legislation. Conversely Roux et al. (2006), in a report that summarises requirements for the conservation of inland water biodiversity, describe the act (2004) as well as the NWA (1998) as the two most important pieces of legislation concerned with the implementation of conservation measures in South African inland waters.

McCafferty et al. (2010) describe the structural change in inland fisheries governance. Where previously there was no national lead agent in inland fisheries, the mandate for this function came under the auspices of the Department of Agriculture in May 2009, which subsequently became the Department of Agriculture, Forestry and Fisheries (DAFF). The policies of the

DAFF, which include food security, economic empowerment and poverty alleviation, now apply to the development of South Africa"s inland fisheries resources, the implication being increased impetus to develop fisheries to achieve the above policies within the DAFF mandate.

2.5 LITERATURE ON SOUTH AFRICA'S INLAND FISHERIES BY SECTOR

Generally, the development and typical life cycle of an inland fishery begins with an initial emphasis on food production through subsistence utilisation, followed by growing commercial interests (Smith, 1986). As economies develop, subsistence and commercial fisheries give way to recreational fisheries, which maximise economic gain through associated industries (Smith, 1986). South African inland fisheries are somewhat anomalous as they have not generally followed this typical evolution, with recreational uses being developed first and subsistence and commercial resource use being recent developments (Andrew et al., 2000; Weyl et al., 2007; Ellender et al., 2009). This can be attributed to several factors including the relatively recent construction of inland impoundments, the associated lack of a fishing tradition in rural communities, apartheid era policies that excluded access to many dams by local communities, and the lack of supporting developmental policies.

Recreational fisheries

> *Recreational anglers...utilise the resource primarily for leisure purposes but may sell some of their catch…They generally have permanent employment, use high technology gear consisting of a fibreglass or graphite rod, and a multiplying or spinning reel, and release, consume or sell a portion of their catch.* (Ellender et al., 2009, Table 2.2, pg. 679)

It is estimated that more than 1.5 million people are involved in freshwater angling in South Africa (Leibold and van Zyl, 2008). For the past century, recreational angling has been the dominant activity on South African impoundments (Hey, 1926a; b; Anon, 1970; 1971; McVeigh, 1978; Andrew et al., 2000; Weyl et al., 2007). It is therefore surprising that this sector remains has not been quantified and that the only attempts at quantifying recreational angling have been in the Transvaal in the 1960s (LeRoux, 1965) and 1970s (Cadieux, 1980a; b). Beside these studies, only three other studies have been undertaken: by van der Waal (2000) who looked at fishery resources in the Mutshindudi River catchment in Limpopo province; and by Ellender et al. (2009; 2010a; b) who described user group dynamics and quantified the harvests from Lake Gariep, South Africa"s largest impoundment.

Recreational angling in South Africa remains the major use of inland fisheries; however, since the mid-1990s there appears to have been an increase in the utilisation of inland fisheries by people whose main motivation for using the resource is subsistence (van der Waal, 2000; Weyl et al., 2007; Ellender et al., 2009).

Subsistence fisheries

> *Subsistence users… live within 15 km of the lake, use basic transport methods to access the lake (walk, bicycle, and a lift in a vehicle), predominantly use artisanal type gear (e.g., handlines), and are reliant on the resource for food and as a primary or supplementary source of income.* (Ellender et al., 2009, Table 2.2, pg. 679)

The emergence of subsistence fisheries on many South African impoundments is a fairly new phenomenon associated with the post-apartheid era. Despite historical development efforts in traditional areas, which included the 1973 appointment of a dedicated fisheries officer with a mandate to encourage harvesting of inland lakes and impoundments, subsistence fisheries failed to develop (Batchelor, 1989). This was attributed largely to the lack of clear policies and associated administrative procedures facilitating the permitting of harvesting (Batchelor, 1989). This situation persists today, and Weyl et al. (2007) attributed the low participation in subsistence fisheries to a lack of angling tradition, and the absence of an institutional framework to facilitate managed and sustainable access to the fish resource in many inland waters. Although subsistence fishing has not yet been provided for in the legal reforms of the post-apartheid constitutional democracy, water management authorities now tend to tolerate informal fishing activities by local communities and, in some instances, have attempted to promote fishing projects. As a result subsistence use of impoundments is increasing (Weyl et al., 2007; Ellender et al., 2010a, b).

In a case study conducted to assess the fisheries resources in the North West Province, Weyl et al. (2007) reported that of the 10 dams surveyed, six had some sort of subsistence angling activity. On Lake Gariep, subsistence angling dominated the fishery, accounting for 61% of fishing effort (Ellender et al., 2009). Ellender et al. (2010a) also showed that there were some

450 regular subsistence anglers making use of the resource from adjacent settlements (Ellender et al., 2010b). There are few other descriptions of subsistence angling on impoundments and available reports focus on the Eastern Cape Province (Andrew et al., 2000, Rouhani, 2003). In the Ntenetyana Dam, Alfred Nzo District Municipality, Eastern Cape, approximately 20–30 fishers from various communities living around the dam were recorded to be angling in the dam using handlines (Rouhani, 2003). Therefore, although largely undocumented, subsistence use of inland fisheries is likely to be much more widespread than is indicated by the available publications.

Recent anecdotal evidence indicates that the subsistence sector is becoming an increasingly important sector in rural livelihoods. Subsistence fishing therefore needs consideration in the long term planning process for inland fisheries.

Commercial fisheries

> *A commercial fishery 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, pg. 3).

Commercial inland fisheries are underdeveloped as a result of a history of limited access to resources, low demand for fresh water fish, the lack of an inland fisheries policy and unclear fisheries management objectives (Weyl et al., 2007). Commercial fishing in the form of single licences is only permitted on a limited scale on a few dams (e.g. Gariep, Bloemhof and Molatedi Dams) (Weyl et al., 2007). Although commercial fisheries remain largely undocumented, historically, commercial fisheries operated on a few impoundments including the Kalkfontein Dam, Bloemhof Dam (Orange–Vaal River system) and Darlington Dam (Sundays River system) (Merron and Tómasson, 1984; Potts, 2003). Despite these attempts to develop commercial fisheries on larger impoundments in South Africa the commercial viability of these enterprises has been marginal.

There have been numerous attempts to develop formal small-scale commercial fisheries in rural communities (e.g. Jackson, 1980; Schramm, 1993; Andrew, 2001). The more recent attempts are summarised in Table 2.3. Unfortunately, few fisheries developed or remained operational after the initial project interventions. The reasons for this lack of success are unclear but have been attributed to: the perceived low value of the resource; lack of a clear guiding policy; little historic involvement in fishing; the limitation of artisanal and subsistence fishing to the former homeland areas under the apartheid era; a cultural resistance to fishing (Andrew, 2001); and the concerns of management authorities that the support of subsistence and commercial use may threaten fish populations (Andrew et al., 2000).

The overriding reason for the lack of development of commercial inland fisheries is probably economic. Recent estimations on the profitability of various commercial fisheries options on Lake Gariep (Potts et al., 2004) and Darlington Dam (OLF Weyl et al., 2010) found that the low fish price (ZAR 6–10 kg^{-1}) coupled with the absence of a formal marketing system for inland fish precluded the economic viability of even small commercial enterprises in these water bodies. In addition, they showed that employment possibilities in commercial fisheries were relatively low, and pointed out that commercial fisheries would most likely result in considerable conflict with other users of the resource. As a result, employment gains from commercial fisheries were likely to be countered by employment losses from tourism at sites where recreational fisheries were well established.

Commercial fisheries assessments and recent developments are summarised in Table 2.3. Despite such assessments, the only marginally successful, non-subsidised commercial fishery still in operation is located at Bloemhof Dam in the Free State. While catch data from these fisheries are returned to local nature conservation offices and are compiled in internal reports, they are not published in an openly accessible form. As a result the literature on commercial level enterprise and catch rate is extremely sparse and consists of non-standardised or even anecdotal data. Whitehead (1978), for example, reports catches of one ton per day for 100 days from Darlington Dam; Batchelor (1989) reported that commercial operators in the Free State harvested 469 tons from various dams in 1984; and Andrew et al. (2001) reported catches of 3.6 tons in 120 days for Tyefu Dam in the Eastern Cape. Such data lack the information on fishing effort required for any further analyses.

Perhaps most exemplary of the lack of information are the data available for Lake Gariep, South Africa‟s largest inland water body. The fisheries potential of this dam was recognised as early as 1972, and Hamman (1981) developed a detailed management plan for the fishery. Despite this, commercial fishery development remained dormant until 1992, when a small-scale commercial operation was initiated near the dam wall. This operation failed after some years, but Potts et al. (2004), reported two commercial operators on the dam in 2002. To date, the only reported data for any of these formal ventures is a short mention of commercial catches in Potts et al. (2004) which states that, *"a total of 4160 fish with a combined mass of 10 292Kg were captured between January 2000 to January 2001 in the gillnet and seine net* *fishery. The dominant species in terms of number and mass was the common carp and sharptooth catfish, while the other species were caught in very small numbers"*(p. 22).

Table 2.3 Summary of available literature and proposed subsistence or commercial fisheries development by water body. Prov. = Province; EC = Eastern Cape; FS = Free State; KZN = Kwazulu Natal; NW = North West; LP = Limpopo; GP = Gauteng; MP = Mpumalanga; NC = Northern Cape.

Waterbody	Prov	Description	Main References
Gariep Dam	FS/EC	Fisheries assessments and various attempts to develop fisheries	Hamman, 1981 Jackson, 1981a; b Potts et al., 2004 Winker, 2007 Ellender et al., 2010a; b
Darlington Dam	EC	Commercial fishery in 1970's & economic feasibility study conducted in 2010	Whitehead, 1978 Jackson, 1973 OLF Weyl et al., 2010
Umtata Dam	EC	Attempt to develop fishery unsuccessful	Schramm, 1993 Andrew, 2001
Pikoli-; Tyefu-; Kat River-; Laing-; Lubisi-;Sinqemeni-;Sheshego-; Binfield Park-; Dimbaza-; Ndlambe Dams	EC	Attempts with varying success to set up small scale fisheries 1999-2000.	Schramm, 1993 Andrew et al., 2000 Andrew, 2001 Potts, 2003 Potts et al., 2006
Cata and Mnyameni Dam	EC	Development of recreational fishery	Rouhani et al., 2010
Xonxa Dam	EC	Fishery established in 1980 (unsuccessful); Fishery potential re-evaluated and quantified for yellowfish and catfish in 2010	Schramm, 1993 Duncan-Brown, 1980 Burton et al., 2002 Richardson et al., 2009
Macubeni-; Indwe-; Nqadu Dams	EC	Fishery assessment indicated limited scope for development of moggel, yellowfish and tilapia.	Burton et al., 2002

Fisheries assessments depend on the availability of commercial and recreational catch data and compilations of available raw data are an urgent national requirement that are necessary not only for assessments of yield, but also for decision making and economic feasibility analyses.

Managed sport fisheries

An important, but largely undocumented element of inland fisheries is the commercial management of private dams and public waters for sport fishing, particularly trout fishing, which forms the basis of a substantial tourism based local economy in suitable areas of Mpumalanga, KwaZulu-Natal and the Eastern Cape (Hecht and Britz, 1990; Du Preez and Lee, 2010).

The trout fishery and associated economy of Rhodes Village in the Eastern Cape was surveyed by Du Preez and Lee (2010), highlighting the value of recreational fishing as a means of stimulating tourism based local economic development (LED). A unique inland fishery management system for the local self-sustaining trout population has been created whereby recreational trout fishing in the rivers and streams in and around Rhodes Village is managed on behalf of riparian landowners by private individuals, the Mosheshs‟s Ford Angling Club and the Wild Trout Association (WTA). The waters include the upper Kraai, Bell, Kloppershoekspruit, Vlooikraalspruit, Bokspruit, Sterkspruit and Riflespruit. Recreational anglers pay a fee to fish and may also employ the services of a professional angling guide if desired (Du Preez and Lee, 2010).

2.6 LITERATURE ON THE SUITABILITY OF INLAND WATERS FOR FISHERIES DEVELOPMENT

Fishery yields of South African dams

South Africa is a water scarce country and, apart from historic traditional fisheries on the

Pongola Floodplain in northern Kwazulu-Natal (Merron and Weldrick, 1995) and the Orange River in the Northern Cape (Heeg and Breen, 1982), opportunities were not widely available for fisheries to develop until the dam-building era of the 20th century (Andrew et al., 2000). The primary function of these impoundments was to supplement urban and agricultural water supplies, as well as for hydroelectricity. As a result, approximately 3150 impoundments with a surface area >1.2 ha have been constructed countrywide (DWA, unpublished database) (Figure 2.4). During the period from 1800 to 1940, impoundment numbers increased steadily to approximately 400, and since then that figure has increased by more than six times (Figure 2.5). These impoundments have created significant inland water resources amounting to a surface area of more than 3000 km^2.

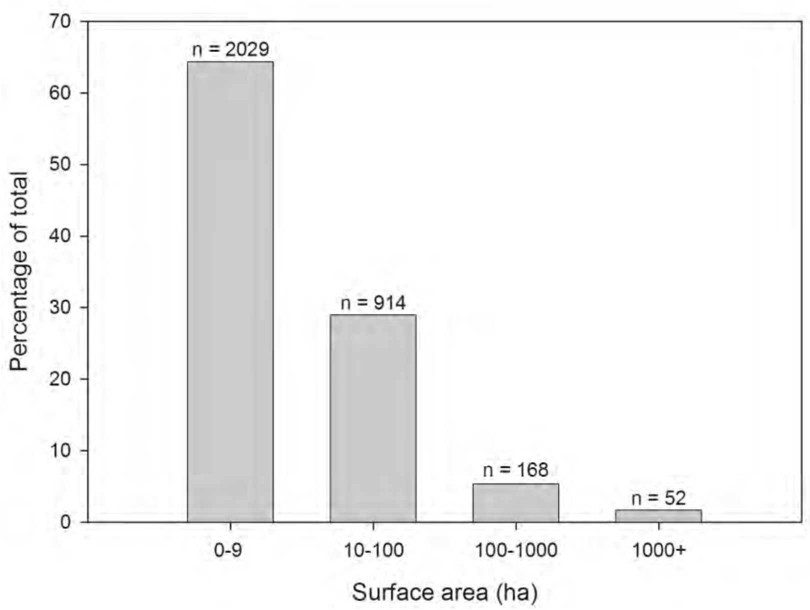


Figure 2.4 Proportion of South African impoundments categorised by surface area.

Unfortunately, there are almost no studies on annual harvest rates from inland water bodies in South Africa. Annual catch rates have only been determined for recreational fisheries in

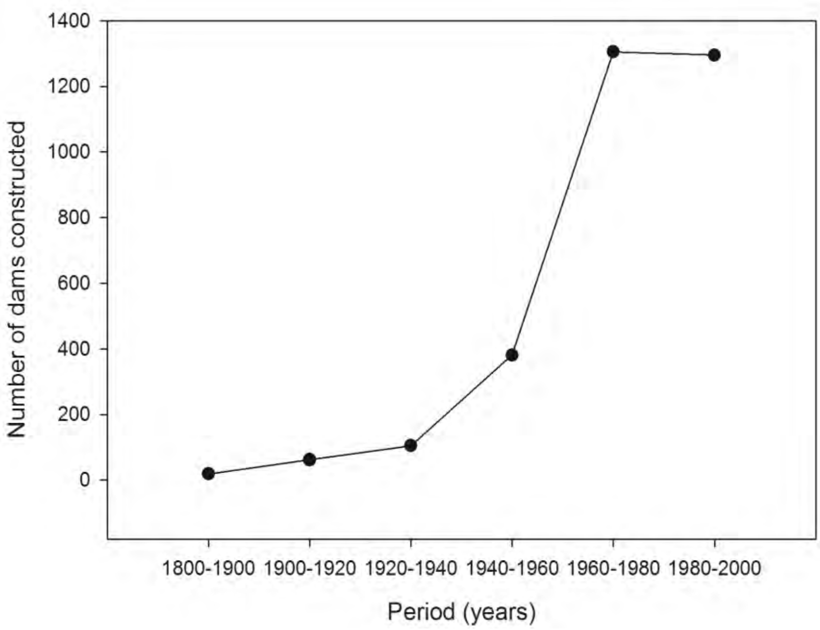


Figure 2.5 Number of impoundments constructed by 20-year time frame in South Africa between 1800 and 2000. (source data: DWA, unpublished database).

Hartbeespoort Dam (Cochrane, 1987), Lake Gariep (Ellender et al., 2010a), and Darlington Dam (OLF Weyl et al., 2010). In each of these dams estimates are based on one-year assessments because of the lack of dedicated monitoring surveys. It is not known where the National inland fisheries yield of 2300 $t.yr^{-1}$ used in FAO reports on inland fisheries in southern Africa (Marshall and Maes, 1994; Van den Bossche and Bernacsek, 1990) was derived from, but it most likely includes the 695 $t.yr^{-1}$ estimated from recreational fishers in Hartbeespoort Dam in the 1980s (Cochrane, 1987) and some of the yields reported by Batchelor (1989).

An estimate of total inland fisheries production in South Africa of 2300 $t.yr^{-1}$ is provided in FAO reports on inland fisheries in southern Africa (Van den Bossche and Bernacsek, 1990; Marshall and Maes, 1994).

As a result of this lack of prior fisheries data, direct estimates of fish production cannot be determined, and all assessments of potential fish yield for South Africa are derived from applying empirical relationships to morphological and chemical data. Such relationships, like the Schlesinger and Regier (1982) global temperature-adapted morpho-edaphic index (MEI) model, only give rough indications of potential fish yield. These are summarised in Table 2.4. A conservative estimate of average fish production of 40 $kg.ha^{-1}$, based on documented studies, indicates that the potential fish production from these water bodies could potentially yield 1000–2000 t yr^{-1}. Allocations between recreational, subsistence and commercial fisheries are likely to be problematic as there is limited published information available to decision makers regarding the value of extant fisheries and the multiple user groups that may access water resources, leading to uncertainty regarding potential conflict areas between these sectors (McCafferty et al., 2010).

Potential fishery production from small water bodies

Fisheries in the southern African region, an area encompassing those countries belonging to the Southern African Development Community (SADC), are primarily located on major lakes (e.g. lakes Tanganyika and Malawi) or in large man-made dams [e.g. Kariba (Marshall and Maes, 1994; OLF Weyl et al., 2010)]. In many cases, the potential for further development of these fisheries is limited and some are already considered to be maximally- or overexploited (Marshall and Maes, 1994; OLF Weyl et al., 2010). This is not the case for smaller reservoirs constructed for water supply purposes, which have significant fisheries potential but which are largely undeveloped (Marshall and Maes, 1994).

Table 2.4 Summary of potential fish yield by species from studies on South African impoundments.

Waterbody	Prov.	Surface area (ha)	Species	Actual Estimate ($t\ yr^{-1}$)	Reference
Darlington Dam	EC	4000	*Labeo umbratus*	365	Whitehead, 1978
Darlington Dam	EC	4000	*Cyprinus carpio*	11.3	OLF Weyl et al., 2010
			Labeobarbus aeneus	0.15	
			Clarias gariepinus	11.5	
			L. umbratus	0.1	
			Anguilla mossambica	0.25	
			Oreochromis mossambicus	0.15	
Tyefu Dam	EC	10	*L. umbratus*	10.95	Andrew, 2001
Gariep Dam	FS/EC	35956	*C. gariepinus*	6.1	Ellender et al., 2010a
			L. capensis	6.3	
			L. aeneus	6.75	
			C. carpio	70.6	
			All species	89	
Hartbeespoort Dam	NW	2000	*C. gariepinus*	102	Cochrane, 1987
			O.mossambicus	144	
			C. carpio	449	
			All species	695	
Pongolapoort Dam	KZN	13278	*All species*	7.5	Batchelor, 1989
Hudson Nstanwisi	LIM	515	*All species*	3.5	Batchelor, 1989

Unlike other countries in the SADC, which have significant amounts of fisheries data, South Africa did not join the SADC until 1994 and therefore data on small water bodies presented in the Marshall and Maes (1994) review for this country are not comprehensive. That which is presented highlights South Africa‟s limited natural lake area, large number of reservoirs, and fish yield which, in contrast to other SADC countries, is largely accounted for by recreational anglers. While data deficient, the report does provide an estimate of total fish production in South Africa of 2300 $t\ yr^{-1}$, and a map illustrating all the South African impoundments is also included in the report. Importantly, the review also makes mention of the potential that stock enhancement may have in improving the productivity of small reservoirs in the region and highlights the introduction of non-native species in South Africa as an example.

Attempted interventions to establish fisheries

Attempts to establish capture fisheries in inland waters date back to the 1970s. Few have been successful and while there is some literature on the establishment of some fisheries (see Table 2.3), no studies exist that evaluate the success rate or the current number of functioning enterprises. Some of the better documented case studies are summarised below.

Stock enhancement using mullet in the Eastern Cape

In the late 1970s and early 1980s a number of Eastern Cape impoundments were stocked with two species of mullet: *Myxus capensis*; and *Mugil cephalus* (Bok, 1983). The fingerlings were wild caught in Eastern Cape estuaries and subsequently stocked into impoundments to provide opportunities for the development of gillnet fisheries. The stocking was aimed at enhancing the fisheries potential of impoundments with mullets, which were commercially more viable than the resident moggel *Labeo umbratus* and *C. carpio* (Bok 1983). While growth rates and catches were favourable, with yields of up to 500 $kg.ha^{-1}$, the unpredictable recruitment of wild caught fry proved to be a significant bottleneck and constraint to future development of this fishery (Bok 1983).

Fisheries development in rural areas

During the 1970s and 1980s there was a movement toward promoting the use of freshwater fish in impoundments through stocking and training programs in the former homeland areas, and fisheries sections were active in the authorities of Transkei, Ciskei, KwaZulu, Qwaqwa, Venda, Lebowa, Gazankulu and Bophuthatswana (van den Berg et al., 1975; Roode, 1978; van der Waal, 1978a; b; 2000; Mabitsela, 1981; Saayman et al., 1983; Schoonbee et al., 1995; Andrew et al., 2000). A fishery for wild fish stocks was promoted for a short period in 1979/80 on Xonxa Dam in the Glen Grey District (Duncan-Brown, 1980). These homeland authorities promoted commercial angling from dams and ran hatcheries to produce fingerlings for stocking purposes (Andrew et al., 2000; Rouhani and Britz, 2004). There is little evidence suggesting that these efforts resulted in significant benefits for the communities involved (Andrew et al., 2000).

In post-apartheid South Africa, inland fishery projects have been undertaken in a few locations. In the Eastern Cape Province, a community driven fisheries project was undertaken on the Great Fish River, as well as in two small impoundments. The fishery in the Fish River Valley was shown to contribute to food security and income generation for the communities living in that area (Andrew et al., 2000). The Rural Fisheries Programme (RFP) of the Department of Ichthyology and Fisheries Science of Rhodes University was commissioned by the Alfred Nzo District Municipality to survey Ntenetyana Dam to determine its fisheries potential. There was an existent subsistence fishery, and management recommendations indicated that fishery activities could be expanded such that a community-based, small scale fishery was developed incorporating hook and line and seine netting subsistence practices, as well as a recreational fishery component (Rouhani, 2003). The current status of these fisheries has, however, never been evaluated.

Lake Gariep was constructed in 1972 and periodic attempts have been made to harvest fish commercially since 1992 (Potts et al., 2004). In 2004, the Free State Department of Economic

Affairs, Environment and Tourism (DEAET) provided support to the Venterstad Community Fisheries Project (VCFP), which aimed to provide poverty relief to historically disadvantaged communities in Venterstad and Oviston, through facilitating their access to the fishery in specific areas of the lake. An experimental fishing permit was issued by DEAET to allow for the harvesting of an initial quota of 50 $t.yr^{-1}$ of *C. carpio*, sharptooth catfish *Clarias gariepinus* and mudfish *Labeo capensis*. The permit was granted specifically for hook and line angling (Potts et al., 2004). The project shut down after a short running period due to bad planning and management, and a lack of consultation and local knowledge (Potts et al., 2004). Currently the fish resource is used only by subsistence and recreational anglers (Ellender et al., 2009).

The commercial fishery development attempts in Darlington Dam, Eastern Cape, are summarised by OLF Weyl et al. (2010). In 1978, a fishery operation was initiated in Darlington Dam which comprised a team of five fishermen equipped with gillnets and a small boat. The operation provided gutted *L. umbratus* and *C. carpio* to markets both in Grahamstown and Uitenhage. Catch rates were high and it was reported that 1 $t.d^{-1}$ could be harvested. While the operation was profitable, the operation ceased after a year due to the withdrawal of the manager. Subsequently, attempts were made to develop various gillnet fisheries based on these species. In the 1980s, a gillnet fishery that salted and dried fish was set up under the management of Mr. Tiko Hirsch. During this time the dam was also stocked with mullet to supplement the fishery. Due to economic reasons this commercial operator moved to the Free State to begin operations on Bloemhof Dam. No further attempts have been made to develop a commercial fishery on the dam. There was however some reported conflict between this fishery and recreational angling pertaining to competition for the resource and pollution resulting from fish processing on the lakeshore (OLF Weyl et al., 2010).

Biological survey information with fisheries management recommendations

There is a paucity of available literature investigating the biological sustainability of harvesting fish populations in South African impoundments. Surveys on the biology and management of fish populations are limited to three Transkei reservoirs, Xonxa, Lubisi and Umtata (Schramm, 1993; Richardson et al., 2009); two impoundments on the Orange River system in the Freestate, Lake Gariep and Lake Van der Kloof (Hamman, 1981; Allanson and Jackson, 1983; Tómasson, 1983; Tómasson et al., 1985; Potts et al., 2004; Ellender et al., 2009; 2010a; b); five small impoundments in the Eastern Cape (Potts, 2003; Potts et al., 2006); Hartbeespoort Dam on the Crocodile and Magalies river systems in the North West Province (Koekemoer and Steyn, 2005); Darlington Dam on the Sundays River system in the Eastern Cape (OLF Weyl et al., 2010); and the growth and survival of two mullet species (*M. capensis, M. cephalus*) stocked as wild caught juvenile fish into impoundments in the Eastern Cape (Bok, 1983). A summary of these surveys is illustrated in Table 2.5.

On Lake Gariep, post impoundment surveys were conducted over an eight year period on fish population dynamics and production potential of largemouth yellowfish *Labeobarbus kimberleyensis,* smallmouth yellowfish *Labeobarbus aeneus*, *L. capensis*, *L. umbratus*, *C. gariepinus* and *C. carpio*, in order to develop a fisheries management plan (Hamman, 1981). The study concluded that a commercial gillnet fishery could be implemented and an annual catch of 886 tons (multi-species) could be harvested. *Cyprinus carpio* was considered as the species with the largest harvest potential.

In the period between 1978 and 1983, concurrent studies were undertaken on the limnology and fisheries potential of Lake Van der Kloof (previously Lake le Roux) (Allanson and Jackson, 1983; Tómasson, 1983; 1985; Tómasson et.al., 1983) It was concluded that the physical characteristics of the lake inhibited the harvest potential and that approximately 150–200 tons could be harvested annually. The targeted species would predominantly be *L. capensis* and *L. aeneus*, the latter of which could sustain intensive exploitation while *L. capensis* could complement catches, but variable annual recruitment and growth were cited as inhibiting extensive harvest potential (Tómasson, 1983; Tómasson et.al., 1983).

Schramm (1993) conducted gillnet surveys to investigate the fisheries potential of three Transkei reservoirs (Xonxa, Lubisi, Umtata) and documented the reproductive biology of the fish populations to determine their sustainability. Only Xonxa reservoir displayed favourable catch rates for the establishment of a fishery. The biological characteristics of *L. aeneus*, upon which the fishery would be based, were also favourable for sustainable exploitation. The fisheries potential of Xonxa reservoir was revisited by Richardson et al. (2009), and the biology of *L. aeneus* and *C. gariepinus* were investigated to provide input parameters for stock assessment models upon which fisheries development and management could be based. The study indicated that two sustainable fisheries could be developed: a gillnet fishery for *L. aeneus* (60 mm stretched mesh), which could harvest 23 $t.y^{-1}$; and a longline fishery for *C. gariepinus* yielding a maximum of 4 $t.y^{-1}$ (Richardson et al., 2009).

Table 2.5 Summary of potential yields and recommended harvest rates per hectare from studies on South African impoundments.

Waterbody	Prov.	Surface Area (ha)	Fish Production Indicator	Species	Potential Yield (t yr^{-1})	Recommended harvest rate ($t.ha^{-1}.yr^{-1}$)	Reference
Darlington	EC	4000	Potential Yield	*C. gariepinus*	22-98	6	OLF Weyl *et al*. 2010
			Potential Yield	*O. mossambicus*	2-9	1	
			Potential Yield	*C. carpio*	3-12	1	
			Potential Yield	*L. aeneus*	3-15	1	
			Potential Yield	*L. capensis*	6-26	2	
			Potential Yield	*L. umbratus*	67-299	17	
			Recreational Harvest	*All species*	104-460	26	
Dimbaza Dam	EC	46.2	Potential Yield	*L. umbratus*	2.16	47	Potts, 2003
Kat River Dam		214	Potential Yield	*L. umbratus*	0.17	8	
Laing Dam		211	Potential Yield	*L. umbratus*	1.73	8	
Ndlambe Dam		16.2	Potential Yield	*L. umbratus*	1.18	73	
Sinqemeni Dam		9.3	Potential Yield	*L. umbratus*	1.62	174	
Xonxa Dam	EC	1450	Potential Yield	*L. aeneus*	23	16	Richardson *et al*. 2009
			Potential Yield	*C. gariepinus*	4	3	
			Potential Yield	*All species*	27-139	19	
van der Kloof Dam	FS/NC	13340	Recreational Harvest	*L. capensis*	75-100	6	Allanson & Jackson, 1983
			Recreational Harvest	*L. aeneus*	75-100	6	
Hartbeespoort Dam	NW	2000	Potential Yield	*All species*	200-300	100	Koekemoer and Steyn, 2005
Madikwe Dam		431.8	Recreational Harvest	*C. gariepinus*	5.5	13	Rouhani 2004
Molatedi Dam			Recreational Harvest	*O. mossambicus*	4	5	
			Recreational Harvest	*C. gariepinus*	9.5	13	
Ngotwane Dam		401.3	Recreational Harvest	*C. gariepinus*	8	20	
Roodekopjes Dam		1571	Recreational Harvest	*O. mossambicus*	1	1	
				C. gariepinus	4	3	
Vaalkop Dam		1110	Recreational Harvest	*C. gariepinus*	5.5	5	
			Recreational Harvest	*O. mossambicus*	2	2	

The life histories and fisheries potential of populations of *L. umbratus* from five small Eastern Cape reservoirs (Katriver, Laing, Sinqemeni, Ndlambe and Dimbaza) were investigated (Potts, 2003; Potts et al., 2006). The research concluded that *L. umbratus* populations in small, shallow, slightly enriched reservoirs would be more suitable for exploitation as these populations were faster growing and were therefore more likely to sustain fishing pressure than populations from more oligotrophic reservoirs (Potts, 2003; Potts et al., 2006).

Koekemoer and Steyn (2005) conducted a survey of the fish community of Hartbeespoort Dam. Based on the catch composition in experimental gillnets, they concluded that the eutrophic state of the dam favoured a fish community dominated by benthic feeding *C. gariepinus* and *C. carpio*. The authors hypothesised that the removal (through harvesting) of 200–300 tons of these two species would help restore zooplankton and macrobenthos communities and shift the fish community towards one dominated by Mozambique tilapia *Oreochromis mossambicus*. Harvesting was to be undertaken by a community fishery project using mainly gillnets. Unfortunately there are no subsequently published data available on harvests or the response of fish communities to harvesting.

A study on the response of *L. umbratus*, *C. carpio* and *C. gariepinus* to current recreational angling, as well as two proposed commercial level fisheries (longline and gillnet fishery), was undertaken on Darlington Dam (OLF Weyl et al., 2010). Stock assessment models indicated that a 100 mm mesh size gillnet fishery was feasible, although initial harvest levels for a gillnet fishery should be conservative and annual harvests should not exceed 60 tons until the full impact on the stock is determined (OLF Weyl et al., 2010). It was estimated that the current recreational fishery targeting *C. gariepinus* on Darlington Dam could increase its catch five-fold before the spawner biomass would be reduced to critical levels. From the biological and experimental fishing (longlines) information obtained for *C. gariepinus*, a commercial fishery could harvest the species sustainably (OLF Weyl et al., 2010).

From the aforementioned examples, it is evident that few biological studies have been undertaken to determine the biological sustainability of harvesting fish from South African impoundments. Without information on the biology of species targeted by fisheries, development is severely hampered as the life history characteristics of a species directly influence their vulnerability to exploitation and, consequently, also the economic feasibility of the fishery.

Value of inland fisheries

South African inland fisheries are largely overlooked as a "beneficial use" of water in the literature on water resource governance and management. Studies such as Weyl et al. (2007) on fisheries in the North West Province and the valuations of recreational fisheries by Leibold and Van Zyl (2008), Brand et al. (2009) and Du Preez and Lee (2010) provide an initial insight into the value of the current inland fisheries.

What is evident is that while commercial fisheries have a long history of failure in South African inland waters, the recreational value of these resources is considerable. A non-peer reviewed study on the value of recreational fisheries in South Africa, commissioned by the South Africa Deep Sea Angling Association (SADSAA) in 2007, estimated that the average annual expenditure by anglers affiliated to angling clubs was ZAR 7 500 angler yr^{-1} and that the economic impact of these anglers, who represent about 10% of participants, was estimated at ZAR 900 million yr^{-1} (Leibold and Van Zyl, 2008). While up-calculations of this value for the unaffiliated anglers cannot be made with any confidence, the report demonstrates the economic contribution that the recreational sector makes to the national economy.

Brand et al. (2009) valued yellowfish-dependant recreational angling on the Vaal River in the region of ZAR 133 million per season. Du Preez and Lee"s (2010) survey of the economic value of the trout sport fishery to Rhodes Village in the Eastern Cape showed that trout fishing was an important contributor to local tourism, generating ZAR 13.5 million and employing 85 people in a rural village of 600 people, where only 15% of the population were formally employed. Average expenditure was ZAR 5 052 per angler per trip, which averaged 5 days. The study was conducted concurrently to the development of the alien species zoning regulations contained within the NEM:BA and estimated the potential loss in jobs and revenue to Rhodes Village; the angler survey revealed that 39 angling-related jobs and ZAR 5.5 million annual income would be lost if trout were to be eradicated from the local rivers and dams.

From a subsistence use perspective, Ellender et al. (2009; 2010b) showed that at least 59% of the total angling effort in a portion of Gariep Dam was exerted by a minimum of 448 regular subsistence anglers. They cautioned that future development of commercial fisheries could create competition for resources and markets with the extant subsistence sector. As a result, subsistence users of inland fisheries in South Africa require formal recognition so that their rights to resource use is secured and their livelihoods protected.

The implementation of sustainable development requires that choices regarding environmental resource use, biodiversity conservation and livelihoods need to be informed by evaluations of ecosystem goods and services. These studies exemplify the need for future fisheries development to be guided by sound information that minimises the negative economic impacts of future fisheries development and to secure the livelihoods of subsistence users.

2.7 CONCLUSIONS

While inland fisheries in South Africa undoubtedly contribute to South Africa‟s economy through the economic impact of recreational fisheries and provide food security to rural people living in their vicinity, there is a general lack of literature upon which a national inland fisheries strategy can be based. The available literature is temporally disjunct, site specific and predominantly not peer-reviewed.

Apart from a recent paper which describes the fisheries sectors using Lake Gariep (Ellender et al., 2009) there is no recent description of any of the inland fisheries operating in South Africa. Proper descriptions of each sector incorporating data on harvest rates, utilisation patterns and economic contributions are needed urgently.

Unfortunately, inland fisheries are not routinely monitored. Membership in formal recreational angling organisations are reported to be in the region of 150 000 people (Leibold and van Zyl, 2008). Subsistence and recreational use by non-affiliated anglers are likely to be even greater. This lack of knowledge obviously constrains the decision making process, because there are no data against which to gauge the impact of interventions such as the development of a commercial fishery. On Lake Gariep, for example, a commercial fishery employing, at most, 10 people would most likely negatively impact on the livelihoods of 448 subsistence users (Ellender et al., 2010a; b).

Catch rates and harvests are only available for four case studies (Cochrane, 1987; van der Waal, 2000; Ellender et al., 2010a; OLF Weyl et al., 2010). This is a major bottleneck in assessing the potential of inland fisheries because the *de facto* open access nature of inland fisheries to recreational and subsistence users (Weyl et al., 2007) may already have led to unsustainable harvest rates and over-fishing in some dams. Globally, for example, there is increasing recognition that the impact of recreational angling (fishing with a rod, line and hook) on fish stocks is as significant as that of many commercial fisheries (Cooke and Cowx, 2004; Arlinghaus and Cooke, 2005). Catch data are therefore urgently required, because without such data it is largely impossible to determine whether additional fisheries could or should be developed. As a direct result of the lack of catch data, all estimates of potential yield and production in the country are based on applying empirical relationships to morphological and chemical data for water bodies. While these relationships have been shown to be more than incidental (Ryder, 1965), they are, at best, only very rough indications of potential yield. Some data are, however, available. Recreational anglers have good competition data and nature conservation authorities keep records on catches and licence allocations. A collation of such data in a centralised database would provide important planning information for a variety of different impoundments.

There have been numerous attempts to develop fisheries in rural areas. Documented evidence shows that almost all have failed. Others have never been reassessed after the initial development and so there are no actual data upon which the success or failure of interventions could be analysed.

Economic assessments of inland fisheries are also very few. Those that have been undertaken, however, indicate that recreational fisheries contribute significantly to provincial and national economies (Cadieux, 1980; Brand et al., 2009; Du Preez and Lee, 2010; Leibold and Van Zyl, 2008). This lack of information on the value of fisheries is a global problem, and Cowx and Gerdeaux (2004) point out that fisheries tend to be poorly- or under-valued in multiple aquatic resource user scenarios. Further valuation studies, such as that of Du Preez and Lee (2010) showing the benefits of recreational fishing to rural communities, are required if informed choices are to be made regarding the promotion of inland fisheries for rural livelihood development.

Additional information limitations include information on inland fisheries governance, fishery governance systems, licensing, resource allocations and policy. User conflicts, particularly between recreational and subsistence and commercial fishers, are mentioned in some publications (Weyl et al., 2007; OLF Weyl et al., 2010) and exist in many fisheries. However, there is little documented evidence on these conflictsand understanding the causes behind them is essential for fisheries development and policy formulation.

The present literature survey reveals an urgent need for research covering the biological, social, economic and governance aspects, if inland fisheries are to be developed in a rational and sustainable manner which promotes South Africa"s national policy goals. Addressing all of these gaps is beyond the scope of this thesis. However, to contribute to the state of knowledge, the thesis will attempt to describe recreational fisheries in South Africa and compile available recreational and fisheries-independent survey data in order to provide baseline information for South Africa"s data-deficient inland fisheries.

CHAPTER 3:

Organised freshwater angling in South Africa: A descriptive synthesis of information

3.1 INTRODUCTION

Globally, the importance of recreational angling to socio-economic structures at both local and national levels is well documented (Cowx et al., 2010). Recreational fisheries are commonly associated with benefits such as job and tourism creation and associated revenue generation (Arlinghaus et al., 2002; Cooke and Cowx, 2004), particularly in industrialised countries where there is a commonly observed shift from commercial to recreational fishing activities with increased economic development (Smith, 1986; Ellender, 2008; Cowx et al., 2010). In Chapter 2, the nature of South Africa"s inland fisheries was reviewed, indicating that development has not followed this typical evolutionary pattern and that recreational anglers represent the dominant resource user group in inland fisheries. However, in contrast to the USA and Europe, where there is a history of inland recreational fishery assessments (Welcomme, 2001; Cowx and Arlinghaus, 2008; Parkkila et al., 2010), there is very little qualitative or quantitative information on the dynamics of freshwater angling in South Africa. This is unfortunate because the actions of anglers, how they utilise the fisheries resource and where fisheries of interest are located, are often crucial in understanding and effectively managing and developing fisheries resources (St Martin, 2001; Arlinghaus and Mehner, 2003; Ellender, 2008).

The majority of anglers in South Africa are informal participants in that they are not affiliated to any organisation or club through which they conduct their angling activity. However, a smaller proportion of anglers comprise multi-faceted, highly organised formal angling bodies that provide an excellent overview of the diversity of freshwater angling in South Africa. Furthermore, freshwater angling organisations may prove to be important partners for managers and decision makers. In recognition of their role as stakeholders in inland fisheries, the purpose of this chapter is to provide a synthesis of available information regarding the activities of freshwater angling organisations in the country, and lists impoundments that these anglers have identified as having high recreational angling value.

3.2 MATERIALS AND METHODS

Key informant interviews with organised angling officials were conducted in Johannesburg. During these interviews, information was collected regarding the structure of organised angling bodies, the number of participants within each structure, competition format and frequency, as well as descriptive information regarding how the angling activity is conducted. Once contact had been established with these representatives, further queries and appeals for information were conducted telephonically or via email. In addition, the facilitator of the NEM:BA mapping process (see Chapter 2), was interviewed and provided the maps for the different angling species.

3.3 RESULTS AND DISCUSSION

The structure of organised freshwater recreational angling in South Africa is shown in Figure 3.1. It is important to note that all organised angling in South Africa falls under the auspices of the International Sport Angling Confederation (CIPS, Confédération Internationale de la Peche Sportive), an organisation comprised of approximately 50 million members worldwide that represents saltwater and freshwater angling interests as well as the sport of casting (http://www.cips-fips.com/cips/index_en.html). Under this global body, two international federations, namely the International Freshwater Sport Fishing Federation (FIPS-ed) and the International Fly Sport Fishing Federation (FIPS-Mouche), are concerned with international freshwater angling and its organisation. At a national level, angling organisations then fall under these two federations. In South Africa, these are:

1. The South African Freshwater Bank Angling Federation (SAFBAF),
2. The South African Federation of Artificial Lure and Fly Angling (SAFALFA).

Both SAFBAF and SAFALFA are controlled, on a national level, by the South African Sport Anglers and Casting Confederation (SASACC). However, in terms of their international representation, SAFBAF fall under the FIPS-ed banner, while the activities of SAFALFA are controlled by FIPS-mouche (J. Pledger SASACC president. *pers comm*, 2010).

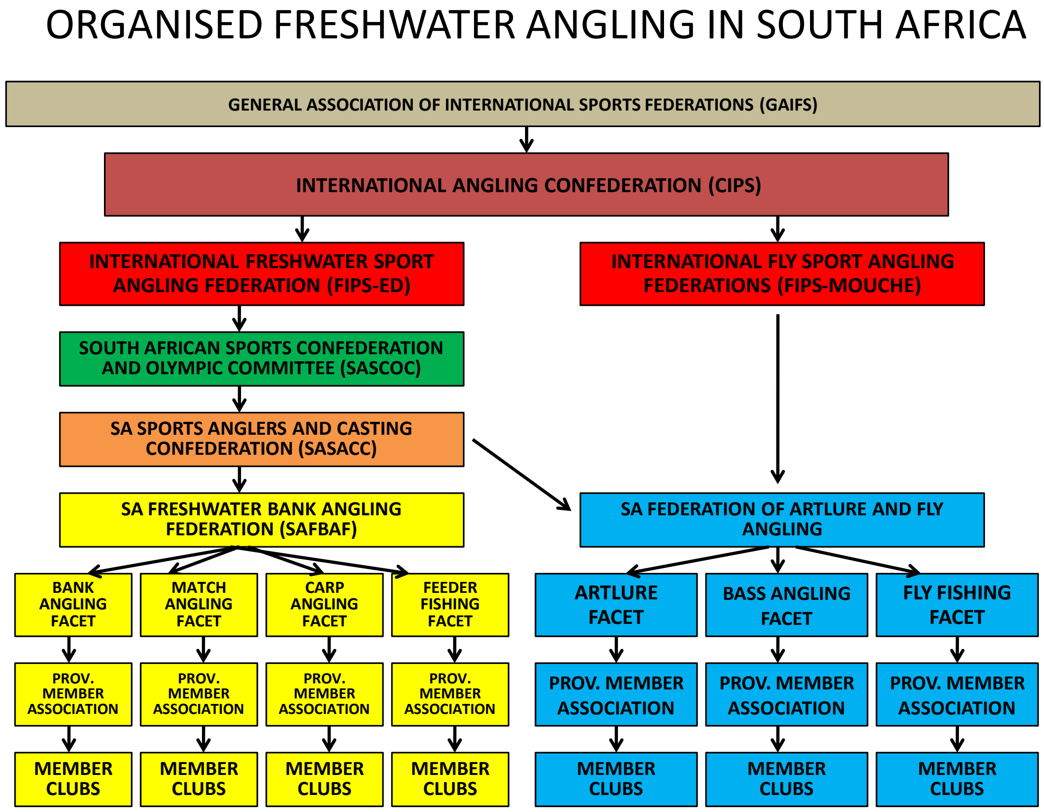


Figure 3.1 Structure of organised freshwater angling in South Africa (adapted from South African Sport Anglers and Casting Confederation (SASACC) Constitution: Annexure B).

3.3.1 South African Freshwater Bank Angling Federation (SAFBAF)

The South African Freshwater Bank Angling Federation (SAFBAF) is the controlling body for four organised angling facets, namely bank angling, carp angling, match angling, and feeder fishing. The facets themselves do not have distinct administrative bodies and their activities are controlled and convened through representatives on the SAFBAF administration. There are currently more than 5300 SAFBAF registered anglers in the country (Table 3.1).

Table 3.1 SAFBAF - Number of affiliated clubs and registered anglers within those clubs by province (as of 2010).

Province	Clubs	Registered Anglers
Gauteng	27	899
Gauteng-North	12	621
KwaZulu-Natal	13	390
Limpopo	6	164
Mpumalanga	13	405
Northern Cape	10	198
North East Mpumala	19	280
North West	9	296
Eastern Province	5	126
Central Gauteng	19	720
Central Northwest	8	166
Southern Cape	6	62
Free State	24	725
Western Province	7	257
Total	**169**	**5309**

Bank angling

In Bank Angling, a baited hook is cast out and the participant waits for a fish to eat the bait. During angling competitions, fishing zones are demarcated along the shoreline, the number and size of the zones depending on the number of teams or participants in the event. Within each zone each participant is allocated a lot, generally no wider than 30 m, which determines the area to be fished by that participant (Figure 3.2). The water in front of each lot is commonly "ground-baited" by the angler, a practice which involves the dispersal of bait such as maize meal, nuts and/or seeds over an area to attract fish to the fishing site (T Spencer, SAFBAF Convenor, *pers comm*, 2010). In competition, anglers are permitted to fish with a maximum of two rods at a time and two hooks per rod.

All freshwater fish species captured within an angler‟s fishing area are considered eligible for weigh-in at competitive events with the exception of native yellowfish (*Labeobarbus*) species which are to be released immediately. Captured fish are commonly kept in keep-nets, the entire contents of which are weighed after the allocated fishing period or as regularly as possible (every 2–3 hours) (F. Visagie, SAFBAF Secretary, *pers comm*, 2010). Five points are allocated to the angler for each fish caught and 10 points are allocated per kilogram of all fish contained within the keep-net. The duration of the angling period is most commonly eight hours for each day of the competition. While several species may be caught bank angling, the majority of competitive bank anglers target carp *Cyprinus carpio,* and competitive events are only conducted on dams where this species is abundant (Visagie, *pers comm*, 2010).

Figure 3.2 Bank anglers on Lake Gariep. (Source: SAIAB, O.Weyl)

Carp angling

Carp angling is a form of bank angling for which participants use similar gear, are also restricted to a maximum of two rods and ground-bait areas before and during fishing, but which exclusively targets carp. Only common carp *Cyprinus carpio* (scaled-, mirror- and leather- morphs) and grass carp *Ctenopharyngodon idella*, a recent invader of the Vaal system, of over 1.5kg are eligible for weigh-in at competitions. Fishing teams, comprising two people, fish within an area, referred to as a "peg", that is between 20 m and 70m in width. Points are allocated for fish caught within the peg, and the team with the heaviest bag weight (all fish retained in the keep net) is allocated one point, the next heaviest bag is allocated two points etc, such that the team with the lowest points is the victor (F. Visagie, SAFBAF Secretary, *pers comm*, 2010).

Figure 3.3 Rod and reel used for carp angling on a specialised stand. The insert shows a hair-rig that separates hook from bait in this form of angling (Insert source: http://en.wikipedia.org/wiki/Hair_rig)

The duration of the angling period varies between different tiers of competition, but the minimum angling time is 24 hours at club level, 48 hours at provincial level and 72 hours at national level tournaments. An important regulation is that no bait may be placed on the hook; bait must be attached to the hook in the form of a hair rig which allows the bait to be presented without sitting directly on the hook (Figure 3.3, insert).

Match angling

As with bank angling, match anglers attempt to catch as many fish (regardless of species) with as high a mass as they can within a certain time frame. Match anglers commonly fish off elevated platforms erected in the water a short distance off the bank; from these they cast into and ground bait their allotted area or “peg” (Figure 3.4). Here ground-baiting or “feeding” may only be done using catapults to launch the bait or alternatively using hands. Participants may also only use one rod at a time.

Figure 3.4 A match angler playing a fish during the Women‟s World Match Angling Championships, Bloemhof Dam, 2010 (Source Mr. Fred Visagie, Secretary SAFBAF).

Two distinct types of fishing rod are used by match anglers: (1) a conventional rod and reel which is actively cast and (2) a 14 m pole with internal elastic that is used to "ship" out a float without any casting action (T Spencer, SAFBAF Convenor, *pers comm,* 2010).

Feeder fishing

Feeder fishing is a recently-formed facet of competitive bank angling in South Africa. The aim of feeder fishing is the same as bank angling; however, the angler uses only one rod and reel, a hook, and a single baiting device known as a "feeder". This feeder is typically in the form of a small cage into which bait is placed and cast out 25–50m in front of the angler, within his allotted area or "peg". Ground baiting the area is only permitted in the absence of a hook. As with match angling, the anglers commonly fish off erected platforms within small, defined pegs (T. Spencer, Competitive angler, *pers comm*. 2010).

Dams of importance to SAFBAF

It must be recognised that bank angling is driven by the availability of the alien common carp, *Cyprinus carpio* (Figure 3.5). This species was the first of the popular alien recreational angling species to be introduced into South Africa (Winker, 2010; Skelton and Weyl, 2011; Van Rensburg et al., 2011). Since its official introduction in 1896, this species has been spread widely by anglers, and their ability to invade a variety of different habitats has resulted in their presence in almost every river system in the country (McCafferty et al., 2010; Skelton and Weyl, 2011). During 2009, priority areas for sport angling were discussed with SASACC during consultative meetings for NEM:BA planning (McCafferty et al., 2010). Dams were prioritised according to their level of utilisation – a ranking process for each dam according to the type of organised angling tournaments held at the dam, e.g. club, provincial, regional, national and international. The resultant priority list is available in Appendix I.

Figure 3.5 A recreational angler displaying the preferred target of South African bank anglers, the common carp *Cyprinus carpio*.

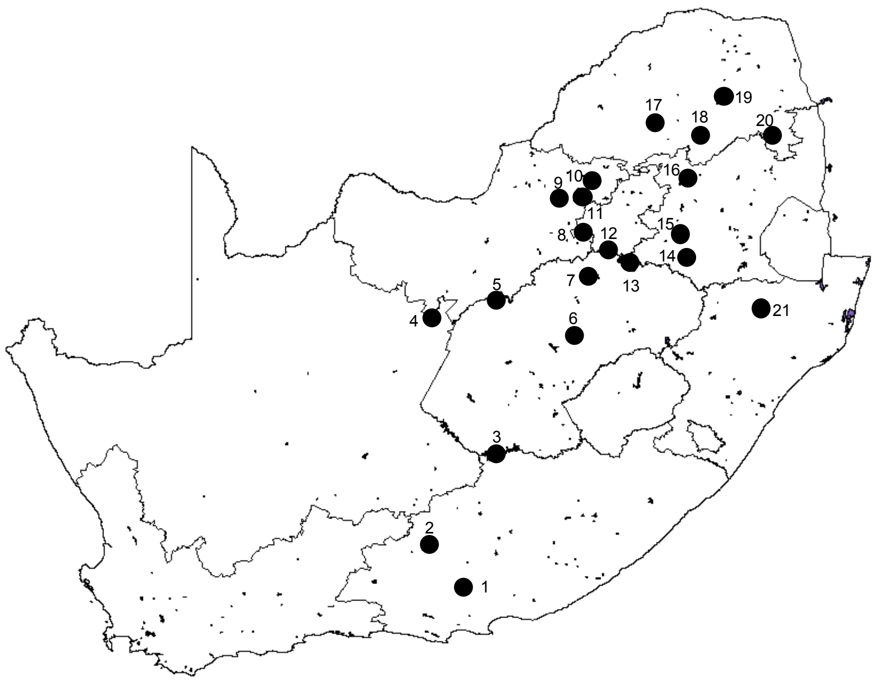
A summary of the number of dams, their ranking following consultation with organised angling officials, and their average surface area is presented in Table 3.2.

Table 3.2 Ranking of 172 dams in order of importance by the South African Sport Anglers and Casting Confederation (SASACC). Importance is ranked from 1=highest, with national and international fishing tournaments to 5=not important or only occasionally used by social recreational anglers.

	Full Supply Capacity (million m^3)			
Rank	**Smallest**	**Largest**	**Average**	**Number of Dams**
1	5	5340	571	22
2	1	480	111	31
3	2	2616	159	38
4	1	3171	240	32
5	1	333	59	49

In total, only 22 dams were considered as high priority to the SAFBAF fraternity in that they were used to host national and international competitions under the SASACC and were used frequently by recreational anglers. Others, summarised in Appendix I, are used at varying levels but on a national scale, only 172 dams were recognised as potential angling venues by the people consulted during the NEM:BA process.

Figure 3.6 illustrates the dams which were considered high priority bank angling dams in South Africa, and a list of these dams is provided in Table 3.3. The majority of high priority bank angling impoundments are located either in the Free State, North West, and Mpumalanga provinces, or in the adjacent lowveld in the Limpopo province. Only two impoundments, Darlington Dam and Van Ryneveld Dam, were located in the Eastern Cape (excluding Gariep Dam which borders the Free State) and one in KwaZulu-Natal.



1. Darlington
2. Van Ryneveld
3. Gariep
4. Spitskop
5. Bloemhof
6. Allemanskraal
7. Koppies
8. Klipdrif
9. Olifantsnek
10. Bospoort
11. Buffelspoort
12. Vaal Barrage
13. Vaal Dam
14. Grootdraai
15. Trichardtsfontein
16. Loskop
17. Doorndraai
18. Flag Boshielo
19. Klaserie
20. Tzaneen
21. Klipfontein

Figure 3.6 Dams of highest priority to the South African Freshwater Bank Angling Federation. Names of dams are provided in Table 3.3.

Mean full supply capacity and surface area are included in tables 3.2 and 3.3 respectively to illustrate that SAFBAF associated angling facets generally utilise dams with large dams with large surface areas (>1 000 ha) which is probably a result of the considerable area of shoreline required for competitive bank angling events.

Table 3.3 Summary of dams, and their surface areas (hectares), of highest priority to the South African Freshwater Bank Angling Federation (SAFBAF). Numbers indicate position on map (Figure 3.6).

No.	Impoundment	Province	Surface Area (ha)
1	Darlington	EC	4 000
2	Van Ryneveld	EC	1 000
3	Gariep	EC/FS/NC	35 964
4	Spitskop	FS	2 531
5	Bloemhof	FS/NW	4 270
6	Allemanskraal	FS	3 264
7	Koppies	FS	1 362
8	Klipdrif	NW	471
9	Olifantsnek	NW	272
10	Bospoort	NW	379
11	Buffelspoort	NW	136
12	Vaal Barrage	FS/GP	1 349
13	Vaal Dam	FS/GP/MP	32 275
14	Grootdraai	MPU	5 500
15	Trichardtsfontein	MPU	246
16	Loskop	MPU	2 428
17	Doorndraai	LIM	561
18	Flag Boshielo	LIM	2 200
19	Klaserie	LIM	118
20	Tzaneen	LIM	1 164
21	Klipfontein	KZN	296

For comparative purposes the proposed NEM:BA map for the primary target of the bank angler, *C. carpio*, and the zones within which it is legitimised is provided in Figure 3.7. High priority bank angling dams, displayed in Figure 3.6, are all categorised in the light green zone indicating that there is very low restriction on bank angling activities for this species in these

Artificial lure angling

Organised artificial lure angling in South Africa is comprised of 11 Provincial bodies affiliated to SAALAA. SAALAA"s mandate is to represent all aspects of competitive artificial lure angling in South Africa which ultimately involves the hosting of national championships which act as trials for the selection of the national team (Protea anglers) for international competitions (B.Venter, SAALAA, Development and Transformation Officer, *pers comm*, 2011). In artificial lure angling the participant attempts to catch all of the species present within a particular water body, irrespective of the size that a species may attain, using only artificial lures which imitate natural food items or induce an aggressive strike from a species (Figure 3.8). Nationally there are 16 registered clubs containing 484 anglers that compete at various levels of the sport (Table 3.4). Participants fish either from boats or from the shoreline. Competition formats vary depending on the nature of the event i.e. club, provincial, national. Generally, points are awarded based on the number of different species captured and the weight of a particular species. In addition, different points may be allocated depending on whether the fish was caught from a boat or the shore.

Table 3.4 Number of SAALAA affiliated clubs and registered anglers within those clubs by province (as of 2010) (Source: Mr. Bernard Venter)

Province	Clubs	Registered Anglers
Kwazulu Natal	3	172
Northern Gauteng	2	112
Mpumalanga	3	89
Central Gauteng	1	23
Western Province	1	19
Limpopo	1	11
Central North West	1	19
Free State	0	0
Gauteng	1	10
Boland	2	18
Northern Natal	1	11
Total	**16**	**484**

Figure 3.8 A wide variety of artificial lures used in freshwater angling. (Source: SAIAB, O. Weyl)

Bass angling

Bass angling focuses exclusively on the alien largemouth bass *Micropterus salmoides*, the smallmouth bass *Micropterus dolomieu* and spotted bass *Micropterus punctulatus*. These fish were introduced between 1928 and 1937 and have been widely stocked throughout South Africa by early Government initiatives and later, by anglers. Bass are now present in all major river catchments (Skelton and Weyl, 2011). Largemouth bass are the most widely distributed species and are thus the most common target species for anglers. The principles of bass angling are very similar to those of artificial lure angling whereby fishing is conducted using a range of artificial baits. Competitive bass angling is conducted exclusively using high-powered, purpose-built "bass-boats" which allow for large amounts of water to be covered in short spaces of time.

Formalised bass angling in South Africa can be separated into two categories: events administered and run under the auspices and regulations of the South African Bass Angling Association (SABAA) which are held to determine provincial and national angling teams and champions; and “money” events which include the Bass Equalizer Tournament Trail (BETT), the Bass Fishing South Africa (BFSA) Money Trail, and the SA Bass Cast-for-Cash Tournament Trail which offer cash and/or other prizes for the winners of events. This structure is summarised in Figure 3.9. Competitions, their regulations and frequency, differ between the different organisational bodies.

Non-money events

The South African Bass Angling Association (SABAA) is the national administrative body for organised bass angling. The organisation is comprised of five divisional bodies that incorporate different areas within South Africa and include: Northern division (Limpopo, Gauteng North, Mpumalanga); Southern Division (Gauteng Central, Gauteng South, Northern Free State, North West Northern Region); Western division (Western Province, Boland, Northern Cape); Eastern division (Eastern Cape, Border, and Southern Cape); Kwazulu Natal division (Midlands, South Coastal, North Coastal, Northern Kwazulu Natal).

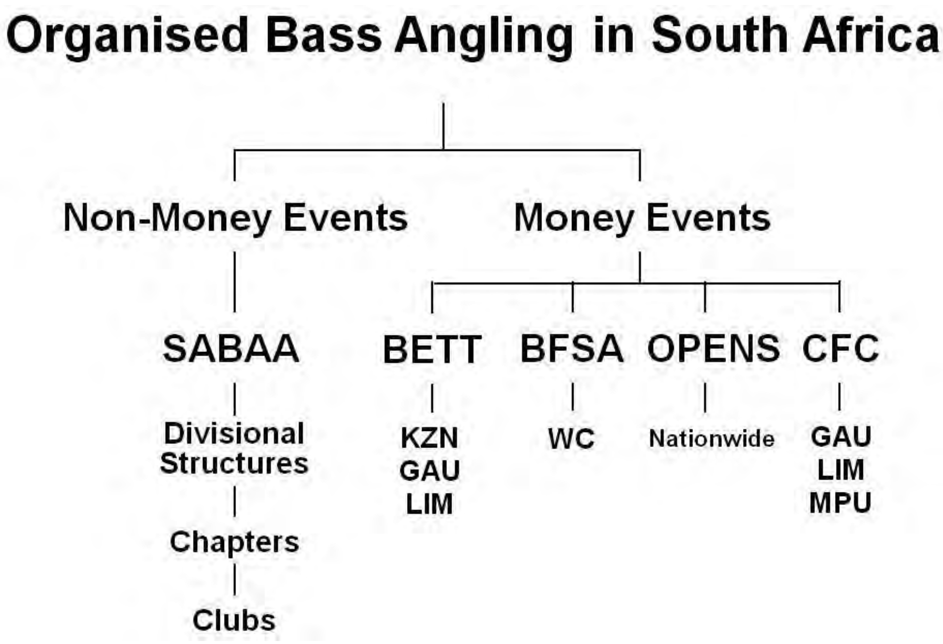


Figure 3.9 The structure of organised bass angling in South Africa (SABAA = South African Bass Angling Association; BETT = Bass Equalizer Tournament Trail; BFSA = Bass Fishing South Africa Money Trail; CFC = SA Bass Cast-for-Cash Tournament Trail; GAU = Gauteng; KZN = KwaZulu-Natal; LIM = Limpopo; WC = Western Cape).

These divisional structures themselves are subdivided into regional chapters affiliated to SABAA, the eligibility of which is determined by a minimum number of affiliated SABAA members. Only anglers affiliated to a recognised SABAA chapter may fish competitively.

Table 3.5 Number of Affiliated Clubs and total number of Registered Anglers (as of 2010) (Source: Mrs. Wendy Watson, Secretary SABAA) (*missing data were not supplied by province*).

Division	Chapters	Registered Anglers
Northern	10	
Southern	8	
Western	5	
Eastern	5	
Kwazulu Natal	10	
Total	**38**	**1184**

Membership within SABAA affiliated clubs is then subdivided into junior, silver and gold card categories. Anglers who purchase a silver card from the Association may fish competitively in club events; gold card holders are allowed to fish in all competitive events (club; divisional; nationals) and are therefore eligible for the receipt of Provincial and National colours, an award which entitles that person to represent their province and/or South Africa in competitive bass angling. There are currently 1184 SABAA-registered bass anglers in the country (Mrs. W.Watson, SABAA Secretary, *pers comm*, 2011).

SABAA affiliated events are typically held over two days, each day comprising an eight hour session, although session length this may vary between six and eight hours at the discretion of the organisers. Results are determined in the following fashion: each angler may weigh in a bag-limit of five fish over 300mm total length. Bass are kept in live-wells within the boat and selectively culled, or released, such that, if captured, a larger specimen is substituted for a smaller specimen in order to increase the overall weight of the bag yet remain within the limit stipulated. Scores are determined based on the overall weight of the bag and the number of fish within the bag such that Total Score = Total Bag Weight(kg) + 1(No. of fish) subject to the fish being alive at the time of weighing. Dead fish can be weighed but the extra point "+1" is not awarded to the angler. At the end of the competition, anglers‟ scores are summed to determine final placements.

The frequency of competitive events administered through SABAA is dependent on the level or tier of competition, be it club, divisional, or national. Clubs affiliated to SABAA commonly hold monthly competitions in order to determine their best anglers over the course of a season. These anglers, subject to the possession of an appropriate silver or gold card, then fish in divisional competitions in which the best anglers from different regions within a division compete against each other and are selected to compete at a national level. Divisional events are typically held four times a year. The top ten anglers from each division then compete in the nationals. From the nationals event, which is held annually, anglers are selected to represent either the Presidents or Protea team and thus achieve national colours for bass angling.

Money events

BETT circuit and competition format

The Bass Equalizer Tournament Trail was established in 2005 and operates separately in three provinces namely Gauteng, Kwazulu Natal, and Limpopo. Unlike SABAA events, in which individuals compete for placements, BETT tournaments involve teams of two anglers who do not have to be affiliated to any club or other body. At present, membership on the BETT circuit over the three provinces totals 462 anglers. The circuit is comprised of nine tournaments, at the end of which the top 20 team‟s are selected to compete in the season-end

"Classic". The winning team at the classic are then crowned "Anglers of the Year" and receive a cash prize.

BETT events are typically held over the course of one day. Similarly to SABAA affiliated events, there is a five fish bag-limit and fish must be greater than 300mm to be eligible for weigh-in. Scores are determined based on the weight of the overall bag such that Total Score = Total bag weight. Dead fish are not weighed, and anglers may be penalised one point at the discretion of the competition organiser if dead fish are presented to the weighmaster.

Bass Fishing South Africa (BFSA) Money Trail

The BFSA Money Trail is a series of monthly competitions held in the Western Cape. As is the case with the BETT circuit, the Money Trail is a two-angler team event open to any participants. Events comprise one eight hour session with a five fish bag-limit; scores being determined based on the overall weight of the teams bag. Cash prizes drawn from anglers‟ entry fees are then awarded to the competitions top five teams.

SA Bass Cast-for-Cash (CFC) Tournament Trail

Cast-for-Cash tournaments comprise a series of monthly, one-day tournaments held separately in three provinces: Gauteng, Limpopo, and Mpumalanga. Events are contested by teams of two anglers although anglers may fish alone. Cash prizes, drawn from anglers‟ entry fees, are allocated to the five teams with the heaviest five-fish limit bags – scores are determined based on the weight of the bag only. The trail is a 10-event season culminating in a final competition, the "Champion of Champions" event, contested by the top 20 teams of the season.

Opens

In addition to SABAA and money trail events, large bass fishing competitions are held annually on a few large impoundments, notably Albert Falls, Clanwilliam, Groenvlei Lake, Inanda, Theewaterskloof, and Wriggleswade Dam, which are "open" to the public. These competitions are called "Classics" and generally attract large sponsorships and commensurate prizes for competitors. Rules and regulations for these competitions are generally similar to those for SABAA competitions with a three or five fish bag limit and a minimum size of >300mm. Prizes are usually awarded for the heaviest bags as well as the biggest fish of the competition.

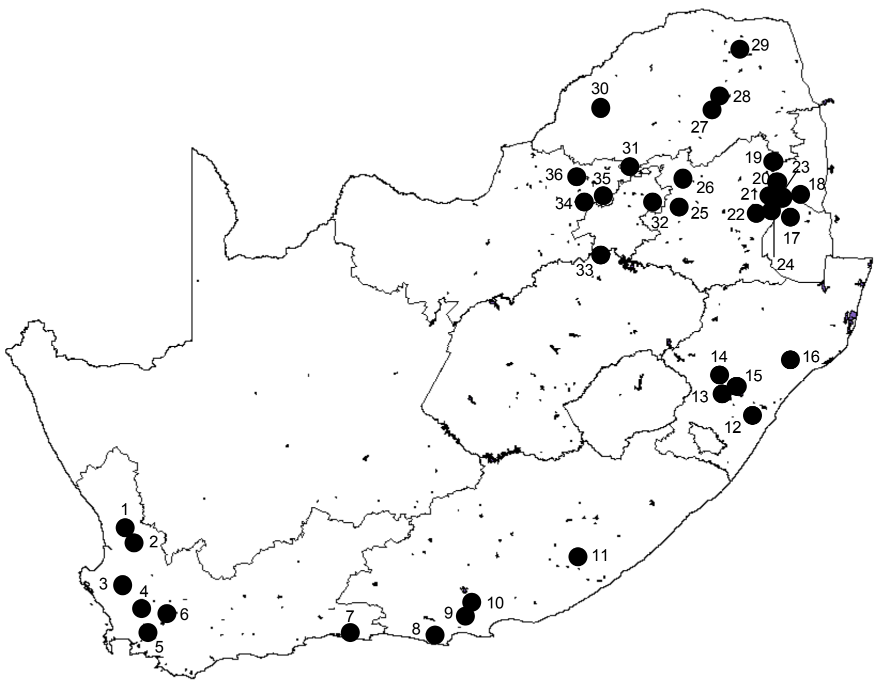
Dams of importance to bass angling

While bass angling is undertaken in many small farm dams and rivers we focus on those water bodies that are considered of importance by members of organised angling, in this case SABAA. Therefore, dams of significance are larger bodies of water (>20 hectares) which have banks or shorelines that allow the angler to launch a vessel and allow for the use of outboard motors. Nationally, only 35 dams were considered of high importance and another 47 of medium level importance by stakeholders consulted during the NEM:BA demarcation process in 2009 (Table 3.6).

Table 3.6 Ranking of 172 dams in order of importance by the South African Bass Anglers Association (SABAA). Importance is ranked from 1 (highest, with national and international fishing tournaments) to 5 (occasionally used by recreational fishers). Source: SAIAB, Dr E. Swartz unpublished NEM:BA planning data.

Full Supply Capacity (million m^3)				
Rank	Smallest	Largest	Average	Number of Dams
1	1	480	140	36
3	1	2616	185	47
5	2	5340	224	89

Figure 3.10 illustrates those dams which were considered as high priority bass angling dams in South Africa, and Table 3.7 provides a summarised list of these dams.



1. Bulshoek
2. Clanwilliam
3. Misverstand
4. Voelvlei
5. Theewaterskloof
6. Quaggaskloof
7. Groenvlei
8. Elandsjacht
9. Loerie
10. Sand River
11. Wriggleswade
12. Inanda
13. Midmar
14. Craigie Burn
15. Albert Falls
16. Goedertrouw
17. Maguga
18. Driekoppies
19. Injaka
20. Klipkoppies
21. Ngodwana
22. Nooigedacht
23. Shaya Longubo
24. Vygeboom
25. Witbank
26. Loskop
27. Ebenezer
28. Tzaneen
29. Nandoni
30. Mokolo
31. Rust de Winter
32. Bronkhorstspruit
33. Vaal Barrage
34. Buffelspoort
35. Hartbeespoort
36. Roodekopjes

Figure 3.10 Dams of highest priority to the South African Bass Angling Association. Groenvlei (Number 7) is a natural lake but included due to its high importance to the bass angling facet.

In comparison to the spatial distribution of high priority bank angling dams, bass angling dams of importance are located in eight provinces in the country (including dams located on province borders). The largest proportion (26%) of these dams is located in Mpumalanga followed by the Western Cape which has (16%). Gauteng has the lowest number of high priority bass dams; however, this is probably mitigated by its close proximity to the cluster of dams in the North West Province, Limpopo, and Mpumalanga. Mean full supply (Table 3.5) and surface area of high priority impoundments (Table 3.6) highlight the fact that organised bass angling is largely conducted on large impoundments, with surface areas greater than 100 ha and averaging approximately 1 000 ha.

Table 3.7 Summary of dams, and their surface areas (hectares), of highest priority to the South African Freshwater Bank Angling Federation (SAFBAF). Numbers indicate position on map (Figure 3.10). Groenvlei is a natural lake but is included due to its high importance to the bass angling facet.

No.	Impoundment	Province	Surface Area (ha)
1	Bulshoek	WC	180
2	Clanwilliam	WC	1 124
3	Misverstand	WC	255
4	Voelvlei	WC	1 524
5	Theewaterskloof	WC	5 059
6	Quaggaskloof	WC	1 688
7	Groenvlei	WC	
8	Elandsjacht	EC	570
9	Loerie	EC	
10	Sand River	EC	33
11	Wriggleswade	EC	1 000
12	Inanda	KZN	1 426
13	Midmar	KZN	1 564
14	Craigie Burn	KZN	207
15	Albert Falls	KZN	2 354
16	Goedertrouw	KZN	1 200
17	Maguga	SWZ	1 042
18	Driekoppies	MPU	1 870
19	Injaka	MPU	811
20	Klipkoppies	MPU	235
21	Ngodwana	MPU	87
22	Nooitgedacht	MPU	763
23	Shaya Longubo	MPU	136
24	Vygeboom	MPU	670
25	Witbank	MPU	1 211
26	Loskop	MPU	2 428
27	Ebenezer	LIM	386
28	Tzaneen	LIM	1 164
29	Nandoni	LIM	1 570
30	Mokolo	LIM	829
31	Rust de Winter	LIM	473
32	Bronkhorstspuit	GAU	861
33	Vaal Barrage	GAU	1 349
34	Buffelspoort	NW	136
35	Hartbeespoort	NW	2 063
36	Roodekopjes	NW	1 571

The NEM:BA map outlining the proposed zones in which the presence of the most common target species for organised bass anglers, largemouth bass *M. salmoides*, is legitimised is presented in Figure 3.11.

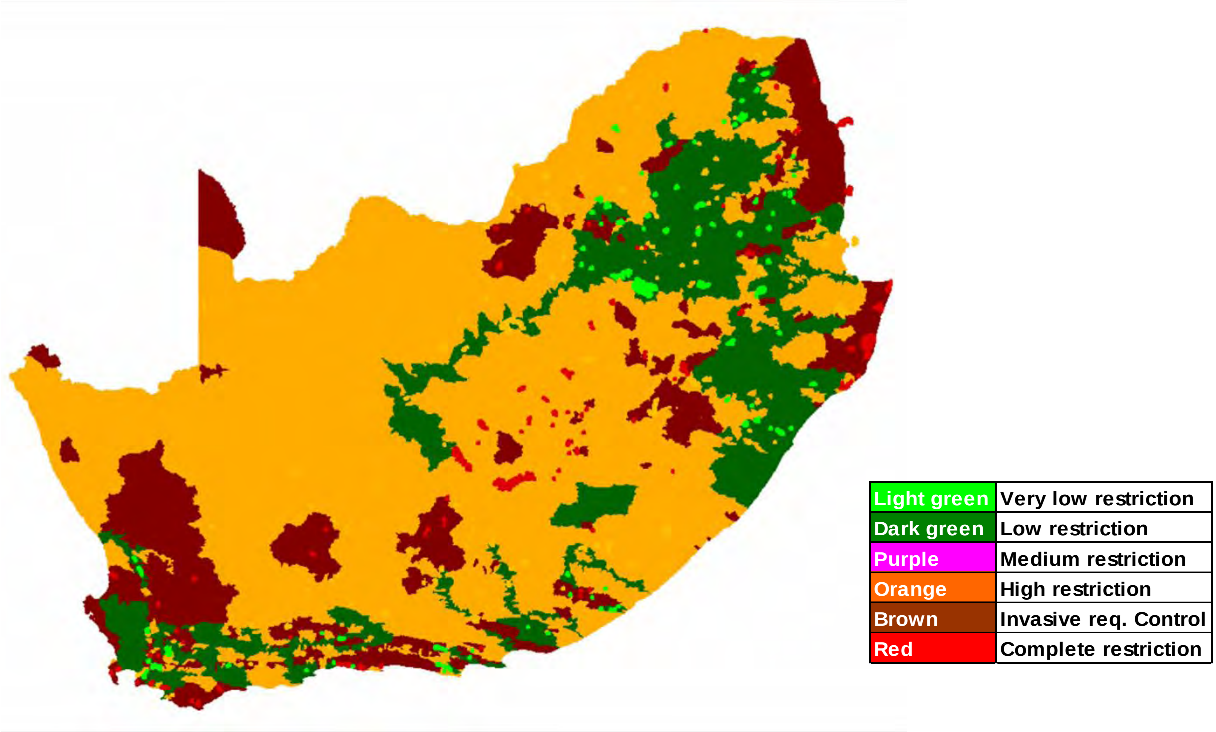


Figure 3.11 National Environmental Management:Biodiversity Act (NEM:BA) map displaying demarcated zones governing the management of *Micropterus salmoides* in South Africa.

The map, in conjunction with Figure 3.11, illustrates that all of the priority dams have been designated "Light green" and thus, "Very low restriction" status. All of the dams considered high priority, as well as others which are ranked lower, have been classified as "Very low restriction". In comparison to the NEM:BA map for *C. carpio* there is far more restriction governing the use of the *M. salmoides* resource which is due to the threat it poses to native fish fauna through outcompeting and from direct predation (Bruton and de Moor, 1988; Skelton, 2001; Weyl, 2011). However, given the requirements of competitive bass anglers at, least in terms of the water bodies they prefer to utilise, higher restrictions on the species does not impact them as their activities are largely concentrated on relatively few, large impoundments in each province.

Fly fishing

Fly fishing is an activity in which an artificial “fly”, is used to catch a variety of different species, both in freshwater and saltwater. The fly is nearly weightless and requires a distinctive casting technique and tackle different to that used in other facets which employ artificial baits (Mills, 2000, Figure 3.12).

Figure 3.12 The author flyfishing for rainbow trout *Oncorhynchus mykiss* in a mountain stream in the Eastern Cape. The insert shows a “fly”, in this instance a dry fly, which is designed to imitate an adult aquatic insect. (Insert: http://www.flycurrents.blogspot.com)

All organised fly fishing in South Africa is administered through the SAFFA and they are the only legal entity that may issue Provincial and National colours in this angling discipline (Mrs S Babich, Vice President, SAFFA, *pers comm.*, 2011). The association is comprised of the provincial bodies: the Kwazulu Natal Fly Fishing Association; Western Province Fly Fishing; Boland Fly Fishing; Central Gauteng Fly Fishing; Limpopo Fly Fishing Union; and

Gauteng North (www.fishingowl.co.za). In order to participate competitively, anglers must be affiliated to a club that falls under the auspices of a provincial structure. All rules and regulations governing competitive fly fishing in South Africa are those outlined by the international fly fishing body under FIPS-Mouche (Mrs S Babich, Vice President, SAFFA, *pers comm*, 2011).

Competitive fly fishing is different from other facets in that anglers are accompanied by marshals and upon capture fish are immediately measured for length (not weighed) and returned to the water by the marshal. Points are awarded for number and size of fish captured and may vary depending on the species in question. The international competition format consists of two, three-hour sessions held over three days (http://www.fips-mouche.com). Commonly, sessions are held on rivers with at least one session held on an impoundment or lake (http://www.fips-mouche.com). In the case of the river session, anglers are assigned a "beat" which determines the area in which they are allowed to fish – this may vary depending on the competition venue. Lake sessions are typically conducted using boats carrying two anglers. Competitive fly fishing is conducted exclusively in freshwater and the target species are commonly salmonids, e.g. trout, although in South Africa several events involve the capture of yellowfishes (Mrs S Babich, Vice President, SAFFA, *pers comm*, 2011).

3.3.3 Recreational boat angling

A facet of recreational freshwater angling that is not covered under the main organisational body for freshwater anglers is boat angling. Information on this sector was difficult to source because these anglers normally associate with marine angling clubs. The Eastern Province Light Tackle Boat Angling Association"s (EPLTBAA) utilisation of Darlington Dam in the

Eastern Cape is, however, a good example of this activity (Figure 3.13). The EPLTBAA utilises this dam for three of their league events every year. From January 2000 to October 2008 there were three boat angling competitions per year. During these competitions anglers generally camp on the lakeshore and fish on two days. Anglers target barbel *C. gariepinus* and common carp *C. carpio* and catches are separated by species. On Darlington Dam this sector accounts for most of the 150 annual boat launches and approximately 720 angler days per year, or 33% of the fishing effort on the dam. Their catches are either donated to the local community or are released.

Figure 3.13 Boat anglers weighing their catches at an annual fishing competition.

3.4 CONCLUSION

The role of recreational anglers as stakeholders with inherent interest in fisheries has been recognised worldwide (Granek et al., 2008), and incorporating anglers into management and development of these resources has been shown to increase the success of resulting policies and regulations (Sullivan, 2003).

Formalised freshwater angling in South Africa is a highly organised, multi-faceted activity, and the functionality of its administrative structures provides further insight into the economic impact these activities have, as highlighted in Chapter 2. It is this high level of organisation that can assist not only in ensuring that the interests of anglers as stakeholders in inland fisheries are recognised, but also in future research into the development and management of these fisheries.

Given the new mandate outlined by the Department of Agriculture, Forestry and Fisheries (DAFF) regarding the development of inland fisheries in South Africa (see Chapter 1), assessments of existing fisheries, the characteristics of user groups, as well as the status of fishery resources are important in providing frameworks for decision-makers such that equitable and conscientious development goals and management schemes are implemented. This chapter has outlined the highly structured nature of formal angling organisations and administration in SA, and it is this level of organisation, with the aid of willing angling representatives and officials, which can supplement fisheries assessments through the dissemination of competition catch records. The utility of such fisheries dependent data is assessed in Chapter 4.

CHAPTER 4:

Assessment and analysis of South African fisheries-dependent recreational angling catch data.

4.1 INTRODUCTION

The importance of recreational angling fisheries, both from an economic impact perspective and the dynamic nature of its organisational structure, were discussed in Chapter 2 and 3. Given the significance of this sector, an assessment of the fishery resource is warranted.

A descriptive summary of the fishery user group is an often ignored aspect, but important in understanding the utilisation of fishery resources (Martin, 2001; Ellender, 2008). Comparisons between user groups and temporal utilisation patterns in different recreational fisheries provide a more holistic idea of the extent and significance of resource utilisation, an important consideration for future planning and management.

Fisheries assessments are typically conducted to determine the status of a fishery (King, 1995), and catch and effort surveys form a large component of investigations into population dynamics, and more particularly, abundance estimates for different fisheries (Quinn and Deriso, 1999). Approaches to estimating indices of abundance commonly utilise fisheries-independent data with a randomly stratified design (Steffanson, 1996; Maunder and Langley, 2004). However, such data are largely unavailable for South Africa"s inland fisheries, and therefore constructing indices of abundance for different impoundments is subject to the availability of fisheries-dependent catch data, an approach commonly used in the assessment of inland and coastal fisheries (Maunder and Punt, 2004). Assessments of recreational fisheries can involve estimation of measures which reflect angling quality other than catch rate, including average weight of fish, proportion of large fish, and probability of capture (Stevens, 1966; North, 1980; North and Hickley, 1989; Spencer and Spangler, 1992; Kerr, 2004; Cain, 2009; Hickey, 2009). Estimates such as these, in conjunction with catch rate information, could be invaluable in determining the relative quality of different fisheries, and what factors may account for varying degrees of angler success in different impoundments.

These abundance indices, typically represented as catch-per-unit-effort (*CPUE*) estimates, provide important baselines against which the future state of individual fisheries can be assessed. In addition, *CPUE* can be correlated with physical and chemical characteristics defining a system, allowing for inference on the relationship between abundance and these explanatory variables (Steffanson, 1996; Campbell, 2004). Fisheries-dependent catch data are, however, only suitable for inferring patterns in relative abundance if the data have been adjusted to account for catch rate-influencing factors other than abundance (Punt et al., 2000; Campbell, 2004; Winker, 2010). In the case of angling competition catch data, *CPUE* estimates must therefore be standardised such that spatial, temporal and other effort factors are accounted for in order to make abundance indices comparable between systems. Causal relationships between standardised *CPUE* and environmental characteristics of different systems can then be investigated.

The first objective of this chapter is to use competition catch data to describe utilisation trends of competitive recreational angling events by investigating patterns in participation, temporally and spatially, and investigating the scale and frequency of different events and tournament circuits. The second objective is to provide baseline *CPUE* data for future assessments of the recreational fishery. The third objective is to derive standardised estimates of abundance and indicators of angler success in different impoundments, and to investigate their relationship with physico-chemical explanatory variables. This information is then used to determine the potential for a predictive model of abundance and angler success in the absence of fisheries-dependent information, which model could aid in identifying dams suitable for future development of fisheries.

4.2 MATERIALS AND METHODS

Preliminary assessment of angling catch data applicability

In Chapter 2, the need for catch rate and/or harvest data for assessments of existing fisheries and for management decisions regarding the development of new fisheries was stressed. Competition catch data may provide important sources of information for assessments of inland fisheries. Given that different facets target different species and that competition formats and angler objectives vary between them, a preliminary assessment of the availability and utility of data from different angling competition formats for providing estimates of abundance was conducted. This preliminary assessment provided the framework on which data collection and analysis would proceed.

Contacts established in the synthesis of descriptive information contained within this chapter were additionally asked to submit competition catch data from their facet of interest; alternatively, referrals were made to representatives tasked with the compilation of catch records. Table 4.1 summarises the availability and utility of competition catch data from different facets in providing estimates of abundance (*CPUE*) based on facet-specific formats and regulations. Bank angling, including the carp angling facet, provided the best data for theoretical estimates of catch per unit effort (*CPUE*) as the total number of fish captured by an angler during a particular angling session was recorded.

Table 4.1 Summary of the type of data recorded at organised freshwater angling facets in South Africa including information on where (Dams, Rivers) competition events are held. Bank Angling* = conventional bank angling; match angling; feeder fishing; Dams** = events held primarily on dams with a few events held on rivers.

Facet	No. Fish Recorded	W/L Recorded	W/L Limit	Events	Utility	Availability
Bank Angling*	Total Fish	W - Total Fish	None	Dams	Good	Good
Carp Angling	Total Carp	W - Total Fish	None	Dams	Good	Poor
Bass Angling	Total Bass/Bag	W - Total Fish	Fish > 300mm	Dams	Good	Good
Artlure	Total No. of Spp	W - Biggest Fish/Spp	None	Dams**	Poor	Good
Fly Fishing	Total Eligible Spp	L - Total Eligible Spp	Fish > x Length	Rivers/Dams	Poor	Poor

The availability of bank angling data, in terms of the ease with which data could be obtained, was good. Catch records from the carp angling facet were, however, difficult to source. The availability of bass angling catch records, in comparison to other facets, was excellent and, while there is a fish limit imposed at events, both in terms of the number of fish that can be weighed and a minimum size limit, which has implications in terms of calculating total catch during a competition, catch rates of legal fish could still be determined and compared. The artlure angling facet awards points to anglers for the number of species and the size of the largest specimen of each species caught. Therefore, while the availability of data was good, its utility in determining *CPUE* was limited as the total number of fish caught by an angler during an event is not recorded. The utility of fly fishing catch records for the purposes of this study are questionable because the majority of the angling activities of this facet are conducted on rivers. Additionally, data from competitions were either not compiled or housed by a designated angling official and/or appeals for data from this facet were not responded to.

Given the preliminary assessment of data sources in organised recreational angling, efforts were focussed on obtaining bass and bank angling data from as many competitive events and for as many impoundments as possible based on their overall availability and utility.

General

Bass and bank angling catch data were collected using both on-site and off-site surveys. On-site surveys were conducted via personal attendance at competition events. After prior arrangement with event administrators, weigh-in stations were manned, fish were weighed and the results were collected directly from the weighmasters (officials appointed to regulate the weigh-in and ensure the process is unbiased). Box 4.1 provides a summary of the weigh-in process at bass fishing competitions and the rules and regulations. Off-site surveys largely consisted of meetings with organised bass and bank angling representatives and correspondence with these representatives via telephone and email. Catch records were sent via email or collected in person. In addition, catch records published by angling clubs and organisations on the internet were accessed online.

Box 4.1 A typical weigh-in station observed at competitive bass angling events in South Africa. Note the weighmaster in the background.

The weigh-in at competitive bass angling events is a carefully monitored process with strict regulations. On arrival at the weigh-in, anglers are required to place the tag given to them before the start of the angling day on a well-marked board which indicates that they have completed their session and are eligible for the weigh-in process. If a competitor is found not to have placed their tag on the board, they are disqualified regardless of whether they have completed the weigh-in process.

Only the competitor is allowed to handle his/her fish at the weigh-in and it is the competitors" responsibility to present the fish for weighing; weighmasters do not handle the fish. Identity discs or cards are presented to the weighmaster to ensure correctness of scoring. A minimum of two scales are required at National level competitions although this may vary at lower tier events depending on the number of participants and/or at the organisers" discretion. Scales are calibrated and accurate to the nearest 10g. Fish are returned directly to the water after weigh-in. All fish are released and dead fish are penalised. If observed to be suffering from barotrauma, fish are placed in a separate tank where an official may deflate the swim bladder through the insertion of a needle, after which the fish is released.

Analysis of bass angling catch records

Analysis of the bass angling catch records comprised two components:

1. A descriptive analysis of the available catch information in order to characterise competitive bass angling activities in South Africa.

2. Statistical analyses of the catch records encompassing:
    a. Measures of angler success.
    b. Standardised catch per unit effort (*CPUE*) indices to compare catch rates in different impoundments.
    c. Modelling with physical and environmental variables in order to determine their influence on angler success and *CPUE*.
    d. Investigating the potential for the development of a predictive model of *CPUE* incorporating identified influential physical and environmental variables using multiple regression analysis.

Descriptive analysis

Data were compiled in order to characterise competitive bass angling in terms of angler participation, both spatially and temporally. Spatially, the level of use of different impoundments was assessed in terms of competition formats and attendances, while seasonal trends in participation were investigated to determine if there was a temporal dynamic to bass angling activities.

Statistical analysis

The conceptual framework for analysis of the catch records is presented in Figure 4.1.

The catch data compiled were divided into three datasets: (1) a binary dataset indicating the presence/absence (1 or 0) of catch, (2) a binary dataset indicating the presence/absence (1 or 0) of a limit bag; (3) a continuous dataset containing only positive *CPUE* observations.

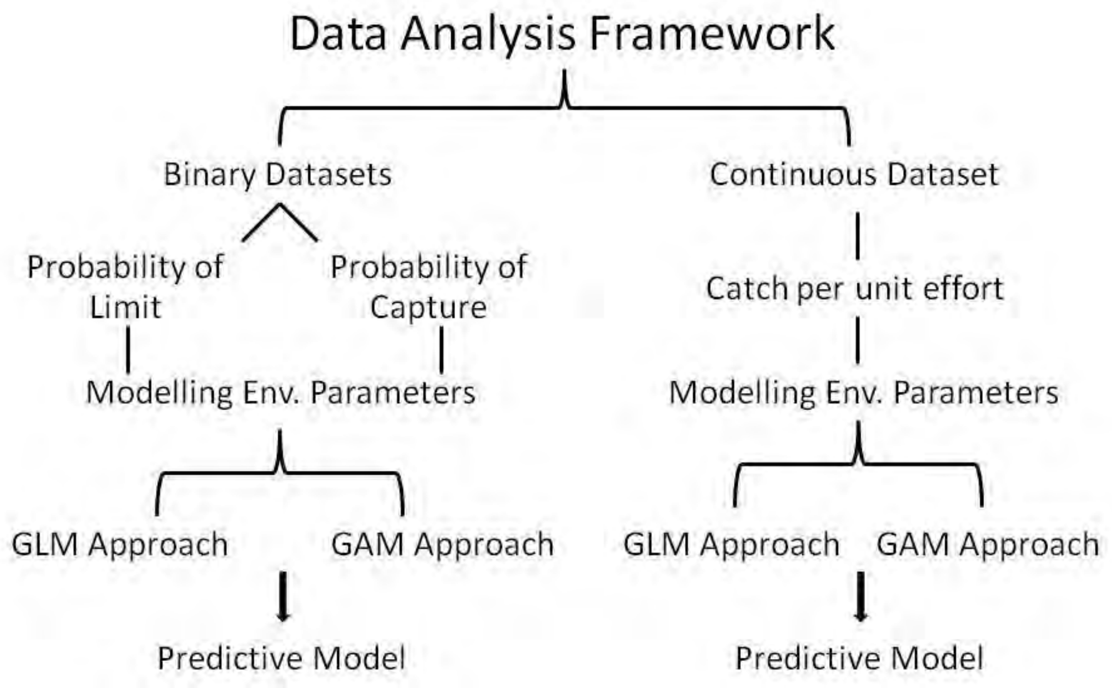


Figure 4.1 Conceptual design for the analysis of bass angling competition records with potential outcomes. GLM and GAM refer to generalised linear- and generalised additive models , respectively.which were used to standardise the data by modelling with environmental variables.

Datasets

Capture and Limit Probability

Angler success was defined as the probability of an angler catching at least one fish during one day of angling. Data were excluded for this analysis if they comprised catch records that were aggregated for two or more days. A binomial dataset was created such that:

$PC = 1 = \geq 1\ fish$

$PC = 0 = 0\ fish$

where *PC* is the determinant of angler success.

Limit probability was defined as the probability of an angler capturing a limit bag of five fish during one day angling. By necessity, catch records used for these analyses had to include information on the numbers of fish caught and, as with angler success, could not be aggregated over 2 or more days such that differences in numbers could not be distinguished for each day. Furthermore, as a pre-standardisation measure, only data from competitions with five-fish limits were analysed for this component. A binomial dataset was created such that:

PLIM = 1 = Limit bag (*5 fish*)

PLIM = 0 = Non-limit bag (*0–4 fish*)

where *PLIM* is the probability of limit per impoundment.

For comparisons between impoundments and other bass fisheries, these statistics were combined with measures commonly implemented in assessments of bass fisheries in the United States of America (USA), namely the average weight of bass and the average winning bag limit per impoundment respectively.

Mean weight of fish was calculated per impoundment as:

$$\bar{x}_{fish} = \frac{total\ weight}{total\ numbers}$$

and average winning bag as:

$$\bar{x}_{Wbag} = \frac{Sum\ of\ winning\ bags\ (kg)}{Number\ of\ Events}$$

Catch Per Unit Effort (*CPUE*)

Catch per unit effort (*CPUE*) estimates for each dam were calculated such that:

$$CPUE\ (kg.angler^{-1}.h^{-1}) = \frac{catch\ (kg)}{time\ fished\ (h)}$$

or for competitions involving teams of two anglers:

$$CPUE\ (kg.angler^{-1}.h^{-1}) = \frac{catch\ (kg)}{no.anglers} / time\ fished(h)$$

A continuous dataset containing only positive observations was created for the *CPUE* data. Non-zero *CPUE* estimates were then calculated using a delta-model approach which adjusts the *CPUE* estimate by the probability of an angler having caught at least one fish (*PC*) (Maunder and Punt, 2004; Ellender et al., 2010a).

Modelling

Two modelling approaches were used to standardise the *PC, PLIM* and *CPUE* information: generalised linear models (GLMs) and generalised additive models (GAMs). GLMs represent the most frequently applied method to standardising catch per unit effort (*CPUE*) information (Maunder and Punt, 2004; Venables and Dichmont, 2004; Winker, 2010). The fundamental assumption of these models is that the response variable, in this case *PC*, *PLIM*, and *CPUE*, originates from a known statistical distribution (e.g. lognormal, gamma, binomial) and that expected values of *PC*, *PLIM*, and *CPUE* are derived from a linear combination of explanatory variables (Maunder and Punt, 2004). The relationship between the i^{th} value of the response variable Y_i and a combination of predictor variables X_i can be determined via a differentiable and monotonic link function such that:

$$g(\mathrm{E}(Y_i)) = \alpha + \mathbf{X}_i^{\mathrm{T}} \beta$$

where g represents the link function specific to the selected statistical distribution, and where α and β represent the intercept and vector of estimable coefficients respectively (Maunder and Punt, 2004; Winker, 2010).

GAMs are a less commonly implemented approach to standardising *CPUE* and differ from GLMs in that an additive predictor replaces the linear predictor used in GLMs such that:

$$g(\mathrm{E}(Y_i)) = \alpha + f_i(\mathbf{X}_i^{\mathrm{T}}\beta)$$

where f is a non-linear smooth function.

GAMs, through the integration of smoothing curves, allow for increased flexibility when modelling the curvature of the response surface of continuous predictor variables, and are partially non-parametric (Hastie, 2001;Maunder and Punt, 2004; Zuur et al., 2007; Winker, 2010). This is advantageous when the relationships between the predictor and response variables are unknown and non-linear – such relationships are estimated, unlike GLMs which are contingent on parametric assumptions defining their functional form (Zuur et al., 2007).

Choice of Error Distribution

As the dataset was comprised two components, a discrete, binary component (*PC* and *PLIM*) and a continuous component with only positive *CPUE* values, the choice of appropriate error distribution is contingent on the component being modelled. Binary presence/absence data were modelled as the product of a logistic regression with a logit link function using a binomial distribution (McCullagh and Nelder, 1989; Dobson 2002; Ellender, 2008; Winker, 2010).

A gamma distribution was selected for modelling the positive *CPUE* data. The log-normal is the most commonly used distribution when modelling catch rates, on the basis that the positively skewed nature of *CPUE* data lends itself to normalisation via natural logarithm transformation (Campbell, 2004; Maunder and Punt, 2004; Winker, 2010). However, the positive *CPUE* data obtained from bass competitions were characterised by high numbers of very small *CPUE* values (<0.05 kg.angler^{-1}.h^{-1}) which were problematic as they could not be normalised. This problem is common with log-normal approaches to standardising data that is highly positively skewed; it is commonly dealt with by adding a constant to the zero, or in this case very small *CPUE* values (Maunder and Punt, 2004). In order to determine which distribution was the most appropriate, trial models with log-normal and gamma distributions were created, and their goodness-of-fit measures were graphically assessed using quantile-quantile (Q-Q) plots (Dunn and Smyth, 1996; Ellender, 2008; Winker, 2010). The very low *CPUE* values tended to violate the assumptions implicit to log-normal distributions even after the addition of an arbitrary constant. Conversely, quantile residuals from untransformed positive *CPUE* values modelled using a gamma distribution better approximated the expected normal distribution.

Standardising nominal catch data

In order to determine what environmental variables may affect *PC*, *PLIM* and catch rates on different dams, nominal *PC, PLIM* and *CPUE* had to be standardised to account for fisheries-dependent variations including seasonal (e.g. year and month) and effort (e.g. day length, number of anglers, competition type) factors. Following standardisation of nominal data, *PC*, *PLIM* and *CPUE* per dam were modelled against environmental variables using GLMs and

GAMs in order to determine how well environmental variables could predict angler success as well as catch rates.

PC and PLIM

As the data were binomially distributed, explanatory variables were modelled using a logit link function for a binomial distribution of the form:

$$\mathrm{logit}(p(x_i)) = \ln\left(\frac{p(x_i)}{1-p(x_i)}\right) = \mathbf{W}_{\boldsymbol{i}}^{\boldsymbol{T}}\,\boldsymbol{\alpha}$$

where $\mathbf{W}_i$ is the vector that specifies the explanatory variables for the i^{th} value of the response variable x and $\boldsymbol{\alpha}$ denotes the vector of coefficients. The predicted PC can be calculated as a function of explanatory variables that are fixed to standard conditions, $\mathbf{W}_0^T$, and the estimated coefficient vector $\hat{\boldsymbol{\alpha}}$, such that:

$$\hat{p} = \frac{\exp(\mathbf{W}_{\mathbf{0}}^{\boldsymbol{T}}\hat{\boldsymbol{\alpha}})}{1+\exp(\mathbf{W}_{\mathbf{0}}^{\boldsymbol{T}}\hat{\boldsymbol{\alpha}})}$$

and

$$\hat{p} = \frac{\exp f_i(\mathbf{W}_{\mathbf{0}}^{\boldsymbol{T}}\hat{\boldsymbol{\alpha}})}{1+\exp f_i(\mathbf{W}_{\mathbf{0}}^{\boldsymbol{T}}\hat{\boldsymbol{\alpha}})}$$

for a GLM and GAM respectively.

CPUE Indices

The gamma error model was applied to the positive *CPUE* observations such that explanatory variables were modelled using a logarithmic link function of the form:

$$CPUE_{\text{pos},\, i} = \mu_i = \exp(\mathbf{X}_{\boldsymbol{i}}^{T}\, \boldsymbol{\beta})$$

Hence, the expected value for a standardised set of explanatory variables was calculated as:

$$\mathrm{E}[CPUE_{\text{pos}}(\mathbf{X}_{\boldsymbol{i}}^{T}\, \boldsymbol{\beta})] = \hat{\mu}_i$$

and

$$\mathrm{E}[CPUE_{\text{pos}}\, f_i\, (\mathbf{X}_{\boldsymbol{i}}^{T}\, \boldsymbol{\beta})] = \hat{\mu}_i$$

for a GLM and GAM respectively.

Model Selection

Models were selected using a stepwise forward selection procedure, in which predictor variables are either included or excluded in order to minimise the Akaike"s Information Criterion (AIC) score. The weight of evidence for each combination of predictor variables are defined as:

$$AIC = 2k - 2LL$$

where k is the number of model parameters and LL denotes the maximised log-likelihood function of the fitted model. The smallest possible AIC was used to determine the most parsimonious combination of explanatory variables. In addition, the quality of fit for different models was assessed through analyses of deviance (Ortiz and Arocha, 2004). Adding explanatory variables to the model results in deviance alterations from the null model and, as these alterations are approximately χ^2- distributed, the significance of additional variables or factors can be assessed using the χ^2 statistic (Winker, 2010). The quality of fit for different models can then be evaluated by comparing the deviance of these models to that of the null model which is fitted without any explanatory variables (Swartzman et al., 1992; Winker, 2010), such that:

$$R^2 = 1 - \frac{\text{Residual deviance}}{\text{Null deviance}},$$

where R^2, the coefficient of determination, refers to the relative predictive power of the model, the residual deviance refers to the total deviance explained by the model and null deviance refers to the deviance explained by the overall mean of the response (Winker, 2010).

Model Validation

The underlying assumptions of normality, homogeneity of variance and independence need to be verified for both GLMs and GAMs in order for the model predictions to be validated (Zuur et al., 2007). Post-hoc diagnostic statistics for the models in the form of residual plots were graphically assessed in order to determine if assumptions were violated.

Selecting environmental variables for modelling

Variables were compiled on the basis that they were readily attainable, simplistic physico-chemical variables that were available for each impoundment. Certain variables (e.g. total phosphorous) were only available for a limited number of dams and were therefore excluded from the analysis. Variables were obtained from the South African Department of Water Affairs, Reservoirs Database (2009) and "The South African Atlas of Climatology and Agrohydrology" (Schulze et al., 2008). For comparative purposes, special attention was paid to obtaining variables which have been commonly implemented in predictive yield models (e.g. conductivity, mean depth, temperature) (Table 4.2).

Table 4.2 A summary of physico-chemical variables which were used as predictor variables in the analysis of bass angling catch records.

Variable	Description
Alt	Altitude (m)
Rain	Mean annual rainfall (mm)
Cond	Mean conductivity (µS/cm)
TDS	Mean total dissolved solids (mg/L)
pH	Mean pH
Alkalinity	Mean alkalinity (mg/L)
Surface	Max. Surface area (ha)
Capacity	Max. Capacity (m^3)
Depth	Mean depth (m)
Temp	Mean annual air temperature (°C)
Age	Years since construction

Preliminary analyses revealed high correlations between conductivity and TDS, as well as pH and alkalinity. As information for TDS and alkalinity was available for fewer dams than conductivity and pH, they were excluded from the modelling process. Additionally, mean depth information for several of the impoundments was unavailable or erroneous. Capacity was, therefore, included as a variable, and its interaction with surface area was viewed as a proxy for depth.

All variables were log-transformed such that variances were independent of means, as well as to remove heteroscedasity (Sokal and Rohlf, 1995).Response variables were then tested for normality using the Shapiro–Wilk test.

In order to avoid modelling using environmental variables which were correlated, a correlation matrix was generated to determine which variables were suitable for inclusion (Table 4.3).

Table 4.3 Matrix correlation coefficients between physical and environmental parameters obtained for 21 bass impoundments. Marked correlations are significant at $p<0.05$ (Spearman rank correlation).

Variable	**Alt**	**Rain**	**Surface**	**Capacity**	**Temp**	**pH**	**Cond**	**Age**
Alt	1							
Rain	**0.49***	1						
Surface	0.24	0.32	1					
Capacity	0.26	**0.58***	0.42	1				
Temp	0.11	**0.54***	0.19	0.34	1			
pH	**0.46***	**0.48***	-0.01	0.19	0.1	1		
Cond	0.03	-0.02	-0.15	-0.07	-0.27	**0.70***	1	
Age	0.38	0.41	-0.05	-0.03	0.35	-0.26	-0.03	1

There was significant correlation between climate variables, rainfall and temperature, and altitude. Additionally, pH was highly correlated with conductivity. In order to remove the effect of redundant variables on the modelling process, Principal Component Analysis (PCA) was applied. PCA is a data reduction technique that aims to reduce the dimensionality of multiple, original variables by converting these values into a smaller set of uncorrelated variables called principal components, which account for most of the variability of the original variables (Joliffe, 2002; Zuur et al., 2007). The amount of variation explained by each of the principal components is illustrated in Figure 4.2. Most of the variation is captured in components 1 and 2. The choice of the number of components to include was graphically assessed using the "elbow of capture" principle, which suggested that the first three principal components, explaining 77% of the total variation in the data, should be extracted. A summary of the variables considered for modelling *PC*, *PLIM* and *CPUE* is presented in Table 4.4.

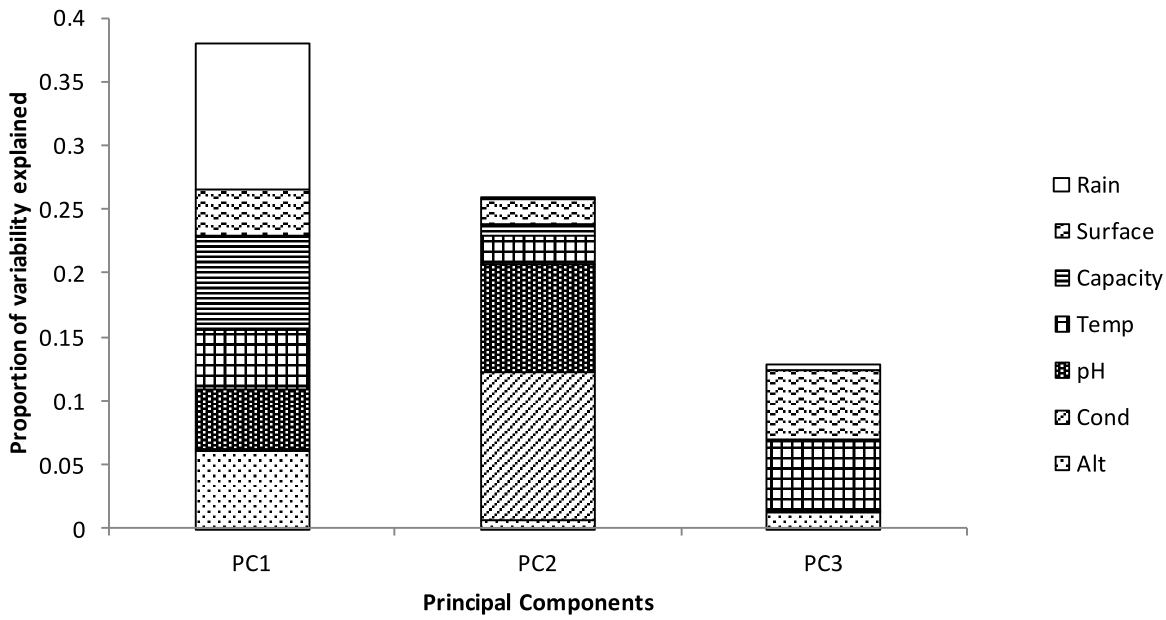


Figure 4.2 The proportion of variability explained by the first three principal components extracted from the bank angling dam environmental variables with contribution by each environmental variable.

Despite correlation of some of the environmental variables, model selection was initially conducted with each variable. If the model included variables which were correlated these were removed and substituted for principal components in order to account for redundancy in the explanatory variables.

Non-parametric bootstrap

A non-parametric bootstrap procedure was applied in order to estimate confidence intervals for the standardised *PC, PLIM* and *CPUE* values (Efron and Tibshirani, 1986). The procedure involves generating random values by resampling the residuals with replacement and adding them to each predicted *PC*, *PLIM*, and *CPUE* value, such that new datasets are generated. Five hundred new datasets were generated, to which the final model was fitted in order to obtain sets of "new" *PC*, *PLIM*, and *CPUE* values (Efron and Tibshirani, 1986;

Hilborn and Walters, 1992; Winker, 2010). The bootstrap data were summarised using the percentile method (Buckland, 1984) to calculate 95% confidence intervals.

All model fitting, model selection and bootstrapping were conducted in *R version 2.14.0* (R Development Core Team, 2009).

Table 4.4 Explanatory variables used for standardisation of bass angling catch data

Predictor	Type	Description
Season	Categorical	Summer; Winter
Type	Categorical	Money; Non-Money Competitions
Dam	Categorical	All dams where data were applicable
Day Length	Categorical	Angler hours i.e.Product of number of anglers and time fished (5; 8; 9; 10; 16; 18 hours)
Alt	Continuous	Altitude (m)
Rain	Continuous	Mean annual rainfall (mm)
Surface	Continuous	Surface area (ha)
Capacity	Continuous	Capacity (m^3)
Temp	Continuous	Mean annual air temperature (°C)
Age	Continuous	Years since construction
pH	Continuous	Mean pH
Cond	Continuous	Mean conductivity (µS)
Comp1	Continuous	Principal Component 1
Comp2	Continuous	Principal Component 2
Comp3	Continuous	Principal Component 3

Multiple regression analysis

The potential for a predictive model of *PC, PLIM*, and *CPUE*, in the absence of fisheries-dependent factors, was investigated using multiple regression analysis. The most influential environmental variables identified during the standardisation process were correlated with *PC*, *PLIM*, and *CPUE*. The strength of the correlations were assessed to determine if an empirical model, incorporating only physico-chemical factors, could be used to predict angler success and catch rates in different impoundments.

Analysis of bank angling catch records

General

Bank angling catch data were collected and analysed as conducted for bass angling catch data, with the exception of measures of angling success, which were not applicable given the aggregated nature of the majority of the data.

Datasets

Only one, continuous dataset was created for statistical analyses containing only positive *CPUE* observations as many of the competition records did not report zero catches.

CPUE estimates for the dataset were calculated as described for bass angling catch records.

Modelling

Modelling approaches, including choice of error distribution, model selection and model validation as outlined above, were used to standardise the *CPUE* information.

Selecting environmental variables for modelling

Environmental variables were obtained as outlined for bass angling catch records. A summary of the predictor variables used in the modelling process is presented in Table 4.2.

All variables were log-transformed and tested for normality using the Shapiro–Wilk test. In order to avoid modelling using variables which were correlated, a correlation matrix was generated to determine which variables were suitable for inclusion (Table 4.5).

Table 4.5 Matrix correlation coefficients between physical and environmental variables obtained for eight bank angling impoundments. Marked correlations are significant at $p<0.05$ (Spearman rank correlation).

Variable	**Alt**	**Rain**	**Surface**	**Capacity**	**Temp**	**pH**	**Cond**	**Age**
Alt	1							
Rain	**0.91***	1						
Surface	0.44	0.15	1					
Capacity	0.44	0.14	**0.98***	1				
Temp	-0.61	-0.52	-0.18	-0.29	1			
pH	-0.21	-0.19	-0.19	-0.27	0.53	1		
Cond	-0.54	-0.35	-0.29	-0.37	**0.87***	0.14	1	
Age	0.38	0.39	-0.03	-0.02	-0.34	-0.05	-0.28	1

There was significant correlation between climate variables rainfall and altitude and the morphometric variables surface area and capacity. Additionally, conductivity was highly correlated with temperature. Principal Component Analysis (PCA) was applied to remove the effect of redundant variables on the modelling process. The first three principal components explained 87% of the variation in the environmental variables; the contribution of each variable to the first three principal components is illustrated in Figure 4.3. A summary of the variables considered for modelling *CPUE* is presented in Table 4.6.

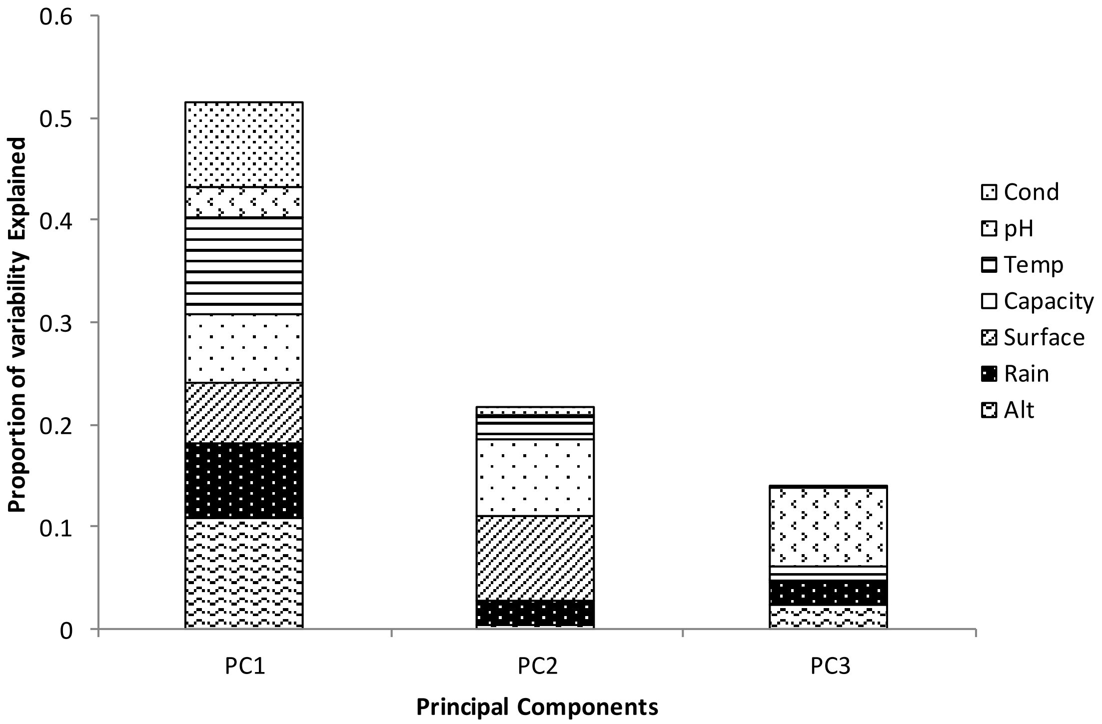


Figure 4.3 The proportion of variability explained by the first three principal components extracted from the bank angling dam environmental variables with contribution by each environmental variable.

Table 4.6 Explanatory variables used for standardisation of bank angling catch data

Predictor	Type	Description
Season	Categorical	Summer; Winter
Type	Categorical	Club; Divisional (League/National)
Dam	Categorical	All dams where data were applicable
Anglers	Categorical	Number of participating anglers
Alt	Continuous	Altitude (m)
Rain	Continuous	Mean annual rainfall (mm)
Surface	Continuous	Surface area (ha)
Capacity	Continuous	Capacity (m^3)
Temp	Continuous	Mean annual air temperature (°C)
Age	Continuous	Years since construction
pH	Continuous	Mean pH
Cond	Continuous	Mean conductivity (µS)
Comp1	Continuous	Principal Component 1
Comp2	Continuous	Principal Component 2
Comp3	Continuous	Principal Component 3

Model selection was initially conducted with each variable; if these were autocorrelated they were substituted for principal components in order to account for redundancy in the explanatory variables.

Non-parametric bootstrap

Non-parametric bootstrapping was applied, as described for bass angling catch records, to estimate confidence intervals for standardised *CPUE* values.

Multiple regression analysis

Multiple regression analysis was conducted using standardised *CPUE* and explanatory environmental variablesto determine the potential for a predictive model, as described for bass angling catch records.

4.3 RESULTS

Bass angling catch records

A total of 10 760 bass angling records representing a total of 88 374 angler hours was collected for a total of 27 impoundments in South Africa. The location of these impoundments is illustrated in Figure 4.4. Most of the data were obtained from provinces with established organised bass angling structures or where professional competition circuits are run. Twenty-two of the impoundments were listed as being of high priority to organised bass angling during the NEM:BA process (see Chapter 3). A summary of the number of catch records, for what years and months, and the number and type of events obtained for each impoundment is presented in Table 4.7. The number of catch records obtained for different impoundments varied considerably, from 10 to 2489 ($\bar{x}$ = 398.5; SD = ± 499.0).

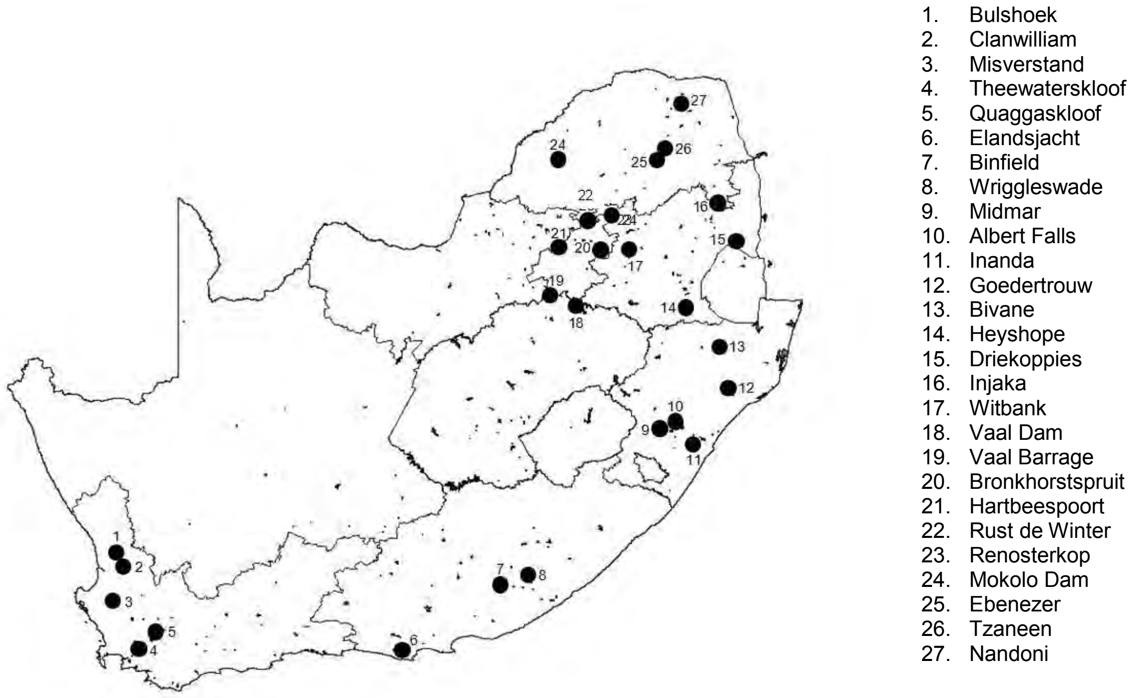


Figure 4.4 Impoundments in South Africa from which bass angling competition data were obtained.

Catch records were obtained for a total of 219 competitive events held over a period dating from 1999 to 2011. The number and type of events for which data were available is summarised in Figure 4.5. The majority of catch records (68%) were available from 2007–2011 and obtained from club (48%) and divisional (30%) type events. Data were available from money events from 2007, the proportion of which increased every year until 2011. Overall, the majority (82%) of catch records were available from tournaments organised by and affiliated to SABAA. Monthly trends in number and type of competitions are illustrated in Figure 4.6. Most tournaments (83%) are held in the summer months (September–April) and those events which are held in the winter months (May–August) are mostly club events (67%) with some professional competitions (22%). Tournament duration ranged from 1 day to 3 days; most tournaments lasted 2 d (57%) or 1 d (42%). Angler participation in the tournaments ranged from 5 to 208 anglers ($\bar{x}$ = 39.8; SD = ± 27.5) and the average number of anglers varied depending on the event type (Figure 4.7). The number of competitions from which data were collected for each impoundment ranged from 1 to 37 ($\bar{x}$ = 8.2; SD = ± 7.8). Average winning bag weights were greatest at Goedertrouw Dam in KwaZulu-Natal (11.7 ±3.5 kg) and lowest at Witbank Dam in Mpumalanga (2.5 ±0.001 kg), while the overall average winning bag was 6.6 ±1.0 kg.

Table 4.7 Number of catch records obtained for each impoundment with associated number of events, event types (Club = Club; Divs = Divisionals; Nats = Nationals; Cash = Cash ; Open = Opens), years and months.

Impoundment	Indv. Catch records	Events	Event Type(s)	Years	Months
Albert Falls	802	16	Club; Divs; Cash	2007-2010	Feb-Jun;Aug-Dec
Binfield	208	4	Club	2004-2006	Jan;Apr;Sep-Oct
Bivane	227	4	Club; Divs	2005;2009-2010	Mar-May
Bronkhorstspruit	146	8	Club; Cash	2008-2010	Feb;Apr-May;Sep-Oct
Bulshoek	10	1	Cash	2010	Sep
Clanwilliam	760	11	Divs;Cash;Nats;Ints	1999;2002-2003;2005-2006;2008-2011	Mar;Aug-Nov
Driekoppies	171	3	Club;Divs	2010	Jan-Feb
Ebenezer	24	1	Cash	2011	Feb
Elandsjacht	724	5	Divs	2004-2005;2008-2010	Jan-Apr;Sep-Oct
Goedertrouw	451	7	Club;Divs;Cash	2008-2010	Mar;Aug;Nov
Hartbeespoort	89	4	Club;Cash	2006;2008-2009; 2011	Feb; Sep; Nov
Heyshope	38	1	Divs	2011	Feb
Inanda	962	12	Club;Divs;Cash;Open	2007-2011	Jan;Apr-May;Jul-Aug;Nov
Injaka	26	2	Divs	2009	Oct
Midmar	405	6	Divs;Cash	2008-2010	Feb-Mar;Sep-Oct
Misverstand	121	6	Divs	2000;2002-2004;2007;2009	Jan;Mar;Nov
Mokolo	315	7	Club;Divs;Cash	2007-2011	Jan;Mar;Nov
Nandoni	74	2	Club;Ints	2009-2010	Mar;Dec
Quaggaskloof	606	18	Divs;Cash	2002-2003;2005-2011	Jan-Apr;Oct-Dec
Renosterkop	221	7	Club;Cash	2009-2011	Jan-Mar;Dec
Rust de Winter	715	22	Club;Divs;Nats;Cash	2003-2011	Jan-Mar;May;Jul-Sep;Nov-Dec
Theewaterskloof	183	8	Divs;Cash	2000;2003-2004;2009-2011	Jan-Mar;Sep;Nov
Tzaneen	252	6	Club;Divs;Nats;Cash	2008;2010-2011	Jan;Mar;Aug
Vaal Barrage	388	11	Club;Divs	2003-2005;2007-2008;2010	Jan-Apr;Jun;Aug;Oct-Nov
Vaal Dam	85	4	Club	2009	Feb;Oct-Nov
Witbank	268	8	Club;Divs;Cash	2004-2005;2007-2011	Jan-Feb;Apr-May;Nov
Wriggleswade	2489	37	Club;Divs;Open	2004-2011	Jan-May;Aug-Dec

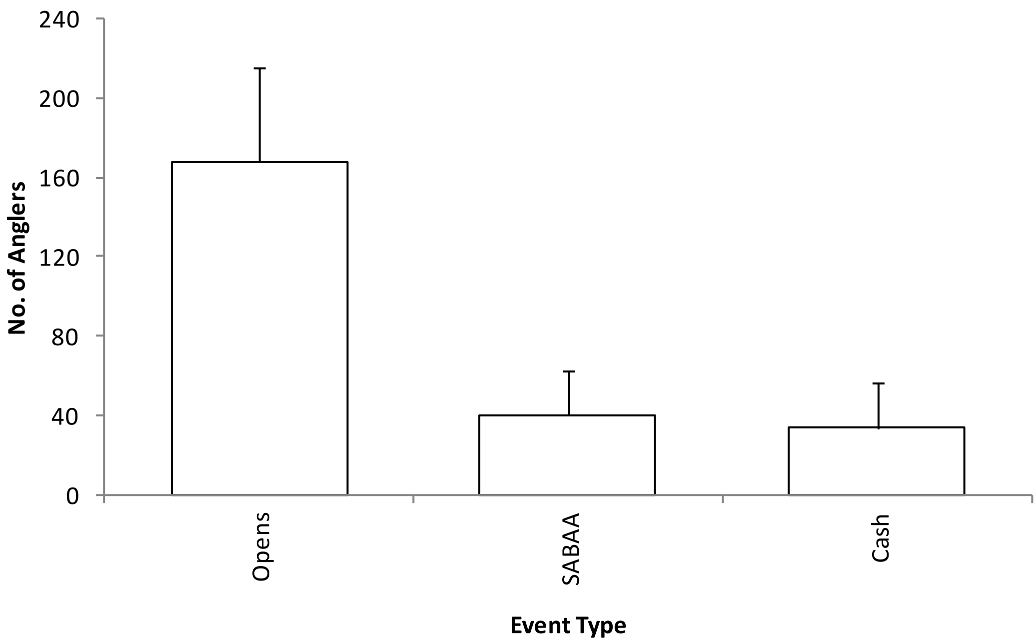


Figure 4.7 Average angler attendance at different bass angling competition event types. Error bars represent standard deviation.

Probability of capture and limit

Model Fitting

Impoundments included in these analyses had to have catch data which included zero catches. Catch records from impoundments in the Western Cape did not contain zeros and were excluded from analyses of *PC* and *PLIM* reducing the number of impoundments to 17 in total. The model statistics for the best-fitting model used to standardise *PC* for each impoundment are illustrated in Table 4.8. *PC* was best explained by a GLM of the form:

$$PC_{Dam} = \beta_{\text{Dam}} + \beta_{\text{Type}} + \beta_{\text{Season}} + \beta_{\text{DL}} + \varepsilon \qquad (4.1)$$

The model components were all highly significant in explaining variation in angler success, however, the variables “Type” and “DL” explained the greatest amount of variability. Estimated coefficients from Eq. 4.1, with the exclusion of “Dam”, are provided in Appendix

II. Increasing angler hours ("DL") tends to have a significant positive relationship with *PC* while there is a negative relationship with the seasonal component "Winter".

Table 4.8 Statistics for the model components of the best-fitting GLM used to model *PC*. The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2 – test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2 – squared for each additional factor.

Probability of Capture (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	*p*	r^2
NULL	8403		9560		9558				
+Dam	8387	16	9188	372	9154	404	4.2	***	0.04
+Type	8386	1	9183	5	9147	7	0.1	***	0.04
+Season	8385	1	8529	654	8491	656	7.2	***	0.11
+DL	8375	10	8363	166	8305	186	2.2	***	0.13
% Deviance Explained							13.7		

Figure 4.8 illustrates the predicted *PC* for 17 impoundments with *PC* standardised to control the factors season ("Summer"), day length ("DL" = 8 hours), and event type ("Type" = Non-Money events).

PC was lowest at Binfield Dam (27%) in the Eastern Cape and highest at Nandoni Dam (92%) in Limpopo, with average *PC* = 0.70 ± 0.17. *PC* estimates from the GLM were more conservative than nominal *PC,* although trends between dams were similar. Overall, the mean size of bass captured was 0.85 ±0.19 kg. fish^{-1}, with the largest and smallest average size bass captured in Goedetrouw Dam ($\bar{x}$ = 1.35 ±0.64 kg. fish^{-1}) and Elandsjacht ($\bar{x}$ = 0.57 ±0.22 kg. fish^{-1}) respectively.

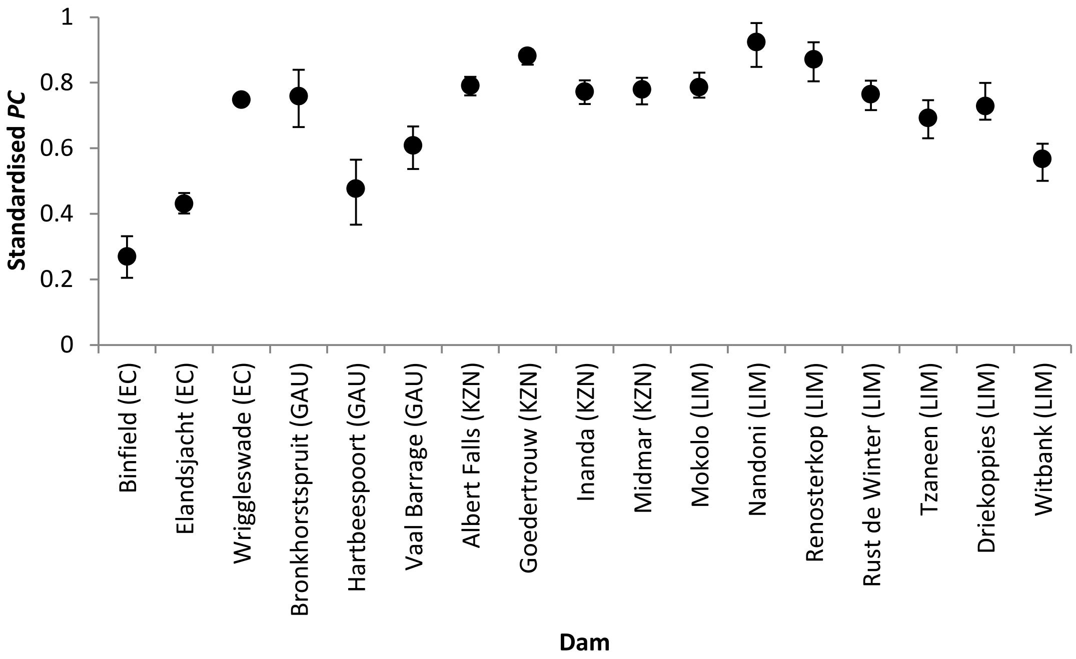


Figure 4.8 Predicted *PC* for 17 impoundments (EC = Eastern Cape; GAU = Gauteng; KZN = Kwazulu-Natal; LIM = Limpopo). Error bars represent 95% upper and lower confidence intervals.

Modelling PC and PLIM using Environmental Variables

The models that best described *PC* were of the form:

$$PC = DL + Alt + Temp + Cond + Surface + Surface{:}Capacity \quad (4.2)$$

$$PC = DL + s(Cond) + te(Surface{:}Capacity) \quad (4.3)$$

for the GLM and GAM respectively, where "*s*" and "*te*" refer to the non-linear smooth functions. Model statistics are illustrated in Table 4.9. All of the covariates included by the models were highly significant; however, different combinations of variables were selected for by the different models. The GLM included the covariates "Alt", „Temp" as well as "Surface". Notably, the GAM selected only the variables "Cond" and the "Surface:Capacity" interaction but explained more of the deviance (13.4%) in *PC* then the GLM (10.8%) when compared to *PC* standardised per dam (13.6%). Comparisons between the model predictions of the GLM and GAM and the standardised *PC* estimates are illustrated in Figure 4.9. Estimates of *PC* derived from the GAM generally simulated the *PC* values more accurately than those estimates produced by the GLM. In particular, the GLM over-predicted *PC* for Binfield, Elandsjacht, Hartbeespoort and Tzaneen Dams. The GAM (Eq. 4.3) explained almost all of the variation in standardised *PC* (99%) compared to the 63% explained by the GLM (Eq. 4.2) (Figure 4.10). Figure 4.11 illustrates *PC* as a function of the most significant environmental covariates contained within the GLM ("Surface" and „Temp") and the GAM ("Cond" and "Surface*Capacity").

Table 4.9 Statistics for the model components of the best-fitting GLM used to model *PC*. The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2 – test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2 – squared for each additional factor.

Probability of Capture (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	*p*	r^2
NULL	8403		9560		9558				
+DL	8393	10	8934	626	8912	646	6.76	***	0.07
+Alt	8392	1	8883	51	8859	53	0.55	***	0.07
+Temp	8391	1	8734	149	8708	151	1.58	***	0.09
+Cond	8390	1	8723	2	8695	13	0.14	***	0.09
+Surface	8389	1	8579	144	8549	146	1.53	***	0.11
+Surface:Capacity	8388	1	8557	22	8525	24	0.25	**	0.11
% Deviance Explained							10.8		
Probability of Capture (GAM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	*p*	r^2
NULL	8403		9560		9558				
+DL	8393	10	8934	626	8911	646	6.76	***	0.07
+s(Cond)	8390	3	8711	223	8684	227	2.55	***	0.09
+te(Surface:Capacity)	8379	12	8377	334	8325	359	4.13	***	0.13
% Deviance Explained							13.4		

PC increases with increasing surface area and shows a slight increase with increasing temperature. The relationship with conductivity is much clearer; *PC* tends to reach an optimum at around 200 μ.S and then decreases steadily with increasing conductivity. The surface plot indicates that *PC* is highest in dams with large surface areas and low capacities, i.e. large, shallow dams, and lowest in large, deep dams. Generally however, *PC* tended to increase in smaller, deeper dams.

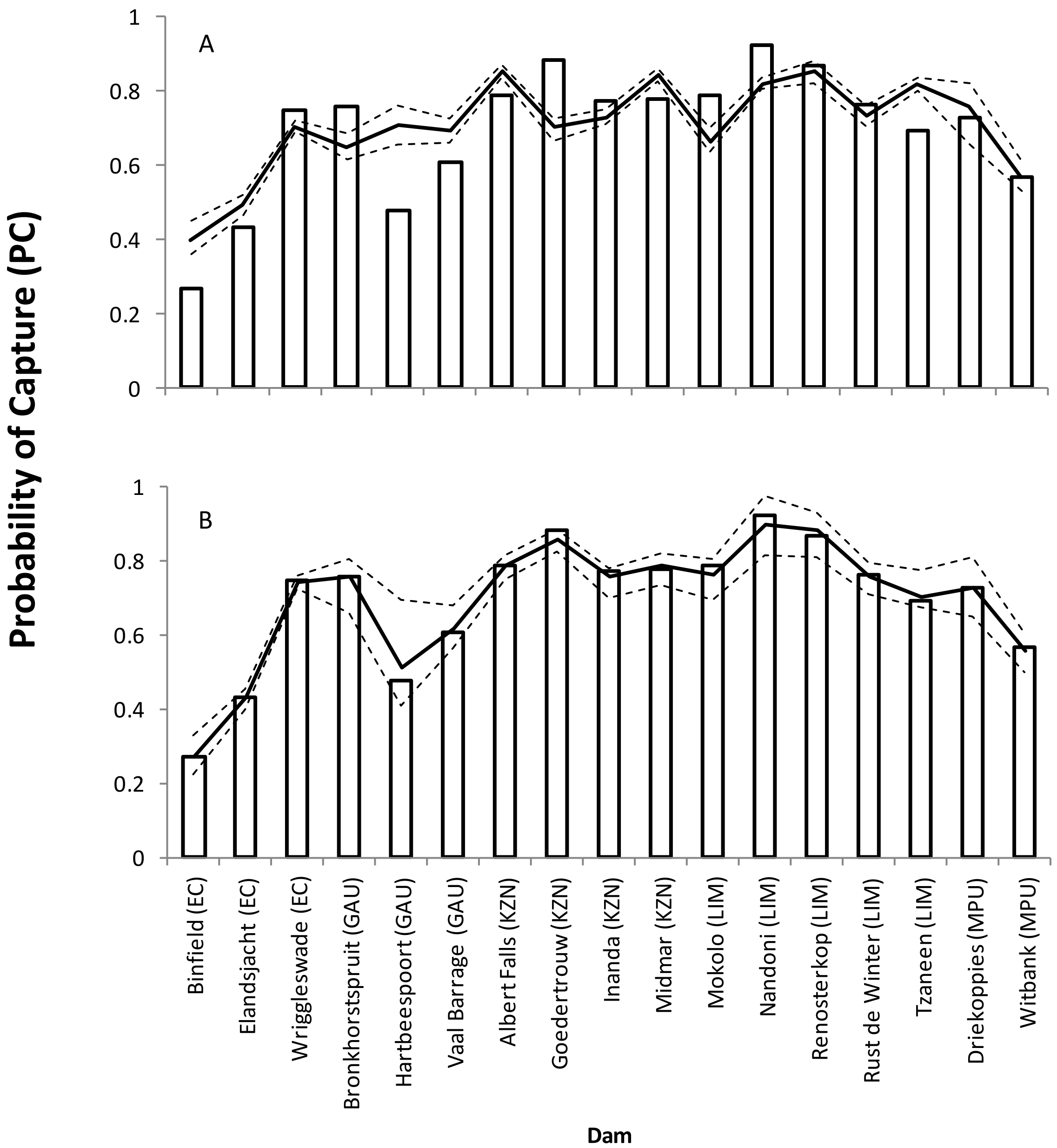


Figure 4.9 Standardised *PC* for 17 impoundments (bars) compared to the mean (solid lines) of non-parametrically generated *PC* estimates fitted using a GLM (A) and a GAM (B) incorporating environmental variables. Dashed lines represent the upper and lower 95% confidence intervals for the mean *PC* estimates.

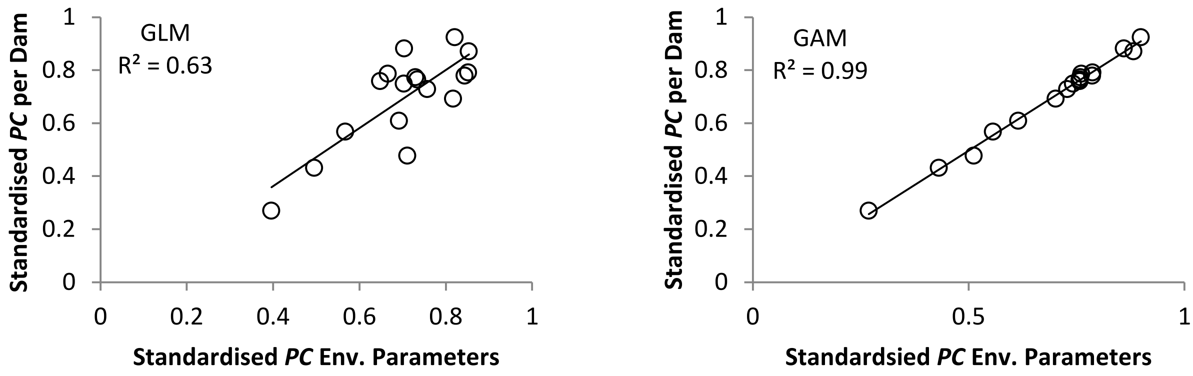


Figure 4.10 Correlation between *PC* modelled using GLM and GAM approaches incorporating environmental variables and *PC* standardised per dam using bass angling competition catch data.

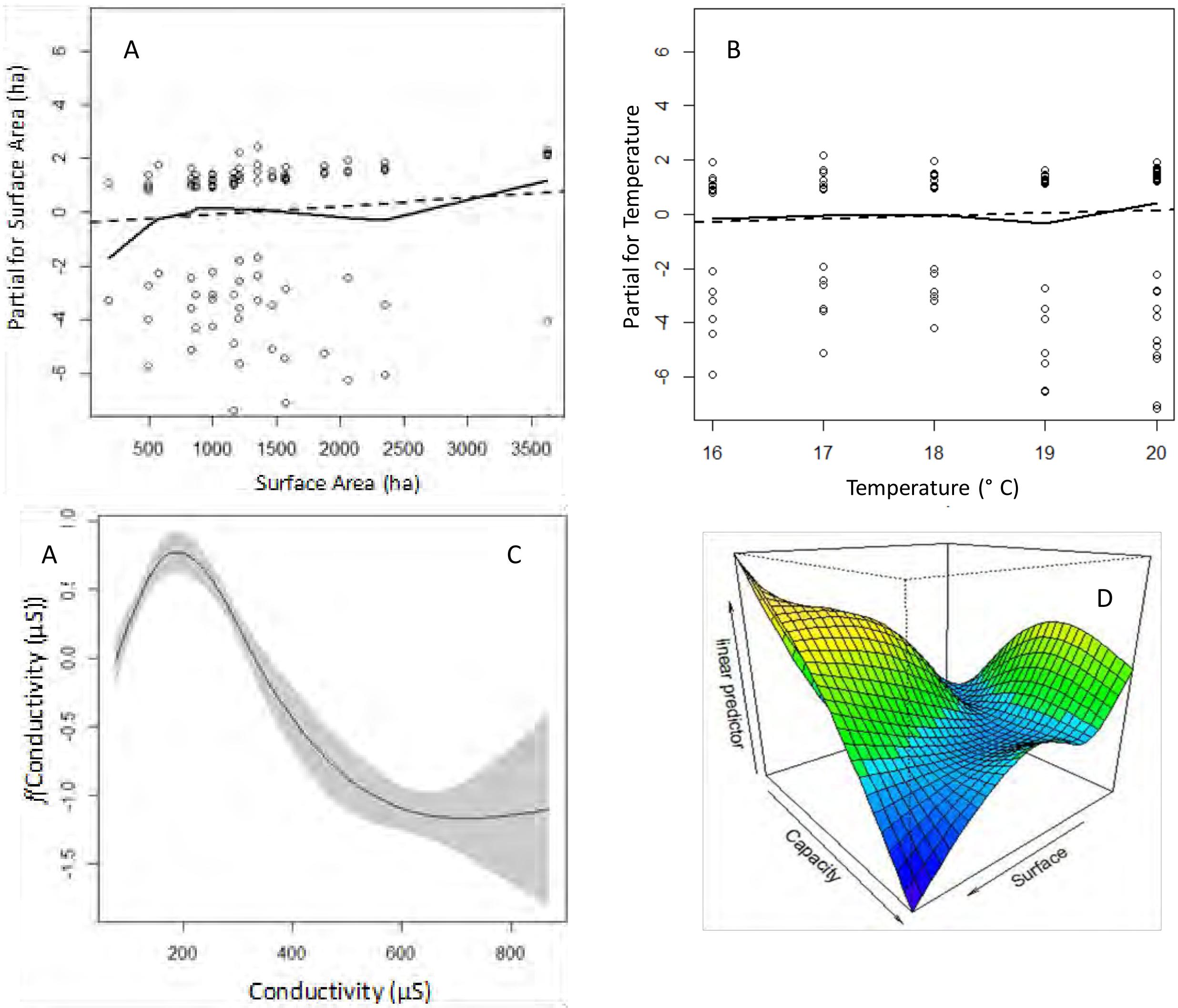


Figure 4.11 Effect of the most significant environmental variables on *PC* modelled using a GLM (A; B) and a GAM (C; D). "Partial" refers to "Partial Residual Plot" in which the effect of the predictor is assessed while taking into account other components in the model. "*f*" refers to the smoothing spline fitting the effect of the predictor to the explanatory variable.

Probability of limit

Probability of a limit bag was best explained by a GLM of the form:

$$PLIM_{Dam} = \beta_0 + \beta_{\mathrm{Dam}} + \beta_{\mathrm{Season}} + \beta_{\mathrm{DL}} + \varepsilon \qquad (4.4)$$

The model statistics are illustrated in Table 4.10. The model components differed from that of the GLM used to standardise *PC* in that the variable “Type” was excluded. However, the total deviance explained by the model components was only 10.8%, compared to the 13.6% explained in the GLM for *PC*. Of the model components, with the exception of “Dam”, the variable “DL” was the most explanatory variable and accounted for a significant 2.9% of the variation in *PLIM* and the estimated coefficients indicated a positive relationship with *PLIM* (Appendix II). Similarly to *PC*, “Season”, although significant, explained a much smaller proportion (0.19%) of the deviance, although there was a negative relationship between *PLIM* and the coefficient “Winter”.

Table 4.10 Statistics for the model components of the best-fitting GLM used to model *PLIM*. The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2 – test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2 – squared for each additional factor.

Probability of Limit (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	*p*	r^2
NULL	5689		7273		7271				
+Dam	5673	16	6749	524	6715	556	7.65	***	0.08
+Season	5672	1	6739	10	6703	12	0.18	***	0.08
+DL	5667	5	6557	182	6511	192	2.86	***	0.10
% Deviance Explained							10.7		

Standardised *PLIM* for the 17 impoundments, controlling for seasonal ("Summer") and day length ("DL" = 8 hours) factors, is illustrated in Figure 4.12. *PLIM* was highest at Nandoni Dam (62%) and lowest at Hartbeespoort Dam (<5%) in Gauteng, with the average *PLIM* = 0.28 ±0.18.

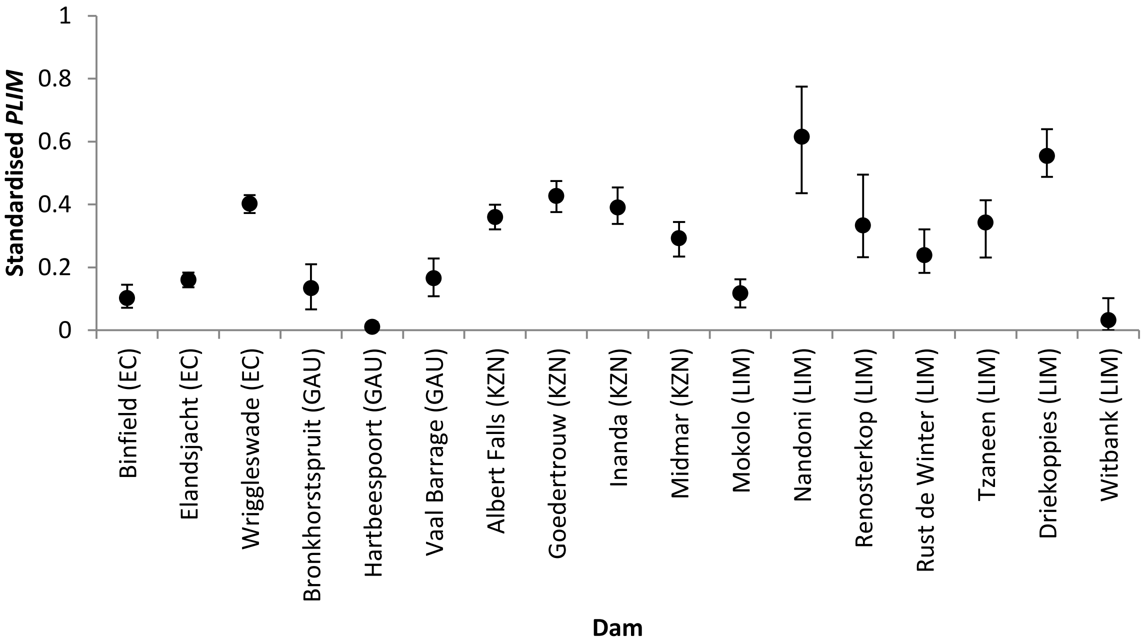


Figure 4.12 Predicted *PLIM* for 17 impoundments (EC = Eastern Cape; GAU = Gauteng; KZN = Kwazulu-Natal; LIM = Limpopo). Error bars represent upper and lower confidence intervals.

Models incorporating environmental variables that best described *PLIM* were such that:

$$PLIM = Season + DL + Temp + pH + Surface + Surface*Capacity + \varepsilon \quad (4.5)$$

$$PLIM = Season + DL + s(Alt) + s(Cond) + s(Surface) + s(Capacity) + te(Surface*Capacity) + \varepsilon \quad (4.6)$$

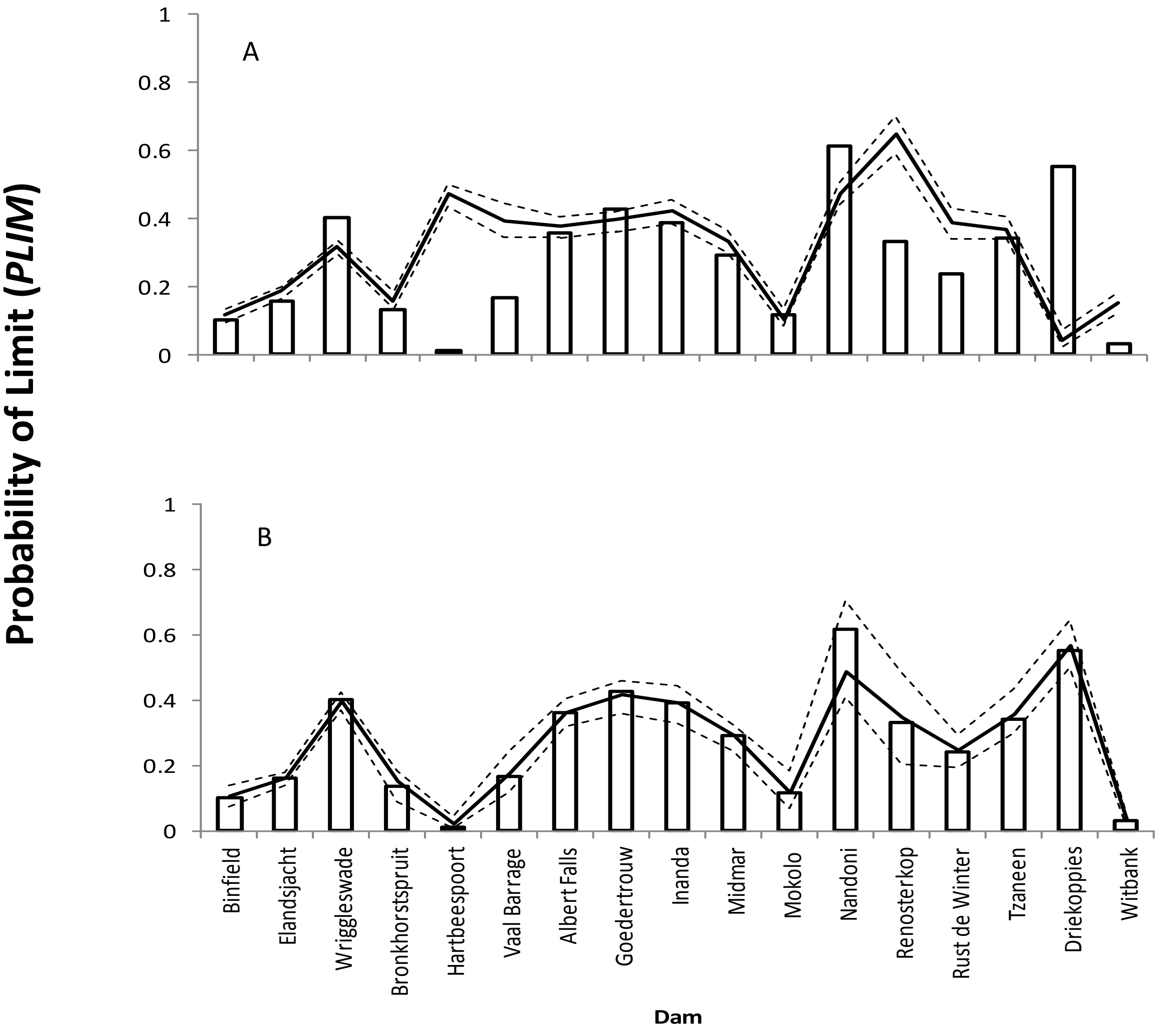
for the GLM and GAM respectively.

The models selected for different combinations of environmental covariates; the GLM included "Temp" and "pH" while the GAM included "Alt" and "Cond" effects. Both models selected for the "Surface*Capacity" interaction effect. Components for the models are presented in Table 4.11. All model components for the GLM were highly significant with the exception of "Season" and the "Surface*Capacity" interaction; "Season" was also not as significant in explaining *PLIM* as the other variables included in the GAM.

Table 4.11 Statistics for the model components of the best-fitting GLM and GAM incorporating environmental variables used to model *PC*. The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2 – test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2 – squared for each additional factor.

Probability of Limit (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	p	r2
NULL	5689		7273		7271				
+Season	5688	1	7266	7	7262	9	0.12	**	0.001
+DL	5683	5	6938	328	6924	338	4.65	***	0.048
+Temp	5682	1	6845	93	6829	95	1.31	***	0.061
+pH	5681	1	6768	77	6750	79	1.09	***	0.072
+Surface	5680	1	6720	48	6700	50	0.69	***	0.079
+Surface*Capacity	5679	1	6717	3	6695	5	0.07	*	0.079
% Deviance Explained							7.9		
Probability of Limit (GAM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	*p*	r^2
NULL	5689		7273		7271				
+Season	5708	-19	7266	7	7262	9	0.12	**	0.001
+DL	5703	5	6938	328	6924	338	4.65	***	0.048
+Alt	5701.3	1.7	6748	190	6729	195	2.68	***	0.075
+Cond	5699.3	2	6669	79	6644	85	1.17	***	0.086
+Surface	5698.3	1	6638	31	6610	34	0.47	***	0.091
+Capacity	5697.3	1	6584	54	6554	56	0.77	***	0.099
+Surface*Capacity	5691.3	6	6550	34	6515	39	0.54	***	0.104
% Deviance Explained							10.4		

Comparisons of predicted *PLIM* generated through non-parametric bootstrapping of the GLM and GAM with *PLIM* standardised per dam indicate that the GAM simulated the *PLIM* values far more accurately than the GLM (Figure 4.13). In particular, the GLM overpredicted *PLIM* at Hartbeespoort, Vaal Barrage, Renosterkop, and Rust de Winter dams and underpredicted for Driekoppies Dam. Conversely, *PLIM* estimates were largely captured by the GAM model. Similarly to *PC*, the GAM explained 96% of the variation in *PLIM* standardised per dam compared to the GLM which explained less than 10% (Figure 4.14).



Figure

incorporating environmental variables. Dashed lines represent the upper and lower 95% confidence intervals for the mean *PLIM* estimates.

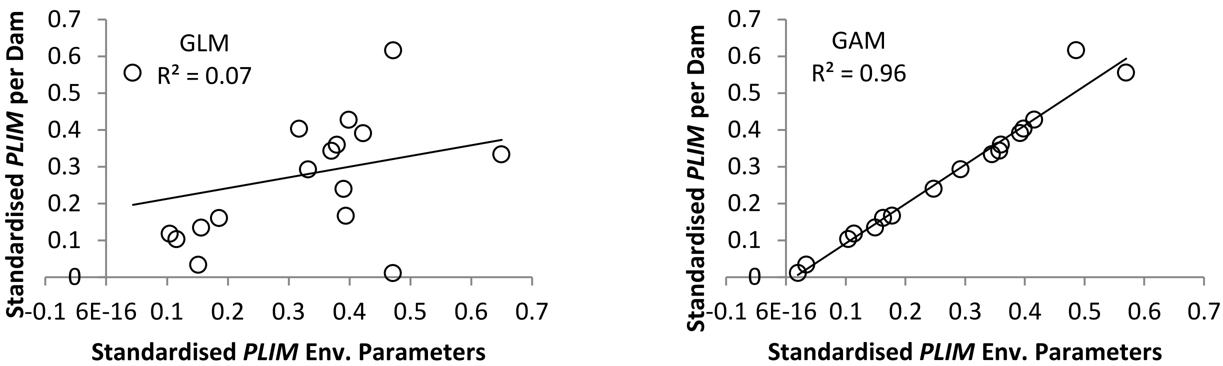


Figure 4.14 Correlation between *PLIM* modelled using GLM and GAM approaches incorporating environmental variables and *PLIM* standardised per dam.

The most significant model components and their influence on *PLIM* are presented in Figure 4.15 for the GLM and GAM respectively.

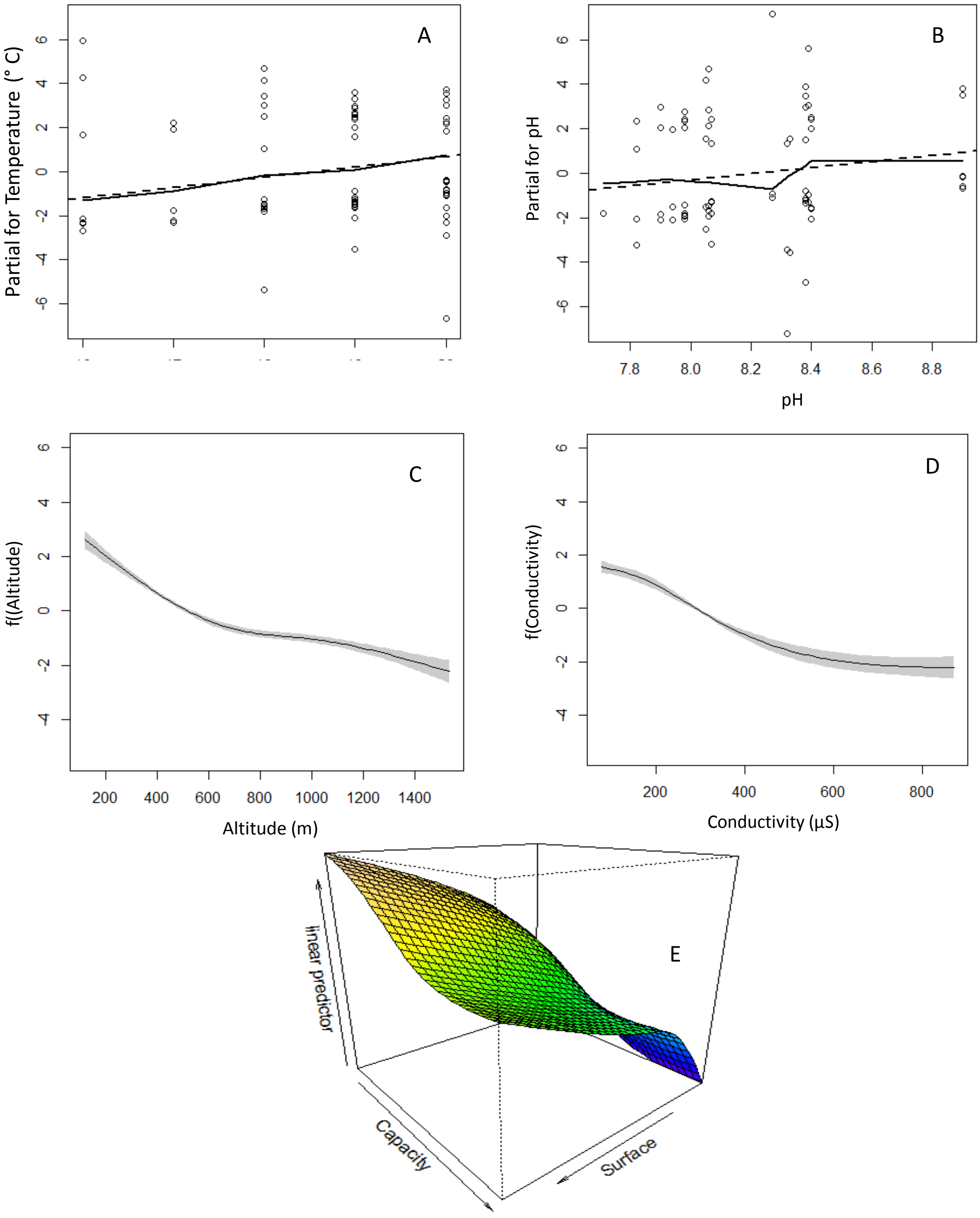


Figure 4.15 Effect of the most significant environmental variables on *PLIM* modelled using a GLM (A; B) and a GAM (C; D; E). "Partial" refers to "Partial Residual Plot" in which the effect of the predictor is assessed while taking into account other components in the model. "*f*" refers to the smoothing spline fitting the effect of the predictor to the explanatory variable.

PLIM tends to increase with increasing temperatures and, to a lesser degree, increasing pH. Dams at higher altitudes have a higher *PLIM* and, similarly to *PC,* optimum *PLIM* is found in dams with low conductivity. The surface plot describes the interaction between surface area, capacity and *PLIM*. Optimum *PLIM* is found in dams with large surface areas and small capacities, i.e. large, shallow dams, while reaching a minimum in dams with small surface areas and large capacities, i.e. small, deep dams. This is a similar trend to that observed in the *PC* models.

$CPUE_{POS}$

The model statistics for the best-fitting model used to standardise $CPUE_{POS}$ for each impoundment are presented in Table 4.12. Standardised $CPUE_{POS}$ was best modelled using a GLM such that:

$$CPUE_{pos} = CPUE = Dam + Type + DL + Season \; + \varepsilon \qquad (4.7)$$

Table 4.12 Statistics for the model components of the best-fitting GLM used to model *PC*. The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2-test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2-squared for each additional factor.

CPUE Standardisation (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explained	*p*	r^2
NULL	6074		-1344		3183				
+Dam	6054	20	-2307	963	2731	452	14.2	***	0.14
+Type	6053	1	-2544	237	2633	98	3.08	***	0.04
+DL	6049	4	-2702	158	2567	66	2.07	***	0.03
+Season	6048	1	-2706	4	2564	3	0.09	**	0.001
% Deviance Explained							**19.4**		

Overall, the GLM explained 19.4% of the total variation in the data, more so than that for *PC* and *PLIM*. All the model components were significant; however, the factor "Dam" explained the majority of the variation (14.2%). Of the fisheries-dependent factors, "Type" and "DL" were both highly significant, whereas the temporal factor “Season”, while significant, did not account for as much variation in the data.

In order to compare *CPUE* between dams, *CPUE* was standardised to a day length of 8 hours, the summer season, and a non-money event type. Predicted *CPUE* per dam is illustrated in Figure 4.16. Mean maximum and minimum *CPUE* was predicted at Goedertrouw Dam (0.6 $kg.angler^{-1}.h^{-1}$) and Witbank Dam (0.19 $kg.angler^{-1}.h^{-1}$) respectively, with an average *CPUE* for all 21 impoundments of 0.37 ±0.11 $kg.angler^{-1}.h^{-1}$.

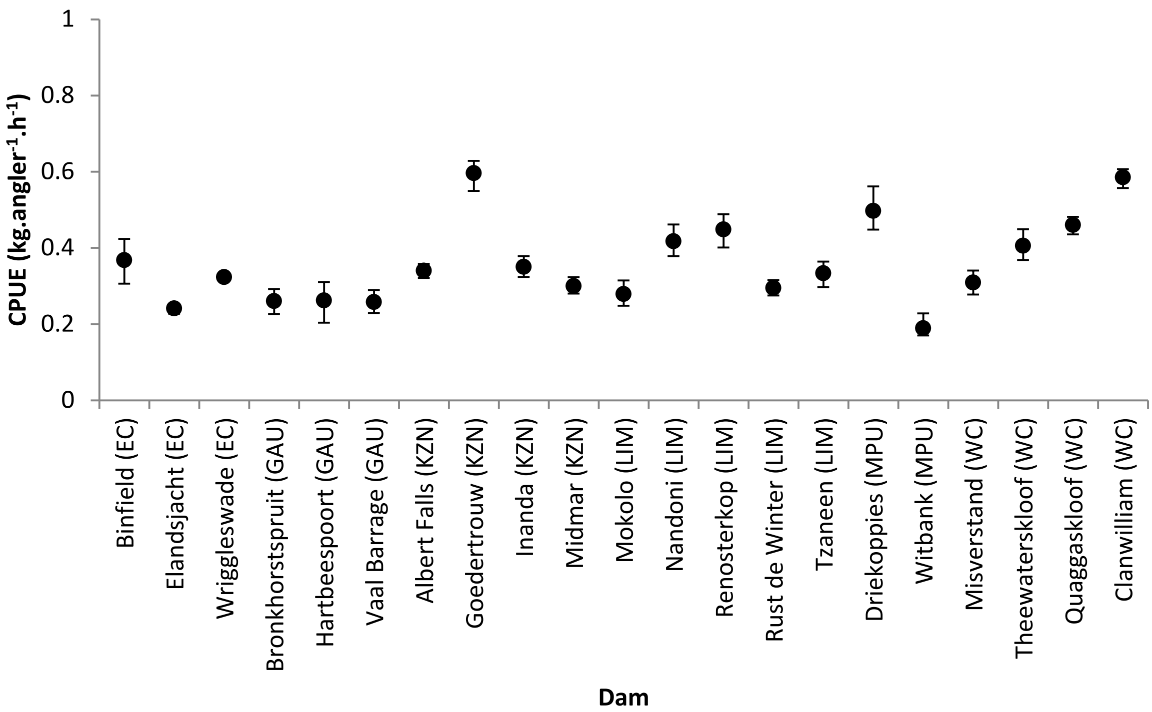


Figure 4.16 Predicted *CPUE* for 21 impoundments standardised to a day length of 8 hours, summer season, and non-money event types (EC = Eastern Cape, GAU = Gauteng, KZN = KwaZulu-Natal, LIM = Limpopo; MPU = Mpumalanga; WC = Western Cape). Error bars represent upper and lower confidence intervals.

$CPUE_{POS}$ was modelled using environmental variables such that:

$$CPUE_{POS} = Type + DL + Season + Rain + Cond + Surface + \varepsilon \quad (4.8)$$

$CPUE_{POS} = Type + DL + Season + s(Alt) + s(Cond) + s(Surface) + s(Capacity) + te(Surface*Capacity) + \varepsilon \quad (4.9)$

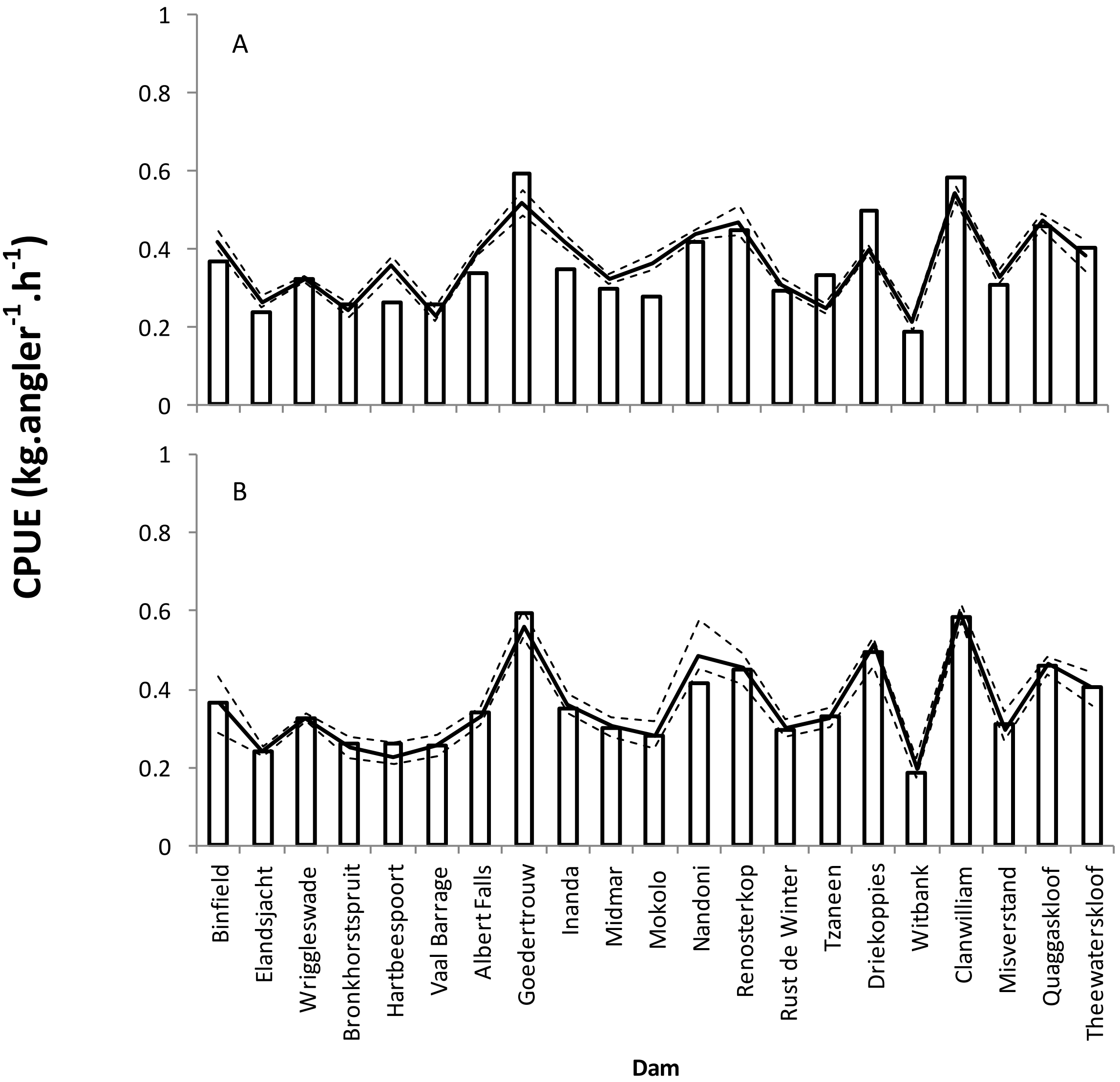
for the GLM and GAM respectively.

Both models incorporated the environmental covariates "Cond" and "Surface"; however, the GLM selected for the variable "Rain", whereas the GAM selected "Alt" and "Capacity," as well as the "Surface:Capacity" interaction. Model components for the GLM and GAM are presented in Table 4.13. Overall, the GAM explained 19.5% of the total variability in *CPUE* standardised per dam compared to the 14.5% of the variation explained by the GLM. All of the model components for both models were highly significant ($p<0.001$), with the exception of "Capacity" in the GAM ($p<0.05$).

Table 4.13 Statistics for the model components of the best-fitting GLM and GAM incorporating environmental variables used to model $CPUE_{POS}$.The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2 – test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2 – squared for each additional factor.

CPUE Standardisation (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explained	p	r2
NULL	6097		-1347		3188				
+Type	6073	1	-1711	364	3010	178	5.58	***	0.056
+DL	6069	4	-1739	28	2993	17	0.56	***	0.061
+Season	6068	1	-1825	86	2953	40	1.34	***	0.074
+Rain	6067	1	-2109	284	2827	126	4.27	***	0.113
+Cond	6089	1	-2224	115	2777	50	1.77	***	0.129
+Surface	6088	1	-2284	60	2750	27	0.97	***	0.137
% Deviance Explained							**14.5**		
CPUE Standardisation (GAM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explained	p	r2
NULL	6097		-1347		3188				
+DL	6092	4	-1637	290	3047	141	4.42	***	0.04
+Season	6091	1	-1702	65	3016	31	0.97	***	0.05
+s(Alt)	6088.2	2.8	-2128	426	2819	197	6.18	***	0.12
+s(Cond)	6085.2	3	-2412	284	2697	122	3.83	***	0.15
+s(Surface)	6082.2	3	-2512	100	2653	44	1.38	***	0.17
+s(Capacity)	6079.2	3	-2537	25	2640	13	0.41	**	0.17
+te(Surface*Capacity)	6078.2	1	-2708	171	2567	73	2.29	***	0.19
% Deviance Explained							**19.5**		

Figure 4.17 illustrates the predicted $CPUE_{POS}$ for the GLM and GAM incorporating environmental covariates compared to $CPUE_{POS}$ standardised by dam following non-parametric bootstrapping of the models.



Figu

M

(B) incorporating environmental variables. Dashed lines represent the upper and lower 95% confidence intervals for the mean $CPUE_{POS}$ estimates.

As for *PC* and *PLIM*, the bootstrap-generated means for the GAM simulate the dam standardised $CPUE_{POS}$ estimates more accurately than the GLM. In particular, the GLM overestimated $CPUE_{POS}$ at Hartbeespoort and Mokolo Dams while largely underestimating the higher $CPUE_{POS}$ estimates for Goedertrouw, Driekoppies and Clanwilliam Dam. Correlations between $CPUE_{POS}$ standardised by dam and the environmental GLM and GAM illustrate the differing amounts of variation explained by the models, with the GLM accounting for 76% of the variation compared to the GAM which accounts for 96% (Figure 4.18).

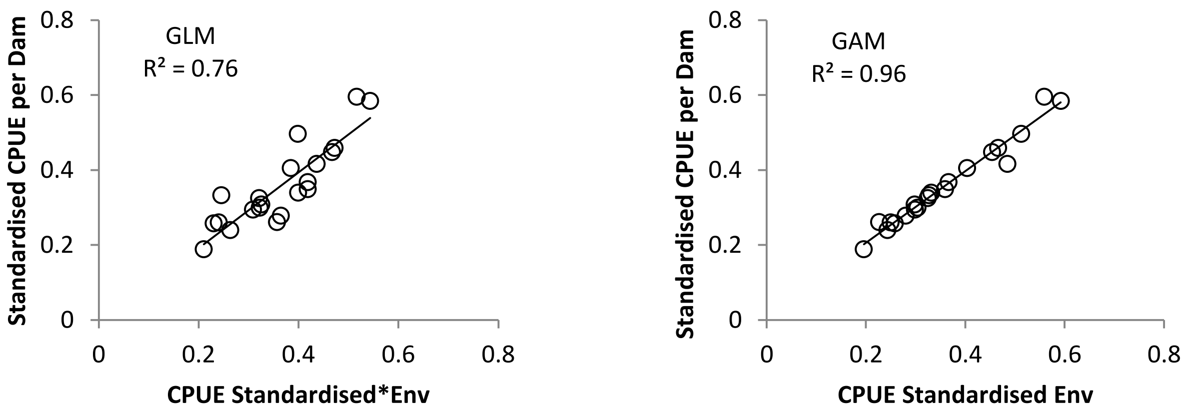


Figure 4.18 Relationship between *CPUE* standardised by dam and *CPUE* estimates derived from a GLM and GAM incorporating environmental variables.

Significant model components for the GLM and GAM, and their influence on $CPUE_{POS}$, are illustrated in Figure 4.19. The GLM described a slight decrease in $CPUE_{POS}$ from dams in areas of low to high rainfall (A), and a decrease in $CPUE_{POS}$ with a decrease in conductivity (B). $CPUE_{POS}$ also increased with increasing surface area (C). Model components from the GAM indicated that $CPUE_{POS}$ decreased with increasing altitude (D), reached an optimum at low conductivity values before decreasing as conductivity values increase (E), and increased with increasing surface area (F).

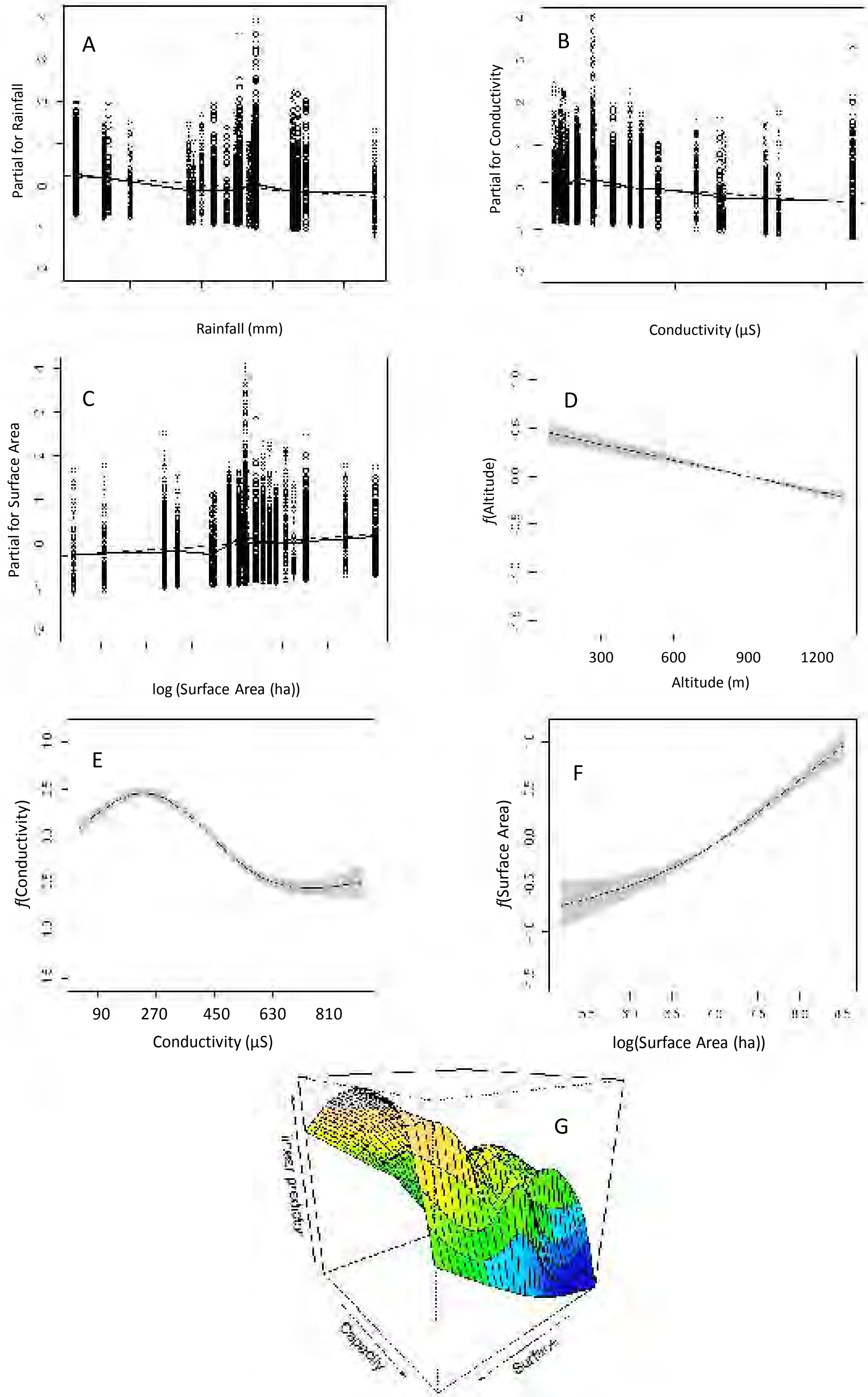


Figure 4.19 Effect of the most significant environmental variables on $CPUE_{POS}$ modelled using a GLM (A; B; C) and a GAM (D; E; F; G). "Partial" refers to "Partial Residual Plot" in which the effect of the predictor is assessed while taking into account other components in the model. "*f*" refers to the smoothing spline fitting the effect of the predictor to the explanatory variable.

The surface plot (Figure 4.19, G) illustrates that higher $CPUE_{POS}$ values are predicted for dams with large surface areas and low to medium capacities; $CPUE_{POS}$ is predicted to be lowest in impoundments with small surface areas and high capacities, i.e. small, deep dams.

Zero-Adjusted CPUE

Standardised $CPUE_{POS}$ estimates were corrected to account for zero catches in the data using the standardised *PC* estimates, with the exception of the Western Cape impoundments where $CPUE_{POS}$ was corrected using the mean standardised *PC* estimates obtained for impoundments where zeroes were recorded such that:

$$CPUE_0 = CPUE_{POS} \times PC \qquad (4.10)$$

In order to compare $CPUE_0$ between dams, $CPUE_0$ was standardised to a day length of 8 hours, the summer season, and a non-money event type. Predicted $CPUE_0$ per dam is illustrated in Figure 4.20. Similarly to $CPUE_{POS}$, maximum $CPUE_0$ was recorded at Goedertrouw Dam (0.52 $kg.angler^{-1}.h^{-1}$). Minimum $CPUE_0$ was recorded at Binfield Dam (0.1 $kg.angler^{-1}.h^{-1}$) with a mean $CPUE_0$ of 0.25 ± 0.2 kg. angler.h-1. The trends observed in standardised estimates of $CPUE_{POS}$ (Figure 4.16) were similar when they were zero-adjusted using *PC* (Figure 4.20).

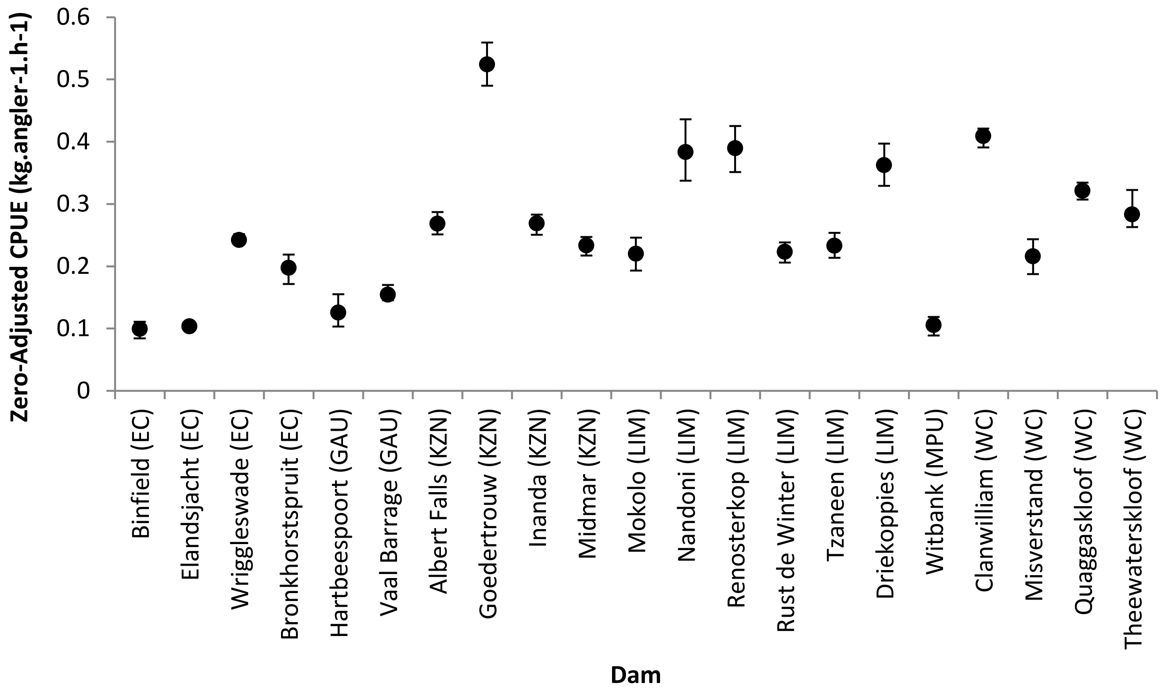


Figure 4.20 Predicted $CPUE_0$ for 21 impoundments standardised to a day length of 8 hours, summer season, and non-money event types (EC = Eastern Cape, GAU = Gauteng, KZN = KwaZulu-Natal, LIM = Limpopo; MPU = Mpumalanga; WC = Western Cape). Error bars represent upper and lower confidence intervals.

$CPUE_0$ was modelled using the environmental variables:

$$CPUE_0 = Type + DL + Season + Alt + Surface + Cond + Temp + \varepsilon \quad (4.11)$$

$$CPUE_0 = Type + DL + Season + s(Alt) + s(Cond) + s(Surface) + s(Capacity) + te(Surface*Capacity) + \varepsilon \quad (4.12)$$

Both of the models incorporated the same environmental variables with the exception of "Temp" and the "Surface:Capacity" interaction variable incorporated in the GLM and GAM respectively. Model components for the GL and GAM are presented in Table 4.14. Overall, the GLM explained 14% of the variability in $CPUE_0$ standardised per dam compared to the 26% of the variation explained by the GAM.

Table 4.14 Statistics for the model components of the best-fitting GLM and GAM incorporating environmental variables used to model $CPUE_0$.The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2-test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2-squared for each additional factor.

$CPUE_0$ Standardisation (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	p	r^2
NULL	6074		-4878		3477				
+Type	6073	1	-5148	270	3337	140	4.0	***	0.04
+DL	6069	4	-5172	24	3321	16	0.5	***	0.04
+Season	6068	1	-5308	136	3252	69	2.1	***	0.06
+Alt	6067	1	-5440	132	3187	65	2.0	***	0.08
+Cond	6066	1	-5721	281	3053	134	4.2	***	0.12
+Surface	6065	1	-5847	126	2994	59	1.9	***	0.14
+Temp	6064	1	-5887	40	2975	19	0.6	***	0.14
$CPUE_0$ Standardisation (GAM)									
NULL	6074		-4878		3477				
+Type	6073	1	-5148	270	3337	140	4.0	***	0.04
+DL	6069	4	-5172	24	3321	16	0.5	***	0.04
+Season	6068	1	-5308	136	3252	69	2.1	***	0.06
+s(Alt)	6065.1	2.9	-5441	133	3186	66	2.0	***	0.08
+s(Cond)	6062.2	2.9	-6053	612	2900	286	9.0	***	0.17
+s(Surface)	6059.3	2.9	-6456	403	2723	177	6.1	***	0.22
+s(Capacity)	6056.6	2.7	-6462	6	2718	5	0.2	***	0.22
+te(Surface:Capacity)	6047.6	9	-6820	358	2567	151	5.6	***	0.26

All of the model components for both models were highly significant (p<0.001). Figure 4.21 illustrates the predicted $CPUE_0$ for the GLM and GAM incorporating environmental covariates compared to $CPUE_0$ standardised by dam following non-parametric bootstrapping of the models. Given the much higher proportion of variability explained by the GAM, it is not surprising to observe that the bootstrap-generated means from the GAM simulated the dam standardised $CPUE_0$ far more accurately than the GLM which largely under- or overpredicted the $CPUE_0$ means.

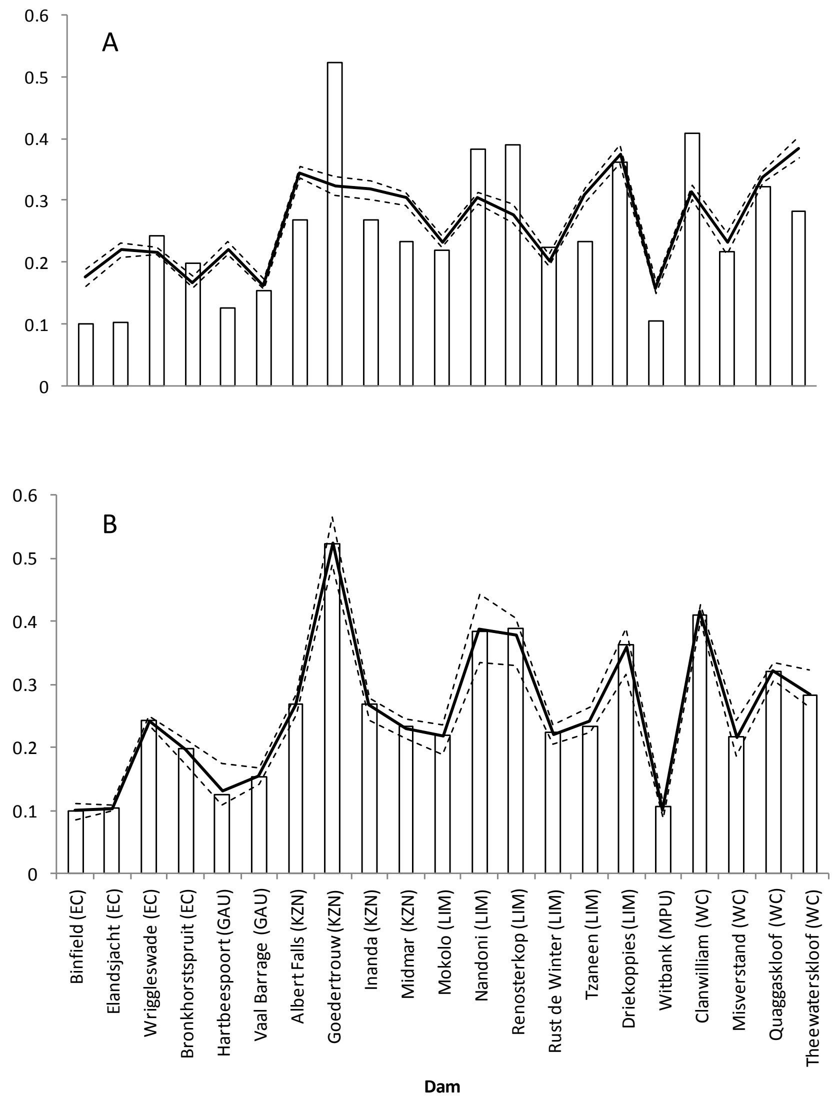


Figure 4.21 Standardised $CPUE_0$ for 17 impoundments (bars) compared to the mean (solid lines) of non-parametrically generated $CPUE_0$ estimates fitted using a GLM (A) and a GAM (B) incorporating environmental variables. Dashed lines represent the upper and lower 95% confidence intervals for the mean $CPUE_0$ estimates.

Correlations between $CPUE_0$ standardised by dam and the environmental GLM and GAM illustrate the differing amounts of variation explained by the models, with the GLM accounting for 76% of the variation compared to the GAM which accounts for 96% (Figure 4.22).

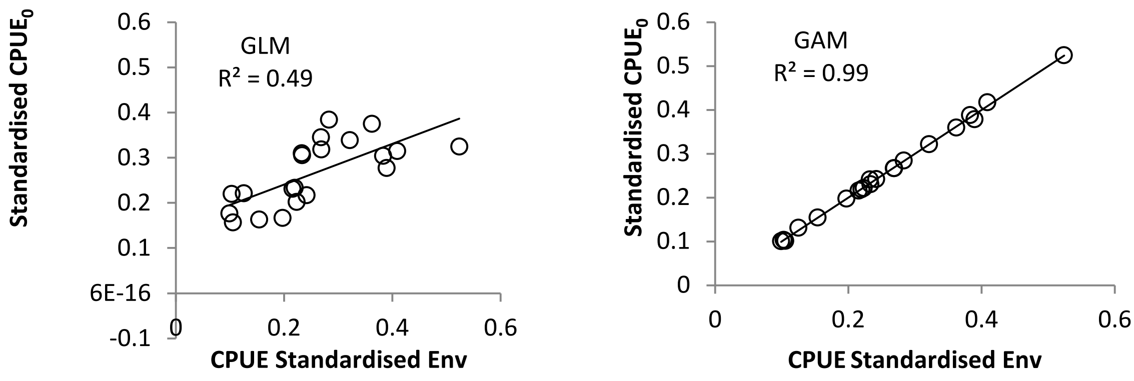


Figure 4.22 Relationship between *CPUE* standardised by dam ("Standardised $CPUE_0$) and *CPUE* estimates derived from a GLM and GAM incorporating environmental variables ("*CPUE* Standardised Env").

Significant model components and their influence on $CPUE_0$ are not illustrated as the relationship is similar to the environmental variables modelled against $CPUE_{POS}$ namely, a decrease in $CPUE_0$ with increasing altitude and conductivity, and higher predicted $CPUE_0$ in dams with large surface areas and small to medium capacities (Figure 4.19).

Summary

The standardised *PC*, *PLIM* and *CPUE* values, as well as the mean weight of fish and average winning limit weight are summarised in Table 4.16. Included in the summary are statistics compiled from bass tournaments conducted on a statewide level in the USA, for comparison with South African bass fisheries. Overall, dams in South Africa had similar *PC* and *PLIM* estimates, and higher $CPUE_{POS}$, $CPUE_0$ and average winning bag weights than bass fisheries in five states of the USA. The mean size of bass was larger in the five states than in South African impoundments however.

Table 4.15 Summarised *PC*, *PLIM*, and *CPUE*(kg.angler^{-1}.h^{-1}) estimates for 21 impoundments including average angler attendance (Mean P), average fish size, average limit size, and average winning bag. Estimates in the lower portion of the table were obtained from statewide tournament surveys conducted in the USA ((1) Quertermus (2010); (2) Abernethy (2010); (3) Tennessee Wildlife Resources Agency (2008); (4) Hickey (2009); (5) Bureau of Fisheries (2009)). "-" indicates where no information was available or data were unavailable .

Dam	Province	*Mean P*	*PC*	*PLIM*	$CPUE_{POS}$	$CPUE_0$	Mean Size (kg)	Mean Limit (kg)	Mean Winning Bag (kg)
Binfield	EC	52	0.27	0.10	0.37	0.10	0.88	4.7	6.28
Elandsjacht	EC	45	0.43	0.16	0.24	0.10	0.56	2.82	4.83
Wriggleswade	EC	50	0.75	0.40	0.32	0.24	0.71	3.62	5.57
Bronkhorstspruit	GAU	16	0.76	0.13	0.26	0.20	0.71	3.51	4.47
Hartbeespoort	GAU	22	0.48	0.01	0.26	0.13	1.14	5.84	6.95
Vaal Barrage	GAU	35	0.61	0.17	0.26	0.15	0.74	3.4	3.88
Albert Falls	KZN	42	0.79	0.36	0.34	0.27	0.83	4.36	6.42
Goedertrouw	KZN	38	0.88	0.43	0.60	0.52	1.37	7.29	11.71
Inanda	KZN	63	0.77	0.39	0.35	0.27	0.83	4.38	8.65
Midmar	KZN	58	0.78	0.29	0.30	0.23	0.75	3.87	8.48
Mokolo	LIM	38	0.79	0.12	0.28	0.22	0.85	4.34	6.64
Nandoni	LIM	37	0.92	0.62	0.42	0.38	0.94	4.89	8.21
Renosterkop	LIM	32	0.87	0.33	0.45	0.39	0.97	4.62	7.74
Rust de Winter	LIM	28	0.76	0.24	0.29	0.22	0.84	3.51	6.04
Tzaneen	LIM	33	0.69	0.34	0.33	0.23	0.78	3.37	5.36
Driekoppies	MPU	36	0.73	0.55	0.50	0.36	0.9	4.9	7.55
Witbank	MPU	36	0.57	0.03	0.19	0.11	0.7	2.46	2.46
Clanwilliam	WC	-	-	-	0.58	0.41	1.3	6.57	7.55
Misverstand	WC	-	-	-	0.31	0.22	1.2	6.64	7.04
Quaggaskloof	WC	-	-	-	0.46	0.32	1.02	5.15	7.94
Theewaterskloof	WC	-	-	-	0.40	0.28	0.96	5.22	7.15
TOTAL		39	**0.70**	**0.28**	**0.36**	**0.26**	**0.85**	**4.23**	**6.54**
State		*Mean P*	*PC*	*PLIM*	$CPUE_{POS}$	$CPUE_0$	Mean Size (kg)	Mean Limit (kg)	Mean Winning Bag (kg)
Georgia (1)	USA	-	0.73	0.22	0.21	0.15	0.81	-	4.9
Alabama (2)	USA	18	0.84	0.36	0.35	0.29	0.86	-	-
Tennessee (3)	USA	41	0.67	0.25	0.18	0.12	1.12	-	5.7
Kentucky (4)	USA	40	0.49	0.14	0.25	0.12	1.05	-	6.27
Mississippi (5)	USA	35	0.48	0.48	0.23	0.11	0.85	-	6.3
TOTAL			**0.64**	**0.29**	**0.24**	**0.16**	**0.94**		**5.79**

A simple summary of the important environmental characteristics of dams for which high to optimum *PC, PLIM*, $CPUE_{POS}$ and $CPUE_0$ are predicted is presented in Table 4.17. Overall, large, shallow dams with low conductivities are good predictors of high *PC*, *PLIM*, $CPUE_{POS}$ and $CPUE_0$ with low altitude dams producing higher *PLIM* and *CPUE* values.

Table 4.16 Summary of the environmental characteristics of dams for which optimum *PC*, *PLIM*, and *CPUE* are predicted.

Estimator	*Optimum Dam Characteristics*
PC	Large; shallow; low conductivity
PLIM	Large; shallow; low altitude; low conductivity
$CPUE_{POS}$; $CPUE_0$	Large; shallow-medium depths; low altitude; lower conductivities

Empirical prediction of PC, PLIM and CPUE

Influential environmental variables identified in the GAM and GLM models of *PC, PLIM* and *CPUE* were combined in a multiple regression approach to investigate the potential for predictive models for impoundments where no fisheries data were available. The models which explained the most variation in *PC, PLIM,* $CPUE_{POS}$ and $CPUE_0$ were, respectively:

PC = 0.61 - 0.44 (*Conductivity* (µS)) + 0.84 (*logSurface Area* (ha)) – 0.31 (*logCapacity* (m^3)) (R^2 = 0.49; p<0.05) (4.13)

PLIM = 3.4 - 0.95 (*Altitude* (m)) – 0.74 (*Conductivity* (µS)) + 1.35 (*logSurface Area* (ha)) – 1.1 (*Capacity* (m^3)) (R^2 = 0.74; p<0.05) (4.14)

$CPUE_{POS}$ = 0.61 – 0.59 (*Altitude* (m)) – 0.32 (*Conductivity* (µS)) + 0.465 (*logSurface Area* (ha)) - 0.22 (*logCapacity* (m^3)) (R^2 = 0.53; p<0.05) (4.15)

$CPUE_0$ = 0.19 – 0.5 (*Altitude* (m)) – 0.41 (*Conductivity* (µS)) + 0.74 (*logSurface Area* (ha)) – 0.2 (*logCapacity* (m^3)) (R^2 = 0.52; p<0.05) (4.16)

Predictive models of *PC*, *PLIM*, $CPUE_{POS}$, and $CPUE_0$ explained a significant 49%, 74%, 53% and 52% of the variation in standardised *PC*, *PLIM*, $CPUE_{POS}$ and $CPUE_0$ (Figure 4.23).

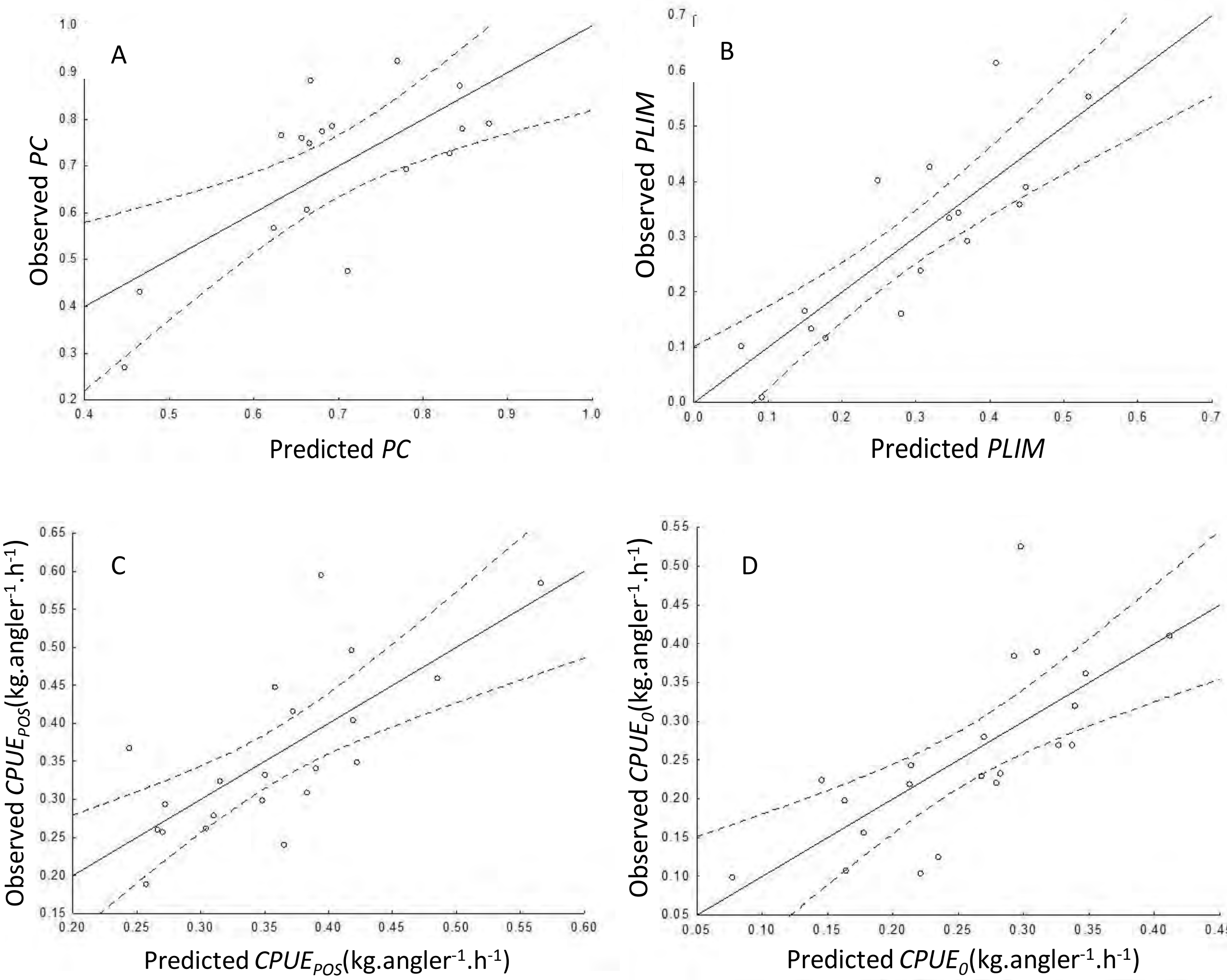


Figure 4.23 Correlation between *PC* (A), *PLIM* (B), $CPUE_{POS}$ (C) and $CPUE_0$ (D) standardised *CPUE* and predicted *CPUE* as a product of the most explanatory environmental variables outlined in the GLM and GAM analysis

Estimates predicted from these models, including error, are summarised in Table 4.18. Regression coefficients from the models highlight the trends outlined in the GLM and GAM models used to standardise *PC*, *PLIM*, $CPUE_{POS}$, and $CPUE_0$: negative relationships with altitude and conductivity, a positive relationship with surface area, and a negative relationship with capacity (See Appendix II).

Table 4.17 Observed and predicted *PC, PLIM*, $CPUE_{POS}$ and $CPUE_0$ derived using empirical models. Error describes the residual around the predicted estimate.

Dam	PC	Pred PC	Error	PLIM	Pred PLIM	Error	$CPUE_{POS}$	Pred $CPUE_{POS}$	Error	$CPUE_0$	Pred $CPUE_0$	Error
Binfield (EC)	0.27	0.45	-0.18	0.10	0.06	0.04	0.37	0.24	0.12	0.10	0.09	0.01
Elandsjacht (EC)	0.43	0.47	-0.03	0.16	0.28	-0.12	0.24	0.37	-0.13	0.10	0.22	-0.11
Wriggleswade (EC)	0.75	0.67	0.08	0.40	0.25	0.15	0.32	0.31	0.01	0.24	0.22	0.02
Bronkhorstspruit (GAU)	0.76	0.66	0.10	0.13	0.16	-0.02	0.26	0.27	-0.01	0.20	0.17	0.03
Hartbeespoort (GAU)	0.48	0.71	-0.23	0.01	0.09	-0.08	0.26	0.30	-0.04	0.12	0.20	-0.07
Vaal Barrage (GAU)	0.61	0.66	-0.05	0.17	0.15	0.02	0.26	0.27	-0.01	0.16	0.17	-0.01
Albert Falls (KZN)	0.79	0.88	-0.09	0.36	0.44	-0.08	0.34	0.39	-0.05	0.27	0.35	-0.08
Goedertrouw (KZN)	0.88	0.67	0.21	0.43	0.32	0.11	0.60	0.39	0.20	0.53	0.29	0.23
Inanda (KZN)	0.77	0.68	0.09	0.39	0.45	-0.06	0.35	0.42	-0.07	0.27	0.33	-0.06
Midmar (KZN)	0.78	0.85	-0.07	0.29	0.37	-0.08	0.30	0.35	-0.05	0.23	0.30	-0.07
Mokolo (LIM)	0.79	0.69	0.09	0.12	0.18	-0.06	0.28	0.31	-0.03	0.22	0.21	0.01
Nandoni (LIM)	0.92	0.77	0.16	0.62	0.41	0.21	0.42	0.37	0.04	0.38	0.31	0.08
Renosterkop (LIM)	0.87	0.84	0.03	0.33	0.35	-0.01	0.45	0.36	0.09	0.39	0.30	0.09
Rust de Winter (LIM)	0.76	0.63	0.13	0.24	0.31	-0.07	0.29	0.27	0.02	0.22	0.19	0.04
Tzaneen (LIM)	0.69	0.78	-0.09	0.34	0.36	-0.01	0.33	0.35	-0.02	0.23	0.29	-0.06
Driekoppies (LIM)	0.73	0.83	-0.10	0.55	0.53	0.02	0.50	0.42	0.08	0.36	0.38	-0.02
Witbank (LIM)	0.57	0.62	-0.06	0.03	-0.01	0.04	0.19	0.26	-0.07	0.11	0.13	-0.02
Clanwilliam (WC)							0.58	0.57	0.02	0.41	0.68	-0.27
Misverstand (WC)							0.31	0.38	-0.07	0.22	0.28	-0.06
Quaggaskloof (WC)							0.46	0.48	-0.03	0.32	0.71	-0.39
Theewaterskloof (WC)							0.40	0.42	-0.01	0.28	0.34	-0.06

Bank angling catch records

Descriptive analysis

A total of 1 841 bank angling catch records was obtained from 15 impoundments, comprising a total of 331 740 angler hours. The location of these impoundments is illustrated in Figure 4.24. Nine of the impoundments were listed as being of "high priority" to SAFBAF anglers during the NEM:BA consultation process (see Chapter 3). Most of the impoundments are located on the Highveld of the country in the Free State, Mpumalanga, Gauteng and North West Provinces at altitudes greater than 1 000m. Data were obtained for three dams in the Eastern Cape and only one in the Western Cape; no data were available from dams in Kwazulu-Natal and Limpopo. Overall, bank angling data were not available on as wide a spatial scale as that observed with bass angling data.

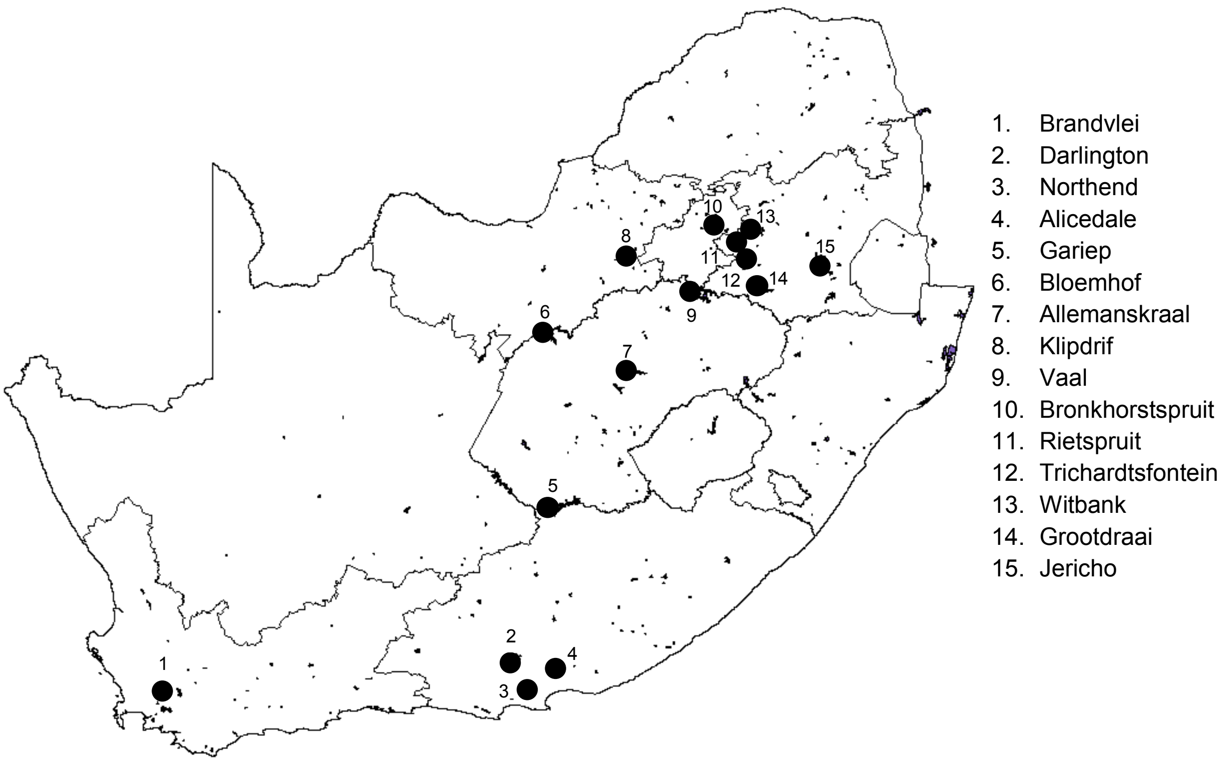


Figure 4.24 Impoundments in South Africa from which bank angling competition data were obtained.

A summary of the number of catch records obtained for each impoundment, for what years and months, as well as the number and type of events is provided in Table 4.19.

Table 4.18 Number of catch records obtained for each impoundment with associated event, event types, years and months.

Impoundment	Catch Records (n)	Events	Event Type(s)	Year	Month	% Aggregated
Alicedale	236	2	League	2009-2010	Jan;Sep	0
Allemanskraal	4	4	Nationals	2003;2010	Mar-Apr;Nov	100
Bloemhof	50	50	Club; Nationals	2003-2011	Feb-Apr;Oct-Dec	100
BrandVlei	1	1	Nationals	2011	Mar	100
Bronkhorstspruit	3	3	Nationals	2003;2007	Mar;Nov-Dec	100
Darlington	604	10	League; Nationals	2006-2010	Jan-Mar;Sep-Nov	10
Gariep	670	4	Club	2006-2007	Jan;Apr;Nov-Dec	0
Grootdraai	12	12	Club; Nationals	2001;2004;2006;2008;2010-2011	Feb-Apr;Jun;Oct	100
Jericho	1	1	Nationals	2004	Mar	100
Klipdrif	12	12	Club; Nationals	2003-2007;2009-2011	Feb-Apr;Dec	100
Northend	6	6	Club; Nationals	2003;2005-2007;2010	Feb;Oct-Dec	100
Rietspruit	2	2	Nationals	2004-2005	Mar	100
Trichardstfontein	7	7	Club; Nationals	2007-2010	Feb-Mar;Jul-Aug;Dec	100
Vaal	162	162	Club; Nationals	2003-2007;2009-2010	Jan-Dec	100
Witbank	66	2	Club	2009	Oct;Dec	0

The number of catch records obtained for each impoundment varies considerably, ranging from 1 to 670 ($\bar{x}$ = 122.4; SD = ± 220). However, the majority of the catch records that were available were in aggregated format such that the entire catch obtained by all anglers at an event was reported, resulting in one catch record for that impoundment. Disaggregated catch information where individual catches for each angler, including information on species captured, were only available for four impoundments (Alicedale, Darlington, Gariep, and Witbank). Species composition of angler catches for these impoundments is illustrated in Figure 4.25. While these figures represent only four impoundments, the dominance of common carp *C. carpio* in the catches supports what was outlined in Chapter 3, namely that this species represents the preferred target for bank anglers in South African dams.

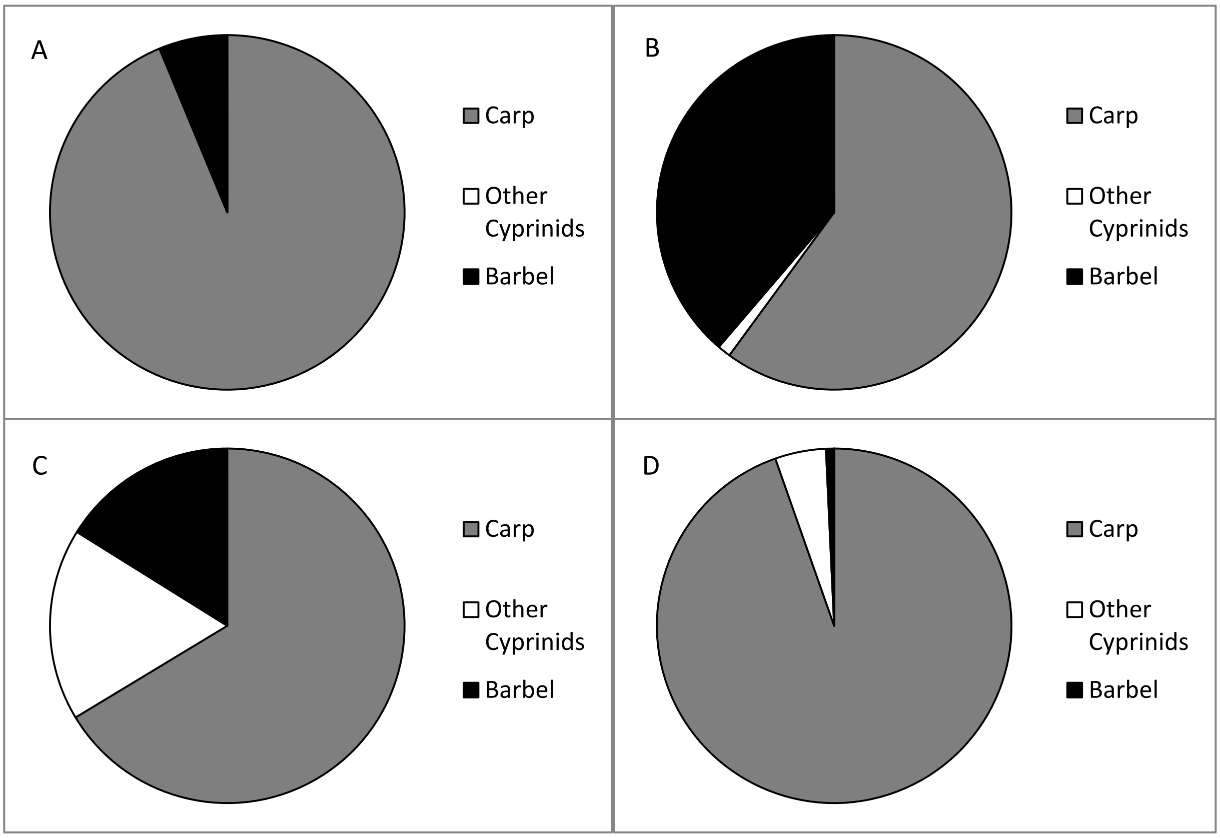


Figure 4.25 Species composition of bank angling catches from competitions held on four impoundments (A = Alicedale; B = Darlington; C = Gariep; D = Witbank).

Figures 4.26 and 4.27 illustrate the yearly and monthly availability of data, with associated contributions by different event types, respectively. The number of catch records available increased from 2003 with the most obtained from 2010. Only records from the first half of 2011 were obtained. The majority of data (61%) were obtained from national-tier competitions followed by Club events (34%) with a smaller contribution from league events (5%). Monthly trends illustrate that most tournaments (93%) are held in the summer months, from September to April. In particular, the high number of records available from national events during the month of March indicates that this is the preferred period for holding these events. Tournament duration ranged from 1 day to 4 days; the majority (52%) of competitions were held over one day followed by three day (27%) and two day (20%) events.

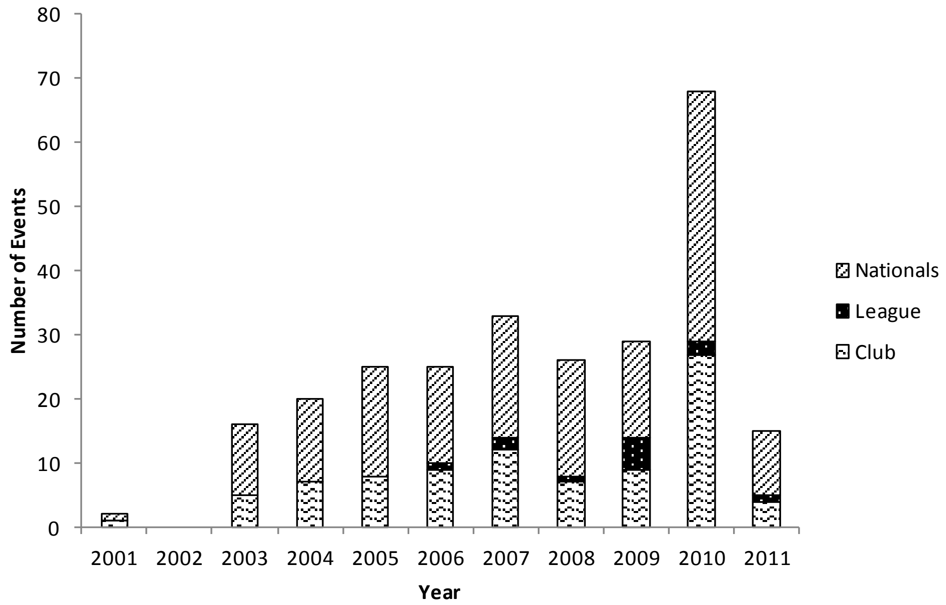


Figure 4.26 The number of tournament events and event types for which data were available and assessed over the 1999–2011 period.

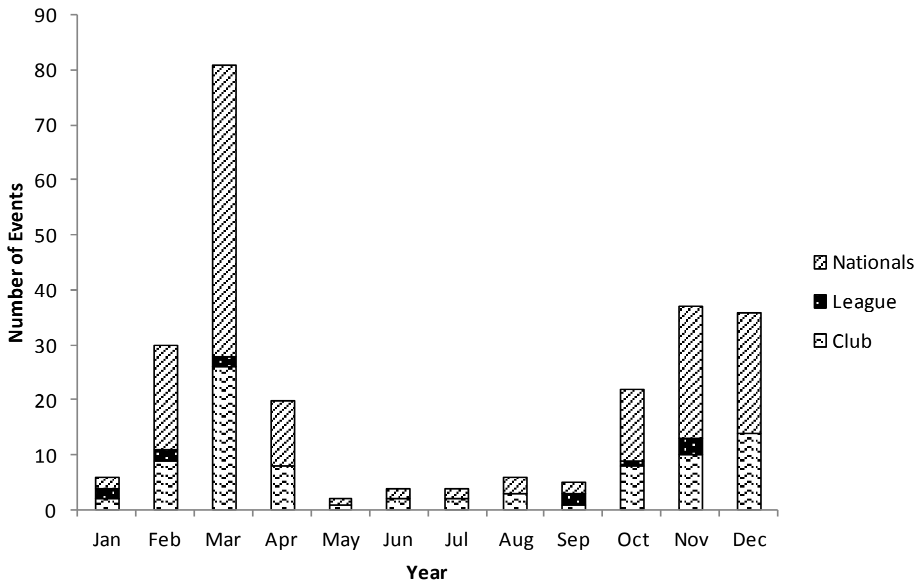


Figure 4.27 The number of tournament events and event types for which data were available and assessed per month over the 1999–2011 period.

The three day events are largely national competitions, while club and league events are more commonly of shorter duration. Angler participation at different tournaments ranged from 21

CPUE

The model statistics for the best-fitting model used to standardise *CPUE* for each impoundment are presented in Table 4.20. Standardised *CPUE* was best modelled using a GLM such that:

$$CPUE = Dam + Type + Anglers + \varepsilon \qquad (4.17)$$

Table 4.19 Statistics for the model components of the best-fitting GLM and GAM incorporating environmental variables used to model *CPUE*. The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2-test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2-squared for each additional factor.

CPUE Standardisation (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	*p*	r^2
NULL	1718		4539		2146				
+Dam	1711	7	4149	390	1755	391	18.2	***	0.18
+Type	1710	1	4137	12	1744	11	0.5	**	0.19
+Anglers	1709	1	4106	30	1715	29	1.4	***	0.20
% Deviance Explained							**20.1**		

Overall, the GLM explained 20.1% of the variation in the *CPUE* data. All of the model components were highly significant; however, the factor "Dam" explained the majority of the variation (18.2%). Estimated coefficients from Eq. 4.17, with the exclusion of "Dam" coefficients, are provided in Appendix III (Table 1). *CPUE* tends to have a positive relationship with the event type components "Div", indicating higher catch rates in these competitions, and a slightly negative relationship with increased numbers of anglers.

Figure 4.29 illustrates the predicted *CPUE* for the eight impoundments with *CPUE* standardised to control the factors day length ("DL" = 8 hours) and event type ("Type" = Divisional events). *CPUE* was highest at Gariep Dam (3.5kg.angler^{-1}.h^{-1}) in the Eastern

Cape/Free State province and lowest at Witbank Dam in Mpumalanga (0.55kg.angler^{-1}.h^{-1}), with an average of 1.79 ± 1.08 kg.angler^{-1}.h^{-1}.

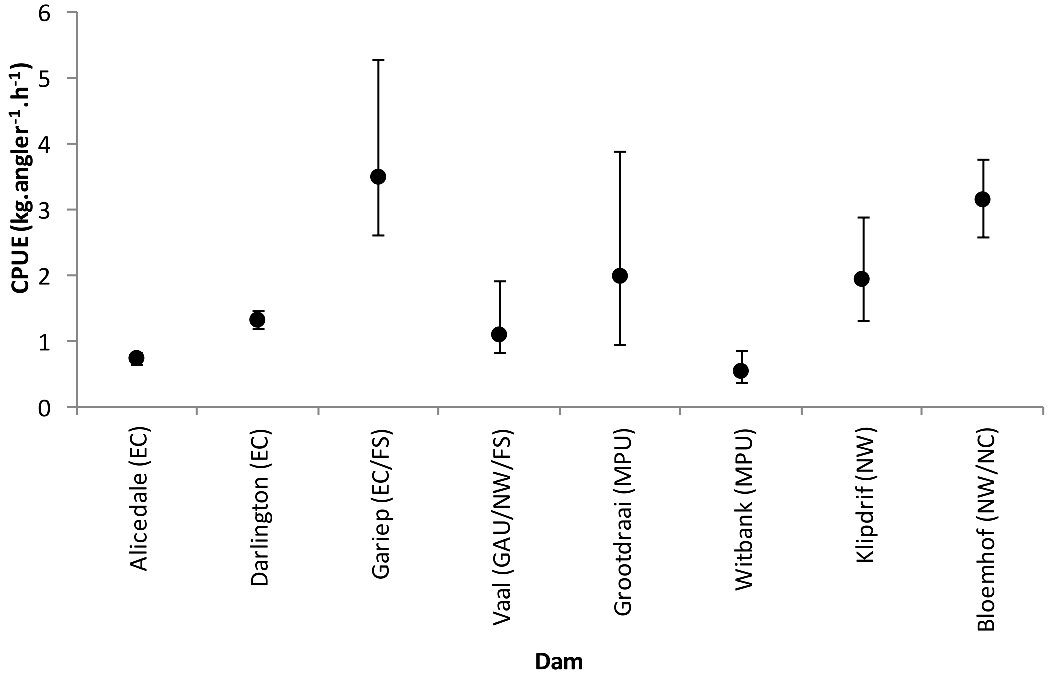


Figure 4.29 Predicted *CPUE* for eight bank angling impoundments standardised to a day length of 8 hours and divisional event types (EC = Eastern Cape, GAU = Gauteng; FS = Free State; MPU = Mpumalanga; NW = North West; NC = Northern Cape). Error bars represent 95% upper and lower confidence intervals.

Modelling CPUE using Environmental Variables

CPUE was modelled using environmental variables such that:

$$CPUE = Type + Anglers + Rain + Cond + Surface + \varepsilon \qquad (4.18)$$

$$CPUE = Type + Anglers + s(Rain) + s(Cond) + s(Surface) + \varepsilon \qquad (4.19)$$

for the GLM and GAM respectively.

Both models incorporated the same environmental covariates. Model components for the GLM and GAM are presented in Table 4.21. Overall, the GAM explained 19.6% of the total variability in *CPUE* standardised per impoundment compared to the 19.2% of the variation explained by the GLM. All of the model components were highly significant (p<0.001), with the exception of "Type" in both the GLM and GAM (p<0.05).

Table 4.20 Statistics for the model components of the best-fitting GLM and GAM incorporating environmental variables used to model $CPUE_0$.The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2-test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2-squared for each additional factor.

CPUE Standardisation (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	*p*	r^2
NULL	1718		4539		2146				
+Type	1717	1	4525	14	2129	17	0.8	**	0.01
+Anglers	1716	1	4432	93	2032	97	4.5	***	0.05
+Rain	1715	1	4422	10	2019	13	0.6	***	0.06
+lnCond	1714	1	4269	153	1870	149	6.9	***	0.13
+lnSurface	1713	1	4119	150	1733	137	6.4	***	0.19
% Deviance Explained							**19.2**		
CPUE Standardisation (GAM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	*p*	r^2
NULL	1718		4539		2146				
+Type	1726	1	4524	15	2129	17	0.8	**	0.01
+Anglers	1725	1	4432	92	2032	97	4.5	***	0.05
+s(Rain)	1722.6	2.4	4299	133	1898	134	6.2	***	0.12
+s(lnCond)	1719.6	3	4116	183	1726	172	8.0	***	0.20
% Deviance Explained							**19.6**		

Figure 4.30 illustrates the predicted *CPUE* for the GLM and GAM incorporating environmental covariates compared to *CPUE* standardised by dam following non-parametric bootstrapping of the models. The bootstrap-generated means and confidence intervals for the GLM do not capture the estimates for Gariep, Vaal, Grootdraai and Witbank Dams. In particular, mean *CPUE* at Gariep Dam is overpredicted. Comparatively, the GAM simulates the dam standardised *CPUE* estimates more accurately; however, Gariep, Hartbeespoort and Vaal Dam *CPUE* estimates are overpredicted although they are captured by the lower

confidence intervals. Overall, the confidence intervals predicted by the GAM are wider than the GLM but account for the estimated mean *CPUE* for each impoundment.

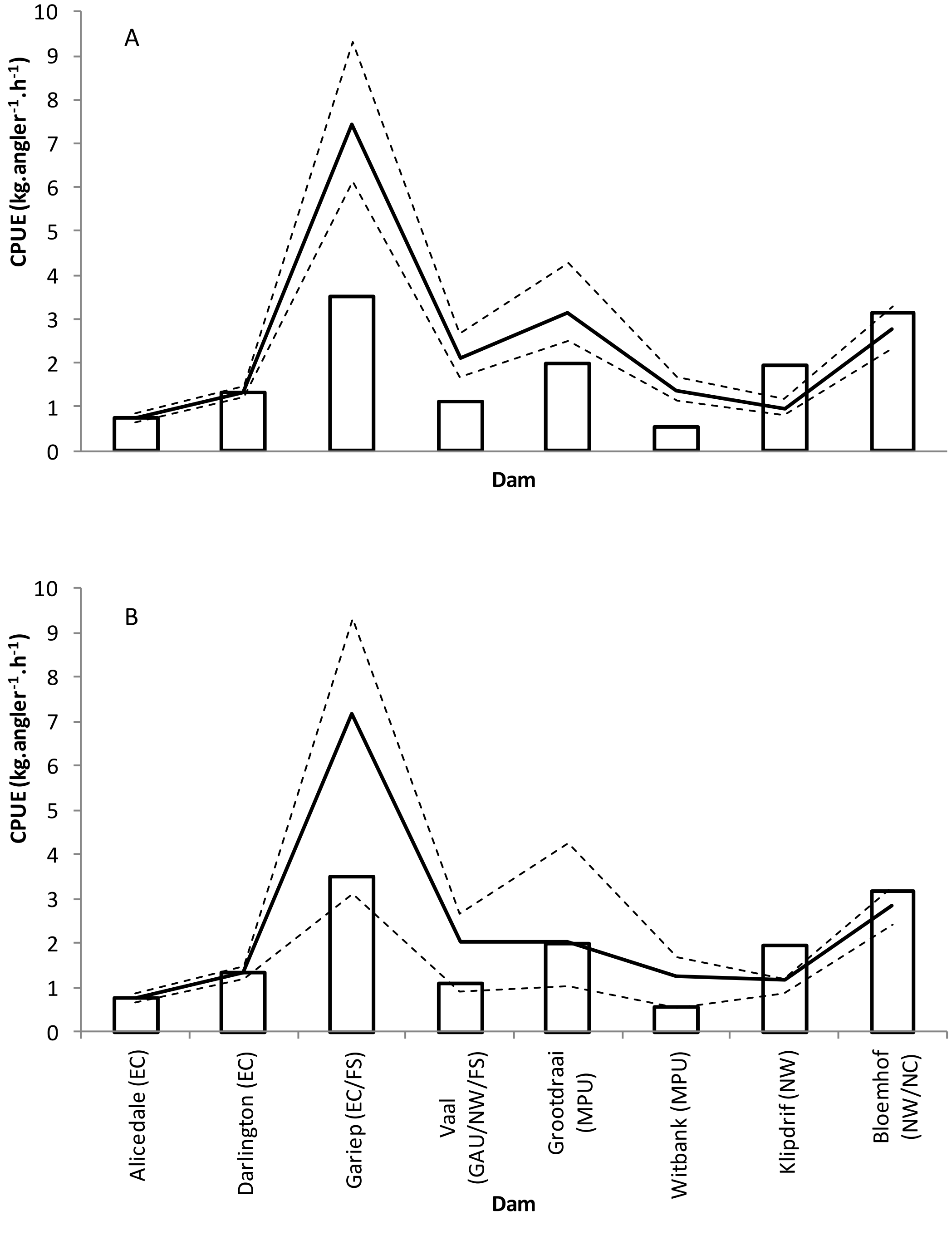


Figure 4.30 Standardised *CPUE* for eight bank angling impoundments (bars) compared to the mean (solid lines) of non-parametrically generated *CPUE* estimates fitted using a GLM (A) and a GAM (B) incorporating environmental variables. Dashed lines represent the upper and lower 95% confidence intervals for the mean *CPUE* estimates.

Correlations between *CPUE* standardised by dam and the environmental GLM and GAM are presented in Figure 4.31. Both the GLM and GAM account for similar amounts of variation (60% and 62% respectively) in the *CPUE* data.

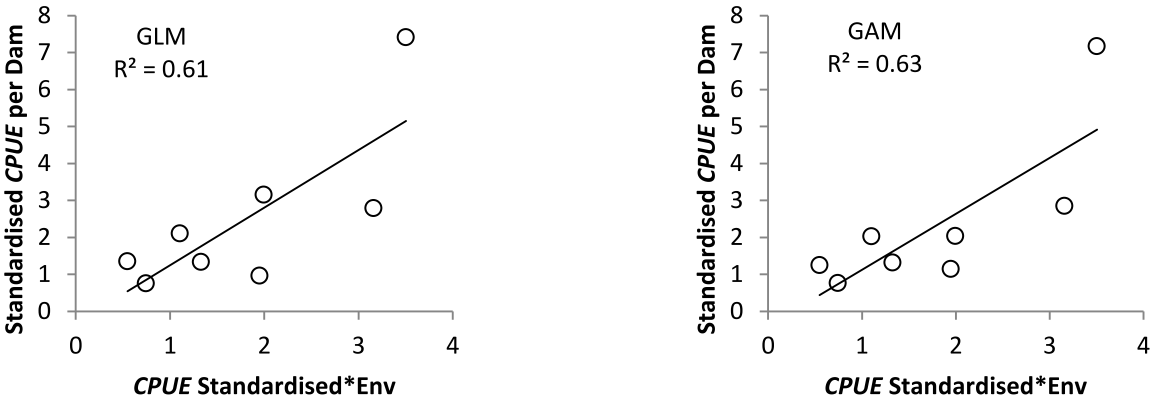


Figure 4.31 Relationship between *CPUE* standardised by dam and *CPUE* estimates derived from a GLM and GAM incorporating environmental variables.

Significant model components for the GLM and GAM, and their influence on *CPUE* are illustrated in Figure 4.32. The GLM describes a slight decrease with increasing conductivity (A) and an increase with increasing surface area (B). The "Rain" component from the GAM indicates that *CPUE* is fairly constant in areas with rainfall of approximately 300–600mm before decreasing to a minimum at approximately 700mm. *CPUE* is therefore predicted to be highest in dams with larger surface areas, lower conductivities, and in areas with lower rainfall. The influence of rainfall on *CPUE* is, however, less pronounced.

Empirical prediction of CPUE

Influential environmental variables identified in the GLM and GAM models of *CPUE* were combined in a multiple regression approach to investigate the potential for a predictive model of *CPUE* for impoundments where no fisheries data were available. The model which explained the most variation in *CPUE* was of the form:

$CPUE = 5.84 - 0.54\ (Conductivity\ (\mu S)) + 0.5\ (logSurface\ Area\ (ha)) - 0.33\ (Rainfall\ (mm))$

$(R^2 = 0.63;\ p = 0.21)$ (4.20)

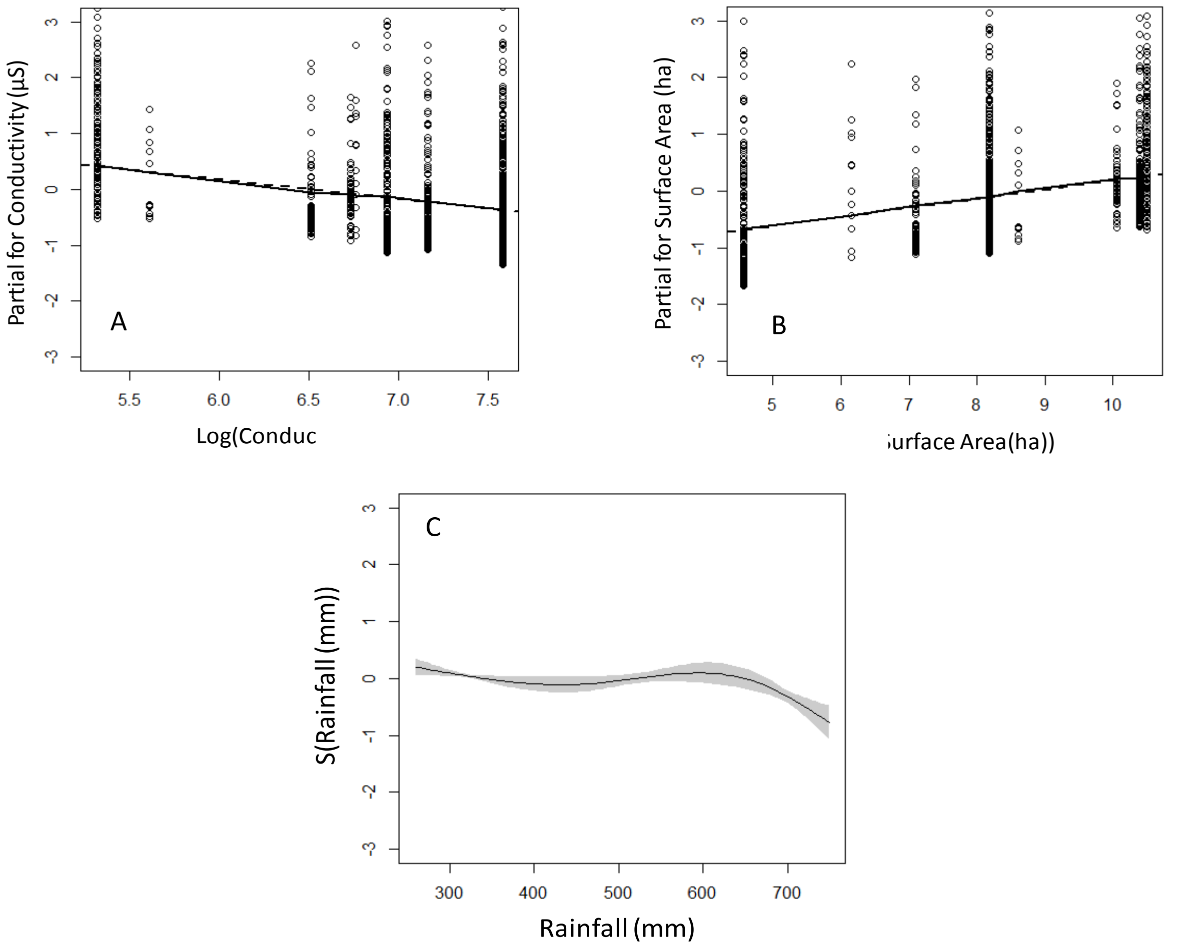


Figure 4.32 Effect of the most significant environmental variables on *CPUE* modelled using a GLM (A; B) and a GAM (C). "Partial" refers to "Partial Residual Plot" in which the effect of the predictor is assessed while taking into account other components in the model. "*f*" refers to the smoothing spline fitting the effect of the predictor to the explanatory variable.

.

The predictive model explained 63% of the variation in standardised *CPUE* per dam. The relationship between these explanatory variables and *CPUE* was, however, not significant (p = 0.21, ANOVA). (Figure 4.33) The model captures six of the eight dams inside the upper and lower confidence intervals, although the *CPUE* for two dams is largely underpredicted. The regression coefficients for the explanatory variables in Eq. 4.20 describe a situation which was outlined in the GLM and GAM models used to standardise *CPUE*. Higher catch rates are expected in dams which have lower conductivities, large surface areas, and which are situated in lower rainfall areas.

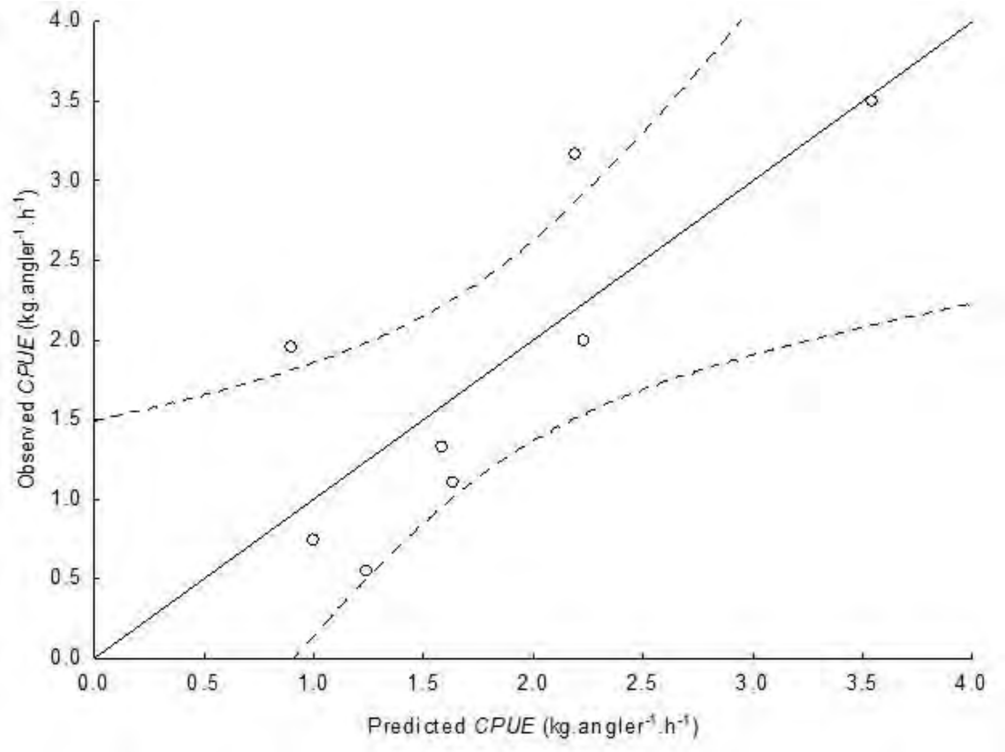


Figure 4.33 Correlation between standardised *CPUE* and predicted *CPUE* as a product of the most explanatory environmental variables outlined in the GLM and GAM analysis. Dashed lines represent upper and lower 95% confidence intervals.

Table 4.21 Observed CPUE and predicted (Pred) CPUE derived using an empirical model. Error describes the residual around the predicted estimate.

Dam	*Prov*	*CPUE*	*Pred CPUE*	*Error*
Alicedale	EC	0.75	1.00	-0.25
Darlington	EC	1.33	1.58	-0.26
Gariep	EC/FS	3.50	3.54	-0.04
Vaal	GAU/NW/FS	1.10	1.64	-0.54
Grootdraai	MPU	2.00	2.23	-0.23
Witbank	MPU	0.55	1.25	-0.70
Bloemhof	NW/NC	3.16	2.19	0.97
Klipdrif	NW/NC	1.95	0.90	1.05

4.4 DISCUSSION

Bass angling catch records

Meta-analysis of catch records from South Africa‟s bass fisheries reveals both spatial and temporal trends. Catch records were obtained from impoundments located in six provinces (Western and Eastern Cape; KwaZulu-Natal; Gauteng; Limpopo, and Mpumalanga), highlighting that utilisation of the bass resource occurs throughout the species‟ distributional range, a fairly wide geographical area (Skelton and Weyl, 2011). However, the number of impoundments from which catch records were available indicates that competitive angling activity, within each province, is largely centred on a small number of recognised dams. This may be explained by a combination of factors. All competitive bass angling is conducted using purpose-made bass boats (see Chapter 3) and competition events are therefore dependent on a sufficiently large area of water for angling to be conducted safely and without crowding. Additionally, these dams are more likely to have adequate boat launching facilities, which promote efficient and convenient entry and exit from the water for the angler. Another important consideration is that, although largemouth bass are present in all of South Africa‟s major river systems, they are a largely lacustrine species that, because of their habitat preferences, have become established in standing waters across South Africa (de Moor and Bruton, 1988; Skelton, 2001). Given that largemouth bass are structure-oriented fish, preferring areas with submerged and floating vegetation, standing timber (Savino and Stein, 1989) and manmade structures, they are inclined to be targeted in these areas by competitive anglers. Larger dams, in conjunction with having more space to accommodate large numbers of boating anglers, are probably characterised by more extensive, and importantly, more diverse habitat than smaller farm dams, which is a drawcard for anglers whose efforts are generally concentrated around different types of structure.

The majority of catch information was obtained from anglers and/or officials affiliated to SABAA, probably due to this organisation having higher membership figures and average tournament participation than money event circuits, and having divisions that encompass a far larger area and therefore more impoundments. Fewer catch records were available from money-based tournament circuits, which may be a result of the relatively recent advent of money competitions in South Africa, and because these tournaments are held predominantly in only three provinces, and less frequently than those organised by clubs affiliated to SABAA. In addition, the appointment of catch record representatives or officials charged with the compilation of catch records in executive structures within the SABAA promotes the housing of well formatted records, which are more comprehensive than those housed or published by money event organisers.

Most records were obtained from events conducted from 2007–2011, with a paucity of data available prior to this for many dams. Lack of data from this period is most likely a combination of angler attitudes or a lack of awareness regarding the usefulness of catch records as potential aids for the improvement and/or management of their resource and secondly a regular reshuffling of administrators in organised angling bodies resulting in mislaid information (Nortje, *pers comm*, 2010). Data availability by month highlights the largely seasonal nature of organised bass angling (Figure 4.7). Most events were held during the summer months, with comparatively fewer events held in winter, a trend which is similarly found in bass fisheries in the USA (Kerr, 2004; Cain, 2009; Hickey, 2009). Those events that were held during the winter period were mostly professional events, a result of the format of these tournament circuits, which run throughout the year as opposed to club or divisional events that generally follow a seasonal format (fishing is conducted during the warmer, summer months).

Similarly to seasonal trends, average tournament duration of 1 or 2 days, as well as average angler participation ($\bar{x}$ = 39; SD = ± 27.5) was similar to that reported by Wilde et al. (1998) in their assessment of bass tournaments in Texas, USA ($\bar{x}$ = 35 participants), as well as Tennessee, Kentucky and Mississippi. Angler attendances varied depending on the event type with particularly large attendances at "Open" events. This is probably a result of increased incentive due to the numerous and high-value prizes on offer at such competitions which attract both competitive and casual anglers.

Probability of Capture

The most explanatory model for *PC* where "Dam" and fisheries-dependent factors were included as covariates only explained 13.7% of the total variation in the data. Due to the low resolution of the angler data obtained, typical temporal variables, more specifically year and month effects which are almost always included in GLMs to standardise fisheries-dependent data (Maunder and Punt, 2004), could not be used as explanatory variables. However, the temporal variable "Season" was included and accounted for the majority of the total deviance explained by the model (Table 4.8). Higher *PC* was predicted for summer than winter (Appendix II, Table 1, Eq. 4.1), which may be explained by increased temperatures and more active foraging by bass during this period, increasing the vulnerability to capture (Ridgway, 2002). Overall, the factor "Day Length" had a positive relationship with *PC,* which is to be expected as the chances of catching at least one fish increase with increased effort hours.

Modelling standardised *PC* with environmental covariates using a GLM and a GAM produced differing model components, and variation in the amount of variability explained by the two modelling approaches. The GLM (Eq. 4.2) included more environmental covariates yet explained less variability in *PC* than the GAM (Eq. 4.3). Results of non-parametric bootstrapping of both models also indicated that the GAM simulated the mean standardised *PC* more effectively than the GLM (Figure 4.10). These results suggest that relationships between *PC* and environmental variables are best modelled using an approach which accounts for non-linearity in predictor variables. The more parsimonious nature of the GAM suggests that non-linear relationships between conductivity and the surface:capacity interaction are more important in describing *PC* than linear combinations of increased explanatory variables as included in the GLM.

The influence of environmental variables on *PC* (Figure 4.12) suggests that dams with large surface areas, small capacities, lower conductivities and higher temperatures are optimum. The relationship with surface area and capacity indicates that large, shallow dams provide the best *PC,* with a smaller peak for small, deep dams. Shallower impoundments generally promote the development of aquatic vegetation due to higher rates of nutrient cycling and larger euphotic zones (Grobbelaar, 1985). Submerged and floating aquatic vegetation constitutes the preferred habitat of *M. salmoides* (Savino and Stein, 1989; Cooke and Philipp, 2009), and dams with greater areas of preferred habitat may provide anglers with better opportunities of catching at least one fish in areas which are likely to see more active feeding behaviour than deeper areas devoid of structure. The influence of conductivity on *PC* is probably related to water clarity. High conductivity is generally a result of high total dissolved solids (TDS) in the system (Mustapha, 2009) and high conductivity dams are more likely to be turbid, low visibility systems with increased amounts of TDS. Lower conductivity is generally indicative of increased water clarity and, as *M. salmoides* is a visual predator, foraging efficiency and associated vulnerability to capture are likely to be higher in these systems (Guy and Willis, 1991; Sweka and Hartman, 2003; Paukert and Willis, 2004;) resulting in higher predicted *PC*.

Probability of Limit

The initial GLM used to standardise *PLIM* per impoundment only explained 10.7% of the total variation in the data which, as with *PC*, may be a result of the low resolution of the data, which meant more explanatory fisheries-dependent variables could not be included in the model. Of the components in the model, the factor “Dam” explained the greatest proportion of variability, suggesting that *PLIM* is influenced by the impoundment being fished (the characteristics of these impoundments were thus subsequently investigated in GLMs and GAMs incorporating environmental covariates for each system).

The influence of season, while significant, was less explanatory for *PLIM* than *PC* although there was a negative relationship between *PLIM* and the estimated coefficient “Winter” (Appendix II, Table 2, Eq. 4.2), indicating that *PLIM* was generally higher in the warmer months of summer. As with *PC*, this may be associated with increased feeding behaviour and vulnerability to capture during the warmer months. The covariate “DL” was more explanatory however and, as with *PC*, showed a positive relationship with *PLIM* and increasing effort hours (Appendix II, Table 2).

Comparisons between the GLM and GAM incorporating environmental variables show that the GAM explained more of the variability in *PLIM* than the GLM, although it incorporated an additional covariate. However, the proportion of variability explained by the GAM was much greater and, judging from the model selection process, the inclusion of an extra variable was warranted (Figure 4.14). Such a large difference in explained deviance between the GLM and GAM indicates the importance of non-linearity in explanatory relationships between *PLIM* and predictor variables.

The influence of environmental variables on *PLIM* suggest that anglers are more likely to obtain a bag limit (5 fish) in impoundments situated at lower altitudes, with warmer temperatures, lower conductivities and higher pH values (Figure 4.16). The surface:capacity interaction indicates that, similarly to *PC*, high *PLIM* is expected in large, shallow impoundments and lowest *PLIM* tends to be predicted for small, deep dams. Overall, the most explanatory environmental variable was altitude. The effect of altitude is not significantly correlated with temperature effects, although one would expect a decrease in temperature with increasing elevation. The 17 impoundments for which *PLIM* was investigated were situated in a variety of climatic regions from cool temperate in the Eastern Cape, subtropical in Kwazulu Natal, the Highveld in Gauteng and Mpumalanga and the Lowveld in Limpopo. These climate regions are regulated by forces such as the Benguela and Agulhas currents, as well as high pressure cells inland (Tyson and Preston-Whyte, 2000). Changes in elevation are not strong predictors of maximum or minimum temperatures; however, those areas situated at low elevation are subjected to less fluctuation in maximum and minimum temperatures than those observed in areas such as the Highveld of the country (Tyson and Preston-Whyte, 2000). *PLIM* is therefore predicted to be higher at low altitudes which are less subjected to cool temperature extremes observed inland at higher altitudes. Altitude was also significantly and positively correlated with rainfall. Dams in high elevation areas are thus likely to receive more rainfall than those in low elevation areas. Higher rainfall is often associated with increased run-off, which is linked to turbidity increases and loss of water clarity (Webb et al., 1995; Duane Nellis et al., 1998). Therefore, dams with longer periods of higher water clarity may be expected to produce higher *PLIM*s than those situated at higher altitudes where rainfall and turbidity effects are more pronounced. The influence of conductivity and temperature on *PLIM* is largely the same as that observed for *PC,* with expected *PLIM* higher in dams with low conductivities and warmer temperatures.

$CPUE_{POS}$ and $CPUE_0$

The GLM used to standardise $CPUE_{POS}$ per impoundment explained a total of 19.4% of the variation in *CPUE*. The factor "Dam" accounted for the majority (14.2%), indicating that variation within dams accounts for a large proportion of angler catches. The estimated coefficients from the factor "Type" (Appendix II, Table 3, Eq. 4.3) indicate that *CPUE* was higher in non-money events than in money events. This result can probably be explained by the fact that one would expect higher $CPUE_{POS}$ for anglers fishing SABAA events as they are likely to be more accomplished anglers, who represent the top level bass angler in South Africa, in comparison to money events which are open events and host anglers with a range of skill levels. Additionally, club events, as well the majority of divisional events, are generally held on one or two dams over the course of a year; increased familiarity and experience with "home" waters, similar to a skipper effect accounted for in standardisation of marine fisheries data (Maunder and Punt, 2004; Chen and Chiu, 2009) could also account for the slightly better catches during non-money events. Estimated coefficients from the factor "DL" indicate that *CPUE* generally decreased with increased angler hours (Appendix II, Table 3. Eq. 4.7) suggesting that, as a result of the limits imposed at bass fishing competitions, increased angler effort, in the form of two anglers (DL = 16), did not result in higher catch rates.

Comparatively, the GLM used to standardise $CPUE_0$ incorporating the same model components as those used to standardise $CPUE_{POS}$, explained 7% more variability in $CPUE_0$ than the GLM used to standardise $CPUE_{POS}$. Regression coefficients from the model describe the same patterns to those observed in standardisation of $CPUE_{POS}$; higher $CPUE_0$ predicted for non-money events and a decrease with increasing day length (DL). The extra variability explained in the standardisation of $CPUE_0$ confirms that these zero-adjusted estimates are more transparent indicators of catch rate in comparison to $CPUE_{POS}$. However, very similar trends were observed in models of $CPUE_{POS}$ and $CPUE_0$ incorporating environmental variables. This may be explained by the fact that the best-fitting model parameters used to standardise *PC* using environmental covariates were, with the exception of altitude, the same as those used the $CPUE_{POS}$ model. Therefore, estimates of $CPUE_0$, a combination of *PC* and $CPUE_{POS}$, were influenced by similar environmental variables.

The GAM explained far more variability in standardised $CPUE_{POS}$ and $CPUE_0$ than the GLM, and results from non-parametric bootstrapping suggest that the relationships between *CPUE* in different impoundments and environmental predictors are better modelled using a GAM that allows for non-linearity (Figures 4.17, 4.21). The type and number of variables selected by the models differed, yet the large difference in explained variation by both models warrants the inclusion of extra explanatory variables utilised in the GAM.

Environmental variables from both models that influenced $CPUE_{POS}$ and $CPUE_0$ are the same as those identified during the modelling of *PC* and *PLIM*. $CPUE_{POS}$ and $CPUE_0$ were predicted to be higher in impoundments at low elevation, low conductivity, low rainfall, and high surface area (Figure 4.20). The surface plot indicates that predicted $CPUE_{POS}$ is optimum at high surface area and low to medium capacities, a trend similar to that observed in the models of *PC* and *PLIM*. In studies conducted in Texas (Durocher et al., 1984), South Dakota (Guy and Willis, 1991), and Nebraska (Paukert and Willis, 2004), USA, relative abundance of largemouth bass was shown to increase with submerged aquatic vegetation. While there was no measure of submerged aquatic vegetation in this study, it is hypothesised that larger, shallower lakes provide a greater euphotic zone and increased nutrient loading for the development of aquatic vegetation, which may explain high $CPUE_{POS}$ and $CPUE_0$ estimates in these impoundments.

Multiple Regression Analysis

Studies predicting largemouth bass abundance using environmental variables are few. Guy and Willis (1991), in a study concerning correlations between environmental variables and largemouth bass density in South Dakota, USA, developed a predictive model incorporating vegetation cover and water clarity, which explained 51% of the variation in the data, a relationship that the authors considered adequate in informing future development and management of bass fisheries in the state.

Results from the multiple regression analysis suggest that the environmental variables identified as important in explaining *PC, PLIM,* $CPUE_{POS}$ and $CPUE_0$ could be used in predictive models of angling quality and of abundance. From an angling quality perspective, correlations between environmental variables and *PC* and *PLIM* explained 49% and 74% of the variability in the data, a significant proportion that confirms the predictive power of these empirical models. Similarly, environmental variables explained significant amounts of variability in both the positive *CPUE* data and zero-adjusted *CPUE* data (53% and 52% respectively), which suggests that statistically robust, empirically-derived measures of abundance can be achieved using bass angling catch data through standardisation and subsequent identification of environmental influences on *CPUE*.

Conclusion

User trends in South African bass fisheries are largely similar to those observed in five states of the USA, in terms of seasonal utilisation patterns as well as angler participation at tournament events. While statistics compiled for the US fisheries are not a countrywide estimate, the similarity between these fisheries and those in South Africa highlight the relative significance of the bass angling facet in this country in that user trends are comparable with the United States where an estimated 16 million anglers fish for largemouth and Florida bass (Cooke and Philipp, 2009) and where bass anglers contribute 60–70% of the total annual angling expenditure (Schupp, 2002). Comparisons of catch rates and angler success in SA dams presented in Table 4.16 compare favourably with those in the US, suggesting that at least for these five US states, angler success as well as catch rates are slightly better in South African dams than those in the USA. Results such as these highlight that existing bass fisheries in SA, based on their favourable angling quality, should probably be managed as sport-fisheries providing a high quality recreational experience which is comparable with highly managed and monitored fisheries in the USA.

The development of new recreational bass fisheries in South Africa through stocking would have to take into account the existing regulations and policy that are outlined in the National

Environmental Management: Biodiversity Act (NEM:BA) (2004), the risks associated with introducing a non-native species and due consideration of the species" ability to acclimate and establish in a new environment (Kohler and Stanley, 1984; Cowx, 1998; Welcomme, 2001). Relationships between environmental variables and angler success and catch rate all demonstrated very similar trends in terms of the impoundment characteristics that would support bass fisheries of higher angling quality. These results may provide baseline recommendations for the viability of stocking largemouth bass into impoundments for the creation of quality recreational fisheries.

Bank angling catch records

In comparison to bass angling catch records, fewer bank angling competition catch records were obtained and for fewer impoundments. Catch records were obtained from impoundments located in six provinces (Western and Eastern Cape; Free State; Gauteng; North West; and Mpumalanga), although the majority of the impoundments were located in provinces situated on the Highveld. While this may suggest that bank angling activities are more popular in these provinces, a conclusion which is supported by club membership as well as the NEM:BA "priority list", an important consideration is that no data, or very limited data, were obtained for provinces (KwaZulu-Natal, Limpopo, Western Cape) where bank angling activities are coordinated by SAFBAF affiliated clubs (see Chapter 2). While efforts were made to obtain data from competitions held on impoundments in these areas, there were low response rates from angling officials, a typical problem associated with off-site surveys of this nature (Roach et al., 1999). Furthermore, there are fewer organised bank angling clubs in these provinces, which resulted in a paucity of information that could be used for the study and in the resultant spatial characteristics of the available data.

Temporally, the majority of the catch records were obtained from 2007–2010 (Fig. 4.27), although the decrease in 2011 can be attributed to the cessation of sampling during this period. Fewer catch records from years pre-2007 may be a result of factors which similarly accounted for limited bass angling catch records from periods of over five years ago; changes in administrative personnel tasked with the collection of catch records led to mislaid catch information (Visagie, *pers comm*, 2010) and lack of angler awareness concerning the value of tournament catch records. Monthly availability of data (Figure 4.28) illustrates the seasonal nature of bank angling activities in South Africa. As was the case in bass angling, very few events were held during the winter months. Additionally, while the duration of bank angling tournaments varied more than that of bass angling tournaments, an important consideration is that many of the tournaments from which data were available were national type events which are governed by a set of regulations enforced by the SAFBAF, i.e. tournaments are always the same length. Club tournament lengths are more likely to vary as administrative decisions are at the discretion of the tournament organiser.

Given that bank angling in South Africa is a unique form of angling (see Chapter 3), comparisons with fisheries in other regions are difficult to make as competitive events are almost always focussed on either carp and/or using methods specific to carp angling or, commonly, match angling formats. Additionally, freshwater tournament survey reports in other regions, particularly in the USA, are largely focussed on game fish species, especially largemouth bass *M. salmoides*, which are the favoured angling fish in that region (Cooke and Philipp, 2009). However, information from carp angling tournaments describe a similar seasonal trend in events, both in the USA and Canada, with events taking place during the summer (www.carptournamentseries.com; www.canadiancarpclub.com).

CPUE

The GLM used to standardise *CPUE* per impoundment explained a total of 20.1% of the variation in *CPUE*. The majority of variability was accounted for by the factor "Dam" indicating that variation between impoundments accounts for a large proportion of angler catches. Estimated coefficients from the factor "Type" (Appendix III, Table 1, Eq. 4.18) indicate that *CPUE* was higher in league and national competitions than in club competitions. Given that league/national competitions comprise anglers that have qualified to fish these events by achieving high catches, higher *CPUE* in these competitions is expected due to their higher skill level compared to anglers fishing in club competitions. Estimated coefficients from the factor "Anglers" suggest that *CPUE* generally decreased with increasing angler participation. The use of ground-bait by bank anglers is a common practice (Arlinghaus and Mehner, 2003; Lewin et al., 2006), and increased angler numbers at a competition are likely to result in larger quantities of ground-bait being deployed into fishable areas. Ground-baiting has been shown to increase catch rates of cyprinid fishes in Polish and German carp fisheries (Wolos et al., 1992; Niesar et al., 2004), and one would expect an increase in catch rates with larger influxes of groundbait associated with greater angler attendances. Conversely, excess groundbaiting has been shown to decrease catch rates of cyprinids (Wolos et al., 1992), potentially due to a saturation or upper limit being reached, in which there is too much groundbait in the water resulting in sated fish that are less interested in the baits presented by anglers (Visagie, *pers comm*, 2010; Spencer, *pers comm*, 2010).

Similar amounts of variation were explained by the GLM and GAM, and results from non-parametric bootstrapping suggest that the relationships between *CPUE* in different impoundments and environmental variables can be modelled using a GLM or a GAM. While GAMs have been shown to effectively account for high non-linearity between response and predictor variables (Guisan et al., 2002; Maunder and Punt, 2004), the small sample size (8 dams) mitigates the need for a GAM,which may be less robust in explaining causal relationships and may overfit the data (Townshend Peterson et al., 2011). Additionally, both the GLM and GAM incorporated the same number of environmental covariates with only a small difference between the amounts of explained variability in *CPUE* ,suggesting that a GLM may be better suited to modelling relationships with a comparatively small dataset.

Both the GLM and GAM incorporated the same environmental variables that influenced *CPUE*. *CPUE* was predicted to be higher in impoundments with low conductivities and high surface areas. The influence of rainfall was also shown to be important. *C. carpio* are the dominant species in bank anglers" bags (Figure 4.26), and higher catch rates in impoundments with lower conductivities was surprising. Egertson and Downing (2004) and Weber and Brown (2011) described high abundances of *C. carpio* in systems with high total dissolved solids (TDS), an environmental variable that is correlated with high conductivities (Mustapha, 2009) and large surface areas. These findings are supported by Petr (2000) who found high and low *C. carpio* biomass in Argentinean systems with high and low conductivities respectively. In particular, highest *CPUE* was predicted for Gariep Dam, the impoundment in the dataset that had the lowest conductivity (Figure 4.30). Findings such as these highlight the difficulty of standardising and predicting catch rates using a small dataset. Other factors that may influence *CPUE* may go unaccounted for as a result of aggregated data – particularly the lack of species information in a fishery that has a preferred target species (*C. carpio*) but regular "bycatch" of other species such as mudfish *L. capensis* and yellowfishes *Labeobarbus* spp (Ellender et al., 2010a; Winker, 2010). Causal relationships between *CPUE* and environmental variables are therefore more difficult to infer when there is an ill-defined target species, e.g. the contribution of other "bycatch" species to the *CPUE* and their relationship with environmental variables may bias conclusions regarding the effect of these variables on *CPUE*. Additionally, as the dataset is small, with data for some impoundments, e.g. Gariep, consisting of only five or fewer events, predictions may not be robust enough to take into account competitions during which catch rates were "exceptional", resulting in inflated estimates of *CPUE* and correlations with environmental variables that may be artefacts.

Multiple Regression Analysis

Despite limitations in the dataset, results from the multiple regression analysis suggest that the environmental variables identified as important in explaining *CPUE* could be used in a predictive model of abundance. The correlation between conductivity, surface area, and rainfall explained 63% of the variability in the standardised *CPUE* data. However, while this relationship was not significant, it provides baseline information on environmental variables, which may account for different abundances in different impoundments. Due to the nature of the data available, these predictions are only based on eight impoundments, and future empirical predictions would be far more robust if more data for more systems were available.

Conclusion

South Africa supports a large bank angling contingent that, including formal and non-formal anglers, accounts for the majority of participation in freshwater angling activities (Leibold and Van Zyl, 2008). In comparison to bass fisheries, however, the availability and quality of the data from bank angling competitions is of poorer quality. The low resolution, aggregated data that were available for assessment hindered investigations into the factors that influence abundance in different impoundments, as a large proportion had to be collapsed and restratified such that it would be appropriate for model fitting. While catch records were obtained for 15 impoundments, standardised estimates of *CPUE* could only be obtained for eight impoundments. In particular, the lack of species information from angler catches at competitions prevented the application of predictive models that take into account contributions from species at different trophic levels, an important consideration when correlating predicted abundance with environmental factors.

The widespread distribution of dams (and rivers) that support populations of the preferred target species of bank anglers, common carp, as well as the well-established deleterious impacts of this species on ecosystems (Zambrano et al., 2006; Kulhanek et al., 2011; Winker et al., 2011) indicate that fisheries development should be focussed on systems in which they are already established, and that management should proceed based on assessments of the extant resource and user group. Results from this study suggest that there is a lack of applicable information for a comprehensive assessment of the bank angling resource which hindered investigation into an economically important activity, which encompasses a far greater area than could be realistically assessed based on the available data. Of particular concern was the poor response from angling officials who did not contribute catch information, having emphasised their willingness to do so. With increased impetus to develop water resources in South Africa, anglers need to become aware of the importance of angling catch records for the management and potential “safeguarding” of their fisheries. Monitoring data facilitates the formulation of recommendations that take the interests of existing users into account, an important consideration for decision-makers.

CHAPTER 5:

Compilation and analysis of fisheries-independent gillnet data from scientific surveys conducted on South African impoundments

5.1 INTRODUCTION

South Africa"s inland water resources, their potential for food production and associated economic and social contributions, have been the subject of research through scientific surveys since the 1960s (see Chapter 2). The majority of this research has focussed on assessing the feasibility of harvest fisheries, investigating both biology and production potential, and these assessments are generally conducted using standardised, randomly stratified sampling techniques and gear which allow for ecological comparisons between different systems (Cochrane, 1987; Steffanson, 1996). This fisheries-independent information is widely considered to be the most applicable for constructing abundance indices (Steffanson, 1996; Maunder and Langley, 2004), and is exempt from additional standardisation measures accounting for gear or behavioural factors that may be required when investigating abundance using fisheries-dependent data (Hilborn and Walters, 1992; Quinn and Deriso, 1999).

The availability of comprehensive fisheries-independent data is often constrained due to logistical and cost implications particularly for fisheries which are considered less economically important, a perspective commonly applied to inland fisheries (Winker, 2010).

In addition, despite research efforts outlined in Chapter 2, there is a general paucity of fisheries data on inland fisheries in South Africa.

Gillnets are used as artisanal gear throughout Africa and are commonly used in harvest fisheries (van der Knaap, 1994). Fisheries development initiatives in South Africa, which may focus on the potential for harvest fisheries, would benefit from a thorough analysis of environmental factors that drive gillnet catch rates of different species in impoundments, and would promote the establishment of such fisheries. In addition, as the gillnet survey information was collected over a twelve year period using the same fleet, the standardised gear provides for estimates of abundance which are not influenced by changes in gear efficiency.

The objective of this chapter is to assess scientific survey information, in the form of gillnetting data, from all available sources in order to: 1. provide baseline *CPUE* data for inland fisheries and, 2. correlate these abundance indices with environmental variables. The potential for these environmental variables as components in a predictive model of abundance, in the absence of fisheries data, will then be investigated. The development of a predictive model may provide decision-makers with an indication of impoundments which may support the establishment of different fisheries.

5.2 MATERIALS AND METHODS

General

Data collection used both direct and indirect methods. Indirect sampling comprised the collection of gillnetting survey records from reports and raw data housed by freshwater researchers at the Department of Ichthyology and Fisheries Science (DIFS) at Rhodes University and from the South African Institute for Aquatic Biodiversity (SAIAB). These gillnet surveys were conducted using the same standardised gillnetting survey fleet as that used for direct sampling. These survey data were then supplemented with data collected from direct surveys. These included sampling trips undertaken during April, May, and July of 2011 to nine impoundments in the Eastern Cape: Binfield, Cata, Glen Melville, Grassridge, Mankazana, Ndlambe, Pikoli, Sandile and Wriggleswade dams; and Mohale Dam in Lesotho. Sampling was conducted using an experimental gillnet fleet consisting of four multifilament nets (45 m x 3m) comprising five randomly positioned panels (9m long x 3m deep) with stretched mesh sizes ranging from 47 mm to 153 mm. Gillnets were set in the evening between 16h30 and 18h00 and lifted between 06h00 and 07h00 the following morning. Nets were randomly deployed parallel to the shoreline. Gillnet catches were separated by species and counted, measured to the nearest millimetre fork length (mm F_L) and weighed to the nearest 0.1kg. Table 5.1 provides a summary of all the gillnet data that were collected.

Descriptive analyses

All gillnet data were assessed to determine differences in species composition and relative abundance for all impoundments. Relative abundance was calculated as the contribution of a species to the overall fish biomass recorded within that impoundment (% weight). Impoundments were subsequently categorised by the dominant species/species group (by biomass) sampled within them.

Table 5.1 Number of gillnet survey records (net nights) obtained for 26 impoundments with associated year and month of survey; D = Direct Sampling; ID = Indirect Sampling.

Impoundment	Province	Net nights	Years	Months	Sampling
Binfield	EC	20	2011	Jul	D
Bospoort	NW	15	2003	Apr;Aug;Nov	ID
Cata	EC	6	2011	Jul	D
Darlington	EC	43	2007-2008	Feb;Apr;Jun-Nov	ID
Dimbaza	EC	5	2000	Feb;May	ID
Gariep	EC/FS	120	2007-2008	Jan;Mar;May-Jun;Aug;Oct	ID
Glen Melville	EC	10	1999-2000;2011	May;Aug;Nov	D;ID
Grassridge	EC	6	2011	Apr	D
Koster	NW	15	2003	Apr;Aug;Nov	ID
Laing	EC	65	1998-1999	Jan-Aug;Oct-Dec	ID
Lindleyspoort	NW	23	2003-2004	Mar-Apr;Aug;Nov	ID
Lotlamoreng	NW	7	2003-2004	Mar-Apr;Nov	ID
Madikwe	NW	22	2003-2004	Mar-Apr;Aug;Nov	ID
Mankazana	EC	10	2011	Apr;Jul	D
Mohale	LES	6	2011	Mar	D
Molatedi	NW	30	2003-2004	Mar-Apr;Aug;Nov	ID
Ndlambe	EC	4	2011	Apr	D
Ngotwane	NW	21	2003-2004	Mar-Apr;Aug;Nov	ID
Pikoli	EC	8	1999;2011	Apr;Jun-Jul;Sep	D;ID
Roodekopjes	NW	28	2003-2004	Mar-Apr;Aug;Nov	ID
Sandile	EC	18	2011	Jul	D
Taung	NW	20	2003-2004	Mar-Apr;Nov	ID
Umtata	EC	16	1999-2000	Feb;May;Sep;Nov	ID
Vaalkop	NW	21	2003-2004	Mar-Apr;Aug;Nov	ID
Wriggleswade	EC	33	2011	May;Jul	D
Xonxa	EC	18	2007	Mar;May;Aug	ID

Data analyses

Limitations

While data were collected for a total of 26 impoundments, because several had small sample sizes, standardisation of *CPUE* data via non-parametric bootstrapping, as conducted in Chapter 4 for fisheries-dependent data, could not be conducted for all impoundments. The following impoundments were excluded from *CPUE* analyses: Cata, Dimbaza, Grassridge, Mohale, and Ndlambe (Table 5.1).

Catch Per Unit Effort (CPUE)

One continuous dataset containing only positive *CPUE* observations was created. Probability of capture was not estimated, as the majority of dams did not have data which included zero catches. Catch per unit effort estimates were calculated from the gillnet dataset such that:

$$CPUE\ (kg.net^{-1}.night^{-1}) = \frac{catch\ per\ net\ (kg)}{time\ fished(night)}$$

Modelling

Modelling approaches outlined in Chapter 4, including choice of error distribution, model selection and model validation, were used to standardise the *CPUE* information.

Selecting environmental variables for modelling

Environmental variables were obtained as outlined for the fisheries-dependent data in Chapter 4. A summary of the variables which were used as predictor variables in the modelling process is presented in Table 5.2. All variables were log-transformed and tested for normality using the Shapiro–Wilk test. In order to avoid modelling using explanatory variables which were correlated, a correlation matrix was generated to determine which variables were suitable for inclusion (Table 5.3).

There was significant correlation between morphometric variables surface area and capacity and altitude. Additionally, conductivity was also highly positively correlated with temperature. Principal Component Analysis (PCA) was applied to remove the effect of redundant variables on the modelling process. The first three principal components explained 70% of the variation in the environmental variables; the contribution of each variable to the first three principal components is illustrated in Figure 5.1.

Table 5.2 A summary of physico-chemical parameters which were used as predictor variables in the catch analysis.

Variable	Description
Alt	Altitude (m)
Rain	Mean annual rainfall (mm)
Cond	Mean conductivity (µS/cm)
TDS	Mean total dissolved solids (mg/L)
pH	Mean pH
Alkalinity	Mean alkalinity (mg/L)
Surface	Max. Surface area (ha)
Capacity	Max. Capacity (m^3)
Temp	Mean annual air temperature (°C)
Age	Years since construction

Table 5.3 Matrix correlation coefficients between physical and environmental variables obtained for 21 impoundments considered in the analysis of *CPUE*. Marked correlations "*" are significant at p<0.05 (Spearman Rank Correlation).

Variable	**Alt**	**Rain**	**Surface**	**Capacity**	**Temp**	**pH**	**Cond**	**Age**
Alt	1.00							
Rain	0.17	1.00						
Surface	**0.42***	-0.21	1.00					
Capacity	0.35	-0.19	**0.95***	1.00				
Temp	0.01	-0.21	-0.20	-0.26	1.00			
pH	-0.07	-0.21	-0.11	-0.13	0.22	1.00		
Cond	-0.14	-0.32	-0.14	-0.33	**0.52***	0.40	1.00	
Age	0.05	-0.23	0.13	0.01	0.29	0.08	0.23	1.00

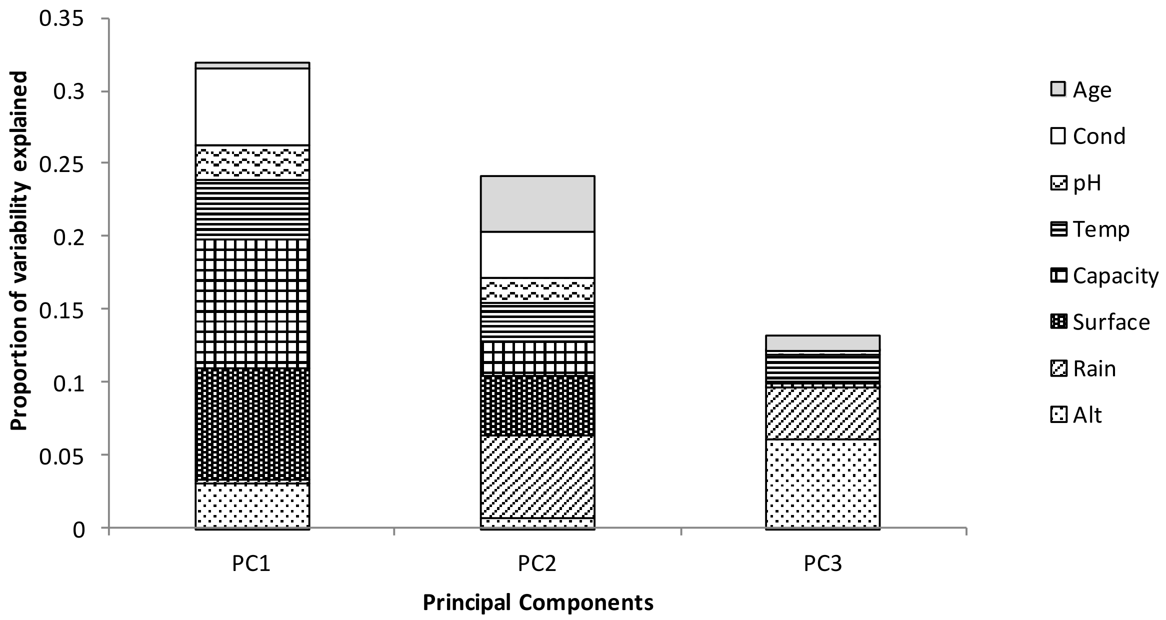


Figure 5.1 The proportion of variability explained by the first three principal components extracted from the gillnet survey data dam environmental variables with contribution by each environmental variable.

A summary of the variables considered for modelling *CPUE* is presented in Table 5.4.

Table 5.4 Explanatory variables used for standardisation of gillnet catch data from 21 impoundments.

Predictor	Type	Description
Dam	Categorical	All dams where data were applicable
Season	Categorical	Summer; Winter
Alt	Continuous	Altitude (m)
Rain	Continuous	Mean annual rainfall (mm)
Surface	Continuous	Surface area (ha)
Capacity	Continuous	Capacity (m^3)
Temp	Continuous	Mean annual air temperature (°C)
Age	Continuous	Years since construction
Cond	Continuous	Mean conductivity (µS)
Comp1	Continuous	Principal Component 1
Comp2	Continuous	Principal Component 2
Comp3	Continuous	Principal Component 3

Categorisation of dams based on relative abundance of species

Following preliminary analyses of the species composition of the gillnet survey data available, overall *CPUE* analyses were conducted for all 21 impoundments (following omission of five dams due to small sample sizes). Additionally, based on the contribution of particular species to the average relative abundance in certain impoundments, their frequency of occurrence and their potential viability as a fishery species, those impoundments in which *C. gariepinus* ($CPUE_{CG}$) and those in which native cyprinids ($CPUE_{NC}$) (*L. aeneus; L. capensis; L. kimberleyensis; L. marequensis; L. molybdinus; L. umbratus,* including endemic and extralimital ranges) were present were analysed in isolation to investigate what environmental factors may drive higher abundances of these species in different impoundments.

Selecting Environmental Variables for Modelling $CPUE_{CG}$ and $CPUE_{NC}$

Environmental variables used to model $CPUE_{CG}$ and $CPUE_{NC}$ were the same as those used in the standardisation of *CPUE* for all impoundments, and are summarised in Table 5.1. All variables were log-transformed and tested for normality using the Shapiro–Wilk test. Correlation matrices of environmental variables specific to impoundments where $CPUE_{CG}$ and $CPUE_{NC}$ were analysed are summarised in Table 5.5 and 5.6.

Table 5.5 Matrix correlation coefficients between physical and environmental variables obtained for 21 impoundments considered in the analysis of $CPUE_{CG}$. Marked correlations "*" are significant at p<0.05 (Spearman Rank Correlation).

Variable	**Alt**	**Rain**	**Surface**	**Capacity**	**Temp**	**pH**	**Cond**	**Age**
Alt	1.00							
Rain	**0.54***	1.00						
Surface	0.02	-0.43	1.00					
Capacity	-0.02	-0.37	**0.95***	1.00				
Temp	-0.35	-0.05	-0.50	-0.51	1.00			
pH	-0.19	-0.26	-0.16	-0.12	0.15	1.00		
Cond	**-0.56***	-0.33	-0.22	-0.35	0.50	0.48	1.00	
Age	-0.15	-0.26	0.05	-0.07	0.30	0.04	0.06	1.00

Table 5.6 Matrix correlation coefficients between physical and environmental variables obtained for 21 impoundments considered in the analysis of $CPUE_{NC}$. Marked correlations "*" are significant at $p<0.05$ (Spearman Rank Correlation).

Variable	**Alt**	**Rain**	**Surface**	**Capacity**	**Temp**	**pH**	**Cond**	**Age**
Alt	1.00							
Rain	0.25	1.00						
Surface	**0.54***	-0.35	1.00					
Capacity	**0.49***	-0.28	**0.95***	1.00				
Temp	-0.08	-0.17	-0.30	-0.42	1.00			
pH	-0.14	-0.26	-0.08	-0.08	0.19	1.00		
Cond	-0.25	-0.44	-0.11	-0.32	**0.56***	0.30	1.00	
Age	-0.03	-0.29	0.17	0.07	0.28	0.02	0.17	1.00

Environmental variables specific to $CPUE_{CG}$ impoundments which were correlated included the morphometric variables surface area and capacity, and the variables altitude and conductivity. Impoundments analysed for $CPUE_{NC}$ were characterised by significant correlation between altitude, surface area and capacity, and temperature and conductivity.

Principal component analysis was applied to remove the effect of redundant variables for both $CPUE_{CG}$ and $CPUE_{NC}$. For variables specific to $CPUE_{CG}$ impoundments, the first three principal components explained 77% of the variation in $CPUE_{CG}$ environmental variables and the contribution of each environmental factor to the principal components is illustrated in Figure 5.2.

PCA applied to $CPUE_{NC}$ impoundment variables extracted three principal components that explained 73% of the variation in the environmental variables. The three principal components extracted with factor contributions to each component are illustrated in Figure 5.3.

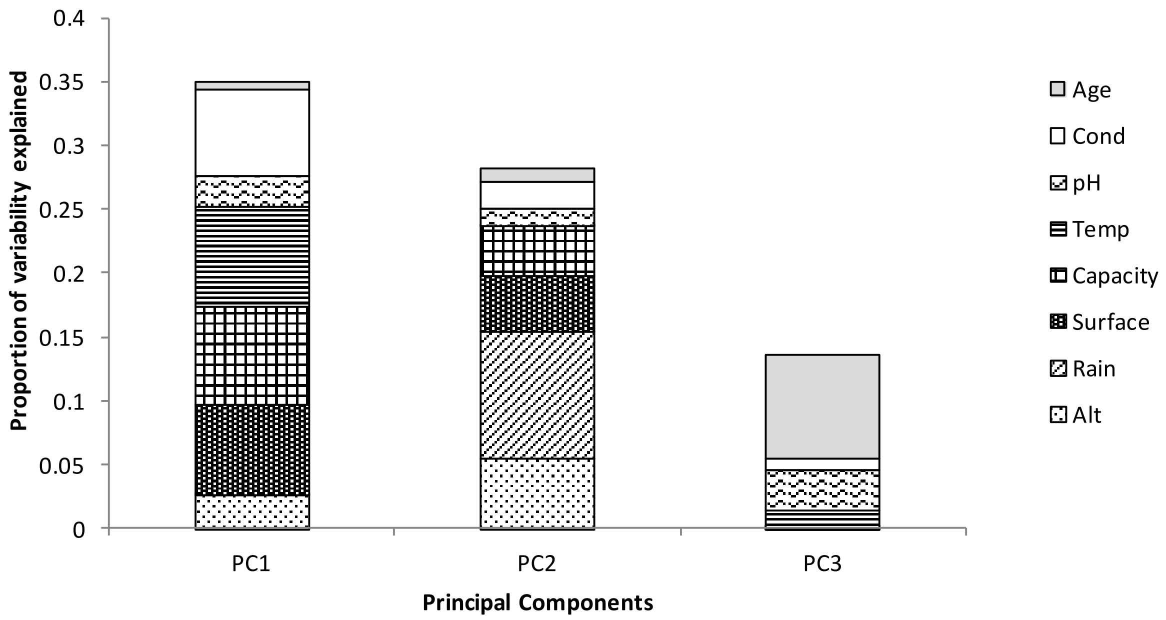


Figure 5.2 The proportion of variability explained by the first three principal components extracted from the gillnet survey data *Clarias gariepinus* dam environmental variables with contribution by each environmental variable.

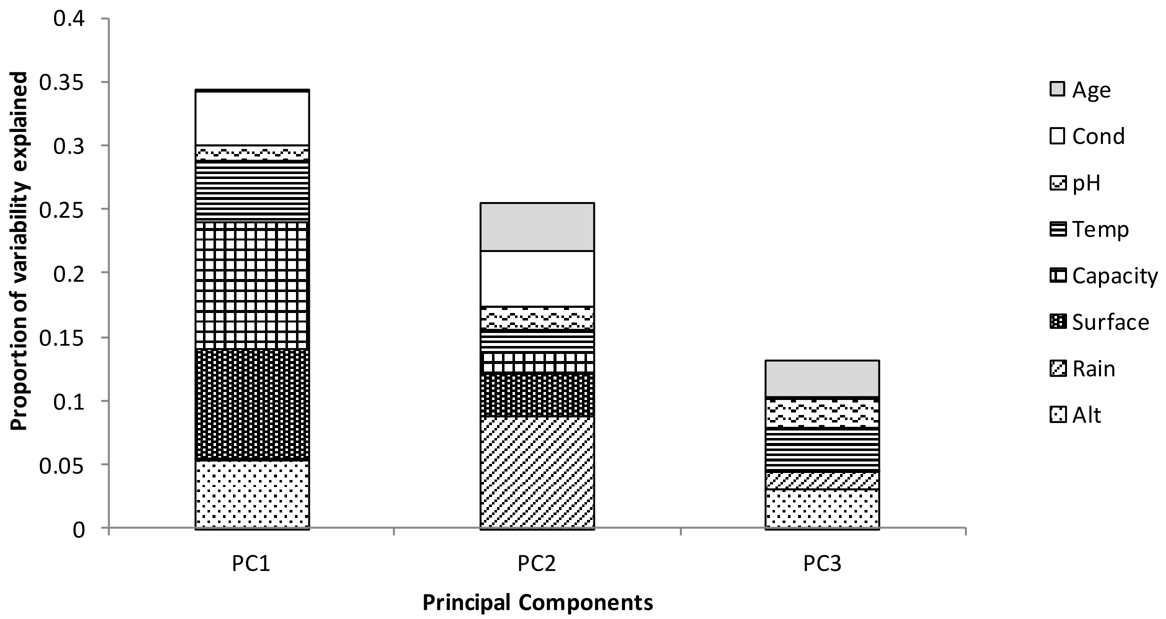


Figure 5.3 The proportion of variability explained by the first three principal components extracted from the gillnet survey data *native cyprinid* dam environmental variables with contribution by each environmental variable.

Model selection was initially conducted with each variable; if these were autocorrelated they were substituted for principal components in order to account for redundancy in the explanatory variables.

Non-Parametric Bootstrap

Non-parametric bootstrapping was applied, as described in Chapter 4, to estimate confidence intervals for standardised *CPUE* values.

Multiple Regression Analysis

Multiple regression analysis was conducted using standardised *CPUE* and explanatory environmental variables to determine the potential for a predictive model, as described in Chapter 4.

5.3 RESULTS

Gillnet survey records totalling 590 net nights were collected for a total of 26 impoundments in South Africa and one impoundment in Lesotho. The location of these impoundments is illustrated in Figure 5.4.

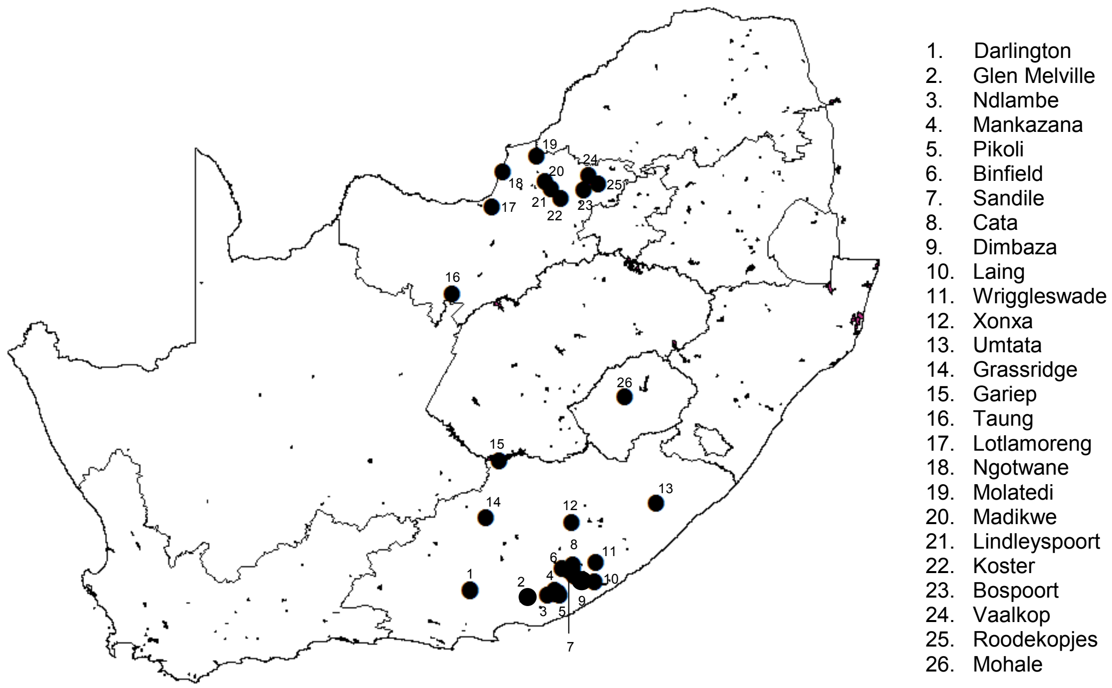


Figure 5.4 Impoundments in South Africa from which gillnet survey data were obtained.

Impoundments for which data were obtained were located primarily in the Eastern Cape (15 impoundments) and the North West Province (10 impoundments), except for Mohale Dam in Lesotho.

Species Number and Composition

The total number of species recorded in each of the impoundments is illustrated in Figure 5.5. The number of species sampled in the impoundments ranged from one (Cata; Dimbaza; Laing; Lombard; Tyefu; Umtata) to eight (Gariep; Roodekopjes) with an average of 4.2 ± 2.3 species sampled per impoundment. The average number of species from impoundments in the Eastern Cape (3.4 ± 2.1) was lower than that of impoundments in the North West (5.3 ± 1.9) although the difference was not significant ($p > 0.05$). The highest number of species (8) were recorded from Gariep Dam on the Orange–Vaal River system, and Roodekopjes Dam on the Crocodile River (part of the Limpopo River catchment).

The species composition of each impoundment, represented as percent composition, is provided in Table 1 (Appendix IV); a summary of the species captured, their frequency of occurrence, and their average contribution to the total sampled biomass is presented in Table 5.7.

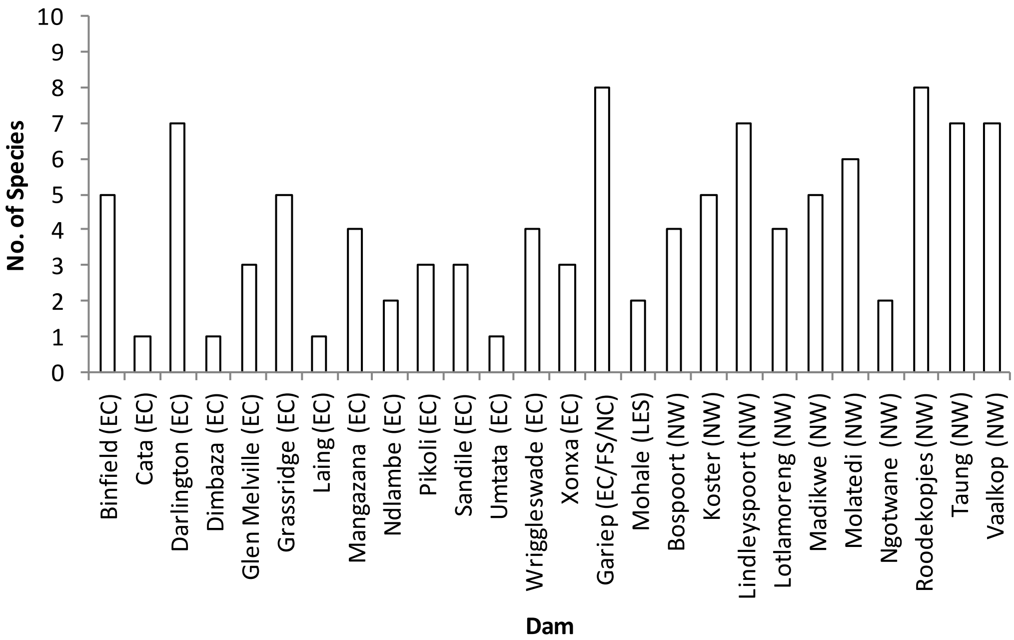


Figure 5.5 The total number of species recorded from gillnet surveys conducted in each of the 26 impoundments (EC = Eastern Cape; FS = Free State; NC = Northern Cape; NW = North West).

Table 5.7 Summary of species present in the gillnet survey data, the status of each species (E = Estuarine; EL = Extralimital; N = Native; NN = Non-native; U = unidentified), their frequency of occurrence based on the number of impoundments in which they were sampled and their average relative abundance. Numbers in bold denote the NEM:BA classification of non-native and extralimital fishes.

Family	Species	Common Name	Status	No. Of Impoundments	Ave. Rel. Abundance (%)
Anguillidae	*Anguilla mossambica*	Longfin eel	N	1	0.68
Austroglanididae	*Austroglanis sclateri*	Rock catfish	N	1	0.15
Centrarchidae	*Lepomis macrochir*	Bluegill sunfish	NN -**1b**	2	3.24
Centrarchidae	*Micropterus salmoides*	Largemouth bass	NN -**2**	7	6.03
Cichlidae	*Chetia flaviventris*	Canary kurper	N	1	0.10
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	N; EL - **2**	10: N(9); EL (1)	16.51
Cichlidae	*Tilapia sparrmanii*	Banded tilapia	N	5	0.34
Clariidae	*Clarias gariepinus*	Sharptooth catfish	N; EL - **2**	14: N(11); EL(3)	44.56
Cyprinidae	*B. spp*	U	N	1	0.10
Cyprinidae	*Barbus mattozi*	Papermouth	N	5	11.56
Cyprinidae	*Cyprinus carpio*	Common carp	NN - **2**	15	14.32
Cyprinidae	*Labeo capensis*	Orange River mudfish	N; EL - **2**	4: N(2); EL (2)	24.98
Cyprinidae	*Labeo molybdinus*	Leaden labeo	N	6	3.98
Cyprinidae	*Labeo umbratus*	Moggel	N; EL - **2**	11: N(8); EL (3)	57.87
Cyprinidae	*Labeobarbus aeneus*	Smallmouth yellowfish	N; EL - **2**	7: N(3); EL (4)	43.22
Cyprinidae	*Labeobarbus kimberleyensis*	Largemouth yellowfish	N	2	13.40
Cyprinidae	*Labeobarbus marequensis*	Largescale yellowfish	N	5	2.87
Mormyridae	*Marcusenius macrolepidotus*	Bulldog	N	1	1.68
Mugilidae	*Mugil cephalus*	Flathead mullet	N	2	39.25
Mugilidae	*Myxus capensis*	Freshwater mullet	E	2	8.77
Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	NN -**2**	1	0.01
Salmonidae	*Salmo trutta*	Brown trout	NN -**2**	1	100.00
Schilbeidae	*Schilbe intermedius*	Silver catfish	N	2	28.18

A total of ten families and 23 species were captured from the impoundments. Eleven species (48%) were strictly native or endemic while five species had endemic and extralimital ranges (22%). Five species (22%) were non-native to South Africa and two species (8%) were considered primarily estuarine (Mugilidae). Approximately 73% of the impoundments in the Eastern Cape contained non-native fishes compared to 40% of impoundments in the North West. Figure 5.6 illustrates the frequency of occurrence of the 23 different fish species in the 26 impoundments. The most frequently encountered species were the common carp *C. carpio* (15 impoundments) and the sharptooth catfish *C. gariepinus* (14 impoundments). Seven species (*A. mossambicus*; *A. sclateri*; *C. flavensis*; *M. lepidotus*; *O. mykiss*; *S. trutta*) were captured in one impoundment only.

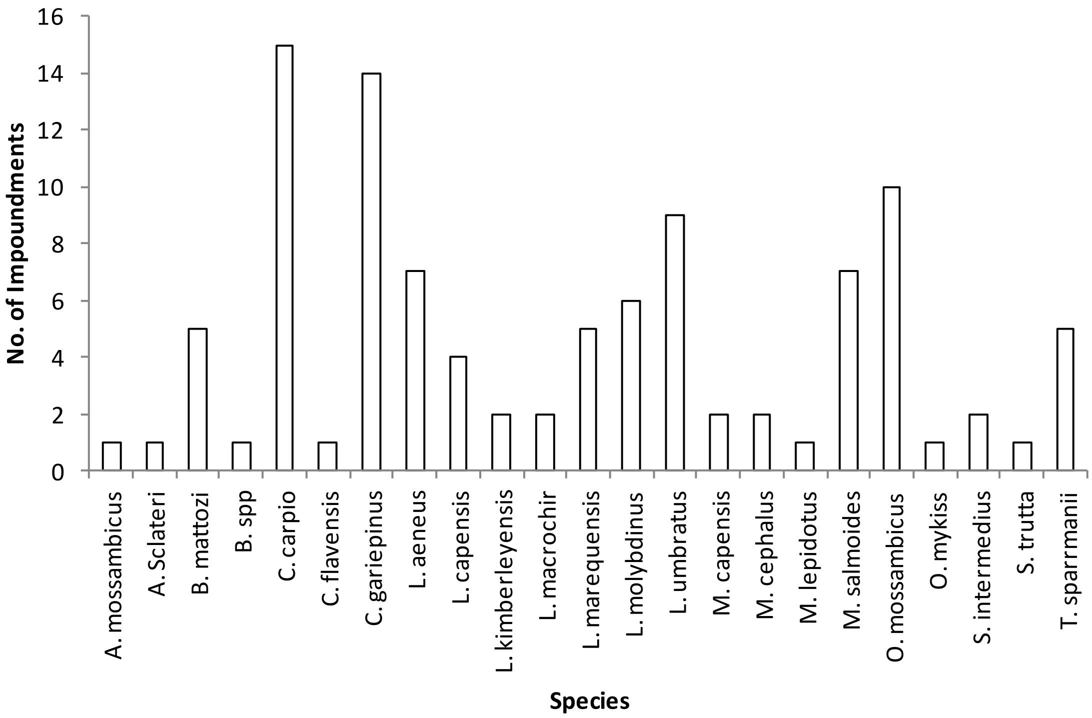


Figure 5.6 Frequency of occurrence of 23 species sampled during gillnet surveys based on the number of impoundments in which they were sampled.

The average relative abundance of each species, in all the impoundments in which they were sampled, is illustrated in Figure 5.7. The relative abundances of the different species must be viewed with caution as, in the case of the salmonid *S. trutta*, the figures may be high but in some cases these species were the only species captured within an impoundment or were only captured within one or two impoundments. The cyprinid *L. umbratus* has the highest relative abundance, followed by *C. gariepinus* and *L. aeneus*. These fishes were also captured within a higher number of impoundments than *M. cephalus,* which although having a high relative abundance was only captured in two impoundments. Figure 5.8 describes the relative abundances of five species which have extralimital distributions, and which were sampled in more than two impoundments.

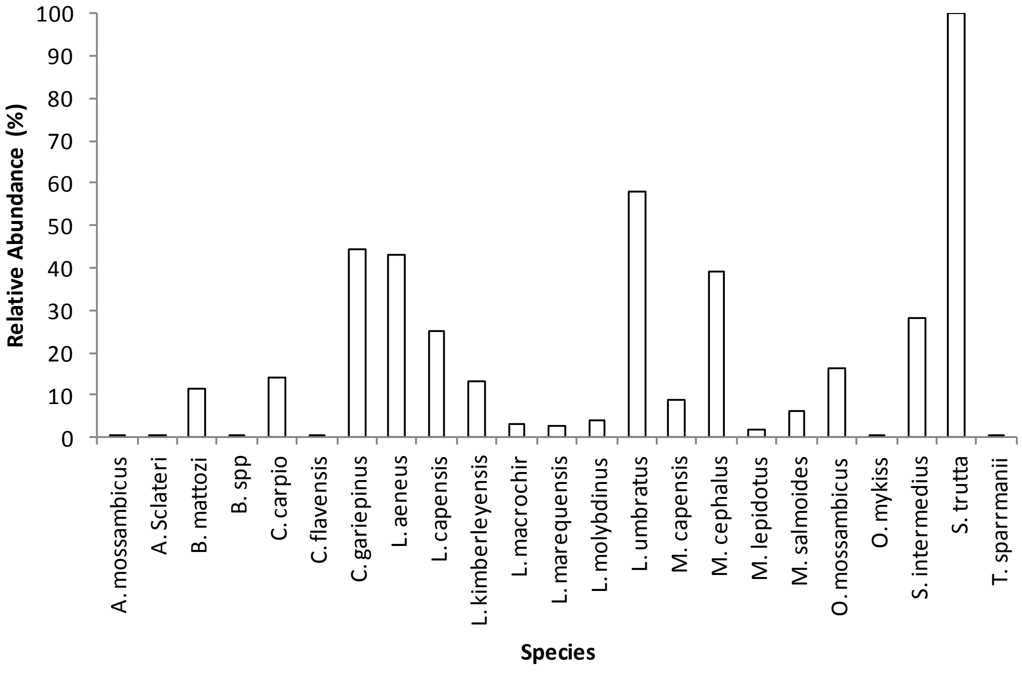


Figure 5.7 The average relative abundance (% biomass) of 23 different species in impoundments in which they were sampled during gillnet surveys

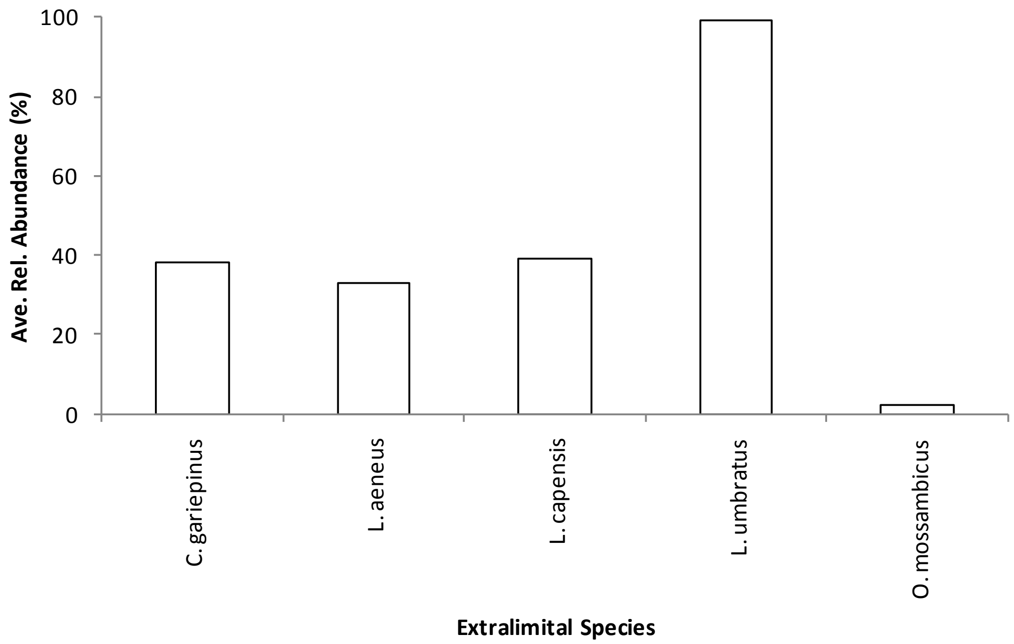


Figure 5.8 The average relative abundance of extralimital species sampled within more than one impoundment.

In impoundments where *L. umbratus* is extralimital (Sandile; Laing; Dimbaza – Keiskamma River catchment (Skelton, 2001)) it contributed 99% to the total biomass of fish sampled within those systems. Where *C. gariepinus, L. aeneus*, and *L. capensis* were sampled in impoundments outside of their natural range they comprised approximately 40% of the relative abundance in these impoundments.

Catch Per Unit Effort (*CPUE*)

CPUE Standardisation

The model statistics for the best fitting model used to standardise *CPUE* for each impoundment are presented in Table 5.8. Standardised *CPUE* was best modelled using a GLM of the form:

$$CPUE = Dam + \varepsilon \qquad (5.1)$$

Overall, the GLM explained 49% of the variation in the data; however, in contrast to *CPUE* standardised for the fisheries-dependent data, only the factor "Dam" was found to be significant in explaining *CPUE* while the temporal component "Season" was found to be insignificant in explaining variability and therefore excluded from the model. Predicted *CPUE* estimates per dam are illustrated in Figure 5.9. Maximum and minimum *CPUE* were predicted at Darlington Dam (67.6 $kg.net^{-1}.night^{-1}$), where the dominant species is *Labeo umbratus,* and Umtata Dam (0.8 $kg.net^{-1}.night^{-1}$), where only *C. carpio* was sampled, respectively. The average *CPUE* for all 21 impoundments was 14.1 ± 14.9 $kg.net^{-1}.night^{-1}$.

Table 5.8 Statistics for the model components of the best-fitting GLM used to model *CPUE*. The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2-test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2-squared for each additional factor.

CPUE Standardisation (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	*p*	r^2
NULL	550		4153		826.3				
+Dam	528	22	3765	388	421.4	404.9	49.0	***	0.49
% Deviance Explained							**49.0**		

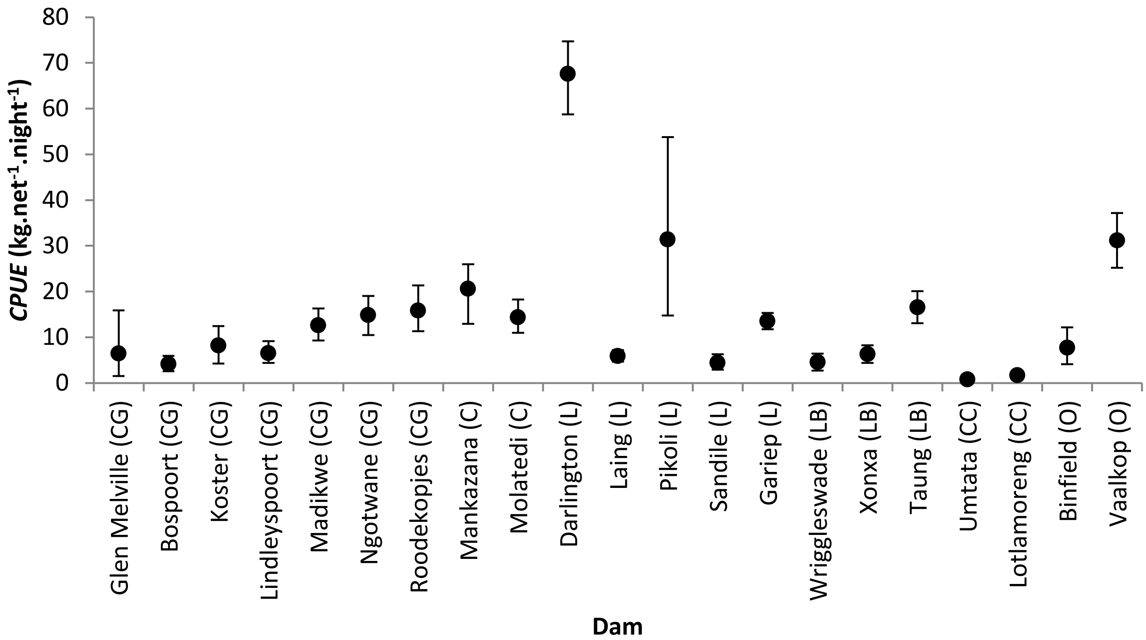


Figure 5.9 Predicted *CPUE* for 21 impoundments (letters in brackets represent the dominant species/species group based on relative abundance: CG = *Clarias gariepinus*; *C = Cichlids*; *L = Labeo*; *LB = Labeobarbus*; *CC = Cyprinus carpio*; *O = Other*). Error bars represent upper and lower confidence intervals.

Table 5.9 summarises the standardised *CPUE* indices for each dam, the number of species sampled, as well as the dominant fish species/group based on relative abundance. *C. gariepinus* is the dominant species in the greatest number of impoundments (seven), followed by *Labeo* spp (five) and *Labeobarbus* spp (three). Figure 5.10 illustrates the average *CPUE* in impoundments characterised by the different dominant fish species/groups. Highest *CPUE* is observed in impoundments where *Labeo* spp were dominant (24.6 ± 24 $kg.net^{-1}.night^{-1}$), followed by *Other* (19.4 ± 16.6 $kg.net^{-1}.night^{-1}$) and *Cichlid* spp (17.5 ± 4.4 kg.net-1.night-1). Impoundments where *C. carpio* are dominant have the lowest average *CPUE* (1.3 ± 0.6 $kg.net^{-1}.night^{-1}$).

Table 5.9 Summary of standardised *CPUE* indices for the 21 impoundments including number of species and the dominant species/group based on relative abundance (EL = Extralimital; N = Native; NN = Non-native).

Impoundment	Province	*CPUE* (kg.net-1.night-1)	Species (n)	Dominant Species/Group
Bospoort	NW	4.12	4	*C. gariepinus* (N)
Glen Melville	EC	6.46	3	*C. gariepinus* (EL)
Koster	NW	8.22	5	*C. gariepinus* (N)
Lindleyspoort	NW	6.53	7	*C. gariepinus* (N)
Madikwe	NW	12.62	5	*C. gariepinus* (N)
Ngotwane	NW	14.86	2	*C. gariepinus* (N)
Roodekopjes	NW	15.81	8	*C. gariepinus* (N)
Mangazana	EC	20.59	4	*Cichlids* (N)
Molatedi	NW	14.39	6	*Cichlids* (N)
Darlington	EC	67.60	7	*Labeo* (N)
Gariep	EC/FS/NC	13.50	8	*Labeo* (N)
Laing	EC	5.89	1	*Labeo* (N)
Pikoli	EC	31.36	3	*Labeo* (N)
Sandile	EC	4.43	3	*Labeo* (N)
Taung	NW	16.52	7	*Labeobarbus* (N)
Wriggleswade	EC	4.56	4	*Labeobarbus (* EL)
Xonxa	EC	6.32	3	*Labeobarbus* (EL)
Lotlamoreng	NW	1.71	4	*C. carpio* (NN)
Umtata	EC	0.78	1	*C. carpio* (NN)
Binfield	EC	7.71	5	*Other* (E)
Vaalkop	NW	31.15	7	*Other* (N)

Prior to modelling *CPUE* with environmental variables, further exploratory data analysis was conducted in order to account for the influence of potential outliers which would bias correlations with model parameters. The standardised *CPUE* indices presented in Figure 5.9 indicate that Darlington Dam is an outlier which was confirmed through visual inspection using boxplots. In order for more accurate identification of environmental variables with predictive potential, Darlington Dam was subsequently removed from analyses of *CPUE*.

Model statistics for the standardisation of *CPUE* for each impoundment, post-removal of Darlington Dam, are presented in Table 5.10. Less of the variability in *CPUE* was explained (32.7%) and the factor "Dam" accounted for all of this variation.

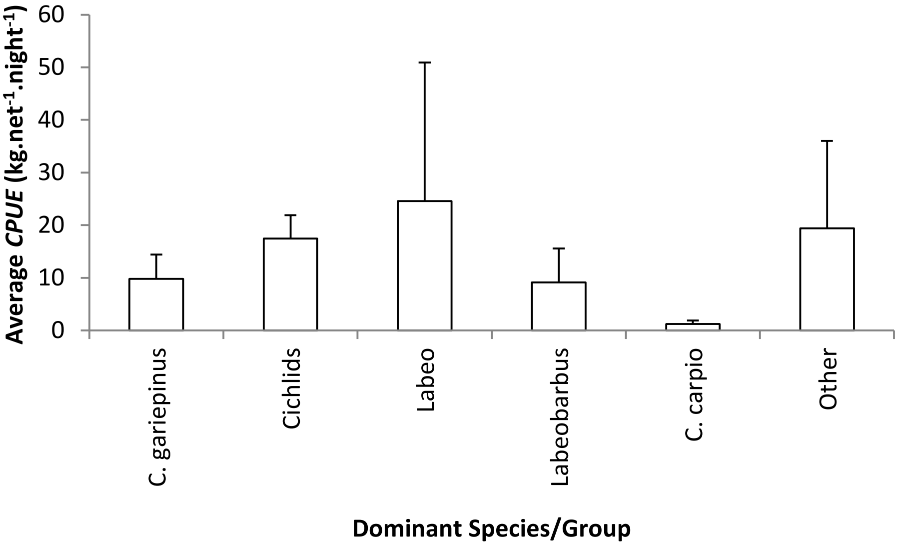


Figure 5.10 Average total *CPUE* (kg. net^{-1}. night^{-1}) in impoundments where *Clarias gariepinus*, *Cichlid* spp*, Labeo* spp, *Labeobarbus* spp, *C. carpio*, and *Other* are the dominant fish species/group.

Table 5.10 Statistics for the model components of the best-fitting GLM used to model *CPUE*. The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2-test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2-squared for each additional factor.

CPUE Standardisation (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explained	*p*	r^2
NULL	496		4165		599.7				
+Dam	477	19	3774	391	403.4	196.3	32.7	***	0.33
% Deviance Explained							**32.7**		

CPUE was modelled using the variables such that

$$CPUE = logSurface + Cond + Age + \varepsilon \quad (5.2)$$

$$CPUE = s(logSurface) + s(Cond) + s(Age) + \varepsilon \quad (5.3)$$

Both the GLM and GAM incorporated the same covariates. The model components for the GLM and GAM are presented in Table 5.11. Overall, the GLM explained a total of 10% of the variability in *CPUE* as opposed to the GAM, which explained 19%. All of the model components in the GLM and GAM were highly significant ($p<0.001$), with the exception of the morphometric variable "Surface" in the GLM ($p<0.05$). Figure 5.11 illustrates the predicted *CPUE* for the GLM and GAM incorporating environmental covariates compared to *CPUE* standardised by dam following non-parametric bootstrapping of the models.

Table 5.11 Statistics for the model components of the best-fitting GLM used to model *CPUE*. The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike‟s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2-test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2-squared for each additional factor.

CPUE Standardisation (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explained	*p*	r^2
NULL	496		3243		599.7				
+lnSurface	495	1	3430	-187	594.9	4.8	0.8	*	0.01
+Cond	494	1	3402	28	564.9	30	5.0	***	0.06
+Age	493	1	3378	24	540	24.9	4.2	***	0.10
% Deviance Explained							**10.0**		
CPUE Standardisation (GAM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explained	p	r2
NULL	496		3243		599.7				
+s(lnSurface)	545	3	3397.5	-154.5	558.8	40.9	6.8	***	0.07
+s(Cond)	542	3	3380	17.5	539.5	19.3	3.2	***	0.10
+s(Age)	540	3	3326.5	53.5	484.2	55.3	9.2	***	0.19
% Deviance Explained							**19.3**		

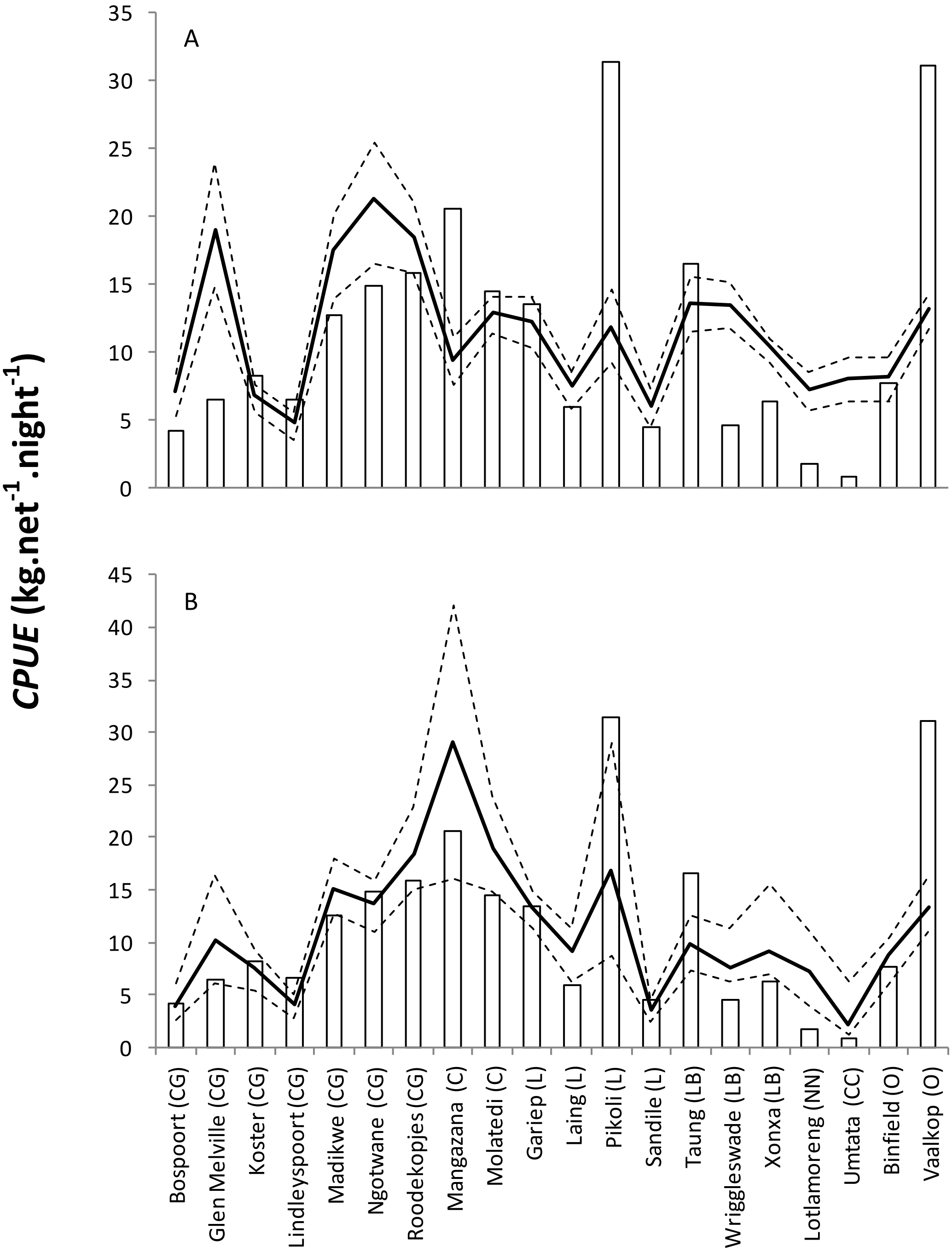


Figure 5.11 Standardised *CPUE* for 20 impoundments (bars) compared to the mean (solid lines) of non-parametrically generated *CPUE* estimates fitted using a GLM (A) and a GAM (B) incorporating environmental variables. Dashed lines represent the upper and lower 95% confidence intervals for the mean *CPUE* estimates.

The GLM largely over- and underpredicted the *CPUE* estimates, particularly for Pikoli and Vaalkop dams where highest standardised *CPUE* per dam was observed. The GAM simulated the means more accurately than the GLM and its wider confidence intervals captured the estimated means more successfully. Correlations between *CPUE* standardised per dam and *CPUE* standardised with environmental variables for both the GLM and the GAM are illustrated in Figure 5.12. The GAM explained approximately 47% of the variability in *CPUE* data compared to the GLM which accounted for only 14%. Significant model components and their influence on *CPUE* are illustrated in Figure 5.13.

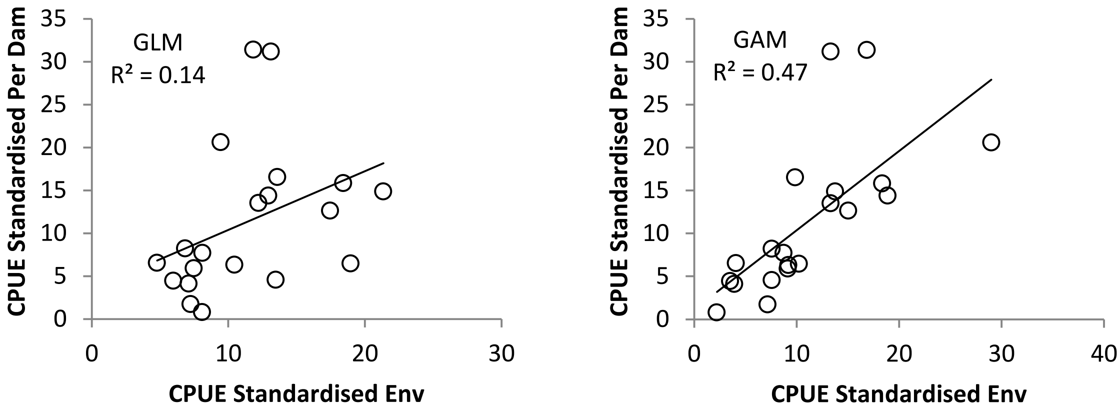


Figure 5.12 Relationship between *CPUE* standardised by dam and *CPUE* estimates derived from a GLM and GAM incorporating environmental variables.

CPUE is predicted to be higher with increased surface areas (A) and increased conductivities (B). Figure 5.13 (C) indicates that *CPUE* increases with increasing conductivity, reaching an optimum before declining thereafter. The relationship with Age describes an increase in *CPUE*, attaining an optimum at around 30 years before declining sharply with increasing age (D).

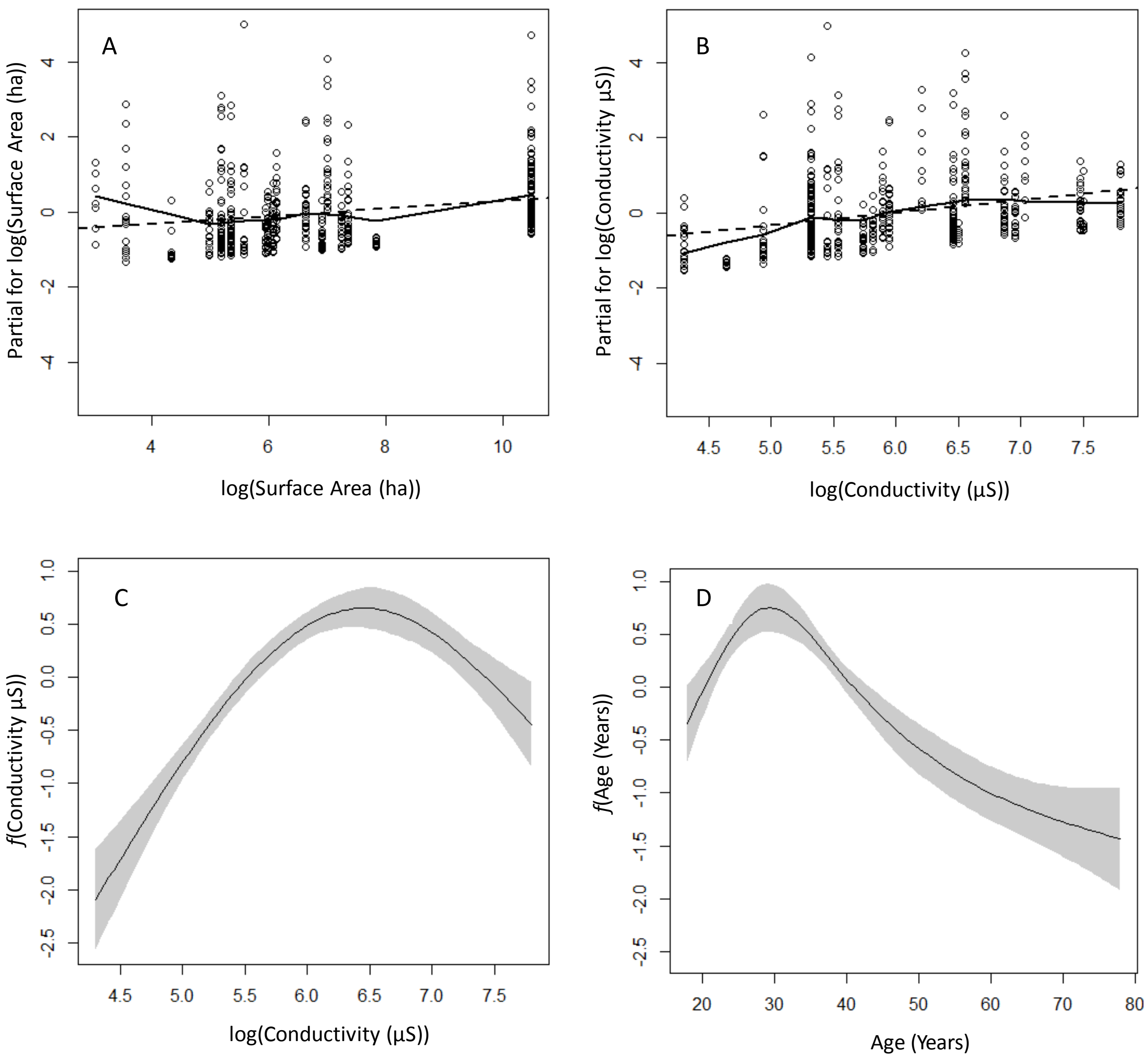


Figure 5.13 Effect of the most significant environmental variables on $CPUE_{ALL}$ modelled using a GLM (A; B) and a GAM (C; D). "Partial" refers to "Partial Residual Plot" in which the effect of the predictor is assessed while taking into account other components in the model. "*f*" refers to the smoothing spline fitting the effect of the predictor to the explanatory variable.

$CPUE_{CG}$ and $CPUE_{NC}$ Standardisation

The model statistics for the best fitting model used to standardise $CPUE_{CG}$ for each impoundment are presented in Table 5.12. Standardised $CPUE_{CG}$ for each impoundment was modelled using a GLM of the form:

$$CPUE_{CG} = Dam + \varepsilon \qquad (5.4)$$

Table 5.12 Statistics for the model components of the best-fitting GLM used to standardise $CPUE_{CG}$. The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2-test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2-squared for each additional factor.

$CPUE_{CG}$ Standardisation (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	*p*	r^2
NULL	176		1156		214				
+Dam	166	10	1131	25	172.2	41.8	19.5	***	0.20
% Deviance Explained							**19.5**		

Overall, the model explained 19.5% of the variability in the data, less than the 32% explained by the same factor ("Dam") when all the impoundments were considered and not grouped into categories. No seasonal component was included by the model. Figure 5.14 illustrates the predicted $CPUE_{CG}$ for the impoundments. Highest and lowest $CPUE_{CG}$ was predicted for Roodekopjes Dam (15.8 kg.net^{-1}.night^{-1}) and Xonxa Dam (271 kg.net^{-1}.night^{-1}) respectively, with a mean $CPUE_{CG}$ for impoundments dominated by *C. gariepinus* of 8.9 ± 4.5 kg.net^{-1}.night^{-1}.

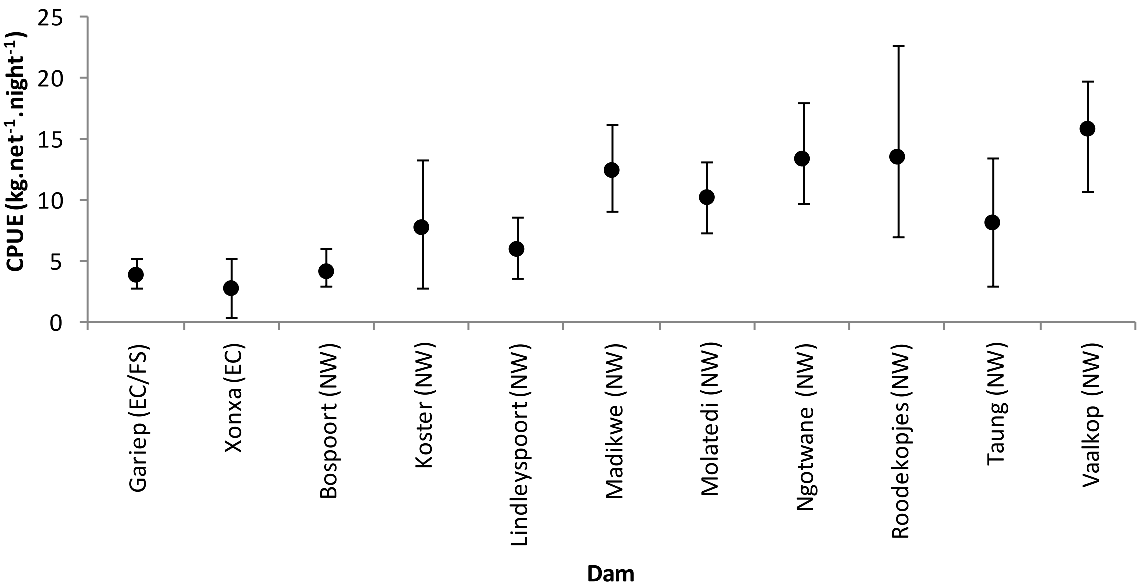


Figure 5.14 Predicted $CPUE_{CG}$ for 7 impoundments containing *Clarias gariepinus* (EC = Eastern Cape; NW = North West). Error bars represent upper and lower 95% confidence intervals.

Modelling $CPUE_{CG}$ using environmental variables

$CPUE_{CG}$ was modelled using environmental variables such that:

$$CPUE_{CG} = Temp + Cond + Age + \varepsilon \quad (5.5)$$

$$CPUE_{CG} = s(Temp) + s(logSurface) + s(Cond) + s(Age) + \varepsilon \quad (5.6)$$

for the GLM and GAM respectively. Both the GLM and the GAM selected for the same variables. Model components are presented in Table 5.13.

Table 5.13 Statistics for the model components of the best-fitting GLM and GAM incorporating environmental variables used to model $CPUE_{CG}$. The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2-test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2-squared for each additional factor.

$CPUE_{CG}$ Standardisation (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	*p*	r^2
NULL	176		1156		214				
+Temp	175	1	1142	14	198.1	15.9	7.4	***	0.07
+ln(Cond)	174	1	1134	8	188.4	9.7	4.5	**	0.12
+Age	173	1	1128	6	181.8	6.6	3.1	**	0.15
% Deviance Explained							**15.0**		
$CPUE_{CG}$ Standardisation (GAM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	*p*	r^2
NULL	176		1156		214				
+s(Temp)	173.8	2.2	1134	22	188.6	25.4	11.9	***	0.12
+s(ln(Surface))	172.8	1	1129	5	182	6.6	3.1	**	0.15
+s(ln(Cond))	171.8	1	1126	3	178.4	3.6	1.7	**	0.17
+s(Age)	169.8	2	1125	3	174.4	5	2.3	**	0.19
% Deviance Explained							**19.0**		

Overall, the GLM explained 15% of the variability in $CPUE_{CG}$ as opposed to the GAM which accounted for 19%. All of the model components included in both the GLM and GAM were significant (p<0.005); the variable "Temp" was highly significant (p<0.001), but explained more variability when incorporated in the GAM. Figure 5.15 illustrates the predicted $CPUE_{CG}$ for the GLM and GAM incorporating environmental covariates compared to $CPUE_{CG}$ standardised by dam following non-parametric bootstrapping of the models. The GAM captured more of the variability in the standardised $CPUE_{CG}$ estimates than the GLM; however, confidence intervals for the GLM were smaller around the generated mean estimates. Correlations between *CPUE* standardised by dam and the environmental GLM and GAM illustrate the differing amounts of variation explained by the models, with the GLM accounting for 63% of the variation compared to the GAM which accounted for 93% (Figure 5.16).

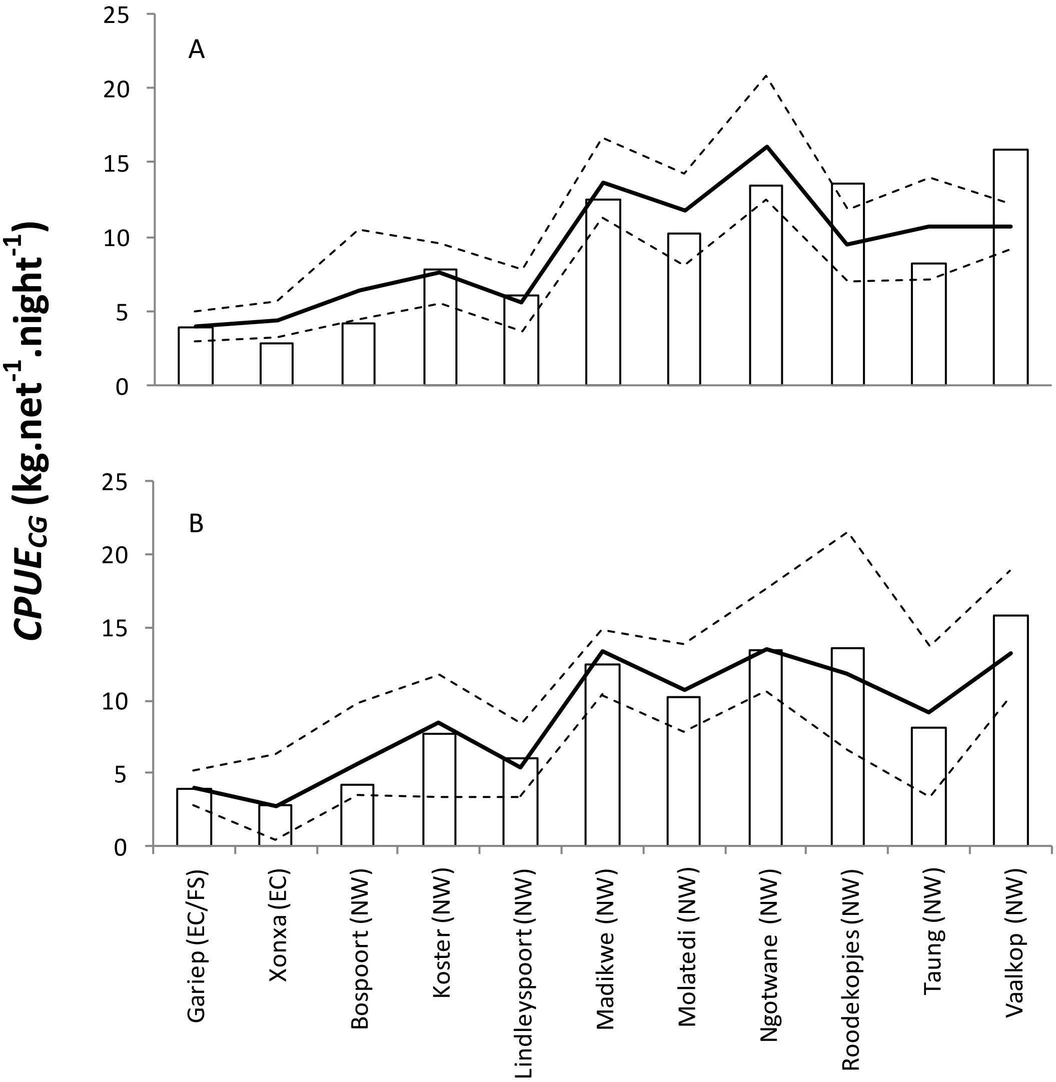


Figure 5.15 Standardised $CPUE_{CG}$ for 7 impoundments (bars) compared to the mean (solid lines) of non-parametrically generated $CPUE_{CG}$ estimates fitted using a GLM (A) and a GAM (B) incorporating environmental variables. Dashed lines represent the upper and lower 95% confidence intervals for the mean $CPUE_{CG}$ estimates. (EC = Eastern Cape; FS = Free State; NW = North West).

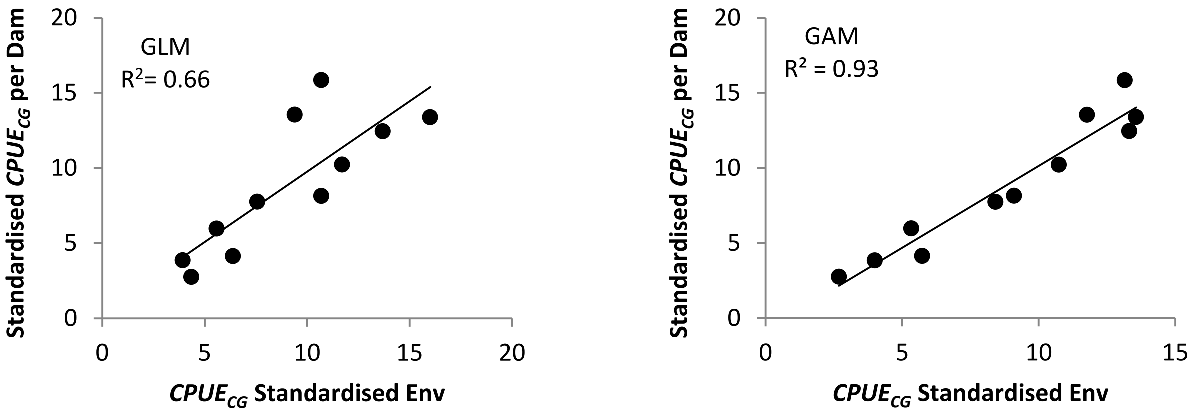


Figure 5.16 Relationship between $CPUE_{CG}$ standardised by dam and $CPUE_{CG}$ estimates derived from a GLM and GAM incorporating environmental variables.

Significant model components for the GLM and the GAM and their influence on $CPUE_{CG}$ are illustrated in Figure 5.17. Both models predicted an increase in $CPUE_{CG}$ with increasing temperature (A; D), higher $CPUE_{CG}$ in younger impoundments (C; F), as well as a slight relationship indicating an increase in $CPUE_{CG}$ with increasing conductivity (B) and surface area (E).

$CPUE_{NC}$

The model statistics for the best fitting model used to standardise $CPUE_{NC}$ for each impoundment are presented in Table 5.14. Standardised $CPUE_{NC}$ for each impoundment was modelled using a GLM of the form:

$$CPUE_{NC} = Dam + \varepsilon \qquad (5.7)$$

Overall the model explained 55% of the variability in the data, more than that accounted for by the same model for $CPUE_{CG}$. Predicted $CPUE_{NC}$ for the 17 impoundments is illustrated in Figure 5.18.

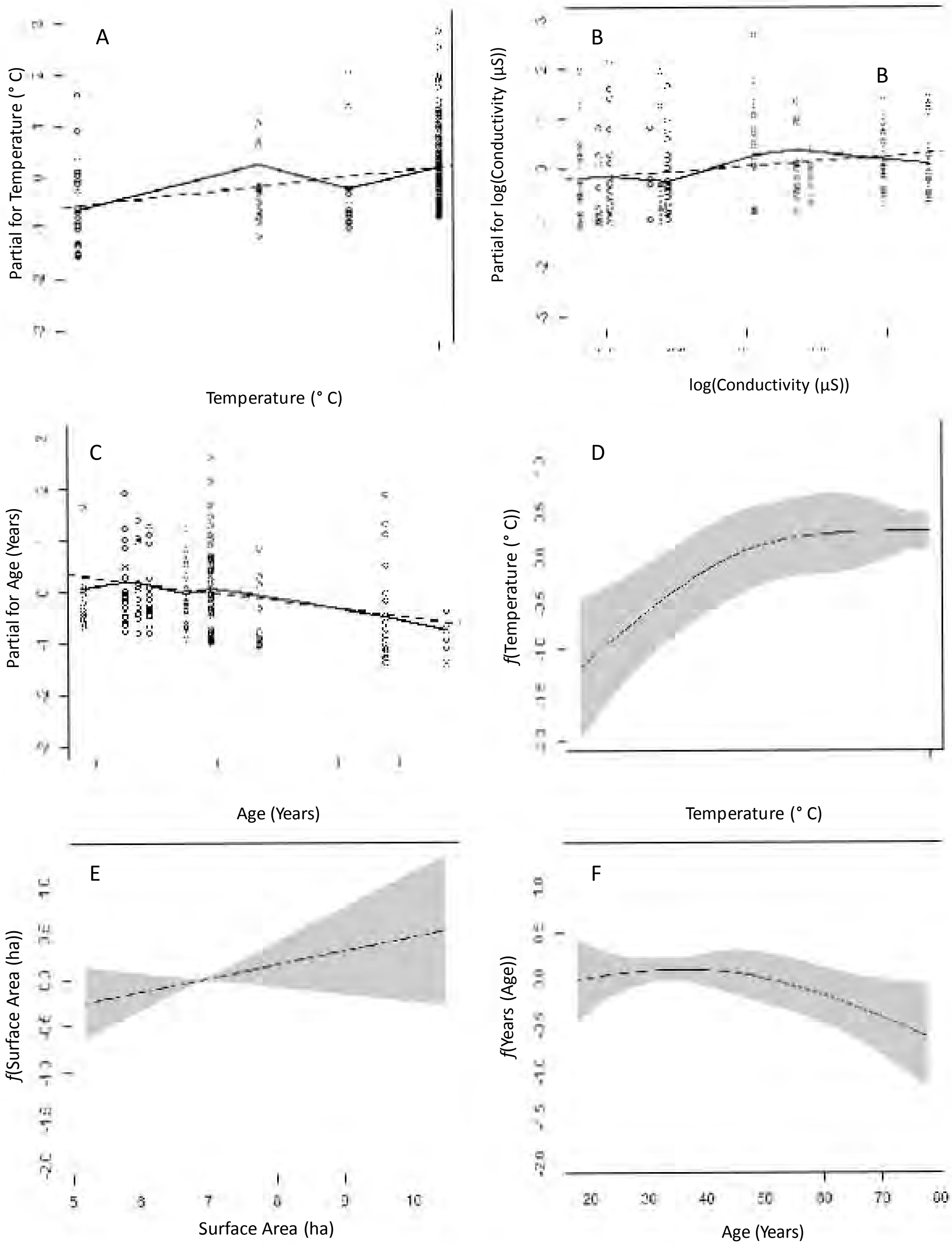


Figure 5.17 Effect of the most significant environmental variables on $CPUE_{CG}$ modelled using a GLM (A; B; C) and a GAM (D; E; F). "Partial" refers to "Partial Residual Plot" in which the effect of the predictor is assessed while taking into account other components in the model. "*f*" refers to the smoothing spline fitting the effect of the predictor to the explanatory variable.

Table 5.14 Statistics for the model components of the best-fitting GLM used to model $CPUE_{NC}$. The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2-test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2-squared for each additional factor.

$CPUE_{NC}$ Standardisation (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	*p*	r^2
NULL	413		2466		552.4				
+Dam	397	16	2221	245	309.6	242.8	44.0	***	0.44
% Deviance Explained							**44.0**		

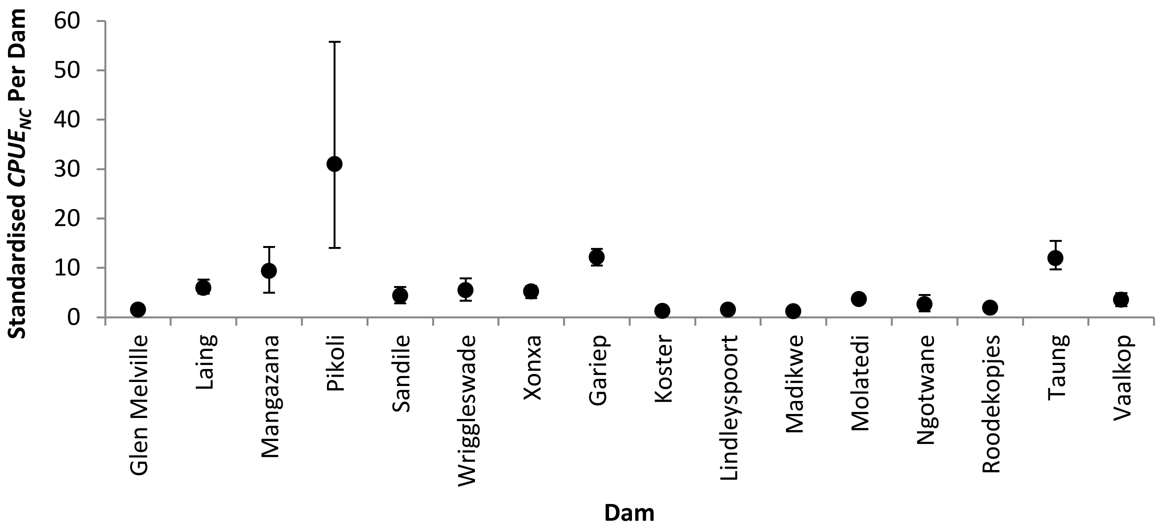


Figure 5.18 Predicted $CPUE_{NC}$ for 16 impoundments containing "native cyprinids". Error bars represent upper and lower confidence intervals.

Pikoli Dam (30.9 kg.net^{-1}.night^{-1}) and Madikwe Dam (1.2 kg.net^{-1}.night^{-1}) had the highest and lowest $CPUE_{NC}$ estimates respectively, with a mean $CPUE_{NC}$ of 6.4 ± 5.7 kg.net^{-1}.night^{-1}.

Modelling $CPUE_{NC}$ Using Environmental Variables

Models incorporating environmental variables that best described $CPUE_{NC}$ were such that:

$$CPUE_{NC} = logSurface + Temp + Age + \varepsilon \quad (5.8)$$

$$CPUE_{NC} = s(Temp) + s(logSurface) + s(Age) + \varepsilon \quad (5.9)$$

for the GLM and GAM respectively.

The model components for the GLM and GAM are presented in Table 5.15.

Table 5.15 Statistics for the model components of the best-fitting GLM and GAM incorporating environmental variables used to model $CPUE_{NC}$. The table summarises the residual degrees of freedom (Res.df), the degrees of freedom, the Akaike"s Information Criterion score (AIC), changes in the AIC (Δ AIC), residual deviance (Res. Dev), changes in the residual deviance (Δ Dev), the percentage of the total deviance explained by the addition of each factor sequentially (% explained), corresponding p-values using a χ^2-test to test for significance (significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001), and the cumulative r^2-squared for each additional factor.

$CPUE_{NC}$ Standardisation (GLM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	*p*	r^2
NULL	413		2466		552.4				
+lnSurface	412	1	2446	20	528.3	24.1	4.4	*	0.04
+Temp	411	1	2388	58	467.5	60.8	11.0	***	0.15
+Age	410	1	2368	20	446.7	20.8	3.8	***	0.19
% Deviance Explained							**19.1**		
$CPUE_{NC}$ Standardisation (GAM)									
Model Structure	Res. df	df	AIC	Δ AIC	Res. Dev.	Δ Dev.	% explain	p	r2
NULL	413		2466		552.4				
+s(Temp)	410	3	2304	162	391	161.4	29.2	***	0.29
+s(ln(Surface))	407	3	2290	14	375	16	2.9	***	0.32
+s(Age)	405	2	2289	1	372	3	0.5	***	0.33
% Deviance Explained							**32.7**		

Overall, the GLM explained 19.1% of the variability in $CPUE_{NC}$ compared to the GAM which explained 32.7% of the variability. All of the model components incorporated in the GLM, with the exception of "logSurface", and GAM were highly significant (p<0.001). Figure 5.19 illustrates the predicted $CPUE_{NC}$ following non-parametric bootstrapping of the GLM and GAM models incorporating environmental covariates compared to $CPUE_{NC}$ standardised by dam. The bootstrap-generated means derived from the GAM simulated the $CPUE_{NC}$ estimates standardised by dam far more accurately than those derived from the GLM which largely underpredicted or overpredicted $CPUE_{NC}$ (e.g. Pikoli and Sandile Dams respectively).

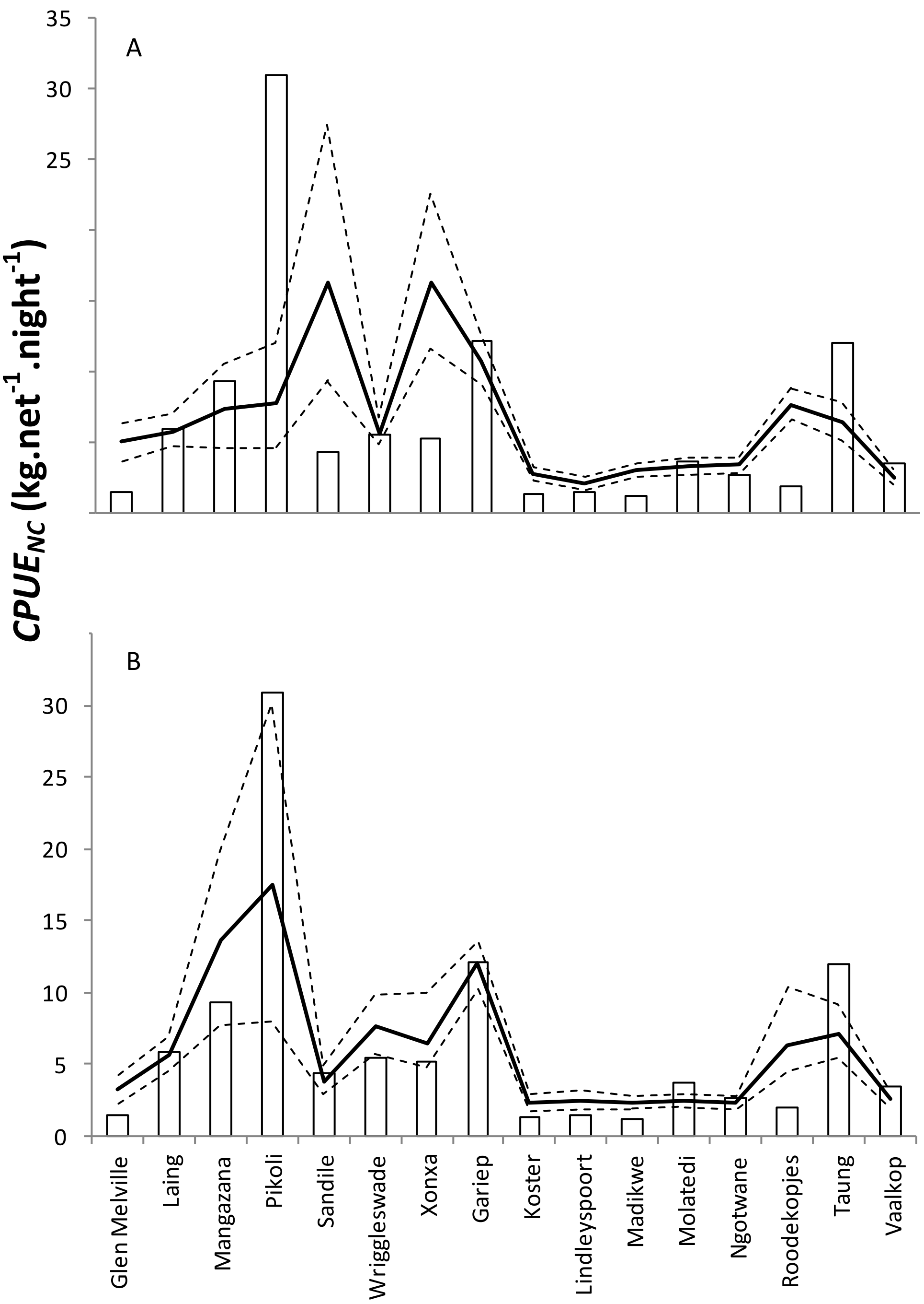


Figure 5.19 Standardised $CPUE_{NC}$ for 17 impoundments (bars) compared to the mean (solid lines) of non-parametrically generated $CPUE_{NC}$ estimates fitted using a GLM (A) and a GAM (B) incorporating environmental variables. Dashed lines represent the upper and lower 95% confidence intervals for the mean $CPUE_{NC}$ estimates.

Correlations between $CPUE_{NC}$ standardised by dam and the environmental GLM and GAM illustrate that the GAM accounts for more variability in $CPUE_{NC}$ than the GLM (Figure 5.20).

However, both of these results are probably influenced by the small sample size of $CPUE_{NC}$ dams (n = 17) which may lead to the GAM overfitting the smoothing curve for $CPUE_{NC}$ resulting in potentially misleading results.

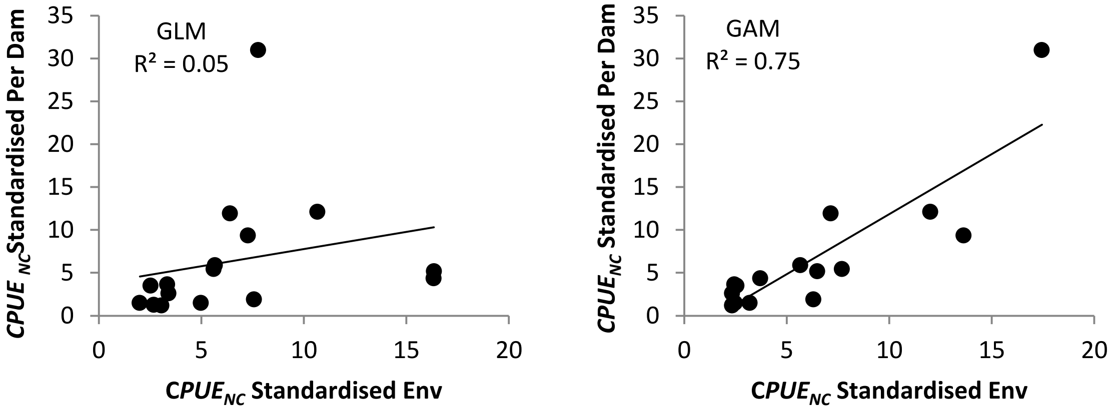


Figure 5.20 Relationship between $CPUE_{CG}$ standardised by dam and $CPUE_{CG}$ estimates derived from a GLM and GAM incorporating environmental variables.

Significant model components and their influence on $CPUE_{NC}$ are illustrated in Figure 5.21. $CPUE_{NC}$ is predicted to decrease with increasing surface area (A) and temperature (B) and decrease with age (C). Figures from the model components of the GAM describe similar overall patterns although (D) and (E) suggests that the GAM overfits the $CPUE_{NC}$ data resulting in an decreasing overall trend with temperature and surface area, but large fluctuations in the smoothing spline.

Empirical Prediction of CPUE, $CPUE_{CG}$ and $CPUE_{NC}$

Influential environmental variables identified in the standardisation of *CPUE*, $CPUE_{CG}$ and $CPUE_{NC}$ were combined in a multiple regression to investigate the potential for a predictive model of *CPUE*, $CPUE_{CG}$ and $CPUE_{NC}$ in the absence of fisheries-dependent data i.e. incorporating only environmental variables.

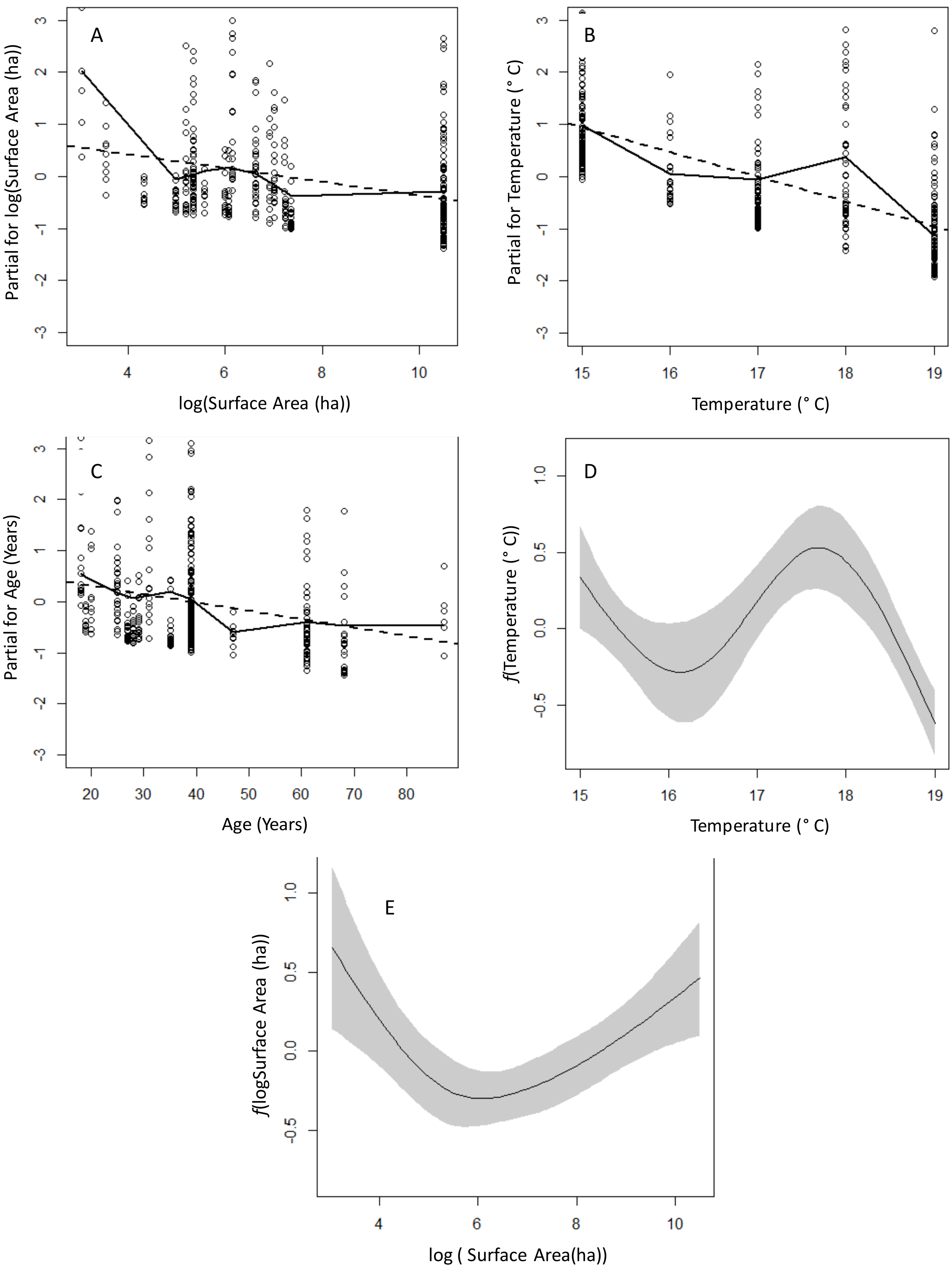


Figure 5.21 Effect of the most significant environmental variables on $CPUE_{CG}$ modelled using a GLM (A; B; C) and a GAM (D; E). "Partial" refers to "Partial Residual Plot" in which the effect of the predictor is assessed while taking into account other components in the model. "*f*" refers to the smoothing spline fitting the effect of the predictor to the explanatory variable.

The models which explained the most variability in *CPUE*, $CPUE_{CG}$ and $CPUE_{NC}$ were, respectively:

$CPUE$ = -3.7 + 0.34 (*logCond* (µS)) - 0.01 (*logSurface Area* (ha)) – 0.31 (*Age* (years)) (R^2 = 0.23; p>0.05) (5.10)

$CPUE_{CG}$ = -42.1 + 0.74(*Temp* (° C)) – 0.36 (*logCond* (µS)) – 0.51(*Age* (years)) + 0.35(*logSurface Area* (ha)) (R^2 = 0.77; p<0.05) (5.11)

$CPUE_{NC}$ = 26.7 - 0.083 (*logSurface Area* (ha)) – 0.48 (*Temp* (° C)) -0.2 (*Age* (years)) (R^2 = 0.31; p>0.05) (5.12)

The predictive model of *CPUE*, $CPUE_{CG}$ and $CPUE_{NC}$ explained 23%, 86% and 52% of the variability in the data respectively. Only the relationship between $CPUE_{CG}$ model variables was significant (p<0.05). The regressions for each model are illustrated in Figures 5.22, 5.23, 5.24, and Table 5.16 summarises the observed and predicted estimates from the models with associated error and average error indicating their predictive capabilities.

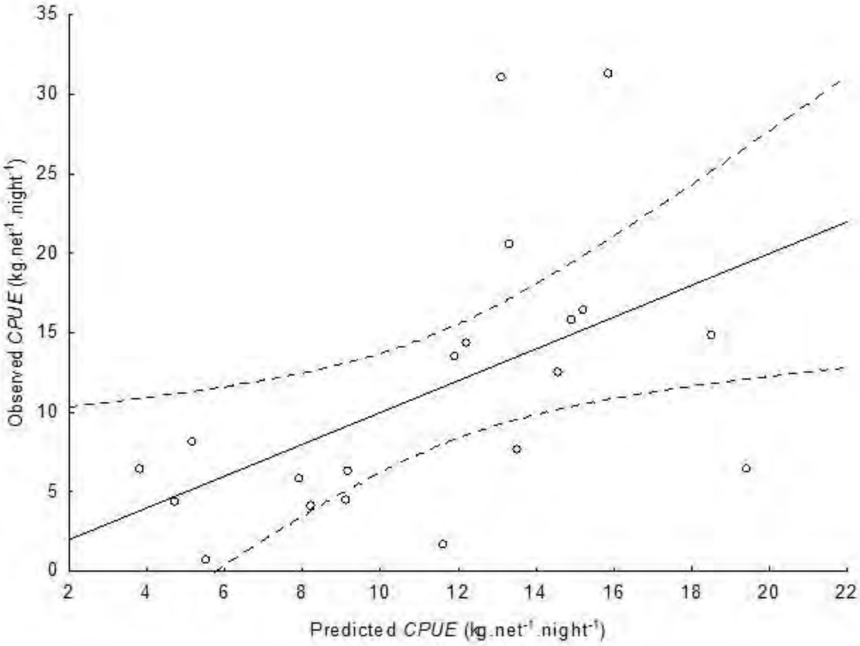


Figure 5.22 Correlation between standardised *CPUE* and predicted *CPUE* as a product of the most explanatory environmental variables outlined in the GLM and GAM analysis. Dashed lines represent upper and lower 95% confidence intervals.

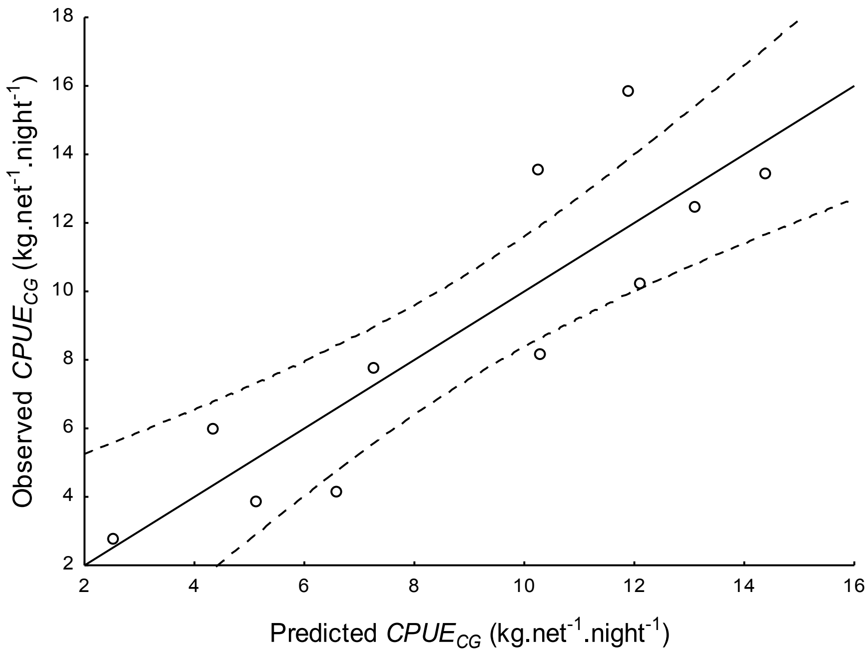


Figure 5.23 Correlation between standardised $CPUE_{CG}$ and predicted $CPUE_{CG}$ as a product of the most explanatory environmental variables outlined in the GLM and GAM analysis. Dashed lines represent upper and lower 95% confidence intervals.

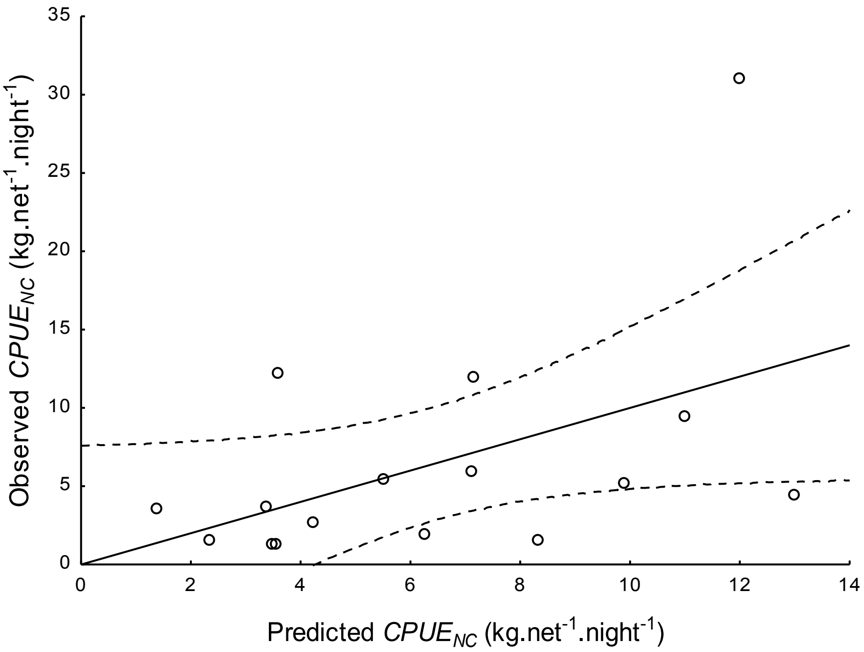


Figure 5.24 Correlation between standardised $CPUE_{NC}$ and predicted $CPUE_{NC}$ as a product of the most explanatory environmental variables outlined in the GLM and GAM analysis. Dashed lines represent upper and lower 95% confidence intervals.

Table 5.16 Observed and predicted *CPUE*, $CPUE_{CG}$ and $CPUE_{NC}$ (kg.net.$^{-1}$.night^{-1}) derived using empirical models. Error describes the residual of the predicted estimate.

Dam	*CPUE*	*PRED CPUE*	*Error*	*CPUE $_{CG}$*	*PRED CPUE $_{CG}$*	*Error*	*CPUE $_{NC}$*	*PRED CPUE $_{NC}$*	*Error*
Bospoort	4.12	8.21	-4.09	4.14	6.59	-2.46	-	-	-
Glen Melville	6.46	19.42	-12.96	6.46	8.14	-1.68	1.49	3.80	-2.31
Koster	8.22	5.14	3.08	7.75	7.26	0.49	1.26	2.59	-1.33
Lindleyspoort	6.53	3.78	2.74	5.97	4.37	1.60	1.50	1.44	0.06
Madikwe	12.62	14.56	-1.94	12.45	13.12	-0.68	1.20	3.30	-2.11
Ngotwane	14.86	18.51	-3.65	13.38	14.40	-1.02	2.61	3.60	-0.99
Roodekopjes	15.81	14.88	0.93	13.54	10.27	3.27	1.92	6.35	-4.43
Mangazana	20.59	13.31	7.28	-	-	-	9.37	4.23	5.14
Molatedi	14.39	12.18	2.21	10.22	12.10	-1.88	3.65	3.92	-0.27
Gariep	13.50	11.92	1.59	3.85	5.14	-1.29	12.13	8.72	3.41
Laing	5.89	7.90	-2.01	-	-	-	5.89	4.22	1.67
Pikoli	31.36	15.85	15.52	-	-	-	31.36	23.31	8.05
Sandile	4.43	4.69	-0.26	-	-	-	4.35	7.05	-2.70
Taung	16.52	15.18	1.34	8.14	10.31	-2.16	11.95	5.39	6.56
Wriggleswade	4.56	9.12	-4.56	-	-	-	5.45	5.43	0.01
Xonxa	6.32	9.17	-2.85	2.75	2.55	0.20	5.17	8.11	-2.93
Lotlamoreng	1.71	11.63	-9.91	-	-	-	-	-	-
Umtata	0.78	5.49	-4.70	-	-	-	-	-	-
Binfield	7.71	13.53	-5.82	-	-	-	-	-	-
Vaalkop	31.15	13.09	18.06	15.84	11.91	3.93	3.50	3.28	0.22
Average Error			**± 5.27**			**± 1.72**			**± 2.80**

5.4 DISCUSSION

Gillnet data were compiled over a smaller geographic area than that covered by fisheries-dependent data from bass and bank angling competitions and were available for only two provinces in South Africa, the Eastern Cape and the North West Province (excluding Mohale Dam, Lesotho). The differences in average species diversity in impoundments between the two provinces highlights the species depauperate ichthyofauna that is characteristic of the Eastern Cape region (Bruton and de Moor, 1988; Kadye and Booth, 2011) compared to the North West which is drained by the more ichthyologically diverse Limpopo and Orange–Vaal River systems (Skelton, 2001).

Overall, of the 23 species sampled, approximately 50% were native to the impoundments" catchments, while 20% were either extralimital or non-native species. High proportions of non-native and extralimital fishes are unsurprising as South Africa has been described as an alien invasive fish hotspot (Leprieur et al., 2008). In particular, the Eastern Cape was characterised by high abundances of non-native species, a result of translocations by anglers and through the action of inter-basin water transfer schemes (de Moor and Bruton, 1988; Skelton and Weyl, 2011, van Rensburg et al., 2011). Of the non-native species, *C. carpio* occurred in the greatest number of impoundments, which is a direct result of its invasive capabilities as well as its translocation into dams and rivers across South Africa (Bruton and de Moor, 1988; Skelton, 2001). The low average relative abundance (approximately 14%) of *C. carpio* in the survey data is probably due to the gillnet avoidance behaviour commonly associated with this species (Hunter and Wisby, 1964; Barthelmes and Doering, 1996; Winker, 2010). Other non-native species that were sampled in more than one impoundment included *M. salmoides,* which occurred in seven impoundments. However, as observed with

C. carpio, this species comprised only 6% of the gillnet catches where it was sampled, which is expected, given its structure oriented habitat preferences. Extralimital species, and in particular *C. gariepinus, L. aeneus, L. capensis* and *L. umbratus*, contributed an average of 40% to the total catches in Eastern Cape impoundments. Given current biodiversity legislation outlined by the NEM:BA, capture fisheries based on species that are either extralimital or non-native to the region are likely to be favoured. This, coupled with the fact that *C. gariepinus* and *L. umbratus* had the highest average relative abundance of all species sampled, highlights the potential these species provide in terms of the development of harvest fisheries.

Catch Per Unit Effort

Standardised *CPUE* indices for the 21 impoundments, in conjunction with species composition information, indicated that the highest predicted estimates were obtained in Darlington and Pikoli Dams, two impoundments dominated by *L. umbratus*. In addition, mean standardised *CPUE* of dams categorised by different fish species/groups described highest *CPUE* estimates for those dams where *L. umbratus* are the dominant species (Figure 5.6). Lowest standardised *CPUE* estimates were obtained for Umtata and Lotlamoreng Dams, both of which are dominated by *C. carpio*. *Labeo umbratus* is selected very effectively by gillnets (Booth and Potts, 2006) and hence, where it is the dominant species component, *CPUE* is likely to be higher than in dams where *C. carpio*, which exhibits net avoidance behaviour, are dominant (Winker, 2010).

Following exclusion of the Darlington Dam outlier and remodelling with the remaining 20 impoundments, the GAM explained more variability in *CPUE* than the GLM, and results from non-parametric bootstrapping illustrate that the partially non-linear GAM simulated the estimated *CPUE* means more accurately than the GLM. However, analysis of environmental variables influencing *CPUE* indicates that, of the GLM components, conductivity and age were the most significant explanatory variables. Interestingly for the GAM, more variability is explained by the variables surface area and age, which suggests one of two things: that the relationship between surface area and *CPUE* is partially non-linearly positive with large fluctuations in *CPUE* occurring with increased surface area or, that the small number of dams being modelled has resulted in overfitting of the GAM smoothing function resulting in conclusions which may be biased and not truly indicative of the relationship (Zuur et al., 2007). In this example, the GLM approach is more robust and provides a better indication of the validity of predictor variables and their influence on the response *CPUE*. However, the "flexible" nature of the GAM means it can still be used in an exploratory capacity in investigating potential explanatory variables for *CPUE*.

Overall, higher catches were predicted with increasing conductivity and surface area, and in younger impoundments. Conductivity is commonly implemented as an empirical predictor of fish production in impoundments (Henderson and Welcomme, 1974; Oglesby, 1977; MRAG (Marine Resources Assessment Group), 1995; Potts, 2003) and is an indicator of the level of nutrients within a system; higher conductivities are associated with higher productivity of phytoplankton and higher fish yields (Ryder, 1965; Ranta and Lindstrom, 1993; MRAG, 1995; Welcomme, 2001). The influence of age of impoundment on *CPUE* may be explained by the higher productivity found in recently constructed impoundments, because more recently flooded terrestrial areas result in increased nutrient input and associated increases in productivity (Hecky and Guildford, 1984; Holz et al., 1997; Winker, 2010). Younger impoundments may therefore provide higher yields than older impoundments in which nutrient levels and productivity have reached equilibrium. The influence of surface area is more difficult to explain as smaller impoundments are generally characterised by smaller surface area to volume ratios and higher levels of productivity per unit area (Jackson and Marmulla, 2001). Standardised *CPUE* estimates, however, indicate that the two highest *CPUE* estimates (post the removal of the Darlington Dam outlier) were obtained for Pikoli Dam (31.36kg.net^{-1}.night^{-1}) and Vaalkop Dam (31.15kg.net^{-1}.night^{-1}) which have surface areas of 21 and 1 110 ha, and where the dominant species were *Labeo umbratus* and *C. gariepinus* respectively. In addition, two similarly high *CPUE* estimates were obtained for Taung (16.52kg.net^{-1}.night^{-1}) and Mankazana Dams (20.59kg.net^{-1}.night^{-1}) which have surface areas of 450ha and 35ha and which are dominated by *L. aeneus* and *O. mossambicus* respectively. From these figures it is evident that, while environmental variables influence catch rates, the overarching factor which determines high catch rates is the presence or absence of suitable target species that can be selected by gillnet gear. Ideally, investigation into environmental factors that influence gillnet catch rates should proceed with datasets that encompass high numbers of impoundments characterised by the presence of the same species or species group. This would allow for more comprehensive assessments of the factors which would inhibit or promote high abundances in impoundments characterised by different physico-chemical variables and allow for the prediction of fisheries potential of impoundments where no fisheries information is available.

Catch Per Unit Effort – Clarias gariepinus

The GLM and GAM used to model environmental variables against $CPUE_{CG}$ generated different mean estimates from the non-parametric bootstrap. The GAM estimated the means more accurately than the GLM (93% and 66%), although this additional explained variability came with the cost of an additional variable. Furthermore, the confidence intervals derived for the GAM were larger than those for the GLM suggesting that the GLM estimated means were more precise. However, given the large difference in explained variability between the models, the inclusion of an extra variable in the GAM is probably warranted and may indicate slightly non-linear relationships between predictor variables and $CPUE_{CG}$ (Figure 5.17).

Modelling of $CPUE_{CG}$ resulted in the identification of four environmental factors which explained significant amounts of variability in catch rates. $CPUE_{CG}$ was predicted to increase with increasing temperature, and showed a slight increase with increasing conductivities. Additionally, $CPUE_{CG}$ was predicted to be higher in younger impoundments and displayed a slight positive relationship with surface area. While *C. gariepinus* is a highly adaptable species and can tolerate a wide range of temperatures (8–35 °C) (Bruton and de Moor, 1988; Skelton, 2001), higher predicted catch rates at high temperatures may be a result of increased productivities of water bodies observed at higher temperatures, a relationship incorporated in yield predictive models such as that described by Schlesinger and Regier (1982) (MRAG, 1995). Higher productivity observed in younger impoundments (and as discussed in the *CPUE* section above) may promote higher abundance of this species in these environments. While the influence of surface area is slight, the relationship between higher catch rates and surface area may be linked to increased regions of shallow, vegetated banks in impoundments with large surface areas, which facilitate successful spawning in *C. gariepinus* and provide cover for juveniles (Bruton and de Moor, 1988; Skelton, 2001). Additionally, surface area is an important morphometric variable in empirical predictions of fish yield (Matuszek, 1978; MRAG, 1995); impoundments with larger surface areas are characterised by increased nutrient mixing as they promote wave action through increased fetch (Dodds and Whiles, 2010). Bruton (1978) described the feeding behaviour of *C. gariepinus* and noted that the species commonly feeds in the surface layers on suspended planktonic matter. Impoundments with large surface areas and increased nutrient mixing may be characterised by increased food availability for this species and therefore higher abundance.

Catch Per Unit Effort – Native cyprinid dominated impoundments

GLM - derived estimates of $CPUE_{NC}$ explained significantly less variability in the data than estimates derived using a GAM (5% and 75%). However, as discussed earlier, the GAM may overfit the data resulting in variability that is almost entirely explained, but difficult to infer relationships from (see Figure 5.21 D;E). That which is significant indicates that $CPUE_{NC}$ is predicted to decrease with increasing surface area and temperature, and decrease with increasing age of impoundments. However, comparisons between the standardised $CPUE_{NC}$ estimates derived from the GAM and the influence of environmental factors suggest that higher abundances of native cyprinids are not necessarily governed by these variables. What is probably more important is the species composition, or dominant cyprinid species, within each impoundment. Higher $CPUE_{NC}$ was observed in small and large dams with different temperature regimes; what is apparent is that the presence of certain native cyprinids, and in particular *L. umbratus*, is the overriding factor determining catch rates within impoundments regardless of their physico-chemical characteristics.

Multiple regression analysis

Multiple regression analysis revealed that the variablesidentified in the standardisation of *CPUE* explain an insignificant 23% of the variability in the data. The nature of the overall dataset in the analysis of *CPUE* suggests that a large proportion of the variability in catches is dependent on the availability of fishes that can be selected by gillnets. In the absence of fisheries information, a broadcast model such as this may be of limited effectiveness in determining dams which would produce high catch rates regardless of species composition. However, regression coefficients from the model outline trends in *CPUE* and environmental variables that may be useful in identifying dams with suitable characteristics to support fish production, i.e. more recently constructed impoundments with higher conductivities.

Results from the multiple regression analysis for $CPUE_{CG}$ suggest that a predictive model for *C. gariepinus* abundance explained a significant proportion of the variability in the data and could therefore be applied to dams in the absence of prior species information. However, the dataset included only eleven impoundments, and therefore the model may not be adequately robust. The significant variability explained by the environmental factors outlines characteristics which could be useful in determining areas where *C. gariepinus* catch rates would be high.

The predictive model of $CPUE_{NC}$ explained an insignificant proportion of variability in the data; however, the model did indicate what environmental variables may be influential in determining areas of high abundance for both *Labeo* and *Labeobarbus* spp. However, predictions could be improved if a greater number of impoundments were available for inclusion in the analysis.

CHAPTER 6:

Conclusions, and recommendations for further research

Globally, inland fisheries have been credited as vital sources of employment, nutrition and recreation that generate significant economic and social welfare benefits (Cowx et al., 2010; Beard et al., 2011). While the potential of South Africa‟s inland fishery resources has been recognised, and in certain limited examples capitalised upon, there has been little research on this important sector which has constrained its development and management (Chapter 2). This thesis contributes to the knowledge base on inland fisheries by describing recreational angling facets and compiling and analysing available catch data from anglers and scientific surveys to determine whether existing data have any predictive utility for directing management.

Characterising the resource users is an important component of fisheries assessments, particularly for inferring spatial and temporal utilisation trends and the extent of participation and resource utilisation (St Martin, 2001; Ellender, 2008). Chapter 3 represents the first attempt at describing the organised freshwater angling sector in South Africa. While the numbers are not representative of the entire angling public, the available data indicates that the sector is multi-faceted and is managed by formal organisations. Recreational anglers mainly target non-native species. This has two important implications for management: firstly, that recreational anglers represent major stakeholders with vested interest in South African inland fisheries; secondly, that biodiversity legislation outlined within the National Environmental Management:Biodiversity Act (NEM:BA) is central to governing future management and development of freshwater recreational fisheries. Any development of new or existing fisheries should therefore take into account conflicts that may arise from such initiatives and the activities of anglers. Additionally, given the contribution of angling to the economy, the development of new fisheries should consider the overall benefits these fisheries may provide as opposed to subsistence or commercial fisheries which despite several development attempts, have not established (Chapter 2). Recreational fisheries development is, however, likely to be constrained by the NEM:BA given this sector‟s reliance on non-native species, particularly where the creation of new fisheries is based upon stocking activities. Development of recreational fisheries is therefore likely to focus on dams that already contain non-native target species. It must also be recognised that estimates of participation from all organised angling structures, in addition to informal angling, are fundamental for decision making with regards to resource rights allocation and management. Research to provide an overall estimate of participation and fishing effort is therefore vital if inland fisheries are to be managed in a meaningful manner.

Recreational angling competition data provided a first insight into not only the catch rates in inland fisheries but also into participation and resource utilisation. One of the limitations of the study was that angling catch data varied in the way it was measured between and within angling facets and data from only two facets, bass angling and bank angling, were useful for predictive modelling.

Such modelling allowed for the correlation of catch data with environmental variables to predict which set of environmental factors lead to higher catches and better fisheries. In bass fisheries, for example, high angling quality and *CPUE* were predicted for impoundments in low altitude areas, with low conductivities, high surface areas and low capacities (Chapter 4) while bank angling *CPUE* was predicted to be highest in large dams with low conductivity situated in low rainfall areas.

Overall, predictive models for bass and bank angling catch rates had a significant degree of biological realism but their usefulness is limited to the species and fishery upon which they were based. It must also be recognised that the models presented in this thesis are preliminary. More robust models would require more data with wider spatial coverage. A major recommendation arising from the thesis is that attempts be made to compile catch data from angling competitions in a centralised database. This would facilitate regular monitoring and provide further baseline information for fisheries development, and would require a significant increase in voluntary action and input on the part of anglers and angling officials.

Assessments of fisheries-independent research survey data highlighted the high proportion of non-native species in South African dams. These assessments demonstrated that survey data were useful for predicting not only mixed-species abundances but could also be used to predict the relative abundance of individual species groups. For these non-angling species, high population abundances were shown to be determined primarily by the same environmental variables that influenced catch rates in the recreational fisheries, as well as age of impoundment and temperature.

On comparison, fisheries-independent data has good utility and is not as species-biased as angling catch data. However, comparisons between the two sources of data are difficult because there were few dams where both gillnet survey and angler data were available. Direct comparisons of efficiency, in terms of CPUE, of the two methods in the same system, were therefore not possible. From a management perspective, gillnet surveys provide a more comprehensive idea of what species are available in a specific locality and are therefore highly appropriate for determining the viability of new fisheries. However, the spatial coverage of data obtained for analyses were limited and a comprehensive gillnet survey on a national level would strengthen the predictive utility of the models based on gilnet survey data. This could be achieved through a similar approach as that taken by the ALCOM (Aquatic Resource Management for Local Communities) project in Zimbabwe (Marshall and Maes, 1994). The project focussed on developing a framework for collection of information, including physico-chemical, fisheries, biology, and socio-economic data, for storage in a centralised database that would be used to develop, manage and enhance fisheries in small dams. These data were then used to develop a model to predict fish yields from small reservoirs (Marshall and Maes, 1994). This example shows that large scale gillnet surveys have been conducted successfully in other African countries and could be implemented in South Africa.

In conclusion, this thesis has made a significant contribution to inland fisheries in South Africa as it represents the first attempt at compiling all available information regarding South Africa‟s inland fisheries, characterised and contextualised the formal recreational angling sector, assessed the applicability of recreational angling catch data in providing estimates of fish abundance in individual impoundments, and investigated the importance of fisheries-independent catch data in future fisheries assessments.

References

ABERNETHY DL (2010) Alabama bass anglers information team (BAIT) annual report. Alabama Department of Conservation and Natural Resources. 33pp.

ALLANSON BR and JACKSON PBN (eds.) (1983) Limnology and fisheries potential of Lake le Roux. South African National Scientific Programmes Report No. 77. 182 pp.

ALLETSON J, ROUHANI QA and JONES CLW (2004) The potential for a community-based angler guiding service on the Pongolapoort Dam in northern Kwazulu-Natal. Report prepared for the Swiss South African Cooperative Initiative, Rural Fisheries Programme, Department of Ichthyology and Fisheries Science, Rhodes University. 47 pp.

ALLISON EH (2005) The fisheries sector, livelihoods and poverty reduction in eastern and southern Africa. In: ELLIS F and FREEMAN HA (eds.) *Rural Livelihoods and Poverty Reduction Policies*, Routledge Publishers, London. pp. 256–273.

ALLISON EH, MVULA PM and ELLIS F (2002) Competing agendas in the development and management of fisheries in Lake Malawi. In: GEHEB K and SARCH MT (eds.) *Africa's Inland Fisheries: The Management Challenge*, Fountain Books, Kampala. pp. 49–88.

ANDREW TG (2001) Final report on the activities of the rural fisheries programme, 1997–2000. Rural Fisheries Programme, Department of Ichthyology and Fisheries Science, Rhodes University. 155 pp.

ANDREW TG, ROUHANI QA and SETI S (2000) Can small-scale fisheries contribute to poverty alleviation in traditionally non-angling communities in South Africa? *African Journal of Aquatic Science* **25** 49–55.

ANON (1936) *Regulations governing fishing in the inland waters of Natal, Union of South Africa.* Natal Provincial Administration. pp 40.

ANON (1944) Cape Provincial Administration. Inland Fisheries Department Report No. 1. pp 1–5.

ANON (1948) Crops from inland waters. *Veld Trust News (January).* pp 6–9.

ANON (1950a) Trout pioneering in the Eastern Cape. No. 3 the debut of A N Stenning, 1896. *Piscator* **16** 117–120.

ANON (1950b) Inland Fisheries Department. Cape Provincial Administration Report No. 7. pp 26–27.

ANON (1952) Smallmouth bass in the Umtata River. *Piscator* **24** 115.

ANON (1959) Importation of carp. *Piscator* **46** 47.

ANON (1961/1962) Trout airlifted to the upper Elandspad. *Piscator* **53** 95–99.

ANON (1968) *The Sportsman's Guide to the Hunting and Fishing Laws of Natal*. Natal Parks, Game and Fish Preservation Board, Durban. pp 1–16.

ANON (1970) Transvaal fisheries management. *Fauna & Flora* **20** 6–7.

ANON (1971) Licence sales are up. *Fauna & Flora* **21** 12.

ANON (1980) Florida bass put in farm dams near Franklin. *Kokstad Advertiser* December: 11.

ANON (1981) Florida bass breed in Natal. *Tight Lines* **22**(2) 10.

ANON (1989) Guidelines for legislation and control of the importation of aquatic animals into southern Africa. South Africa Foundation for Research Development Ecosystems Programmes Occasional Report Series. pp 97–100.

ARLINGHAUS R and COOKE SJ (2005) Global impact of recreational fisheries. *Science* **307** (5715) 1561–1563.

ARLINGHAUS R and MEHNER T (2003) Socio-economic characterisation of specialised common carp (*Cyprinus carpio* L.) anglers in Germany, and implications for inland fisheries management and eutrophication control. *Fisheries Research* **61** 19–33.

ARLINGHAUS R, MEHNER T, COWX IG (2002) Reconciling traditional inland fisheries management and sustainability in industrialised countries, with emphasis on Europe. *Fish and Fisheries* **3** 261–316.

ASHTON PJ, APPLETON CC and JACKSON PBN (1986) Ecological impacts and economic consequences of alien or invasive organisms in southern African aquatic ecosystems. In: MACDONALD IAW, KRUGER FJ and FERRAR AA (eds.) *The Ecology and Management of Biological Invasions in Southern Africa*. Oxford University Press, Cape Town. pp 247–260.

BAINBRIDGE B, DAVIES MTT, ALLETSON J and LAX I (2005) Trout position paper. Federation of South African Flyfishers. 20pp.

BARTHELMES BC and DOERING P (1996) Sampling efficiency of different fishing gear used for fish faunistic surveys in stagnant water bodies. *Limnologica* **26** 191–198.

BATCHELOR A (1989) The Department of Development Aid and Fisheries Development. Paper presented at the 20th regular meeting of the Southern African Regional Commission for the Conservation and Utilisation of Soil (SARCCUS) Standing Committee for Animal Production. Gaborone, Botswana, 22–24 November 1988. 10 pp.

BEARD TD, ARLINGHAUS R, BARTLEY D, COOKE SJ, DE SILVA S, MCINTYRE P and COWX IG (2011) Ecosystem approach to inland fisheries: research needs and implementation strategies. *Biology Letters* 7 481–483.

BOK A (1983) The demography, breeding biology and management of two mullet species (Pisces: Mugilidae) in the Eastern Cape, South Africa. PhD Thesis, Rhodes University, South Africa. 268 pp.

BOOTH AJ and POTTS WM (2006) Estimating gill-net selectivity for *Labeo umbratus* (Pisces: Cyprinidae), and an evaluation of using fyke-nets as a non-destructive sampling gear in small reservoirs. *Fisheries Research* **79** 202–209.

BRAND M, MAINA J, MANDER M and O'BRIEN G (2009) Characterisation of the social and economic value of the use and associated conservation of the yellowfishes in the Vaal River. Report to the Water Research Commission, WRC Report No. KV 226/09. 49 pp.

BRUTON MN (1978) The habitats and habitat preferences of *Clarias gariepinus* (Pisces: Clariidae) in a clear coastal lake (Lake Sibaya, South Africa). *Journal of the Limnological Society of South Africa* **4**(2) 81–88.

BRUTON MN and MERRON SV (1985) Alien and translocated animals in southern Africa: a general introduction, checklist and bibliography. South African National Scientific Programmes Report No. 113. 71 pp.

BRUTON MN and VAN AS JG (1986) Faunal invasions of aquatic ecosystems in southern Africa, with suggestions for their management. In: MACDONALD IAW, KRUGER FJ and FERRAR AA (eds.) *The Ecology and Management of Biological Invasions in Southern Africa.* Oxford University Press, Cape Town. pp 47–61.

BRUWER CA (1982) Multi-purpose use of an eutrophic South African man-made reservoir. *Canadian Water Resources Journal* **7**(2) 238–254.

BRUWER CA and CLAASSENS GCD (1978) Die vispotentiaal van Suid-Afrikaanse damme. *South African Association for the Advancement of Science, Biennial Congress, Stellenbosch*. *The Future and its Challenges* **1** 308–320.

BUCKLAND ST (1984) Monte Carlo confidence intervals. *Biometrics* **40** 811–817.

BUREAU OF FISHERIES (2009) Mississippi bass tournament program 2009 Annual Program. Mississippi Wildlife, Fisheries and Parks. 12pp.

BURTON S, CHALMERS R, COWLEY P, FIELDING P, JONES C, POTTS W, ROUHANI Q, SONGONGO M, TIMMERMANS H, VINE N and WOOD A (2002) A report on the feasibility of inland fisheries and oyster farming in the Emalahlani and Mbashe Municipalities respectively. Rural Fisheries Programme, Department of Ichthyology and Fisheries Science, Rhodes University. 137 pp.

CADIEUX JJ (1979) "Sport fisheries": An investigation into the activity of angling in the Transvaal Province. International Symposium on Research in Sport and Recreation. p 13.

CADIEUX JJ (1980a) Freshwater angling in the Transvaal: its environmental and economic impact. *South African Journal of Science* **76** 492–493.

CADIEUX JJ (1980b) Angling in the Transvaal. *Fauna and Flora Transvaal* **38** 16.

CAIN ML (2009) Statewide registered black bass tournament monitoring: 2006–2008. Indiana Division of Fish and Wildlife. Indianapolis. 35pp.

CAMPBELL RA (2004) CPUE standardisation and the construction of indices of stock abundance in a spatially varying fishery using general linear models. *Fisheries Research* **70** 209–227.

canadiancarpclub.com – Canadian Carp Club. Date Accessed - 10th December, 2011.

carptournamentseries.com - Catch and Release Professional Carp Fishing Tournament Series. Date Accessed - 10th December, 2011.

CHARLES A (2001) *Sustainable Fishery Systems. Fish and Aquatic Resources Series 5*. Blackwell Science Ltd. Oxford, UK. 370 pp.

CHEN C-S and CHIU T-S (2009) Standardising the CPUE for the *Illex argentines* fishery in the Southwest Atlantic. *Fisheries Science* **75**(2) 265–272.

http://www.cips-fips.com/cips/index_en.html - The International Angling Confederation. Date Accessed: 13th February, 2011.

CLARK JR (2004) The yellowfish fishery on the Upper Komati: a landowners perspective. Proceedings of the 8th Yellowfish Working Group Conference, 13–15 May 2004, Badplaas. pp 55–58.

COCHRANE KL (1987) The biomass and yield of the dominant fish species in Hartbeespoort Dam, South Africa. *Hydrobiologia.* **146** 89–96.

COETZEE PW (1977) The history and distribution of freshwater fish in Albany: largemouth bass. *Albany Freshwater Angling Association Newsletter* **32** 3–4.

COKE M and POTT R (1971) The Pongola floodplain pans. *Limnological Society of Southern Africa Newsletter* **16** 20–26.

COOKE SJ and COWX IG (2004) The role of recreational fishing in global fish crises. *BioScience* **54** (9) 857–859.

COOKE SJ and PHILIPP DP (2009) *Centrarchid Fishes: Diversity, Biology, and Conservation.* Wiley-Blackwell. Chichester, UK. 539 pp.

COWX IG (ed.) (1998) *Stocking and Introduction of Fish*. Fishing News Books. Oxford, UK. 456pp.

COWX IG and GERDEAUX D (2004) The effects of fisheries management practises on freshwater ecosystems. *Fisheries Management and Ecology* **11** 145–151.

COWX IG and ARLINGHAUS R (2008). Recreational fisheries in the twenty-first century: towards a code of conduct. In: AAS Ø, ARLINGHAUS R, DITTON RB, POLICANSKY D, SCHRAMM HLR (eds.) *Global Challenges in Recreational Fisheries*. Oxford: Blackwell Science pp 338–352.

COWX IG, ARLINGHAUS R, and COOKE SJ (2010) Harmonizing recreational fisheries and conservation objectives for aquatic biodiversity in inland waters. *Journal of Fish Biology* **76**(9) 2194–2215.

CRASS RS (1964) Freshwater fishes in Natal. *Piscator* **72** 14–18.

DAVIES MTT (1986) Trout - whose responsibility? In: SKELTON PH and DAVIES MTT (eds.) *Trout in South Africa*. Proceedings of a colloquium held in the JLB Smith Institute of Ichthyology, 9th April 1986. ICHTHOS Newsletter. p14–18.

DAY LA (1932) The introduction of trout in Natal. *Salmon and Trout Magazine* **69** 345–352.

DE MOOR IJ and BRUTON MN (1988) Atlas of alien and translocated indigenous aquatic animals in southern Africa. *South African National Scientific Programmes Report* 144. 310 pp.

DE SATGE R (1978) Perspectives on rural communities: some limitations. Collected Papers from the Symposium on Fisheries and Rural Development. 20–21 November 1978, Grahamstown, South Africa. pp 155–163.

DE VILLIERS P (1998) The management of fish populations in the Free State, South Africa: the philosophy. Proceedings of the African Fishes and Fisheries: Diversity and Utilisation Conference, Grahamstown. p 106.

DE VILLIERS P (2003) Freshwater fisheries conservation and management in South Africa with specific reference to the Free State province. In: Proceedings of the 3rd International Conference of the Pan-African Fish and Fisheries Association, 10–14 November 2003, Cotonou, Benin. pp 230–231.

DEDEREN JJ, FOUCHE PSO, GAIGHER IG, GAIGHER MJ, JOHN RP, LIGAVHA M, MASHAU E, MENNE PF, NETHONONDA LO, SZUBARGA A, TODD C, VAN DER WAAL BCW, VAN REE T, VENTER C, WOOD C and WEISSER P (2001) A socio-biological study of the aquatic resources and their utilisation in an underdeveloped rural region, the Mutshindudi River catchment. Report to the Water Research Commission, WRC

Report no. 714/2/01. 150 pp.

DOBSON AJ (2002) *An Introduction to Generalized Linear Models*. Chapman & Hall, London. 225pp.

DODDS WK and WHILES MR (2010) *Freshwater Ecology*. 2nd ed. Academic Press, Massachusetts. 829pp.

DONNELLY BG (1965) The first record of rainbow trout breeding in the Port Elizabeth area. *Piscator* **64** 91–92.

DUANE NELLIS M, HARRINGTON J, JOHN A, WU J (1998) Remote sensing of temporal and spatial variations in pool size, suspended sediment, turbidity, and Secchi depth in Tuttle Creek Resevoir, Kansas: 1993. *Geomorphology* **21**(3–4) 281–293.

DU PLESSIS SS (1961) Trout Pioneer F C Braun (1875–1959). *Fauna and Flora* **12** 17–23.

DU PLESSIS SS and LE ROUX PJ (1965) Sport fisheries in river development with reference to the Orange River Scheme. *South African Journal of Science* **61** (3) 137–146.

DU PREEZ M and LEE DE (2010) The contribution of trout fly fishing to the economy of Rhodes, North Eastern Cape, South Africa. *Development Southern Africa* **27** (2) 241–253.

DUNCAN-BROWN R (1980) Xonxa Fisheries Project: an attempt to stimulate angling in a rural community in Transkei. In: Transkei and Ciskei Research Society, Proceedings of the 6th biennial meeting, Umtata, 7–9 March, 1980. pp 160–161.

DUNN PK and SMYTH GK (1996) Randomized quantile residuals. *Journal of Computational and Graphical Statistics* **5** 236–244.

DUROCHER PP, PROVINCE WC and KRAII JE (1984) Relationship between abundance of largemouth bass and submerged vegetation in Texas reservoirs. *North American Journal of Fisheries Management* **4** 84–88.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (2009) Reservoir Database. Department of Water Affairs and Forestry, Pretoria, South Africa. Date Accessed: April 2010 – January 2012.

ECA (1989) Republic of South Africa, Environmental Conservation Act No. 73 of 1989.

ECCLES DH, HART RC, JACKSON PBN and TÓMASSON T (1983) Possible development options for fisheries: Distribution, structure and relative abundance of fish populations. In: ALLANSON BR and JACKSON PBN (eds.) *Limnology and Fisheries Potential of Lake le Roux*. South African National Scientific Programmes Report no. 77. CSIR, Pretoria. pp 161–171.

EFRON B and TIBSHIRANI R (1986) Bootstrap methods for standard errors, confidence intervals, and other methods of statistical accuracy. *Statistical Science* **1** 54–77.

EGERTSON CJ and DOWNING JA (2004) Relationship of fish catch and composition to water quality in a suite of agriculturally eutrophic lakes. *Canadian Journal of Fisheries and Aquatic Sciences* **61** 1784–1796.

ELLENDER BR (2008) The impact of angling on smallmouth and largemouth yellowfish, *Labeobarbus aeneus* and *Labeobarbus kimberleyensis,* in Lake Gariep, South Africa. MSc Thesis, Rhodes University, South Africa. 111 pp.

ELLENDER BR, WEYL OLF and WINKER H (2009) Who uses the fishery resources in South Africa‟s largest impoundment? Characterising subsistence and recreational sectors on Lake Gariep. *Water SA* **35** 677–684.

ELLENDER BR, WEYL OLF, WINKER H and BOOTH AJ (2010a) Quantifying the annual fish harvest from South Africa‟s largest freshwater reservoir. *Water SA* **36** (1) 45–52.

ELLENDER BR, WEYL OLF, WINKER H, STELZHAMMER H and TRAAS GRL (2010b) Estimating angling effort and participation in a multi-user, inland fishery in South Africa. *Fisheries Management and Ecology* **17** 19–27.

ELLENDER BR, WEYL OLF and SWARTZ E (2011) Invasion of a headwater stream by non-native fishes in the Swartkops River system, South Africa. *African Zoology* **46** 39–46.

ENVIRO-FISH AFRICA (2009) Environmental impact assessment of the proposed eradication of invasive alien fishes from selected rivers in the Cape Floristic Region. Executive summary. Final Environmental Impact Assessment Report, Prepared for Cape Nature. 14 pp. www.fosaf.co.za/documents/Final%20EIA%20Report%20Apr%2009.pdf (accessed 12/12/2011).

FAO (2003) Review of the state of the world fishery resources: inland fisheries. *FAO Fisheries Circular.* No. 942, Rev.1. Rome. 60 pp.

FICK M (2009) Eastern Cape Fly-Fishers (ECFF) and Trout Action Group (TAG) Position Paper on Trout Zoning. Accessed online: http://www.ecff.co.za/files/downloads/ECFF%20TAG%20Position%20Paper%20on%20Zoning%20Jan%202009.pdf (accessed 12/12/2011).

http://www.fips-mouche.com – The International Fly Fishing Federation. Date Accessed: 13 February, 2011.

http://www.fishingowl.co.za – Popular South African Angling Website. Date Accessed 10 January, 2011.

GABIE V (1965) Problems associated with the distribution of freshwater fishes in southern Africa. *South African Journal of Science* **61**(11) 383–391.

GAIGHER CM (1973) The Clanwilliam River: it is not yet too late? *Piscator* **88** 75–78.

GEHEB K and BINNS T (1997) "Fishing farmers" or "farming fishermen"? The quest for household income and nutritional security on the Kenyan shores of Lake Victoria. *African Affairs* **96** 73–93.

GRANEK EF, MADIN EMP, BROWN MA, FIGUIERA W, CAMERON DS, HOGAN Z, KRISTIANSON G, DE VILLIERS P, WILLIAMS JE, POST J, ZAHN S and ARLINGHAUS R (2008) Engaging recreational fishers in management and conservation:

global case studies. *Conservation Biology* **22** 1125–1134.

GROBBELAAR JU (1985) Phytoplankton productivity in turbid waters. *Journal of Plankton Research* **7**(5), 653–663.

GUISAN A, EDWARDS Jr TC and HASTIE T (2002) Generalized linear and generalized additive models in studies of species distributions: setting the scene. *Ecological Modelling* **157** 89–100.

GUY CS and WILLIS DW (1991) Relationships between environmental variables and density of largemouth bass in South Dakota ponds. *Proceedings of the South Dakota Academy of Sciences* **70** 109–117.

HAMMAN KCD (1980) Post-impoundment trends in the fish populations of the Hendrik Verwoerd Dam. *Journal of the Limnological Society of Southern Africa* **6** 101–108.

HAMMAN KCD (1981) Aspekte van die bevolkingsdinamika van die Hendrik Verwoerddam met verwysing na die ontwikkeling van „n visserybestuurplan. PhD Thesis, Rand Afrikaans University, South Africa. 208 pp.

HAMMAN KCD (1986) Alien fish species and conservation with special reference to the Cape Province. In: SKELTON PH and DAVIES MTT (eds.) *Trout in South Africa*. Proceedings of a colloquium held in the JLB Smith Institute of Ichthyology, 9th April 1986. ICHTHOS Newsletter. pp 9–11.

HARRISON AC (1936) Black bass in the Cape Province: second report on the progress of American largemouth black bass. Department of Commerce and Industries, Fisheries and Marine Biological Survey Division, Union of South Africa. Investigational Report No. 7. pp 1–119.

HARRISON AC (1940) The acclimation of freshwater game fish in the Cape Province and its relation to forest areas. *Journal of the South African Forestry Association*, No. 4. pp 5–14.

HARRISON AC (1948) Report on the rivers of Maclear and East Griqualand, April and May 1948. Inland Fisheries Department, Cape Provincial Administration. Report No. 5. pp 15–19.

HARRISON AC (1949) *Freshwater fishing in the Cape South Western Districts, South Africa*. Cape Piscatorial Society, Cape Town. 20 pp.

HARRISON AC (1951) Introduction of exotic fishes to the Cape Province. Paper presented to the first interprovincial inland fisheries conference at Jonkershoek, Stellenbosch, December 1949. *Piscator* **6** 52–61.

HARRISON AC (1952a) Introduction of exotic fishes to the Cape Province. Section III: black bass and bluegills. *Piscator* **22** 57–64.

HARRISON AC (1952b) Introduction of exotic fishes to the Cape Province. Section III: black bass and bluegills (continued). *Piscator* **23** 92–95.

HARRISON AC (1953a) Introduction of exotic fishes to the Cape Province. Section III: black bass and bluegills (continued). *Piscator* **25** 12–15.

HARRISON AC (1953b) The acclimatization of smallmouth bass. *Piscator* **27** 89–96.

HARRISON AC (1953c) Trout pioneering in the Eastern Province. No 8: Atlantic salmon and rainbow trout. *Piscator* **25** 12–15.

HARRISON AC (1954a) Spotted bass in the Buffalo River. *Piscator* **30** 39–40.

HARRISON AC (1954b) Trout pioneering in the Eastern Province. No 9: Drought, sea trout and farewell to Stenning. *Piscator* **30** 47–53.

HARRISON AC (1957) A history of the freshwater fish associations of Cape Town. *Piscator* **41** 214–226

HARRISON AC (1959) Editorial: the menace of carp. *Piscator* **46** 44–53.

HARRISON AC (1962/1963) Notes on the introduction of smallmouth bass to the Berg

River. *Piscator* **56** 81–83.

HARRISON AC (1964/1965) Spotted bass. *Piscator* **62** 127–128.

HARRISON AC (1965/1966) Slow-growing smallmouth bass in Steenbras reservoir. *Piscator* **65** 117–119.

HARRISON AC (1966) Early references to carp in the Cape colony. *Piscator* **66** 23.

HARRISON AC (1967/1968) Thirty years of smallmouth bass. *Piscator* **71** 125–139.

HARRISON AC (1972/1973) Early records of trout stocking in the vleis of the Cape Flats. *Piscator* **86** 114.

HARRISON AC (1975) The early transactions of the Cape Piscatorial Society. Part I. *Piscator* **94** 69–75.

HASTIE T, TIBSHIRANI R and FRIEDMAN J (2001) *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*. 2nd ed. Springer, London. 552 pp.

HECHT T and BRITZ PJ (1990) *Aquaculture in South Africa: History, Status and Prospects*. The Aquaculture Association of South Africa, Pretoria, South Africa. 58 pp.

HECKY RE and GUILDFORD SJ (1984) Primary productivity of Southern Indian Lake before, during and after impoundment and Churchill River diversion. *Canadian Journal of Fisheries and Aquatic Sciences* **41** 591–604.

HEEG J and BREEN CM (1982) Man and the Pongola floodplain. South African National Scientific Programmes Report No. 56. 117 pp.

HENDERSON HF and WELCOMME RL (1974) The relationship of yield to morphoedaphic index and numbers of fishermen in African inland waters. *CIFA Occasional Paper* **1** 1–19.

HEY SA (1926a) Fisheries survey 1926–1927. Inland waters. Report No. 3. Department of Mines and Industries, Union of South Africa.

HEY SA (1926b) Preliminary report on the inland waters of South Africa with regard to the suitability for the introduction of edible fish. Inland waters. Report No. 1. Department of Mines and Industries, Union of South Africa.

HEY D (1941) The establishment and maintenance of freshwater fish in South Africa. *Journal of the South African Forestry Association* **6** 3–25.

HEY D (1977) The history and status of nature conservation in South Africa. In: BROWN AC (ed.) *A History of Scientific Endeavour in South Africa.* Rustica, Cape Town. pp 132–163.

HICKEY K (2009) Kentucky Bass Tournament Results 2009. Kentucky Department of Fish and Wildlife Resources. 32pp.

HILBORN R and WALTERS CJ (1992) Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, New York. 520 pp., 1968–92.

HOLZ JC, HOAGLAND KD, SPAWN RL, POPP A and ANDERSEN JL (1997) Phytoplankton community response to reservoir aging. *Hydrobiologia* **346** 183–192.

HUNTER JR and WISBY WJ (1964) Net avoidance behavior of carp and other species of fish, *Journal of the Fisheries Research Board of Canada* **21** 613–633.

IMPSON ND, BILLS IR and WOLHUTER L (eds.) (2007) Technical report on the state of yellowfishes in South Africa. Report to the Water Research Commission, WRC Report No. KV 212/08, 198 pp.

JACKSON PBN (1973) Internal report on the potential of South African inland waters for commercial fisheries. Unpublished report to the Water Research Commission, Pretoria. 27 pp.

JACKSON PBN (1974) Freshwater fish for farm profit: water, dams and management under the spotlight. *Farmer's Weekly* (*October*). pp 42–47.

JACKSON PBN (1976) Water Resources and Freshwater Fisheries in southern Africa. In: BAKER G (ed.) *Resources of Southern Africa: Today and tomorrow*. The Associated Scientific and Technical Societies of South Africa, Johannesburg. pp 196–207.

JACKSON PBN (1980) Fresh and brackish water fish production as an employment source in the Transkei. In: Transkei and Ciskei Research Society, Proceedings of the 6th biennial meeting, Umtata, 7–9 March, 1980. pp 155–159.

JACKSON PBN (1981a) Fish Harvesting. University of the Orange Free State: Publication Series C: No.3. pp 52–54.

JACKSON PBN (1981b) Orange River dams fish population project. Rhodes University Institute for Freshwater Studies, Progress Report (August). pp 1–11.

JACKSON PBN, CAMBRAY JA, ECCLES DH, HAMMAN KCD, TÓMASSON T and WHITE PN (1983) Distribution, structure and relative abundance of fish populations. In: ALLANSON BR and JACKSON PBN (eds.) *Limnology and Fisheries Potential of Lake le Roux*. South African National Scientific Programmes Report No. 77. 182 pp.

JACKSON PBN (1989) The value of introduced aquatic organisms to the sportfishing industry. South African Foundation for Research Development: Ecosystem Programmes Occasional Report Series No. 44. pp 36–45.

JACKSON DC and MARMULLA G (2001) The influence of dams on river fisheries. In: MARMULLA G (ed.) *Dams, Fish and Fisheries, opportunities, challenges, and conflict resolution*. FAO Fisheries Technical Paper, Rome. 44pp.

JAGANYI J, SALAGAE M and MATIWANE N (2008) Integrating floodplain livelihoods into a diverse rural economy by enhancing co-operative management: a case study of the Pongolo floodplain system, South Africa. Report to the Water Research Commission, WRC

Report No. 1299/1/08. 423 pp.

JOLIFFE IT (2002) *Principal Component Analysis*. Springer, London. 502pp.

JOUBERT P (1984) Daar‟s baars in die? Vaal. *Stywe Lyne (January)*.pp 5–7.

JUBB RA (1962) Prospects for an eel fishery. *Piscator* **56** 84–85.

JUBB RA (1973) The J.G. Strydom Dam: Pongolo River: northern Zululand. The importance of the floodplain pans below it. *Piscator* **86** 104–109.

JUBB RA (1973a) Notes on exotic fishes introduced into South African inland waters. *Piscator* **87** 9–12.

JUBB RA (1973b) Notes on exotic fishes introduced into South African inland waters: cyprinids. *Piscator* **88** 62–64.

KADYE WT and BOOTH AJ (2011) Integrating stomach content and stable isotope analyses to elucidate the feeding habits of non-native sharptooth catfish *Clarias gariepinus*. *Biological Invasions* (In press).

KAPETSKY JM and PETR T (1984) Status of African reservoir fisheries. *CIFA Tech. Pap.* 10. pp 1–325.

KERR SJ (2004) A (2004) *Survey of Competitive Fishing Events in Ontario. Fish and Wildlife Branch. Ontario Ministry of Natural Resources*. Peterborough, Ontario. 14pp.

KING M (1995) *Fisheries Biology, Assessment and Management*. Fishing News Books, Osney Mead, Oxford. 382 pp.

KOCH BS and SCHOONBEE HJ (1980) A fish mark-recapture study in Boskop Dam, Western Transvaal. *Water SA* **6** 149–155.

KOEKEMOER JH and STEYN GJ (2005) Fish community study of Hartbeespoort Dam. Final Report. Department of Agriculture, Conservation, Environment and Tourism. 101 pp.

KOHLER CC and STANLEY JG (1984) A suggested protocol for evaluating exotic fish introductions in the United States. In: COURTENAY RW Jnr. and STAUFFER RJ Jnr. (eds.) *Distribution, Ecology and Management of Exotic Fishes*. Johns Hopkins University Press, Baltimore. 430pp.

KULHANEK SA, RICCIARDI A and LEUNG B (2011) Is invasion history a useful tool for predicting the impacts of the world‟s worst aquatic invasive species? *Ecological Applications* **21** 189–202.

kznwildlife.co.za – Ezemvelo KZN Wildlife, Pietermaritzburg. Date Accessed – 5th September 2010.

LA HAUSSE DE LA LOUVIÈRE P (1987) A brief review of the state of knowledge of the fishes and fishery of the Pongolo floodplain, northern Zululand. Institute of Natural Resources, Pietermaritzburg. 13 pp.

LEPRIEUR F, BEAUCHARD O, BLANCHET S, OBERDORFF T and BROSSE S (2008) Fish invasions in the world‟s river systems: when natural processes are blurred by human activities. *PLosBiology* **6**(2) e28.

LE ROUX PJ (1961) Growth of *Tilapia mossambica* Peters in some Transvaal impoundments. *Hydrobiologia* **18** 165–175.

LE ROUX PJ (1965) The magnitude of freshwater angling in the Transvaal. *Fauna & Flora* **16** 38–39.

LEIBOLD M and VAN ZYL CJ (2008) The economic impact of sport and recreational angling in the Republic of South Africa, 2007: Extensive Report. In: Report of project to scientifically determine the overall economic impact and strategic value of sport & recreational angling in the Republic of South Africa, 49 pp: Development Strategies International, Consultants to Business and Government.

LEWIN WC, ARLINGHAUS R and MEHNER T (2006) Documented and potential biological impacts of recreational fishing: Insights for management and conservation. *Reviews in Fisheries Science* **14** 305–367.

LOWE SR, WOODFORD DJ, IMPSON ND and DAY JA (2008) The impact of invasive fish and invasive riparian plants on the invertebrate fauna of the Rondegat River, Cape Floristic Region, South Africa. *African Journal of Aquatic Scienc*e **33** 51–62.

MABITSELA CK (1981) An ecological investigation of the economically viable fish species in certain dams in Lebowa, South Africa. MSc Thesis, University of the North, South Africa.

MANNING DW (1908) *Trout fishing in the Cape Colony*, Argus Printing and Publishing Ltd., Cape Town. 97 pp.

MARSHALL B and MAES M (1994) Small water bodies and their fisheries in southern Africa. *CIFA Technical Paper* No. 29. Rome, FAO. 68 pp.

MATUSZEK JE (1978) Empirical prediction of fish yields of large North American lakes. *Transactions of the American Fisheries Society* **107** 385–394.

MAUNDER MN and LANGLEY AD (2004) Integrating the standardization of catch-per-unit-effort into stock assessment models: testing a population dynamics model and using multiple data types. *Fisheries Research* **70** 389–395.

MCCAFFERTY JR, WEYL OLF and SWARTZ E (2010) Why should the Department of Agriculture, Forestry and Fisheries consider recreational angling in its long-term plans for inland fisheries? In: Proceedings of the 14th Yellowfish Working Group Conference, 16-17 April, 2010. pp 147–151.

MCCULLAGH P and NELDER JA (1989) *Generalized Linear Models*. 2nd ed. Chapman & Hall, London. 532pp.

MCVEIGH SJ (1978) A preliminary survey of the impoundments of the Western Cape with regard to angling and the development of angling facilities. Report to the Cape Department of Nature and Environmental Conservation, South Africa. 63 pp.

MCVEIGH SJ (1979) Bass in farm dams. *The Cape Angler* **5** 6–14.

MERRON GS and TÓMASSON T (1984) Age and growth of *Labeo umbratus* (Pisces: Cyprinidae) in Lake le Roux on the Orange River, South Africa. *Journal of the Limnological Society of Southern Africa* **10** 5–10.

MERRON GS, BRUTON MN and LA HAUSSE DE LA LOUVIÈRE P (1993) Implications of water release from the Pongolapoort Dam for the fish and fishery of the Phongola Floodplain, Zululand. *Southern African Journal of Aquatic Sciences* **19** (1/2) 34–49.

MERRON GS and WELDRICK SK (1995) Fisheries management of the Phongola floodplain. J.L.B. Smith Institute of Ichthyology, Investigational Report No. 51. 129 pp.

MILLS S (2000) *Freshwater Fishing in South Africa.* Struik Publishers, Cape Town. 208 pp.

MRAG (1995) A synthesis of simple empirical models to predict fish yields in tropical lakes and reservoirs. Marine Resources Assessment Group, London.

MUSTAPHA MK (2009) Limnological evaluation of the fisheries potentials and productivity of a small shallow tropical African reservoir. *Revista de Biologia Tropical* **57**(4) 1093–1106.

MYERS GS (1965) *Gambusia*, the fish destroyer. *Tropical Fish Hobbyist (January)*. pp 31–32 and 53–54.

NEILAND AE, CHIMATIRO S, KHALIFA U, LADU BMB and NYEKO D (2005) Inland fisheries in Africa: Key issues and future investment opportunities for sustainable development. Technical Review Paper - Inland Fisheries. NEPAD. 76 pp. www.fishforall.org/ffa summit/C_Eg/Inland%20Fisheries%20Review%20Paper.doc. (Accessed 07/10/2010)

NEL C (1988) Fishing for food and fun. *Farmers Weekly* pp 40–42.

NEMA (1998) Republic of South Africa, National Environmental Management Act No. 107 of 1998.

NEM:BA (2004) Republic of South Africa, National Environmental Management: Biodiversity Act No. 10 of 2004.

NESS J (1991) Notes on the introduction of trout to the Western Cape and the origins of the Cape Piscatorial Society. *Piscator* **123** 25.

NIESAR M, ARLINGHAUS R, RENNERT B and MEHNER T (2004) Coupling insights from a carp, *Cyprinus carpio*, angler survey with feeding experiments to evaluate composition, quality and phosphorous input of groundbait in coarse fishing. *Fisheries Management and Ecology* **11** 225–235.

NORTH E (1980) The effects of water temperature and flow upon angling success in the River Severn. *Aquaculture Research* **11** 1–9.

NORTH E and HICKLEY P (1989) An appraisal of anglers" catches in the River Severn, England. *Journal of Fish Biology* **34**(2) 299–306.

NWA (1998) Republic of South Africa, National Water Act No. 36 of 1998.

OLDS AA, SMITH MKS, WEYL OLF and RUSSELL IA (2011) Alien invasive freshwater fishes in the Wilderness Lakes system, a wetland of international importance, Western Cape, South Africa. *African Zoology* **46** 179–184.

OGLESBY RT (1977) Relationship of fish yield to lake phytoplankton standing crop, production, and morphoedaphic factors. *Journal of the Fisheries Research Board of Canada* **34** 2271–2279.

ORTIZ M and AROCHA F (2004) Alternative error distribution models for standardization of catch rates of non-target species from a pelagic longline fishery: billfish species in the Venezuelan tuna longline fishery. *Fisheries Research* **70** 275–297.

PARKKILA K, ARLINGHAUS R, ARTELL J, GENTNER B, HAIDER W, AAS O, BARTON D, ROTH E, SIPONNEN (2010) Methodologies for assessing the socio-economic benefits of European inland recreational fisheries. *EIFAC Occasional Paper* **46** 1–102.

PAUKERT CP and WILLIS DW (2004) Environmental influences on largemouth bass *Micropterus salmoides* populations in shallow Nebraska lakes. *Fisheries Management and Ecology* **11** 345–352.

PETR T (2000) Interactions between fish and aquatic macrophytes in inland waters: a review. *FAO Fisheries Technical Paper* No 396 FAO, Rome. 185pp.

PIKE T (1980a) An historical review of freshwater fish hatcheries in Natal. *Piscator* **106** 49–53.

www.piscator.co.za - Cape Piscatorial Society, Cape Town. Date Accessed - 5th September 2010.

POTT R (1973) Anglers - your help is needed. *Fauna & Flora* **24** 1–3.

POTTS WM (2003) Towards the development of species-specific fish production models for small reservoirs in southern Africa. PhD Thesis, Rhodes University, South Africa. 148 pp.

POTTS WM, WEYL OLF and ANDREW TG (2004) Final report on an initial assessment of the fisheries potential of Gariep Dam Prepared by: Enviro-Fish Africa (Pty) Ltd for: Department of Economic Affairs, Environment and Tourism, Northern Region, Province of the Eastern Cape. 38 pp.

POTTS WM, BOOTH AJ, HECHT T and ANDREW TG (2006) The life history and fishery potential of *Labeo umbratus* (Teleostei: Cyprinidae) in five small South African reservoirs. *African Journal of Aquatic Science* **31** (2) 285–295.

PUNT A, WALKER TI, TAYLOR BL and PRIBAC F (2000) Standardization of catch and effort data in a spatially-structured shark fishery. *Fisheries Research* **45** 129–145.

QUERTERMUS C (2010) Tournament creel report: Georgia Bass Chapter Federation. Department of Natural Resources, Georgia. 7pp.

QUINN TJ and DERISO RB (1999) Quantitative fish dynamics. Oxford University Press, Oxford. 542 pp.

RANTA E and LINDSTROM K (1993) Theory on fish yield versus water quality in lakes. *Annales Zoologici Fennici* **30** 71–75.

RICHARDSON TJ, BOOTH AJ and WEYL OLF (2009) Rapid biological assessment of the fishery potential of Xonxa Dam, near Queenstown, South Africa. *African Journal of Aquatic Science* **34** 87–96.

RIDGWAY MS (2002) Movements, home range, and survival estimation of largemouth bass following displacement. *American Fisheries Society Symposium* **31** 525–533.

ROACH B, TRIAL J and BOYLE K (1999) Comparing 1994 angler catch and harvest rates from on-site and mail surveys on selected Maine lakes. *North American Journal of Fisheries Management* **19** 203–208.

ROODE MC (1978) Harvesting of freshwater fish from natural resources: a marketing experiment conducted in the Transkei. *Fish Farmer Transvaal Newsletter* No. 20. pp 2–12.

ROUHANI Q (2001) A report on an assessment of the potential for small-scale fisheries development on Disaneng and Setumo dams in the North-West Province. Rural Fisheries Programme, Department of Ichthyology and Fisheries Science, Rhodes University. 17 pp.

ROUHANI Q (2003) Report for the assessment of the potential for community based small–scale fisheries in Ntenetyana Dam (Alfred Nzo District Municipality). Rural Fisheries Programme, Department of Ichthyology and Fisheries Science, Rhodes University. 12 pp.

ROUHANI Q (2004) A report on the survey of selected large dams in the North West Province: with a view to develop fisheries. Report for the Department Agriculture Conservation and Environment, North West Province, South Africa. 328 pp.

ROUHANI Q and ANDREW TG (1998) Freshwater fisheries for rural development in the Eastern Cape Province of South Africa. Proceedings of the African Fishes and Fisheries: Diversity and Utilisation Conference, Grahamstown. 168 pp.

ROUHANI Q and BRITZ PJ (2004) Contribution of aquaculture to rural livelihoods in South Africa: a baseline study. Report to the Water Research Commission, WRC Report No. TT 235/04. 105 pp.

ROUHANI Q and DAVIES MTT (2003) A report on the survey to determine the potential for recreational and subsistence fisheries in the Alfred Nzo District Municipality. Rural Fisheries Programme, Department of Ichthyology and Fisheries Science, Rhodes University. 20 pp.

ROUHANI Q, HINRICHSEN E and DAVIES MTT (2010) Cata recreational fisheries report: on the feasibility and business plan to develop a recreational fishery in and around Cata dam. Rural Fisheries Programme, Department of Ichthyology and Fisheries Science, Rhodes University. 48 pp.

ROUX DJ, NEL JL, MACKAY HM and ASHTON PJ (2006). Cross-sector policy objectives for conserving South Africa"s inland water biodiversity. Report to the Water Research Commission, WRC Report No. TT 276/06. 100 pp.

RYDER RA (1965) A method for estimating potential fish distribution of north-temperate lakes. *Transactions of the American Fisheries Society* **94** 214–218.

SAAYMAN JE, JOOSTE A, OLIVIER PAS, MOKGALONG N and POLLING L (1983) The cropping potential of Nzhelele Dam, Republic of Venda. Research report at the request of the Venda Development Corporation. 12 pp.

SARCH MT and ALLISON EH (2000) Fluctuating fisheries in Africa"s inland waters: well adapted livelihoods, maladapted management. *Proceedings of the 10th International Conference of the Institute of Fisheries Economics and Trade*, 9–14 July 2000, Corvallis, Oregon, USA. 11 pp.

SAVINO JF and STEIN RA (1989) Behaviour of fish predators and their prey: habitat choice between open water and dense vegetation. *Environmental Biology of Fishes* **24** (4) 287-293.

SCHLESINGER DA and REGIER HA (1982) Climatic and morphoedaphic indices of fish yields from natural lakes. *Transactions of the American Fisheries Society* **111** (2) 141–150.

SCHOONBEE HJ, HECHT T, SAAYMAN JE and POLLING L (1995) Fish population assessment in a temperate Lowveld impoundment of the Transvaal, South Africa. *Water SA* **21** (2) 147–152.

SCHRAMM M (1993) A comparison of Cyprinid fish populations in three large Transkei reservoirs with respect to abundance and reproduction. *Southern African Journal of Aquatic Sciences* **19** 74–88.

SCHULZE RE, MAHARAJ M, WARBURTON ML, GERS CJ, HORAN MJC, KUNZ RP and CLARK DJ (2008) South African atlas of climatology and agrohydrology. WRC Report No 1489/1/08. Water Research Commission, Pretoria, South Africa.

SCHUPP B (2002) The B.A.S.S. perspective on bass tournaments: a 21st century opportunity for progressive resource managers. In: PHILIPP DP and RIDGWAY MS (eds.) Black bass: ecology, conservation, and management. *American Fisheries Society Symposium* **31** 715–716.

SCOTT HA (1982) The Olifants River system: unique habitat for rare Cape fishes. Cape Department of Nature and Environmental Conservation, *Cape Conservation Series* 2.

SETI S (2002) Small-scale fisheries as a vehicle for rural development: a case study of two villages in the former Ciskei, Eastern Cape Province, South Africa. MSc Thesis, Rhodes University, South Africa. 198 pp.

SKELTON PH (1983) Perspectives on the conservation of threatened fishes in southern Africa. *The Naturalist* **27** (1) 3–12.

SKELTON PH (2001) *A Complete Guide to the Freshwater Fishes of Southern Africa*. 2nd ed. Struik Publishers, Cape Town. 395 pp.

SKELTON PH and DAVIES MTT (eds.) (1986) *Trout in South Africa*. Proceedings of a colloquium held in the JLB Smith Institute of Ichthyology, 9th April 1986. ICHTHOS Newsletter.

SKELTON PH and WEYL OLF (2011) Fishes. In: PICKER M and GRIFFITHS C (eds.). *Alien & Invasive Animals*: *A South African Perspective*. Struik Nature, Cape Town. pp 47–70.

SMITH W (1984) Count down for SA bass team. *Tight Lines (October)* pp 14–18.

SMITH CL (1986) The life cycle of fisheries. *Fisheries* **11** (4) 20–2.

SOKAL RR and ROHLF FJ (1995) *Biometry: The Principles and Practice of Statistics in Biological Research*. 3rd ed. Freeman, San Francisco. 887 pp.

SPENCER PD and SPANGLER GR (1992) Effect that providing fishing information has on angler expectations and satisfaction. *North American Journal of Fisheries Management* **12**(2) 379–385.

ST MARTIN K (2001) Making space for community resource management in fisheries. *Annals of the Association of American Geographers* **91** 122–142.

STADTLANDER T, WEYL OLF and BOOTH AJ (2011) New distribution record for the Asian tapeworm *Bothriocephalus acheilognathi* Yamaguti, 1934 in the Eastern Cape Province, South Africa. *African Journal of Aquatic Science* **36**(3) 339–343.

STEFFANSON G (1996) Analysis of groundfish survey abundance data: combining the GLM and delta approaches. *ICES Journal of Marine Science* **53** 577–588.

STEVENS JB (1966) Angler success as a quality determinant of sport fishery recreational values. *Transactions of the American Fisheries Society* **95**(4): 357–362.

SULLIVAN MG (2003) Active management of walleye fisheries in Alberta: dilemmas of managing recovering fisheries. *North American Journal of Fisheries Management* **23**(4) 1343–1358.

SWARTZ E (2009) National Environmental Management Biodiversity Act - unpublished maps.

SWEKA JA and HARTMAN KJ (2003) Reduction of reactive distance and foraging success in smallmouth bass, *Micropterus dolomieu*, exposed to high turbidity levels. *Environmental Biology of Fishes* **67**(4) 341–347.

TAYLOR L and VAN DER WALT IS (1985) Aspects concerning the fish and fisheries development in Lebowa. *Fish Farmer* **37** 9–11.

TENNESSEE WILDLIFE RESOURCES AGENCY (2008) Bass information from tournament entries: 2008 Annual Report. Fisheries Management Division, Tennessee Wildlife Resources Agency, Nashville, Tennessee.

TINLEY KL (1964) Fishing methods of the Thonga tribe in north-eastern Zululand and southern Mocambique. *Lammergeyer* **3** 9–39.

TÓMASSON T (1983) The biology and management consideration of abundant large cyprinids in Lake le Roux, Orange River, South Africa. PhD Thesis, Rhodes University, South Africa. 218 pp.

TÓMASSON T, CAMBRAY JA, ECCLES DH, JACKSON PBN and WHITE PN (1983) Fisheries of Lake le Roux. In: ALLANSON BR and JACKSON PBN (eds.) *Limnology and Fisheries Potential of Lake le Roux*. South African National Scientific Programmes Report No. 77. pp 153–160.

TÓMASSON T, BRUTON MN and HAMMAN KC (1985) The demography and management of large Cyprinids in a reservoir on the Orange River, South Africa. *Fisheries Research* **3** 279–308.

TOWNSEND PETERSON A, SOBERON J, PEARSON RG, ANDERSON RP, MARTINEZ-MEYER E, NAKAMURA M and ARAUJO MG (2011) *Ecological Niches and Geographic Distributions.* Princeton University Press, New Jersey. 336pp.

TYSON PD and PRESTON-WHYTE RA (2000) *The Weather and Climate of South Africa*. Oxford University Press, Oxford. 396pp.

VAN DEN BERG RA, GAIGHER IG and LENYAI SK (1975) The use of small farm dams in the Transkei and Ciskei for the production of table-fish using Aischgrund carp. *Limnological Society of Southern Africa* **1** 11–15.

VAN DEN BOSSCHE JP and BERNACSEK GM (1990) Source book for the inland fishery resources of Africa. *CIFA Technical Paper* No. 18.1. 411 pp.

VAN DER KNAAP M (1994) Status of fish stocks and fisheries of thirteen medium-sized African reservoirs. *CIFA Technical Paper* No 26, 107 pp.

VAN DER WAAL BCW (1978a) Status of fisheries of black states of South Africa. Collected Papers from the Symposium on Fisheries and Rural Development. 20–21 November 1978, Grahamstown, South Africa. pp 171–179.

VAN DER WAAL BCW (1978b) Suggestions towards a fisheries development policy for the black states of South Africa. Collected Papers from the Symposium on Fisheries and Rural Development. 20–21 November 1978, Grahamstown, South Africa. pp 165–170.

VAN DER WAAL BCW (2000) Fish as a resource in a rural river catchment in the Northern Province, South Africa. *African Journal of Aquatic Science* **25** 56–70.

VAN RENSBURG BJ, WEYL OLF, DAVIES SJ, VAN WILGEN LJ, PEACOCK DS, SPEAR D and CHIMIMBA CT (2011) Invasive vertebrates of South Africa. In: PIMENTEL, D. (ed.) *Biological Invasions: Economic and Environmental Costs of Alien Plant, Animal, and Microbe Species.* 2nd Edition., CRC Press, Boca Raton, Florida. pp 326–378.

VENABLES WN and DICHMONT CM (2004) GLMs, GAMs, and GLMMs: an overview of theory for applications in fisheries research. *Fisheries Research* **70** 319–337.

WALMSLEY RD and PIKE T (1989) Current legislation and conservation policy on invasive aquatic animals in South Africa and adjacent states. South Africa Foundation for Research Development Ecosystems Programmes Occasional Report Series. pp 57–67.

WASSERMANN RG, STRYDOM N and WEYL OLF (2011) Diet of largemouth bass, *Micropterus salmoides* (Centrarchidae), an invasive alien in the lower reaches of an Eastern Cape river, South Africa. *Afr. Zool.* **46(2)** 378–386.

WEBB BW, FOSTER IDL, GURNELL AM (1995) Hydrology, water quality and sediment behaviour. In: WEBB BW, FOSTERE, IDL and GURNELL AM (eds.) *Sediment and Water Quality in River Catchments*. Wiley, UK. pp 2–15.

WEBER MJ and BROWN ML (2011) Relationships among invasive common carp, native fishes and physicochemical characteristics in upper Midwest (USA) lakes. *Ecology of Freshwater Fish* **20**(2) 270–278.

WEIR JC (1972) Diversity and abundance of aquatic insects reduced by introduction of the catfish *Clarias gariepinus* to pools in Central Africa. *Biological Conservation* **4** 169–175.

WELCOMME RL (2001) *Inland Fisheries: Ecology and Management*. Blackwell Science Ltd. Oxford, UK. 370pp.

WEYL OLF, POTTS WM, ROUHANI Q and BRITZ PJ (2007) The need for an inland fisheries policy in South Africa: a case study on the Northwest Province. *Water SA* **33** 497–504.

WEYL OLF, BOOTH AJ, WINKER H, TRAAS GRL, MCCAFFERTY JR, PEEL RA and WARTENBERG R (2010) Assessment of the fishery potential for alien species on Darlington Dam. Sundays River Freshwater Fish Research Project, Report No. 5. pp 1–59.

WEYL OLF, RIBBINK AJ and TWEDDLE D (2010) Lake Malawi: fishes, fisheries, biodiversity, health and habitat'. *Aquatic Ecosystem Health & Management* **13**(3) 241–254. DOI: 10.1080/14634988.2010.504695.

WEYL PSR, DEMOOR FC, HILL MP and WEYL OLF (2010) The effect of largemouth bass *Micropterus salmoides* on aquatic macroinvertebrate communities in the Wit River, Eastern Cape, South Africa. *African Journal of Aquatic Science* **35** (4) 273–282.

WHITEHEAD DRC (1978) Practical aspects and economics of exploiting natural fisheries in large impoundments. Collected Papers from the Symposium on Fisheries and Rural Development. 20–21 November 1978, Grahamstown, South Africa. pp 155–163.

WILDE GR, STRICKLAND DW, OSTRAND KG and MUONEKE MI (1998) Characteristics of Texas black bass fishing tournaments. *North American Journal of Fisheries Management* **18**: 972–977.

WINKER H (2007) What can be learnt from angling competitions in large South African dams. Rhodes University Department of Ichthyology and Fisheries Science, Research Report Series 19, p 14.

WINKER H (2010) Post-impoundment population dynamics of non-native common carp *Cyprinus carpio* in relation to two large native cyprinids in Lake Gariep, South Africa. PhD Thesis, Rhodes University, South Africa.

WINKER H, WEYL OLF, BOOTH AJ and ELLENDER BR (2011) Life history and population dynamics of invasive common carp, *Cyprinus carpio*, within a large turbid African impoundment. *Marine and Freshwater Research* **62**(11) 1270–1280.

WOLOS A, TEODOROWICZ M and GRABOWSKA K (1992) Effect of ground-baiting on anglers‟ catches and nutrient budget of water bodies as exemplified by Polish lakes. *Aquaculture Research* **23**(4) 499–509.

ZAMBRANO L, MARTINEZ-MEYER E, MENEZES N and TOWNSHEND PETERSON A (2006) Invasive potential of common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*) in American freshwater systems. *Canadian Journal of Fisheries and Aquatic Sciences* **63** 1903–1910.

ZUUR AF, IENO EN and SMITH GM (2007) *Analysing Ecological Data.* Springer, London. 672 pp.

Appendices

Appendix I

Table AI.1 List of 176 dams that are considered important by two major recreational angling organisations the South African Sport Anglers and Casting Confederation (SASACC) and the South African Bass Anglers Association (SABAA).

Importance is ranked from 1 (highest, with national and international fishing tournaments) to 5 (low importance to organised angling but used by recreational fishers). This list is by no means complete and many other dams are used informally by recreational anglers. It does however provide a starting point towards planning fisheries development activities.

Province	Impoundment Name	River	Closest Town	SASACC	SABAA	Lat	Long	Max Capacity (m^3)
Eastern Cape	Binfield	Tyume	Alice	5	3	26.913	-32.692	36
Eastern Cape	Brakkeduine	Klipdrif	Humansdorp	5	3			
Eastern Cape	Darlington	Sundays	Jansenville	1	5	25.148	-33.152	187
Eastern Cape	De Mistkraal	Little Fish	Somerset East	5	5	0	0	2
Eastern Cape	Grassridge	Groot Brak	Cradock – Middelburg	3	5	25.46	-31.748	46
Eastern Cape	Groendal	Swartkops	Uitenhage	5	3	25.26	-33.689	11
Eastern Cape	Gubu	Gubu	Stutterheim	5	5	27.277	-32.61	8
Eastern Cape	Howisons Poort		Grahamstown	5	3	26.484	-33.386	-
Eastern Cape	Impofu	Krom	Humansdorp	4	1	24.67	-34.08	106
Eastern Cape	Indwe	Doorn	Indwe	5	5	27.333	-31.498	17
Eastern Cape	Jameson	New Years	Grahamstown	5	3	26.44	-33.318	-
Eastern Cape	Kat River	Kat	Seymour	5	5	26.777	-32.575	24
Eastern Cape	Kommandodrift	Tarka	Cradock/Tarkastad	4	5	26.034	-32.086	58
Eastern Cape	Kouga	Kouga	Willowmore /Steytlerville	5	3	24.591	-33.738	128
Eastern Cape	Krom River	Krom	Humansdorp	5	3	24.486	-33.994	35
Eastern Cape	Lake Arthur	Tarka	Cradock	5	5	25.821	-32.211	-
Eastern Cape	Loerie	Loeriespruit	Loerie	5	1	25.041	-33.864	3
Eastern Cape	Milner		Grahamstown	5	3	26.43	-33.312	-
Eastern Cape	Moffet	Bulk	Uitenhage	0	0	0	0	-
Eastern Cape	Nahoon	Nahoon	East London	5	3	27.801	-32.906	19
Eastern Cape	New Years	New Years	Alicedale	2	5	26.115	-33.294	-

Eastern Cape	Rooikrantz	Buffalo	King Williams Town	5	5	27.322	-32.75	4
Eastern Cape	Sand River	Sand	Uitenhage	5	1	0	0	-
Eastern Cape	Settlers	Kariega	Grahamstown	5	3	26.508	-33.414	-
Eastern Cape	Slagboom	Wit	Addo	3	5	25.668	-33.369	-
Eastern Cape	Umtata	Mtata	Umtata	5	5	28.734	-31.541	248
Eastern Cape	Van Stadens - Lower	Van Stadens	Port Elizabeth	0	0	25.21	-33.882	-
Eastern Cape	Van Stadens - Upper	Van Stadens	Port Elizabeth	0	0	25.224	-33.852	-
Eastern Cape	Vanryneveldspas	Sundays	Graaff-Reinet	1	5	24.521	-32.205	46
Eastern Cape	Wriggleswade	Kubisi	Stutterheim	2	1	27.564	-32.576	91
Eastern Cape	Xonxa	White Kei	Queenstown	5	5	27.139	-31.823	115
Free State	Allemanskraal	Sand	Winburg	1	5	27.208	-28.297	174
Free State	Armenia	Leeu	Thaba Nchu	4	5	27.13	-29.348	13
Free State	Erfenis	Groot-Vet	Winburg	2	5	26.836	-28.551	207
Free State	Groothoek	Kgabanyane	Thaba Nchu	4	5	26.866	-29.297	11
Free State	Kalkfontein	Riet	Koffiefontein	2	5	25.258	-29.524	325
Free State	Koppies	Renoster	Koppies	1	5	27.694	-27.229	42
Free State	Krugersdrift	Modder	Bloemfontein	3	5	26.003	-28.869	73
Free State	Rustfontein	Modder	Bloemfontein	4	5	26.629	-29.297	71
Free State	Saulspoort	Liebenbergsvlei	Bethlehem	3	5	28.369	-28.221	15
Free State	Sterkfontein	Nuwejaarspruit	Harrismith	3	3	29.016	-28.427	2616
Free State	Tierpoort	Tierpoort	Bloemfontein	4	5	26.15	-29.411	34
Free State	Welbedacht	Caledon	Wepener	3	5	26.872	-29.881	10

FS and EC	Gariep	Orange	Colesberg/Bethulie	1	5	25.706	-30.691	5340
FS and GP	Vaal Barrage	Vaal	Sasolburg	1	1	27.795	-26.749	0
FS and GP and MP	Vaal	Vaal	Deneysville	1	3	28.138	-26.896	2603
FS and NC	Vanderkloof	Orange	Petrusville	4	5	24.879	-30.152	3171
FS and NW	Bloemhof	Vaal	Bloemhof	1	5	25.651	-27.672	1240
Gauteng	Bon Accord	Apies	Pretoria	3	3	28.19	-25.628	4
Gauteng	Bronkhorstspruit	Bronkhorstspruit	Bronkhorstspruit	2	1	28.691	-25.898	57
Gauteng	Rietvlei	Hennops	Pretoria	2	3	28.275	-25.879	12
Gauteng	Roodeplaat	Pretoria		2	3	28.374	-25.624	41
KwaZulu-Natal	Albert Falls	Mgeni	Pietermaritzburg	2	1	30.405	-29.442	288
KwaZulu-Natal	Craigie Burn	Mnyamvubu	Mooi	4	1	30.294	-29.168	22
KwaZulu-Natal	Driel Barrage	Tugela	Bergville	5	5	29.298	-28.772	8
KwaZulu-Natal	Goedertrou	Mhlatuze	Eshowe	4	1	31.438	-28.768	301
KwaZulu-Natal	Hazelmere	Mdloti	Durban	5	5	31.034	-29.582	17
KwaZulu-Natal	Hluhluwe	Hluhluwe	Hluluwe	3	5	32.158	-28.11	25
KwaZulu-Natal	Inanda	Mgeni	Durban	5	1	30.87	-29.704	241
KwaZulu-Natal	Kilburn	Tugela	Bergville	5	5	29.098	-28.59	0
KwaZulu-Natal	Klipfontein	White Mfolozi	Vryheid	1	3	30.809	-27.822	18
KwaZulu-Natal	Midmar	Mgeni	Howick	3	1	30.194	-29.508	235
KwaZulu-Natal	Nagle	Mgeni	Pietermaritzburg	4	3	30.643	-29.594	23
KwaZulu-Natal	Ntshingwayo	Ngagane	Newcastle	2	5	29.913	-27.994	194
KwaZulu-Natal	Shongweni	Shongweni	Durban	3	5	30.721	-29.856	-

KwaZulu-Natal	Spioenkop	Tugela	Bergville	4	5	29.494	-28.69	270
KwaZulu-Natal	Wagendrift	Boesmans	Estcourt	2	3	29.833	-29.054	55
KwaZulu-Natal	Woodstock	Tugela	Bergville	4	5	29.208	-28.722	373
KwaZulu-Natal	Zaaihoek	Slang	Volksrust	3	5	30.085	-27.427	184
KZN and Swaziland	Pongolapoort	Phongolo	Pongola	4	5	31.95	-27.37	2267
Limpopo	Albasini	Luvuvhu	Louis Trichardt	3	5	30.094	-23.102	28
Limpopo	Dap Naude	Broederstroom	Tzaneen	5	5	0	0	2
Limpopo	Doorndraai	Sterk	Potgietersrus	1	3	28.756	-24.299	43
Limpopo	Ebenezer	Great Letaba	Tzaneen	2	1	29.983	-23.935	69
Limpopo	Flag Boshielo	Olifants	Marble Hall	1	5	29.44	-24.827	185
Limpopo	Glen Alpine	Mogalakwena	Rebone	2	5	28.683	-23.211	18
Limpopo	Klaserie	Klaserie	Klaserie	1	5	31.063	-24.53	5
Limpopo	Middle Letaba	Middle Letaba	Giyani	3	3	30.403	-23.278	171
Limpopo	Mokolo	Mokolo	Ellisras	5	1	27.769	-23.99	145
Limpopo	Mutshedzi	Mutshedzi	Louis Trichardt	4	5	30.174	-22.947	2
Limpopo	Nandoni	Levhuvhu	Thoyoyandou	4	3	0	0	150
Limpopo	Nkumpi1	Nkumpi	Polokwane	5	5	29.314	-24.284	-
Limpopo	Nkumpi2	Nkumpi	Polokwane	4	5	29.315	-24.294	-
Limpopo	Nsami	Nsama	Giyani	4	5	30.764	-23.252	21
Limpopo	Nwanedi	Luphephe	Louis Trichardt	4	5	30.401	-22.635	14
Limpopo	Nwanedzi	Nwanedzi	Louis Trichardt	4	5	0	0	5
Limpopo	Nzhelele	Nzhelele	Louis Trichardt	3	5	30.1	-22.739	51

Limpopo	Rust de Winter	Elands	Rust de Winter	3	1	28.492	-25.229	26
Limpopo	Tzaneen	Great Letaba	Tzaneen	1	1	30.15	-23.788	156
Limpopo	Vondo	Mutshindudi	Louis Trichardt	4	5	30.345	-22.948	30
Limpopo	Warmbad	Buffels	Warmbad	2	3	28.241	-24.847	1
Mpumalanga	Blyderivierspoort	Blyde	Hoedspruit	5	5	30.802	-24.544	54
Mpumalanga	Buffelskloof	Waterval	Lydenburg	5	5	30.264	-24.955	5
Mpumalanga	Da Gama	White Waters	White River	2	3	31.017	-25.15	13
Mpumalanga	Doringpoort	Olifants	Witbank	3	5	29.302	-25.865	-
Mpumalanga	Driekoppies	Lomati	Malelane	3	1	31.532	-25.716	250
Mpumalanga	Grootdraai	Vaal	Standerton	1	3	29.332	-26.93	349
Mpumalanga	Heyshope	Assegaai	Piet Retief	3	3	30.502	-27.025	451
Mpumalanga	Inyaka	Marite	Hazyview	5	1	31.085	-24.884	123
Mpumalanga	Jericho	Mpama	Amsterdam	3	3	30.47	-26.649	59
Mpumalanga	Klipkopjes	White	White River	4	1	31.003	-25.207	3
Mpumalanga	Kwena	Crocodile	Lydenburg	3	3	30.368	-25.368	158
Mpumalanga	Leeupan532IR	Waterval catchment	Secunda	3	5	28.995	-26.566	-
Mpumalanga	Longmere (Witrivier)	White	White River	3	3	31.001	-25.277	3
Mpumalanga	Loskop	Olifants	Middelburg	1	1	29.322	-25.429	361
Mpumalanga	Middelburg	Little Olifants	Middelburg	3	3	29.554	-25.78	48
Mpumalanga	Morgenstond	Ngwempisi	Amsterdam	2	3	30.503	-26.734	100
Mpumalanga	Ngodwana	Ngodwana	Nelspruit	5	1	0	0	10
Mpumalanga	Nooitgedacht	Komati	Carolina	3	1	30.07	-25.965	78

Mpumalanga	Ohrigstad	Ohrigstad	Ohrigstad	5	3	30.633	-24.939	13
Mpumalanga	Primkop	White	White River	4	3	31.071	-25.384	1
Mpumalanga	Rhenosterkop	Elands	Marble Hall	5	5	28.898	-25.095	204
Mpumalanga	Shiyalongubo	Ugutugulo	Barberton	5	1	31.266	-25.755	1
Mpumalanga	Trichardsfontein	Trighardspruit	Trighardt	1	5	29.252	-26.5	-
Mpumalanga	Vygeboom	Komati	Badplaas	4	1	30.622	-25.869	77
Mpumalanga	Westoe	Usutu	Amsterdam	3	5	30.611	-26.495	59
Mpumalanga	Witbank	Olifants	Witbank	2	1	29.31	-25.903	104
Mpumalanga	Witklip	Sand	White River	4	3	30.894	-25.225	12
Northern Cape	Boegoeberg	Orange	Groblershoop	4	5	22.211	-29.063	19
Northern Cape	Douglas	Vaal	Douglas	5	5	23.87	-29.035	16
North-West	Barberspan	Baberspan	Delareyville	2	5	25.588	-26.584	-
North-West	Boskop	Mooi		3	3	27.12	-26.551	21
North-West	Bospoort	Hex	Rustenburg	1	3	27.331	-25.573	15
North-West	Buffelspoort	Sterkstroom	Rustenburg	1	1	27.489	-25.792	10
North-West	Disaneng	Molopo	Mafikeng	2	5	25.343	-25.841	14
North-West	Elandskuil			3	5	26.779	-26.345	-
North-West	Hartbeespoort	Crocodile	Pretoria	2	1	27.857	-25.747	186
North-West	Klerksdorp	Skoonspruit	Klerksdorp	3	5	26.605	-26.802	-
North-West	Klerkskraal	Mooi		3	3	27.153	-26.241	7
North-West	Klipdrif	Loop		1	5	27.314	-26.607	13
North-West	Klipvoor	Pienaars	Borakalalo Reserve	3	5	27.823	-25.147	42

North-West	Kromellenboog	Klein Marico	Zeerust	3	5	26.342	-25.453	9
North-West	Lindleys Poort	Elands	Swartruggens	3	5	26.689	-25.512	14
North-West	Little Marico Poort	Klein Marico	Zeerust	3	5	26.14	-25.526	7
North-West	Madikwe	Tholwane	Zeerust	3	5	0	0	-
North-West	Marico-Bosveld	Groot Marico	Zeerust	2	3	26.39	-25.493	27
North-West	Modimola	Molopo	Mafikeng	3	5	25.515	-25.857	20
North-West	Molatedi	Groot Marico	Zeerust	3	5	0	0	200
North-West	Ngotwane	Ngotwane	Zeerust	5	5	25.809	-25.212	19
North-West	Olifantsnek	Hex	Rustenburg	1	5	27.251	-25.795	13
North-West	Potchefstroom	Mooi		3	5	27.097	-26.667	2
North-West	Rietspruit			1	5	26.81	-26.408	-
North-West	Roodekopjes	Crocodile	Brits	2	1	27.586	-25.41	102
North-West	Sehujwane	Sehujane (Sandsloot)	Zeerust	3	5	25.95	-25.311	4
North-West	Vaalkop	Elands	Rustenburg	2	3	27.469	-25.312	56
NW and NC	Spitskop	Harts	Warrenton	1	3	24.547	-28.092	57
Swaziland	Maguga	Komati	Piggs Peak, Swaziland	5	1	31.253	-26.072	333
Western Cape	Berg River	Berg	Franschoek	5	3	19.061	-33.924	130
Western Cape	Brandvlei	Brandvlei	Worcester	2	1	19.431	-33.712	284
Western Cape	Buffeljags	Buffeljags	Swellendam	5	3	20.54	-34.01	4
Western Cape	Bulshoek	Olifants	Clanwilliam	4	1	18.811	-32.026	4
Western Cape	Calitzdorp	Nels	Calitzdorp	2	5	21.706	-33.488	4
Western Cape	Clanwilliam	Olifants	Clanwilliam	5	1	18.919	-32.24	121

Western Cape	Eikenhof	Palmiet	Grabouw	5	3	19.032	-34.122	28
Western Cape	Elandskloof	Elands	Villiersdorp	5	5	19.286	-33.943	11
Western Cape	Ernest Robertson	Groot Brak	Groot Brak	4	5	22.173	-33.901	-
Western Cape	Floriskraal	Buffels	Laingsburg	4	5	20.985	-33.274	50
Western Cape	Gamkapoort	Gamka	Calitzdorp	4	5	21.638	-33.299	37
Western Cape	Garden Route	Swart	George	4	3	22.513	-33.962	9
Western Cape	Groenvlei	Closed system	Sedgefield	5	1	22.857	-34.029	-
Western Cape	Hartebeeskuil	Hartenbos	Mosselbay	2	3	21.999	-34.095	7
Western Cape	Kammanassie	Kammanassie	Oudtshoorn	4	5	22.412	-33.649	34
Western Cape	Keerom	Nuy	Worcester	5	5	19.705	-33.582	9
Western Cape	Koos Raubenheimer	Klein Leroux	Oudtshoorn	5	3	22.284	-33.406	-
Western Cape	Korinte-Vet	Korinte	Riversdale	5	3	21.166	-34.003	8
Western Cape	Kwaggaskloof	Doorn	Worcester	2	1	19.434	-33.771	173
Western Cape	Lakenvallei	Sanddrifskloof	Ceres	5	5	19.58	-33.361	10
Western Cape	Misverstand	Berg	Piketberg	2	1	18.791	-33.029	6
Western Cape	Paarl	Berg	Paarl	2	5	0	0	-
Western Cape	Poortjieskloof	Groot	Montague	4	5	20.372	-33.867	9
Western Cape	Roode Els	Sanddrifskloof	Sandhills	5	5	19.569	-33.435	7
Western Cape	Stompdrift	Olifants	De Rust	2	3	22.629	-33.513	49
Western Cape	Theewaterskloof	Riviersonderend	Villiersdorp	2	1	19.203	-34.025	480
Western Cape	Voelvlei	Voelvlei	Tulbagh	2	1	19.041	-33.365	158
Western Cape	Wemmershoek	Wemmershoek	Franschoek	5	5	19.096	-33.827	58

APPENDIX II

Table AII.1 Estimated coefficients and standard errors for the model components used to standardise *PC* using fisheries-dependent (Eq. 1) and environmental variables (Eq. 2, Eq. 3). Significance levels are marked as „*", p<0.05, „**", p<0.01, „***", p<0.001.

	Eq. 1				*Eq. 2*				*Eq. 3*		
Model	**Coeff**	**Std. Err**	**Signif**	*Model*	**Coeff**	**Std. Err**	**Signif**	*Model*	**Coeff**	**Std. Err**	**Signif**
Intercept	0.952	0.716	**	Intercept	0.952	0.716	**	Intercept	0.952	0.716	**
DL (7)	2.022	0.615	***	DL (7)	2.022	0.615	***	DL (7)	2.022	0.615	***
DL (8)	0.574	0.125	***	DL (8)	0.574	0.125	***	DL (8)	0.574	0.125	***
DL (9)	1.13	0.121	***	DL (9)	1.13	0.121	***	DL (9)	1.13	0.121	***
DL (12)	0.425	0.752		DL (12)	0.425	0.752		DL (12)	0.425	0.752	
DL (14)	-0.035	0.744		DL (14)	-0.035	0.744		DL (14)	-0.035	0.744	
DL (16)	1.612	0.709	*	DL (16)	1.612	0.709	***	DL (16)	1.612	0.709	*
DL (18)	2.133	0.822	**	DL (18)	2.133	0.822	***	DL (18)	2.133	0.822	**
DL (20)	2.272	0.848	**	DL (20)	2.272	0.848	***	DL (20)	2.272	0.848	**
DL (22)	2.059	0.779	**	DL (22)	2.059	0.779	***	DL (22)	2.059	0.779	**
Winter	-0.384	0.087	***	Alt	-0.0016	0.0015	**	s(Cond).1	0.304	0.059	***
				Temp	0.135	0.0033	***	s(Cond).2	-0.266	0.064	
				Cond	-0.0017	0.0001	***	s(Cond).3	-0.162	0.209	
				Surface	0.0015	0.0007	***	te(Surface,Capacity).1	-6.933	2.68	
				Surface:Capacity	-3.70E-09	0.0000005	***	te(Surface,Capacity).2	-1089	2.806	
								te(Surface,Capacity).3	-11.4	4.037	
								te(Surface,Capacity).4	2.496	0.611	***
								te(Surface,Capacity).5	5.08	0.717	***
								te(Surface,Capacity).6	-5.3	1.409	
								te(Surface,Capacity).7	-5.324	1.622	
								te(Surface,Capacity).8	-3.41	1.574	
								te(Surface,Capacity).9	-1.081	14.44	
								te(Surface,Capacity).10	7.021	0.262	.
								te(Surface,Capacity).11	1.532	0.698	**
								te(Surface,Capacity).12	6.797	0.194	*
								te(Surface,Capacity).13	5.059	9.87	
								te(Surface,Capacity).14	2.587	1.14	*
								te(Surface,Capacity).15	-3.038	5.403	

Table AII.2 Estimated coefficients and standard errors for the model components used to standardise *PLIM* using fisheries-dependent (Eq. 4) and environmental variables (Eq. 5, Eq. 6). Significance levels area marked as „*", p<0.05, „**", p<0.01, „***", p<0.001.

	Eq. 4				*Eq. 5*				*Eq. 6*		
Model	**Coeff**	**Std. Err**	**Signif**	*Model*	**Coeff**	**Std. Err**	**Signif**	*Model*	**Coeff**	**Std. Err**	**Signif**
Intercept	-1.469	0.265	***	Intercept	-47.95	4.567	***	Intercept	-0.181	0.238	***
DL (7)	2.703	0.472	***	DL (7)	3.95	0.446	***	DL (7)	2.781	0.468	***
DL (8)	0.892	0.25	***	DL (8)	1.767	0.222	***	DL (8)	0.95	0.246	***
DL (9)	0.873	0.262	***	DL (9)	2.036	0.216	***	DL (9)	0.945	0.257	***
DL (16)	1.413	0.283	***	DL (16)	2.221	0.242	***	DL (16)	1.521	0.272	***
DL (18)	3.315	0.329	***	DL (18)	2.909	0.254	***	DL (18)	3.248	0.3	***
Winter	-0.415	0.117	***	Winter	-0.402	0.108	***	s(Alt).1	-2.14	0.289	***
				Temp	8	0.822	***	s(Alt).2	1.788	0.185	***
				pH	8,425	1.467	***	s(Alt).3	-2.452	0.246	***
				Surface	1.011	0.249	***	s(Cond).1	0.389	0.087	***
				Surface:Capacity	-0.03	0.013	*	s(Cond).2	-1.663	0.236	***
								s(Cond).3	-2.702	0.305	***
								s(Surface).1	5.627	0.604	***
								s(Surface).2	2.104	0.226	***
								s(Surface).3	4.946	0.531	***
								s(Capacity).1	-3.918	0.438	***
								s(Capacity).2	-2.374	0.265	***
								s(Capacity).3	-4.972	0.555	***
								te(Surface,Capacity).1	3.68	1.716	*
								te(Surface,Capacity).2	7.224	3.906	
								te(Surface,Capacity).3	-2.591	0.635	***
								te(Surface,Capacity).4	-0.004	0.206	
								te(Surface,Capacity).5	1.836	0.27	***
								te(Surface,Capacity).6	-2.083	0.937	*
								te(Surface,Capacity).7	0.781	0.314	*
								te(Surface,Capacity).8	-0.627	0.169	***
								te(Surface,Capacity).9	0.579	1.465	

Table AII.3 Estimated coefficients and standard errors for the model components used to standardise *CPUE* using fisheries-dependent (Eq. 7) and environmental variables (Eq. 8, Eq. 9). Significance levels area marked as „*", p<0.05, „**", p<0.01, „***", p<0.001.

Model	**Coeff**	**Std. Err**	**Signif**	*Model*	**Coeff**	**Std. Err**	**Signif**	*Model*	**Coeff**	**Std. Err**	**Signif**
Intercept	-0.745	0.089	***	Intercept	0.741	0.215	***	Intercept	-0.567	0.059	***
DL (7)	0.193	0.112		DL (7)	0.378	0.112	***	DL (7)	0.189	0.123	
DL (8)	-0.33	0.056	***	DL (8)	-0.255	0.05	***	DL (8)	-0.446	0.061	***
DL (9)	-0.271	0.054	***	DL (9)	-0.262	0.055	***	DL (9)	-0.259	0.059	***
DL (16)	-0.843	0.077	***	DL (16)	-0.539	0.069	***	DL (16)	-0.925	0.064	***
Winter	0.075	0.027	**	Winter	0.244	0.026	***	s(Alt).1	0.037	0.209	
Non-money	0.105	0.062	.	Rain	-0.336	0.02	***	s(Alt).2	-0.215	0.086	*
				Cond	-0.108	0.014	***	s(Alt).3	-0.435	0.068	***
				Surface	0.134	0.016	***	s(Cond).1	0.304	0.056	***
								s(Cond).2	-0.266	0.047	***
								s(Cond).3	-0.162	0.133	
								s(Surface).1	-8.97	2.517	***
								s(Surface).2	2.481	1.096	*
								s(Surface).3	0.66	0.604	
								s(Capacity).1	6.362	1.521	***
								s(Capacity).2	0.794	0.531	
								s(Capacity).3	-0.884	0.621	
								te(Surface,Capacity).1	-10.96	2.676	***
								te(Surface,Capacity).2	-10.89	2.806	***
								te(Surface,Capacity).3	-11.4	4.036	**
								te(Surface,Capacity).4	2.496	0.612	***
								te(Surface,Capacity).5	5.08	0.717	***
								te(Surface,Capacity).6	-5.3	1.409	***
								te(Surface,Capacity).7	-5.352	1.622	***
								te(Surface,Capacity).8	-3.408	1.574	*
								te(Surface,Capacity).9	-1.081	14.44	

APPENDIX III

Table AIII.1 Estimated coefficients and standard errors for the model components used to standardise *CPUE* using fisheries-dependent (Eq. 1) and environmental variables (Eq. 2, Eq. 3). Significance levels are marked as „*“, $p<0.05$, „**“, $p<0.01$, „***“, $p<0.001$.

Model Eq.1	**Coeff**	**Std. Err**	**Signif**	*Model Eq.2*	**Coeff**	**Std. Err**	**Signif**	*Model Eq.3*	**Coeff**	**Std. Err**	**Signif**
Intercept	-0.916	0.241	***	Intercept	-1.527	0.078	***	Intercept	-0.421	0.078	**
Type(Div)	0.627	0.23	**	Type(Div)	1.277	0.138	***	Type(Div)	1.341	0.147	***
Anglers	-0.004	0.0009	***	Anglers	-0.004	0.0008	***	Anglers	0.574	0.125	***
				Rain	-0.002	0.0003	***	s(Rain).1	-0.183	0.195	
				Cond	-0.0007	0.00006	***	s(Rain).2	-0.104	0.146	
				logSurface	0.288	0.021	***	s(Rain).3	-0.779	0.303	*
								s(logCond).1	-0.042	0.011	***
								s(logCond).2	-0.432	0.107	***
								s(logCond).3	-1.005	0.25	***
								s(logSurface).1	0.084	0.012	***
								s(logSurface).2	0.463	0.058	***
								s(logSurface).3	0.929	0.115	***

APPENDIX IV

Table AIV.1 Species composition (%) from gillnet surveys conducted on 26 impoundments in South Africa (and Lesotho).

	DAM									
Species	**Binfield**	**Bospoort**	**Cata**	**Darlington**	**Dimbaza**	**Gariep**	**Glen Melville**	**Grassridge**	**Koster**	**Laing**
A. mossambicus	-	-	-	-	-	-	-	-	-	-
A. Sclateri	-	-	-	-	-	<0.05	-	-	-	-
B. mattozi	-	-	-	-	-	-	-	-	-	-
B. spp	-	-	-	-	-	-	-	-	0.1	-
C. carpio	3.1	16.8	-	2.5	-	4.7	-	<0.1	2.6	-
C. flavensis	-	-	-	-	-	-	-	-	-	-
C. gariepinus	-	46.9	-	23.2	-	6.2	77	0.3	75.4	-
L. aeneus	-	-	-	3.4	-	39.2	2	-	-	-
L. capensis	-	-	-	4.0	-	40.9	-	-	-	-
L. kimberleyensis	-	-	-	-	-	7.7	-	14	-	-
L. macrochir	3.2	-	-	-	-	-	-	75	-	-
L. marequensis	-	-	-	-	-	-	-	-	8.2	-
L. molybdinus	-	-	-	-	-	-	-	-	-	-
L. umbratus	-	-	-	61.6	100	1.3	21	-	-	100
M. capensis	8.8	-	-	-	-	-	-	-	-	-
M. cephalus	77.1	-	-	1.4	-	-	-	11	-	-
M. lepidotus	-	-	-	-	-	-	-	-	-	-
M. salmoides	7.8	-	-	-	-	-	-	-	-	-
O. mossambicus	-	36.1	-	2.4	-	-	-	-	13.7	-
O. mykiss	-	-	-	-	-	<0.05	-	-	-	-
S. intermedius	-	-	-	-	-	-	-	-	-	-
S. trutta	-	-	100	-	-	-	-	-	-	-
T. sparrmanii	-	0.2	-	-	-	-	-	-	-	-

Table AIV.1 (cont.): Species composition (%) from gillnet surveys conducted on 26 impoundments in South Africa (and Lesotho).

	DAM								
Species	**Lindleyspoort**	**Lotlamoreng**	**Madikwe**	**Mangazana**	**Molatedi**	**Mohale**	**Ndlambe**	**Ngotwane**	**Pikoli**
A. mossambicus	-	-	-	-	-	-	-	-	-
A. Sclateri	-	-	-	-	-	-	-	-	-
B. mattozi	19.6	-	7.5	-	19.3	-	-	-	-
B. spp	-	-	-	-	-	-	-	-	-
C. carpio	1.3	57.7	-	-	<0.05	-	-	-	0.6
C. flavensis	-	-	-	-	-	-	-	-	-
C. gariepinus	71.6	3.9	89.6	-	56.8	-	-	85.8	-
L. aeneus	-	-	-	-	-	99.7	-	-	-
L. capensis	-	-	-	-	-	0.3	-	-	-
L. kimberleyensis	-	-	-	-	-	-	-	-	-
L. macrochir	-	-	-	-	-	-	-	-	-
L. marequensis	1.4	-	-	-	0.1	-	-	-	-
L. molybdinus	0.1	-	1.1	-	3.4	-	-	14.2	-
L. umbratus	-	-	-	45.5	-	-	97	-	98.7
M. capensis	-	-	-	-	-	-	-	-	-
M. cephalus	-	-	-	-	-	-	-	-	-
M. lepidotus	1.7	-	-	-	-	-	-	-	-
M. salmoides	-	-	-	8.5	-	-	-	-	0.6
O. mossambicus	4.4	37.8	1.7	45.6	20.3	-	3	-	-
O. mykiss	-	-	-	-	-	-	-	-	-
S. intermedius	-	-	-	-	-	-	-	-	-
S. trutta	-	-	-	-	-	-	-	-	-
T. sparrmanii	-	0.6	<0.05	0.5	-	-	-	-	-

Table AIV.1 (cont.): Species composition (%) from gillnet surveys conducted on 26 impoundments in South Africa (and Lesotho).

	DAM						
Species	**Roodekopjes**	**Sandile**	**Taung**	**Umtata**	**Vaalkop**	**Wriggleswade**	**Xonxa**
A. mossambicus	-	-	-	-	-	0.7	-
A. Sclateri	-	-	-	-	-	-	-
B. mattozi	6.4	-	-	-	5.0	-	-
B. spp	-	-	-	-	-	-	-
C. carpio	2.1	-	1.5	100	-	13.6	8.2
C. flavensis	-	-	-	-	0.1	-	-
C. gariepinus	48.9	-	29.6	-	38.8	-	14.5
L. aeneus	-	-	42.8	-	-	67.6	77.3
L. capensis	-	-	5.2	-	-	-	-
L. kimberleyensis	-	-	19.1	-	-	-	-
L. macrochir	-	-	-	-	-	-	-
L. marequensis	3.5	-	-	-	1.2	-	-
L. molybdinus	0.5	-	-	-	4.5	-	-
L. umbratus	-	98.2	1.6	-	-	-	-
M. capensis	-	-	-	-	-	-	-
M. cephalus	-	-	-	-	-	-	-
M. lepidotus	-	-	-	-	-	-	-
M. salmoides	0.1	1.1	-	-	-	18.2	-
O. mossambicus	11.9	0.7	-	-	20.7	-	-
O. mykiss	-	-	-	-	-	-	-
S. intermedius	26.5	-	-	-	29.8	-	-
S. trutta	-	-	-	-	-	-	-
T. sparrmanii	-	-	0.2	-	-	-	-

APPENDIX V

Pooled baseline catch-per-unit effort (CPUE) estimates from all impoundments prior to standardisation using generalised linear models (GLMs) and generalised additive models (GAMs).

Table AV.1 Pooled catch-per-unit effort (CPUE ($kg.angler^{-1}.h^{-1}$)) estimates (with standard deviation (SD)) obtained from bass angling competition catch records for 27 impoundments.

Dam	***CPUE***	***SD* (±)**
Albert Falls	0.29	0.20
Binfield	0.10	0.19
Bivane	0.25	0.27
Bronkhorstspruit	0.21	0.15
Bulshoek	0.38	0.07
Clanwilliam	0.51	0.22
Driekoppies	0.46	0.33
Ebenezer	0.08	0.03
Elandsjacht	0.12	0.14
Goedertrouw	0.52	0.37
Hartbeespoort	0.15	0.19
Heyshope	0.23	0.24
Inanda	0.20	0.12
Injaka	0.14	0.17
Midmar	0.23	0.17
Misverstand	0.31	0.18
Mokolo	0.29	0.23
Nandoni	0.35	0.20
Quaggaskloof	0.38	0.20
Renosterkop	0.32	0.19
Rust de Winter	0.26	0.23
Theewaterskloof	0.33	0.19
Tzaneen	0.24	0.17
Vaal Barrage	0.18	0.19
Vaal Dam	0.18	0.18
Witbank	0.12	0.14
Wriggleswade	0.24	0.18

Table AV.2 Pooled catch-per-unit effort (CPUE ($kg.angler^{-1}.h^{-1}$)) estimates (with standard deviation (SD)) obtained from bank angling competition catch records for 15 impoundments. "-" indicates where estimates where unobtainable due to small sample sizes.

Dam	***CPUE***	***SD* (±)**
Alicedale	0.63	0.87
Allemanskraal	0.46	0.39
Bloemhof	2.23	1.23
Brandvlei	0.66	-
Bronkhorstspruit	0.56	0.14
Darlington	1.38	3.11
Gariep	1.82	1.38
Grootdraai	0.95	1.05
Jericho	0.52	-
Klipdrif	1.34	0.84
Northend	0.81	0.86
Rietspruit	0.76	0.06
Trichardsfontein	0.88	0.75
Vaal	0.41	0.42
Witbank	0.24	0.26

Table AV.3 Pooled catch-per-unit effort (*CPUE*), $CPUE_{CG}$ and $CPUE_{NC}$ estimates (kg.net^{-1}.night^{-1}) (with standard deviation (SD)) obtained from gillnet survey records for 28 impoundments. "-" indicates where estimates where unobtainable due to small sample sizes.

Dam	*CPUE*	*SD* (±)	$CPUE_{CG}$	*SD* (±)	$CPUE_{NC}$	*SD* (±)
Binfield	6.94	8.94				
Bospoort	4.12	2.94	4.14	2.43		
Cata	0.88	1.37				
Darlington	67.60	29.19			46.61	25.36
Dimbaza	33.72	29.81			33.72	29.81
Gariep	13.50	10.84	3.85	2.97	12.13	10.31
Glen Melville	5.82	9.61	11.19	13.70	1.49	1.02
Grassridge	7.13	2.70	0.12	-	7.10	2.71
Koster	8.22	11.13	7.75	11.83	1.26	0.68
Laing	5.26	5.91			5.89	5.95
Lindleyspoort	6.53	6.06	5.97	5.47	1.50	1.63
Lombard	14.96	9.86			14.96	9.86
Lotlamoreng	1.71	1.42	0.24	0.11	1.20	1.28
Madikwe	12.62	9.01	12.45	8.04	9.37	8.52
Mangazana	20.59	10.93			43.71	29.80
Mohale	43.71	29.80			3.65	2.41
Molatedi	14.39	9.63	10.22	7.74	2.61	3.72
Ndlambe	8.89	4.18			8.65	4.22
Ngotwane	14.86	10.36	13.38	10.57		
Pikoli	31.36	33.27			30.97	33.39
Roodekopjes	15.81	13.71	13.54	16.17	1.92	2.20
Sandile	4.43	3.32			4.35	3.32
Taung	16.52	8.71	8.14	10.17	11.95	7.08
Tyefu	17.83	-			17.83	-
Umtata	0.64	0.72				
Vaalkop	31.15	15.59	15.84	10.37	3.50	3.08
Wriggleswade	3.18	4.54			5.45	5.23
Xonxa	6.32	4.11	2.75	3.22	5.17	2.89