THE IMPACT OF ANGLING ON SMALLMOUTH AND LARGEMOUTH YELLOWFISH, *LABEOBARBUS AENEUS* AND *LABEOBARBUS KIMBERLEYENSIS*, IN LAKE GARIEP, SOUTH AFRICA

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Abstract

A large sportfishery that targets both smallmouth (*Labeobarbus aeneus*) and largemouth (*Labeobarbus kimberleyensis*) yellowfish exists in South Africa. Both species have high conservation priority, and no assessments documenting the effect of angling on *L. aeneus* and *L. kimberleyensis* have been undertaken. The overall aim of this study was to provide an assessment of the impact of angling on *L. aeneus* and *L. kimberleyensis*. The specific objectives of this study were to characterise the sectors utilising Lake Gariep, document catch, effort and total catch for the fishery as well as the locality specific biology of *L. aeneus* and *L. kimberleyensis*. The study was undertaken on Lake Gariep, South Africas largest impoundment, situated on the Orange River system in central South Africa.

Subsistence fishers were the dominant user group, constituting 60 % of the fishery, the remainder constituted recreational anglers. Angler catches were dominated by carp (*Cyprinus carpio*; 74 %), followed by mudfish *(Labeo capensis*; 13 %) and smallmouth yellowfish (8 %). Catches of largemouth yellowfish contributed < 0.5 % to the total catch. The relative abundance of species by weight differed by area (χ^2 test of independence: $\chi^2 = 182$, df = 4, $p \leq 0.05$). On any sampling day time fished was the best predictor for differences in probability of capture (PC) (Wald $X^2(1) = 7.169$, $p = 0.007$). The probability of capturing *L. aeneus* differed significantly between month (Wald $X^2(5) = 20.690$, $p = 0.000$) and region (Wald $X^2(3) = 46.755$, $p = 0.000$). The single best predictor of differences in log abundance and non-zero *CPUE* was region (Factorial ANOVA $p \leq 0.05$).

Mean *CPUE* ranged from 0.21 ± 0.06 kg. $man^{-1}.hr^{-1}$ to 0.82 ± 0.11 kg. $man^{-1}.hr^{-1}$ in the OV region and 0.42 ± 0.10 kg. $man^{-1}.hr^{-1}$ to 1.17 ± 0.24 kg. $man^{-1}.hr^{-1}$ in the GD region. Angler effort was higher in OV than in GD and ranged from 17 ± 3 anglers/day to 45 ± 9 anglers/day and 6 ± 1 anglers/day to 41 ± 8 anglers/day, respectively. Total catch was higher in the GD 46.0 [95 % CI = 15:102.6] t. $period^{-1}$ than the OV region 40.0 [95 % CI = 13.9:89.6] t. $period^{-1}$. The total catch from the Lake Gariep fishery between March and December 2007 was estimated to be 86.0 [95 % CI = 40.4:154.8] t. $period^{-1}$.

Age and growth was determined using whole otoliths. The growth of *L. aeneus* was best described by the von Bertalanffy growth model as $L_t = 481.80\ (1 - e^{-0.22(t+0.61)})$. Gonadal

development for *L. aeneus* was seasonal, with the gonadosomatic index peaking in January, revealing a distinct spawning season. The length at 50 % maturity for female *L. aeneus* was attained at a fork length of 354.7 mm. Natural mortality (*M*) was estimated at 0.55 $year^{-1}$. The growth of *L. kimberleyensis* was described by the von Bertalanffy growth model as L_t = 763.22 (1- $e^{-0.11(t+0.63)}$). Only 6 mature female and 15 mature male *L. kimberleyensis* were recorded during the study period. The smallest mature female was a 390 mm FL stage four female and the earliest recorded mature male was a 337 mm FL, ripe running male. Natural mortality (*M*) was estimated at 0.08 $year^{-1}$ for *L. kimberleyensis*.

Per recruit analysis indicated that current fishing mortality reduces the *L. aeneus* spawner biomass by 7 %, which is considered negligible. *Labeobarbus kimberleyensis* forms an insignificant proportion of anglers catches and stock status is currently considered pristine.

CHAPTER 1: General introduction

The status of yellowfish

The smallmouth yellowfish *Labeobarbus aeneus* (Burchell, 1822) and the largemouth yellowfish *Labeobarbus kimberleyensis* (Gilchrist & Thompson, 1913) are two cyprinid fish endemic to the Orange/Vaal River system. *Labeobarbus aeneus* is a medium sized fish attaining 500 mm FL and 7.8 kg while *L. kimberleyensis* is large, attaining 825 mm FL and 22.2 kg (Skelton, 2001). Both species prefer clear, fast flowing water over a rocky or sandy substrate (Dorgeloh, 1994; Dorgeloh, 1995; Mulder, 1973). *Labeobarbus aeneus* has an omnivorous diet, feeding on zooplankton, algae, vegetation, bivalve mollusks and terrestrial invertebrates and *L. kimberleyensis* is a piscivore (Dorgeloh, 1994; Eccles, 1986; Gaigher and Fourie, 1984). Although widespread throughout the Orange/Vaal River system (IUCN, 2008), they are regarded as high conservation priority species in South Africa (de Villiers and Ellender, 2007 a,b; Gaigher, 1976; Mulder, 1973).

Both species are favoured angling targets in South African inland waters (Gaigher, 1976; Groenewald, 1951; Le Roux, 1968; Skelton, 2001) and consequently, may be at risk of over-exploitation. While both species have at some point been assigned IUCN Red List status, *L. aeneus* has been removed from the near-threatened category and is currently listed as least concern (LC), while *L. kimberleyensis* is now listed as near-threatened (NT) (IUCN, 2008).

Although the justification behind the high conservation priority surrounding the yellowfish stems from anthropogenic factors other than angling, such as habitat degradation and pollution (IUCN, 2008), the effect of angling on the species has never been assessed. With the growing recreational sector targeting yellowfish (Figure 1.1), assessing the impact of angling on the species in South Africa’s largest impoundment, Lake Gariep, is very important. *Labeobarbus aeneus* and *L. kimberleyensis* are the only species occurring in Lake Gariep that have any regulations with regards to their capture. The minimum legal size and bag limit for *L. aeneus* are, 300 mm FL and 2/person/day, respectively. *Labeobarbus kimberleyensis* is a no take species (Nature Conservation Ordinance, No. 8 of 1969).

Figure 1.1 Various South African angling magazines, depicting the popularity of both *L. aeneus* and *L. kimberleyensis* as angling targets.

Fisheries development

In South Africa traditional harvesting of freshwater fish is limited to relatively few systems such as the Phongola River floodplain in northern Kwazulu-Natal, the Orange River in the Richtersveld area of the Northern Cape Province and the Mutshindudi River catchment in Limpopo province (Andrew et al., 2000; van der Waal, 2000). Historically in South Africa, the utilisation of inland fisheries is not a traditional practice of the indigenous peoples, making the emergence of an inland subsistence fishing sector a relatively new phenomenon (Andrew et al., 2000).

Lake Gariep is the largest man-made impoundment in South Africa. The fisheries potential of Lake Gariep was first recognised by Hamman, (1981). Such a large water body obviously has considerable potential to support commercial fishing (Hamman, 1981). Although Lake Gariep was identified as having fisheries potential, few attempts have been made to develop a commercial fishery, and those that have, were unsuccessful (Potts et al., 2004). As a result, the fishery has been utilised almost exclusively by recreational and subsistence anglers using hook and line (Potts et al., 2004).

In 2004, the Department of Economic Affairs, Environment and Tourism (DEAET) initiated the Venterstad Community Fisheries Project (VCFP). The project aimed to provide a source of poverty relief to the surrounding rural communities. An experimental fishing permit was issued by DEAET to the VCFP to harvest 50 tonnes (t) per annum of three species, namely carp (*Cyprinus carpio* Linnaeus, 1758), sharptooth catfish (*Clarias gariepinus* (Burchell, 1822)) and the Orange River mudfish (*Labeo capensis* (Smith, 1841)). This permit was granted specifically for hook and line fishing (Potts et al., 2004). The project shut down after a short running period due to bad management, planning, lack of consultation and local knowledge (Potts et al., 2004). There is however a subsistence and recreational hook and line fishery on Lake Gariep.

Current trends and concerns related to inland fisheries

Inland fisheries provide an essential contribution to local and regional economies, sustaining livelihoods and constituting an important source of recreation (Smith et al., 2005). Recreational and subsistence angling have been respectively defined as: where the fish are caught as a source of leisure or recreation, or where the catch, or part thereof, may be taken home for consumption (Arlinghaus, 2005). Inland fisheries are of a multi-faceted, diverse nature, involving multiple user groups, multiple species and multiple gear types (Arlinghaus et al., 2002; Neiland et al., 2000; Smith et al., 2005; Welcomme, 1998). The nature of inland fisheries has been likened to an evolving organism, characterised by a number of major stages in the life cycle (Smith, 1986). The initial stage consists predominantly of food production, while the second stage is distinguished by an increased interest in recreational activities, and the final stage of conservation (Smith, 1986). Together with the heterogeneous nature of inland fisheries (Arlinghaus et al., 2002; Welcomme, 2001), the evolutionary stage of the fishery also determines the types of user groups and levels of exploitation (Smith, 1986, Arlinghaus et al., 2002). This creates a very unique set of challenges when dealing with the management of inland fisheries.

To address such challenges, Welcomme, (2001) highlighted three major principles that emerged from the Convention on Biological Diversity and the FAO Code of Conduct for Responsible Fisheries – (i) conservation of the diversity of living aquatic resources; (ii) sustainability of the fishery, and (iii) equitable distribution of the benefits of the fishery and related aquatic ecosystems. In addressing the challenges, it is import to highlight the benefits and threats to conservation and resource sustainability.

Traditionally, commercial (Cooke and Cowx, 2004; Cooke and Cowx, 2006) and subsistence (Allan et al., 2005) fishing have been identified as causal factors in the collapse of a large number of inland fisheries. This is as a result of the nature of both commercial and subsistence fishing being consumptive practices. In contrast, recreational fisheries have a perception of being less consumptive (Broadhurst et al., 2005), although recently, recreational fisheries have been identified as playing a major role in the global fish crisis (Balon, 2000; Cooke and Cowx, 2004; Lewin et al., 2006).

Angling has been associated with a variety of deleterious effects that may affect the target species (Bartholomew and Bohnsack, 2005). The most obvious lethal effects are the removal of fish for consumption or sale. There are also less obvious sub-lethal effects as a result of the physiological stress a fish endures during capture and subsequent release, for example, decreased growth rates (Tsuboi and Morita, 2004) and lessened likelihood of long term survival (Broadhurst et al., 2005).

Preliminary indications are that the recreational fishing sector worldwide, is hugely under-estimated as a threat to the sustainability of fishery resources (Arlinghaus, 2005). In South Africa subsistence and recreational angling on an inland impoundment has not been assessed. A detailed assessment of angling catch per unit effort (*CPUE*), size selectivity, angler effort and total catch is necessary to provide information for future management and conservation of yellowfish and other species. Understanding the fisherman, their utilisation trends and the life history traits of the exploited species, may provide a more complete picture on the effect that angling has on *L. aeneus* and *L. kimberleyensis* in Lake Gariep.

Thesis outline

This thesis aims to assess the impact of recreational and subsistence angling on *L. aeneus* and *L. kimberleyensis* in Lake Gariep by: (1) assessing the biology of *L. aeneus* and *L. kimberleyensis* in the lake; (2) documenting catch, effort, size selectivity and total catch for both species from the fishery; and (3) based on the findings, make recommendations for future management of these species. The conceptual sampling framework and potential outcomes of the thesis are summarised in Figure 1.2.

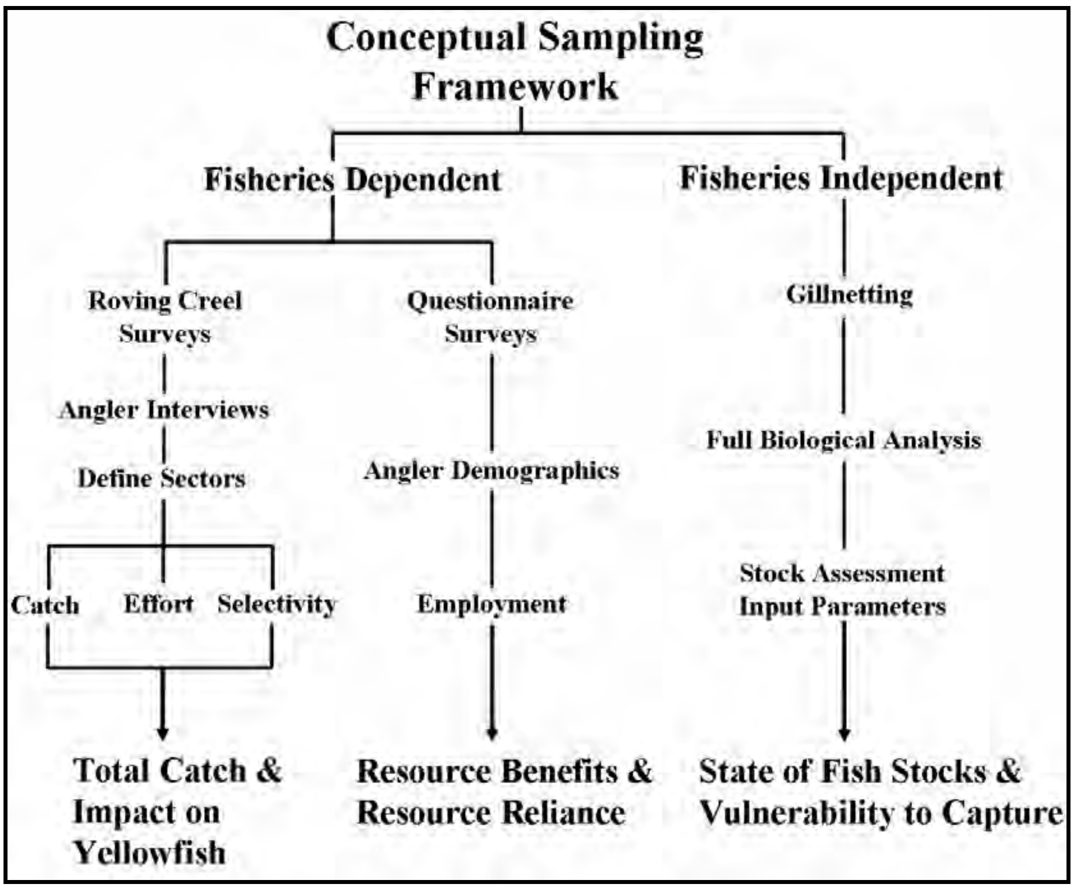

Figure 1.2 The conceptual sample design and possible project outcomes of the assessment of the effects of angling on *L. kimberleyensis* and *L. aeneus* in Lake Gariep between October 2006 and December 2007.

To achieve the aims the study was divided into six chapters. The introductory chapter (Chapter 1) is an overview of the yellowfish, Lake Gariep and problem identification. Chapter two describes the study site, history relating to why the impoundment was constructed, and characteristics of the inflowing Orange River, which greatly influences the physical characteristics of Lake Gariep. The general field methods are also described in chapter two.

Chapter three addresses the biological characteristics of *L. aeneus* and *L. kimberleyensis* in Lake Gariep. Chapter four discusses the human dimensions of the fishery by characterising the anglers into user groups and relates these to reasons for utilising the resource. Chapter five discusses the utilisation patterns of fishery by describing catch rates, fishing effort, selectivity and total yield from the fishery. Chapter six summarises the how the human dimension and utilisation patters affect exploitation of *L. aeneus* and *L. kimberleyensis*. This is then related to the biological characteristics of both species by the application of a spawner biomass-per-recruit (*SBR*) model to assess the effect angling is having on *L. aeneus* and *L. kimberleyensis* spawner biomass.

CHAPTER 2: Study site and general material & methods

Orange River

The Orange River, originates as the Senqu, Mantsonyane and Seati Rivers in southern Lesotho (Keulder, 1979). The river exits Lesotho in the southwest and continues to flow westward for 2 200 km through increasingly arid country, and then spills its water into the Atlantic Ocean, on the common border between Namibia and South Africa. It is South Africa's longest river and drains a catchment of 6500 km^2, and in an undeveloped state, discharged a total of 5500 x 10^6 m^3 of water into the Atlantic Ocean (Keulder, 1979). Being a water scarce country, damming of the Orange River system was proposed as early as the 1950's in the form of the Orange River Development Project (ORDP) (Hamman, 1981; Keulder, 1979; Tómasson, 1983).

Orange River Development Project (ORDP)

The main aims of the ORDP were to make provision for new irrigation development along the Orange River and various other areas within reach of the river by stabilising the water supply to existing irrigation schemes, affording new life to the fertile but water-deficient Great Fish River and Sundays River valleys, supplying water to various urban centres and generating hydro-electric power (Stallebras, 1963). The ORDP has resulted in three reservoirs (Lake Gariep, Lake van der Kloof, Welbedacht Dam; Figure 2.1) and a diversion tunnel, the Orange-Fish Tunnel, with the inlet situated in Oviston.

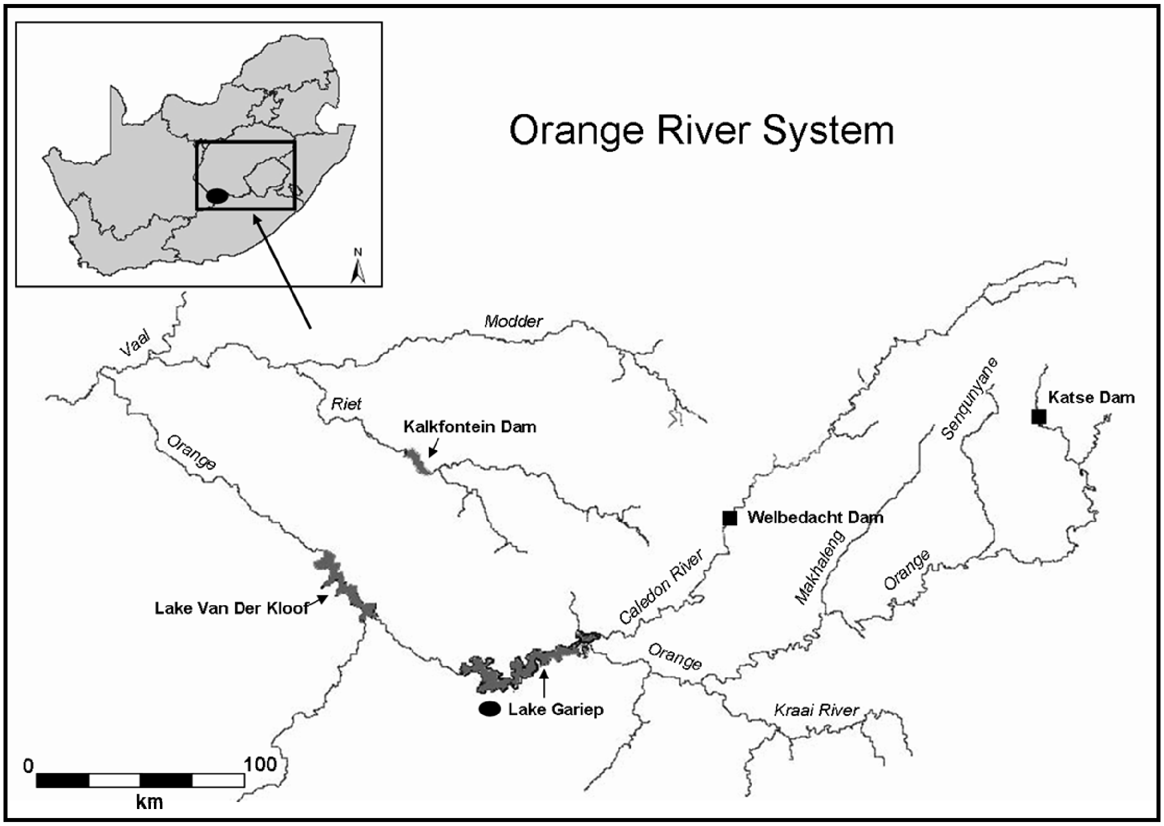

Figure 2.1 Map of the Orange River system, showing the major tributaries and impoundments on the system and highlighting the situation of Lake Gariep within the Orange River System.

Lake Gariep

Lake Gariep (S30 38.703, E25 46.998), South Africas largest impoundment, is situated on the Orange River system between the Northern Cape, Eastern Cape and Free State provinces in central South Africa (Figure 2.2). The Lake Gariep wall is 88 m high (90.5 m above foundation level), with a crest length of 914 m (Hamman, 1981). The Lake was completed in September 1970, and on the 29th of that month, the lake spilled over for the first time (Hamman, 1981). At maximum capacity, Lake Gariep holds 5 952 000 000 m^3 of water has a surface area of approximately 360 km^2, and ~ 400 km of shoreline. Although in places, the width of Lake Gariep may be as wide as 24 km, the average width is 6.5 km (Hamman, 1981). The average depth of the lake is 16.3 m at full capacity (Hamman, 1981).

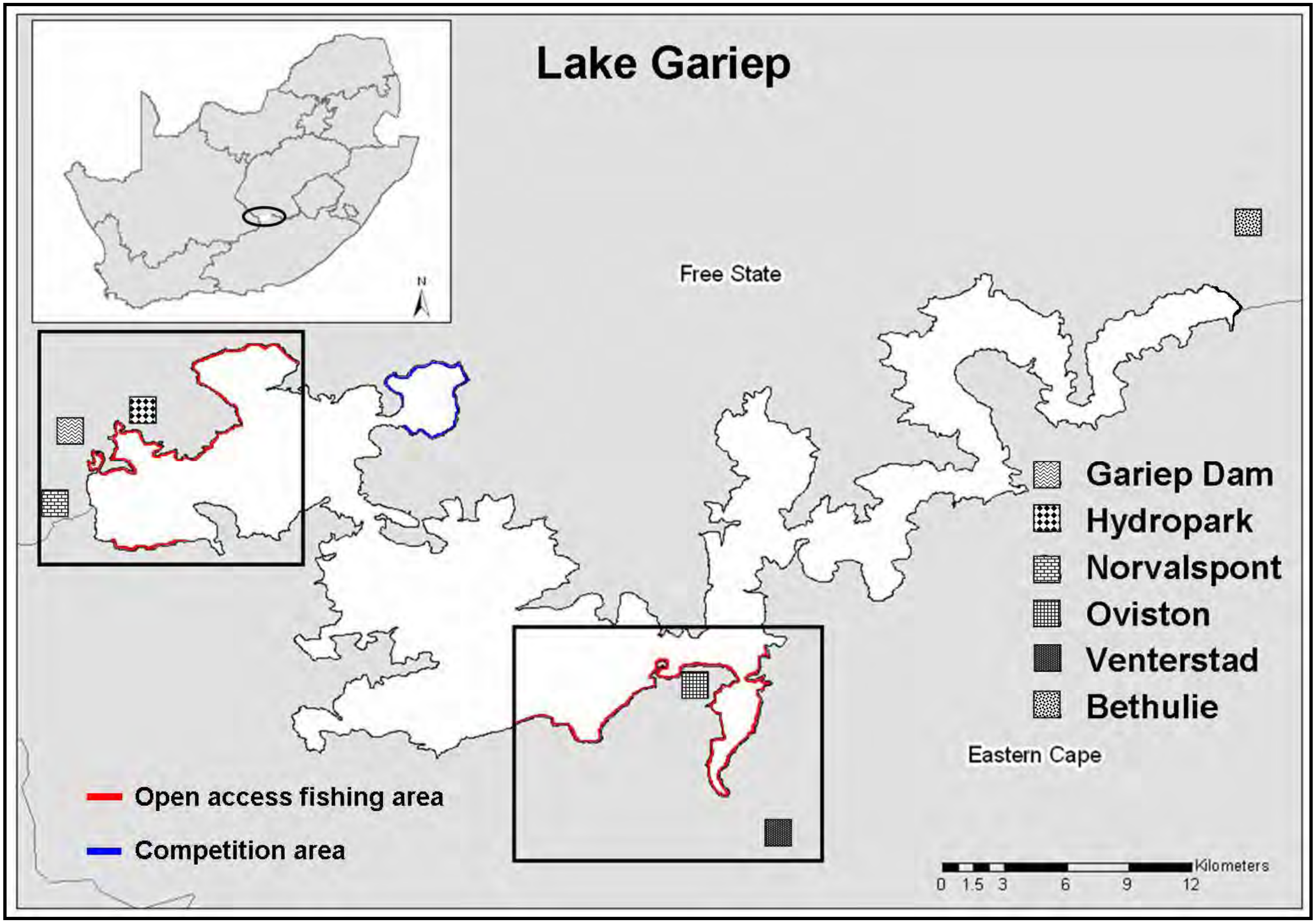

Figure 2.2 A map showing the situation of the communities surrounding Lake Gariep and the open access and competition areas along the shoreline.

Physical characteristics

There is a gradual decrease in precipitation from 2000 mm/annum at the source of the Orange River, to 400 mm/annum in the Lake Gariep region (Keulder, 1979). Rainfall in the region is seasonal with the summer months being considered the "wet season" and the winter months the "dry season" (Keulder, 1979). Lake Gariep, being a hydroelectric impoundment has water level fluctuations relating to power demands of a developing country, rather than the surrounding climate, although on a larger scale season fluctuations still exist (Figure 2.3).

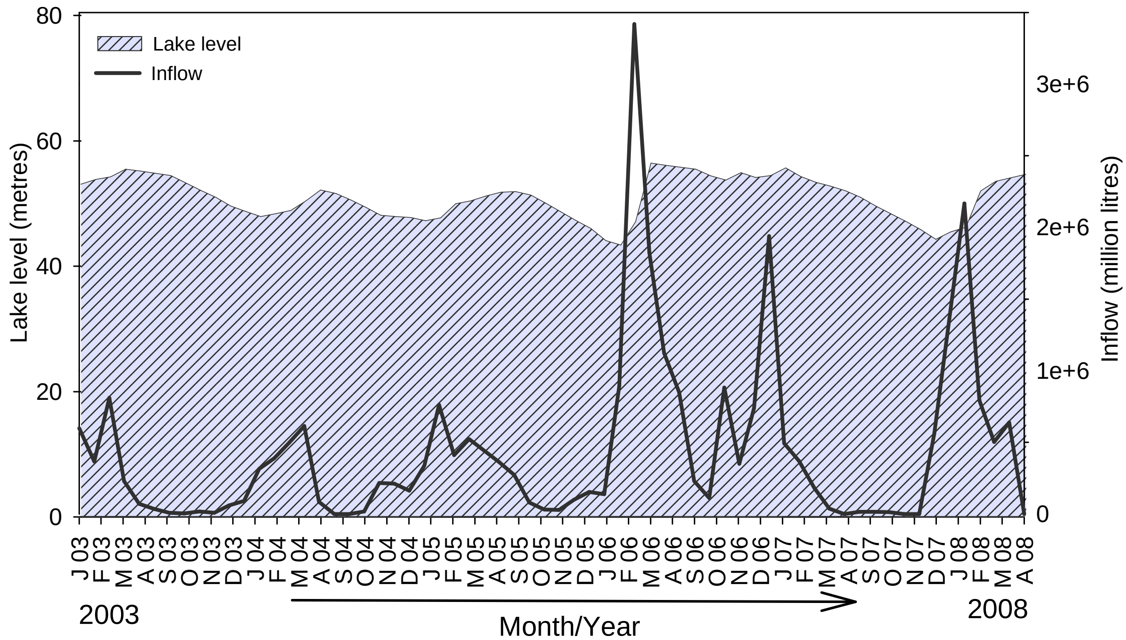

Figure 2.3 Mean monthly lake levels and inflow for Lake Gariep between January 2003 and April 2008. The source data were obtained from the Department of Water Affairs and Forestry (DWAF) long term monitoring data (DWAF, 2008).

Lakeshore characteristics are shown in Figure 2.4. The lakeshore is characterised by extensive, gradually sloping shores that are largely devoid of vegetation, due to both wind action and frequent, rapid fluctuations in water level (Hamman, 1981). During drawdown phases, the exposed areas of the shoreline are colonised by a few plants, predominantly *Argamenone subsiformis* (yellow poppy) and *Polygomium lapathifolium* (pale persicaria) (Cambray et al., 1978). Smaller sections of the shoreline (~ 10 %) are composed of steep rocky areas (Cambray et al., 1978).

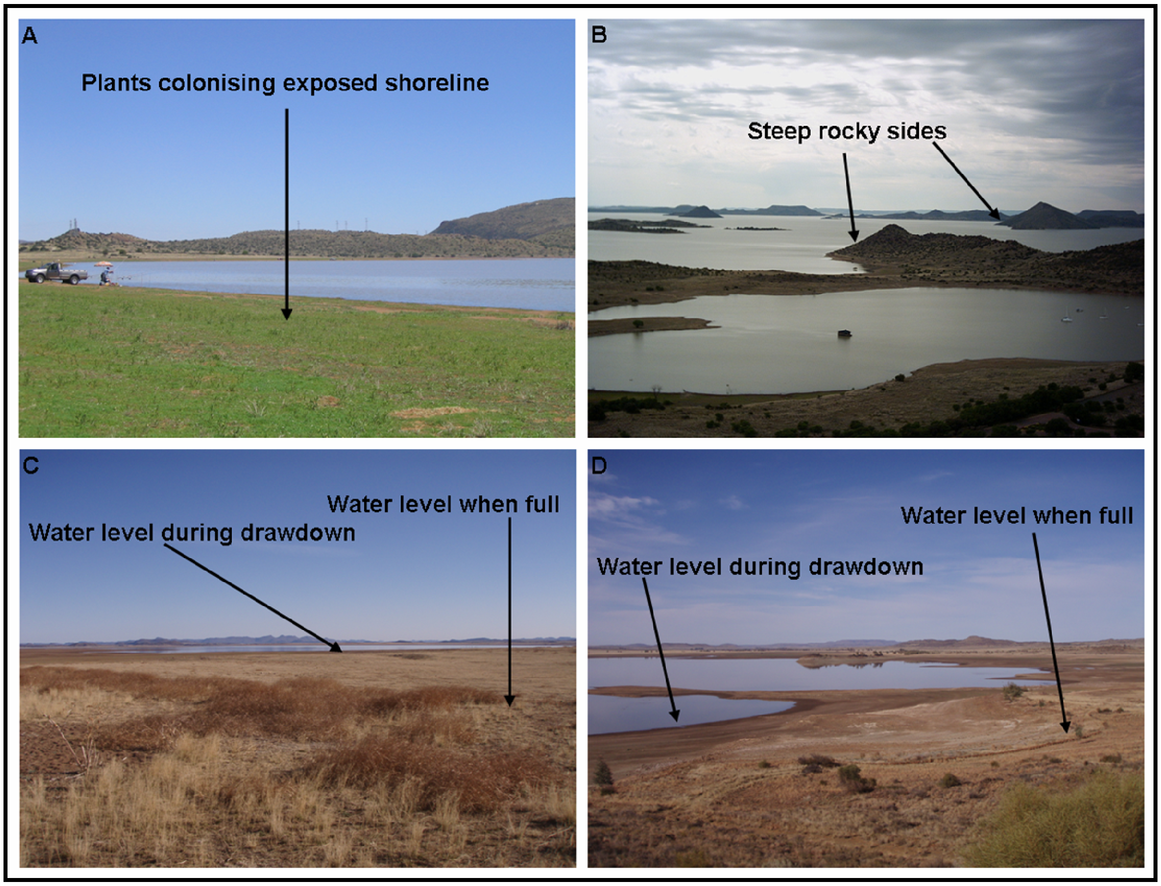

Figure 2.4 Photographs from the Lake Gariep shoreline showing (A) colonisation by plants of the exposed shoreline during the drawdown phase (B) areas of Lake Gariep with steep sides (C) high and low water marks on a gradually sloping shoreline indicating how far the lake recedes in these areas, and (D) high and low water marks on a steeper shoreline.

Lake Gariep is a oligo-mesotrophic impoundment (Keulder, 1979). The Upper Orange River is characterised by relatively low concentrations of dissolved chemicals but high levels of suspended sediments (Keulder, 1979). Due to increased land usage in the Lesotho highlands, heavy pressure is placed on the vegetation in this area resulting in the denudation of large tracts of land. This causes large scale erosion, and the Orange River carries large sediment loads that eventually end up in Lake Gariep (Jubb, 1970). Consequently Lake Gariep is a highly turbid impoundment with a mean secchi depth of 15 cm (Figure 2.5).

Water quality

Bi-monthly water quality readings between March 2007 and May 2008 are summarised in Figure 2.5. Oxygen saturation (%) and concentration (mg/l) and temperature were measured using an OxyGuard oxygen probe and pH, conductivity and total dissolved solids were measured using a Hanna HI98129 Combo pH and Electrical Conductivity meter.

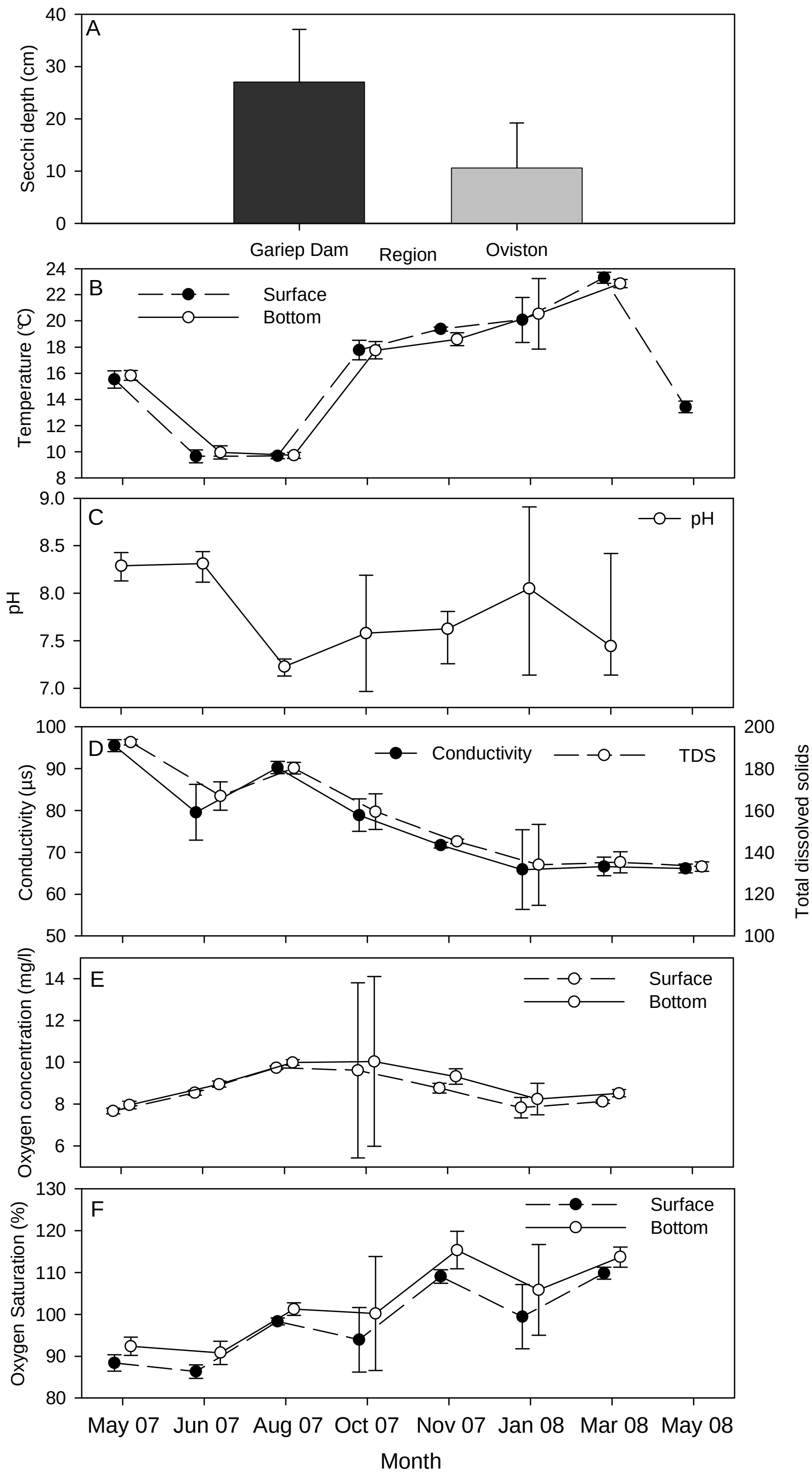

Figure 2.5 Mean (± SE) bi-monthly water quality readings from Lake Gariep between May 2007 and May 2008. (A) Secchi depth (cm); (B) Temperature (° C); (C) pH (error bars are min and max); (D) Conductivity (µs); (E) Oxygen concentration (mg/l); (F) Oxygen saturation (%).

Fish fauna of Lake Gariep

Eight indigenous fish species have been recorded in Lake Gariep, of which seven were recorded in this study (Table 2.1). Three of the four exotic species recorded in Lake Gariep were recorded in this study (Table 2.1).

Table 2.1 Indigenous, indigenous/introduced and exotic species of Lake Gariep (Cambray et al., 1978, Hamman, 1981) (*indicates having been recorded in this study).

Species	Common name
Indigenous	
Cyprinidae	
**Labeo capensis*	Orange river mudfish
**Labeo umbratus* (Smith, 1841)	Moggel
**Labeobarbus kimberleyensis*	Largemouth yellowfish
**Labeobarbus aeneus*	Smallmouth yellowfish
Barbus anoplus Weber, 1897	Chubbyhead barb
Austroglanididae	
**Austroglanis sclateri* (Boulenger, 1901)	Rock catlet
Clariidae	
**Clarias gariepinus*	Barbel
Pseudocrenilabrus philander (Weber, 1897)	Southern mouthbrooder
Introduced	
Cyprinidae	
**Cyprinus carpio*	Carp
Salmonidae	
Salmo trutta Linnaeus, 1758	Brown trout
**Oncorhyncus mykiss* (Walbaum, 1792)	Rainbow trout
Centrarchidae	
**Micropterus salmoides* (Lacepède, 1802)	Largemouth bass

Lakeshore settlements

Four small towns are situated on or near the Lake Gariep shoreline namely, Gariep Dam, Venterstad, Oviston and Bethulie (Figure 2.2). Census data for Oviston/Venterstad and Gariep Dam are summarised in Table 2.2.

Gariep Dam

Gariep Dam (GD) (S30 36.721, E25 29.663) is situated on the western edge of the lake in the Free State Province (Xhariep district municipality, Kopanong local municipality, Ward 5) (Figure 2.2). This town is a result of housing built to accommodate labourers during dam wall construction. The town is largely focused around tourism, the hydroelectric power station and related dam wall maintenance. There are a large number of guesthouses and a resort with the necessary infrastructure for a large tourist influx (± 1000 Beds; Gariep Tourism Association, unpublished data).

Oviston/Venterstad

The Oviston/Venterstad (OV) region lies within the Eastern Cape Province (Ukhahlamba district municipality, Gariep Local municipality, Ward 1). Two settlements fall within this region, Oviston and Venterstad. Although the two towns are separate, they will be discussed together as they utilise the same fishing area along the lakeshore. Oviston (S30 41.777, E25 46.060) is situated on the southern arm of Lake Gariep (Figure 2.2). The town was constructed to house workers involved in building the Orange/Fish River tunnel. Oviston is now considered a retirement village (H. Carey estate agent, pers. comm). Although there are a number of guesthouses, a hotel and resort in the region, the infrastructure for tourism is not as developed (± 150 Beds; Gariep Tourism Association, unpublished data) as in the GD region. Venterstad (S30 46.531, E25 47.901) is situated ~10 km from the southern arm of the lake (Figure 2.2). Venterstad is a service centre for surrounding farmers.

Bethulie

Bethulie (S30 30.081, E25 58.554) is in the Free State Province (Xhariep district municipality, Kopanong local municipality, Ward 3) and is situated on the eastern arm of Lake Gariep near the inflowing Orange River (Figure 2.2). Exploratory surveys showed that the Bethulie fishing area comprised a pan that was separated from the main lake for 90 % of the year, and had more riverine than lake influence. This area was subsequently excluded from further assessment.

Table 2.2 National census data for the two major fishing regions on the Lake Gariep shoreline (Stats SA, 2002).

Characteristics		Oviston/Venterstad		Gariep Dam	
		#	%	#	%
Gender	F	3793	53	6246	53
	M	3344	47	5604	47
Mode Of Transport	Walk	3073	88	5052	88
	Bicycle	38	1	31	1
	Own Vehicle	150	4	275	5
	Lift	235	7	345	6
	Other	9	0	22	0
Personal Income	No income	4602	64	7686	65
	R1 - 800	1958	27	3076	26
	R801 - R1 600	123	2	370	3
	R1 601 - R3 200	217	3	370	3
	R3 201 - R6 400	131	2	236	2
	> R 6 400	104	1	111	1
Population Grouped	Black African	3774	53	7649	65
	Coloured	2623	37	3249	27
	Indian or Asian	0	0	3	0
	White	740	10	950	8
Employment Status	Employed	1498	36	2290	31
	Unemployed	1006	24	1771	24
	Not Econom Active	1691	40	3214	44

Nature reserves

The entire Lake Gariep shoreline, falls under the jurisdiction of Eastern Cape Parks Board (Oviston Nature Reserve-ONR) and Free State Nature Conservation (Gariep Nature Reserve-GNR). Due to the extensive nature of the shoreline (~ 400 km), and logistical constraints of patrolling the shoreline, specific open access fishing areas have been designated by Nature Conservation (Figure 2.2). Anglers are also restricted to fish between 06h00 and 18h00, as these are designated times when the reserves are open. Two open access areas (Venterstad/Oviston and Gariep-Eastern Cape totaling ~ 40 km of shoreline) fall within the Eastern Cape and one falls within the Free State (Gariep Nature Reserve, ~ 35 km). For the purposes of this study the sampling of the fishing areas was separated by region, namely: Venterstad/Oviston and Gariep Dam. For sampling purposes, each region was further divided into a number of strata (Figure 2.6).

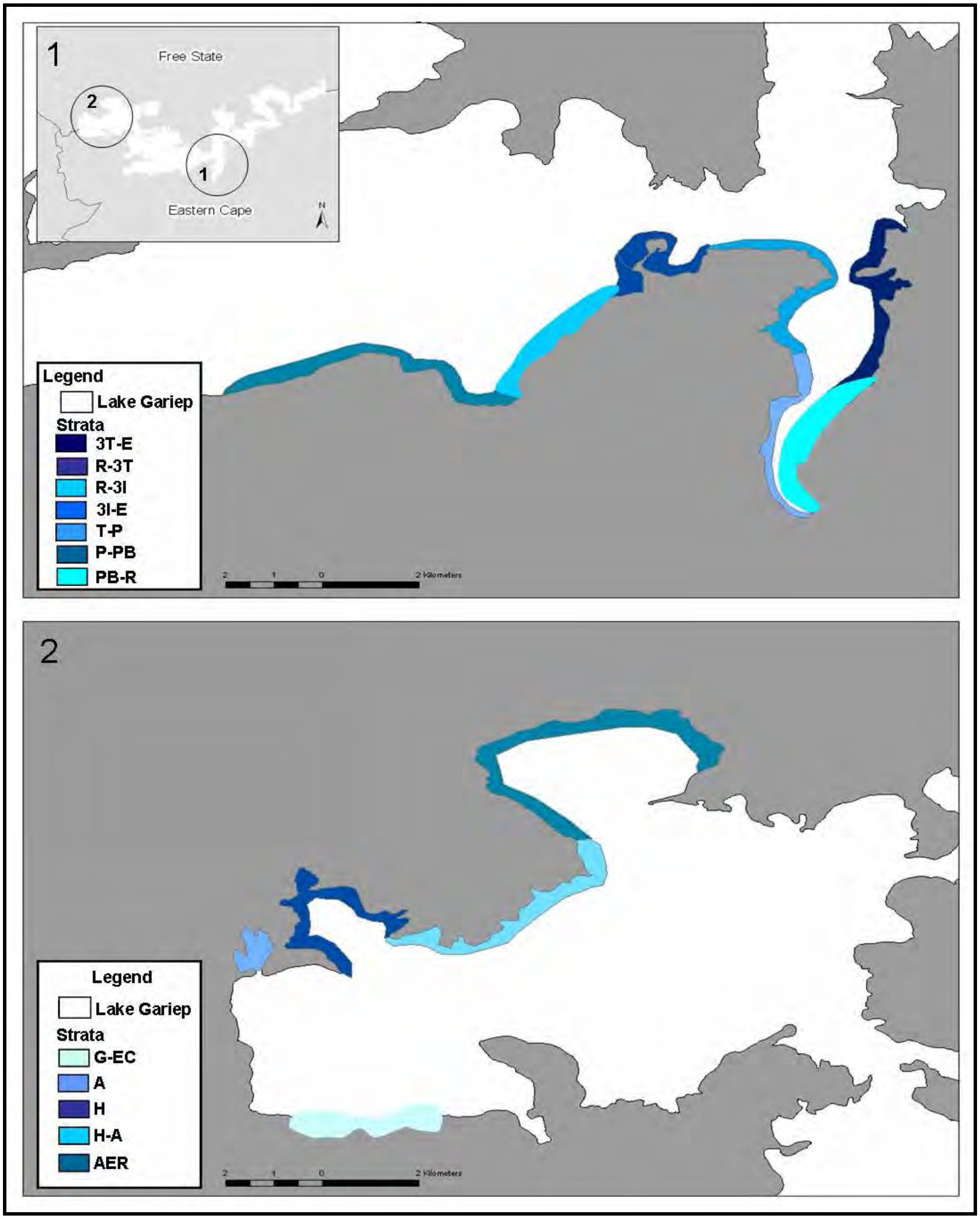

Figure 2.6 Division of the Lake Gariep shoreline in the Oviston/Venterstad (1) and Gariep Dam (2) regions into a number of different strata.

Field sampling methods

Sampling was separated into two broad categories, fisheries dependant, and fisheries independent sampling. Fisheries dependant sampling included bi-monthly Roving Creel Surveys (RCS) and effort counts. Fisheries independent sampling was conducted bi-monthly, and consisted of setting gillnets. Full biological analysis was conducted on all fish caught in the gillnets. Field trip dates and specific activities are summarised in Table 2.3. All fieldwork, angler interviews and biological analysis was conducted personally, to ensure consistency in data collection.

There is a paucity of information on the life history of *L. kimberleyensis*. The conservation status of *L. kimberleyensis* (NT; IUCN, 2008) in South Africa makes it difficult to justify the targeting of large *L. kimberleyensis* for research. As a result, *L. kimberleyensis* were not actively targeted but those caught as a by-catch in the sampling gear were used for biological analysis.

Table 2.3 Details for each sampling trip highlighting when the Exploratory Surveys (ES), Key Informant Interviews (KEI), Roving Creel Surveys (RCS) and Gillnetting (GN) were conducted during the study period between September 2006 and May 2008.

Date	Sample Type	Area Surveyed	Net Nights		Trip Duration
			OV	GD	
October 2006	ES (RCS,KEI)	OV, GD, B			10 Days
December 2006	ES (RCS)	OV, GD, B			10 days
March 2007	RCS, GN	OV, GD	3		14 days
April 2007	GN	OV	3		
May 2007	RCS, GN	OV, GD	10		14 days
June 2007	RCS, GN	OV, GD	20	20	14 days
August 2007	RCS, GN	OV, GD	10		14 days
October 2007	RCS, GN	OV, GD	10		14 days
November 2007	GN	GD	5		
December 2007	RCS	OV, GD			14 days
January 2008	GN	OV, GD	20	20	14 days
March 2008	GN	OV, GD	10		14 days
May 2008	GN	OV, GD	10		14 days

Fisheries dependent sampling

Roving Creel Surveys

Each survey consisted of a two week sampling period with seven days spent in each of the sampling regions (GD and OV). Within each region the fishing area was divided into smaller strata (Figure 2.6). Within each week, five days were sampled (3 randomly selected week days and both weekend days). On each sampling day catches in a randomly selected stratum were sampled. The direction moved through the stratum was also randomised. On any sampling day, a creel survey (for questionnaire see Figure 2.7) was conducted by the surveyor moving unidirectionally at a constant speed through the stratum, until either all anglers were interviewed within that particular stratum or the surveyor ran out of daylight/time.

All fish were measured using either fork length (FL) or total length (TL) depending on the species. The number of specimens and the total weight was recorded for each fish species component of the catch. In a case where the fish could not be weighed (anglers often gutted and dried fish after capture), it was measured, and an approximate weight assigned from the length-weight relationship for that particular species (see Chapter Three; Table 3.1).

To determine fishing effort, counts of fishers in the sampling region were conducted. On each sampling day, all fishers in each stratum were counted twice daily. Each count consisted of an instantaneous count of fishers within that stratum. These instantaneous counts were made possible by the presence of certain vantage points (Figure 2.8), from where the entire stratum could be viewed and the anglers counted using Nikon Action 8 x 42 binoculars. Anglers and the associated vehicles were counted for each stratum and the time of each count recorded.

RHODES UNIVERSITY

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DEPARTMENT OF ICHTHYOLOGY & FISHERIES SCIENCE

Lake Gariep Fisheries

Project Creel/Questionnaire Survey

AREA ____________________

DATE ____________________

NAME ____________________

Q. No.	Date.	Weekday.	Area.
Name/ id.			
S / E	Vehicle type	Make	Year
# Group / # Fishing	Race	Sex	Children u.10
Origin		Transport/Cost	
Usual fishing area		Employed	
#HL / #Rods	Bait	Flavours	Feeding area
Hook size.	Caught/released/Eaten:Spp; #.; wt		
Fish. days/ 7.			
Start			
Interview			
Expected End			
Length.			
Comments: Fish price etc.			

Figure 2.7 Questionnaire used for Lake Gariep Roving Creel Surveys between October 2006 and December 2007.

Figure 2.8 A vantage point on the Lake Gariep shoreline in the Oviston/Venterstad region illustrating the visibility of the entire shoreline within a particular stratum, in order to undertake instantaneous angler count effectively.

Fisheries independent sampling

Bi-monthly gillnetting

Experimental gillnetting was conducted bi-monthly between March 2007 and May 2008. Gillnets were made of six ply, multifilament, green, nylon netting with manufacturer quoted stretched mesh sizes of 44, 60, 75, 100 and 144 mm (Table 2.4). The net hanging ratio was 50 % (height : width). Each fleet was 45 m long x 3 m deep and consisted of five randomly distributed 9 m mesh panels (Table 2.5). Nets were set parallel to the shoreline on the 3 m depth contour. This was done to ensure that all mesh sizes had the same probability of capturing fish.

Bi-monthly samples consisted of two nights, with five nets being set between 17h00 and 19h00 in the evening and lifted between 05h00 and 07h00 the following morning on each night. The soak time for each net was recorded. The specific setting and lifting times for the gillnet fleet was implemented in order to avoid any conflict with the existent recreational and subsistence hook and line angling sector. These anglers would also have to be interviewed during the study, and any conflict between surveyors and anglers may have hampered the results of the study. In addition, an extensive winter (July 2007) and summer (January 2008) gillnet survey was conducted, consisting of 8 x 5 net nights per season.

Table 2.4 Manufacturer quoted stretch mesh sizes (MSQM) and the actual mean stretched mesh sizes and standard deviation used to sample the fishes of Lake Gariep.

MQSM (mm)	Mean mesh size ± St Dev (mm)
144	152.6 ± 1.6
100	105.8 ± 0.9
75	77.2 ± 0.6
60	64.9 ± 0.8
44	46.6 ± 0.9

Table 2.5 Positioning of the randomly distributed mesh sizes with each of the five gillnet fleet used to sample Lake Gariep.

Position	Mesh Size				
Number	Fleet 1	Fleet 2	Fleet 3	Fleet 4	Fleet 5
1	100	75	60	100	75
2	144	60	75	75	144
3	60	44	144	60	44
4	44	100	100	144	100
5	75	144	44	44	60

All fish collected in gillnets were measured to the nearest millimetre FL and weighed to the nearest 0.1 g. Fish were dissected, sexed and visually assigned a stage of maturity (Table 2.6). The gonads were removed from all females larger than the size-at-50 % maturity and weighed. Specifically, Gonadosomatic index (GSI) was used to determine the spawning season and temporal patterns in the gonadal development of mature female fish. The gut was then dissected out and the eviscerated mass of the fish was taken. The asteriscus otoliths were removed and stored for later examination.

Table 2.6 Macroscopic criteria used to stage the gonads of *L. aeneus* and *L. kimberleyensis* (adapted from Weyl and Booth, 1999).

Stage	Characteristics
J-Juvenile	Gonads are a thin band, unable to be accurately sexed.
1-Immature	Gonads able to be sexed, very thin white band in testes and translucent band in ovary.
2-Resting	Gonads able to be distinguished by sex, in males a thin white band and females a thicker transparent ovary.
3-Developing	Both ovaries and testis better developed, ovary looses total transparency and the first signs of pale yellow/green oocytes appear. The testis are creamy white and enlarging.
4-Ripe/Running	The ovaries are large and rigid, the oocytes are bright yellow in colour, the testes are pure white and rigid, if any pressure is applied to either the testes or ovary. Eggs or semen may ooze out.
5-Spent	The ovary and testes appear flaccid and reddish in colour; the remaining eggs in the ovary appear dull grey/yellow.

<u>Age validation</u>

Ageing accuracy is vital in any study on fish life histories (Campana, 2001). A major contributor to ageing accuracy is determining the periodicity of otolith growth increment formation by validation (Campana, 2001). Two methods were used to validate the periodicity of growth increment formation in *L. aeneus* and *L. kimberleyensis* otoliths. The first method was by Marginal Zone Analysis (MZA) and the second by the mark-recapture of chemically-tagged, captive fish. The mark recapture was conducted in ponds from, which recapture of the fish would be possible. The results are described in detail in Chapter Three but the specific design for the chemical marking study is described here.

Ponds were allocated by the Lake Gariep State Fish Hatchery for the age validation experiment (Figure 2.9). The ponds used for the experiment were situated 3 km below Lake Gariep on the banks of the Orange River. Four ponds were used in the experiment, two 40 x 20 x 1 m deep and two 50 x 25 x 1.5 m deep ponds. The layout of the ponds is summarised in Figure 2.10. Lake Gariep water was supplied directly to the pond from a holding reservoir that gravity fed lake water into the ponds. Filling time for the smaller ponds was approximately 24 hours and the larger pond 48 hours. Two weeks prior to the initial stocking, the ponds were filled and allowed to settle before fish were stocked. Stocking densities in each pond were less than one fish per 90 m^3 (for numbers of *L. aeneus* and *L. kimberleyensis* in each pond see Figure 2.10). Throughout the experimental period, ponds were topped up on demand by the Lake Gariep State Fish Hatchery staff. The ponds were allowed to function as naturally as possible and no supplementary feeding of the fish was carried out or any environmental parameters controlled. Temperature fluctuated according to daily and seasonal fluctuations as it would have in the lake, although the ponds are smaller and the fluctuations may be larger.

Figure 2.9 Pond 4 at the Gariep Dam State Fish Hatchery that was used for the mark-recapture of chemically-tagged fish.

All *L. aeneus* and *L. kimberleyensis* for this experiment were captured using a rod and line in the Orange River below Lake Gariep. On capture, fish were placed in a water filled canvas bag to reduce handling damage and carried to an oxygenated holding tank that contained the anesthetic 2-Phenoxyethanol (Sigma-Aldrich Chemicals, Steinheim, Germany) to reduce post capture stress. No fish were captured more than a 15 minute trip away from the ponds. On arrival at the ponds, all fish were measured to the nearest millimetre FL, injected with 0.5 ml of commercially available oxytetracycline (OTC) hydrochloride (HiTet 120; Bayer, Leverkusen, Germany) and either tagged or released without tagging. Fish were tagged with Hallprint® (Victor Harbour, South Australia) T-bar anchor (model TBA-2) tags. Two ponds contained tagged fish and two contained untagged fish.

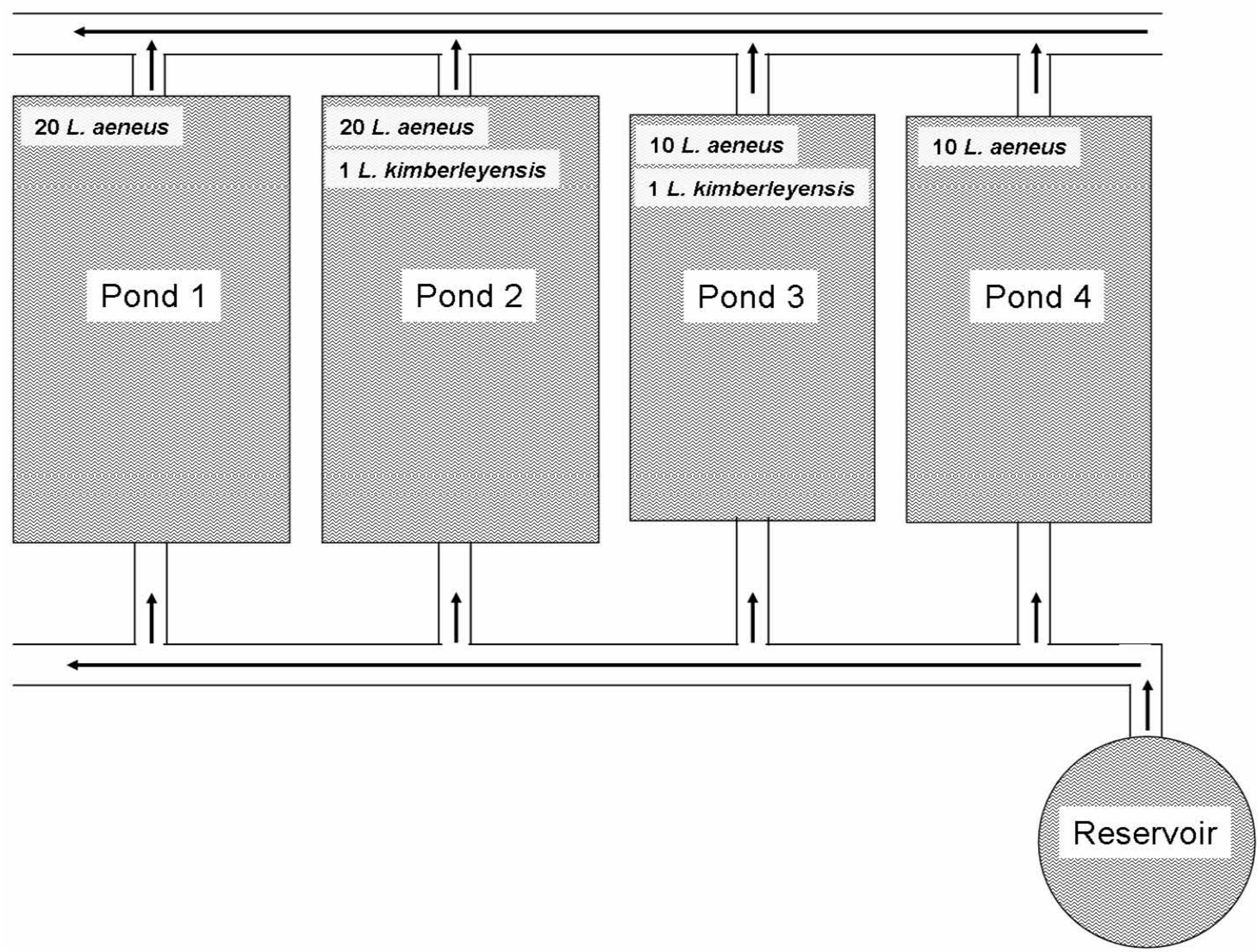

Figure 2.10 Design of the four ponds used in the validation experiment and the number of *L. aeneus* and *L. kimberleyensis* in each pond.

CHAPTER 3: The biology of *Labeobarbus aeneus* and *Labeobarbus kimberleyensis* in Lake Gariep

3.1. Introduction

Information on the life history of fish is important for the conservation and management of fish species (Young et al., 2006). Certain life history characteristics such as growth rates and age and length at maturity are important when considering how vulnerable a fish species may be to exploitation (Jennings et al., 1999; King and McFarlane, 2003).

The biology of *L. aeneus* has been documented in a number of South African waters (Hamman, 1981; Mulder, 1971; Tómasson, 1983; Weyl et al., in press). Although this may be the case, locality specific differences in the life history of the species has been reported (Weyl et al., in press). The life history of *L. aeneus* is characterised by slow growth rates, longevity of approximately 15 years, late maturity and moderate to low fecundity (Hamman, 1981; Mulder, 1971; Tómasson, 1983; Weyl et al., in press). Abundance and recruitment success is variable and highly dependant on environmental conditions (Tómasson et al., 1984).

Labeobarbus kimberleyensis has formed part of three biological studies on inland waters in South Africa (Hamman, 1981; Mulder, 1971; Tómasson, 1983). The large size attained by the species, and the inadequate gear selection to sample the species, has resulted in incomplete information on its life history (Hamman, 1981). It has been suggested that growth rates are slow and maturity is reached fairly late (Hamman, 1981; Tómasson, 1983).

As species that are slow growing and late maturing are vulnerable to exploitation (Jennings et al., 1999; King and McFarlane, 2003), and the biology *L. aeneus* is locality specific, the biology of the species in Lake Gariep needs to be investigated.

The purpose of this chapter is to describe the locality specific biology of *L. aeneus* and *L. kimberleyensis*, which involves determining growth rates, mortality and length and age at maturity. These biological parameters are important in providing baseline information and input for analytical fisheries models.

3.2. Materials & Methods

General

Samples were obtained using gillnets (for specific field methods see Chapter Two). All fish captured in gillnets were sorted to species level and weighed collectively. Catch per unit effort (*CPUE*) was calculated by:

$$\overline{CPUE} = \frac{\sum_{i=1}^{n} \left(C_i / E_i \right)}{n}, \qquad \text{(Equation 3.1)}$$

where Ci is the catch (in weight) of gear i, Ei is the effort expended by gear i and n is the number of gears. Effort units were standardised to net.night^{-1} for gillnets.

Gillnet catch per unit effort data were assessed for normality using Quantile-Quantile Plots (Statistica 8.0, StatSoft®). The data were not normally distributed and therefore log-transformed (ln x + 1) before being tested for differences between season and region with a Multi-Factorial ANOVA (Statistica 8.0, StatSoft®).

Maturity

Gonadosomatic index (GSI), as in Weyl and Booth (1999), was used to determine the spawning season and temporal patterns in gonadal development and expressed as:

$$\text{GSI} = \left[\frac{\text{Gonad mass (g)}}{\text{Eviscerated mass (g)}} \right] \text{x}\, 100 \qquad \text{(Equation 3.2)}$$

During the spawning season, *L. aeneus* were collected and used to determine the mean length-at-50 % sexual maturity (Lm_{50}). Fish were grouped into 10 mm length classes. Fish were considered mature if, during the spawning season, individuals were either stage developing, ripe/running or spent. The proportion of sexually mature fish per length class (ψ) by fork length (L) was fitted with a logistic ogive of the form:

$$\psi = \frac{1}{1 + e^{-(L - Lm_{50})/\delta}}, \qquad \text{(Equation 3.3)}$$

where Lm_{50} is the mean fork length at sexual maturity and δ is the width of the logistic ogive. In order to determine age-at-50 % maturity, the length frequency data were then converted into age frequency and fitted with the same logistic ogive using the age length keys presented in Table 3.5.

Sex ratio

Differences in sex ratio were tested using chi-square analysis. Three size classes (150-250 mm; 250-350 mm; > 350 mm FL) were tested for homogeneity between classes, as well as for unity using χ^2 contingency tables at a significance level of $p \leq 0.05$.

Condition factor

Seasonal condition factor (*CF*) was calculated as:

$$CF = \frac{Mass(ungutted)}{Fork \cdot length(cm)^3} x100$$

(Equation 3.4)

Regression analysis (MS Excel 2003, Microsoft®) and a students t-test (Statistica 8.0, StatSoft®) were used to test for differences between *CF* by length and seasonal *CF* respectively, at a significance level of $p \leq 0.05$.

Length/Weight relationship

The length weight relationship for *L. aeneus* and *L. kimberleyensis* from this study was compared to data from Hamman, (1981), which was included in the analysis. A students t-test (Statistica 8.0, StatSoft®) was used to test for differences between predicted weight at length for this study and Hamman, (1981), at a significance level of $p \leq 0.05$.

Age and growth

Otoliths of both *L. aeneus* and *L. kimberleyensis* were read whole, immersed in methyl-salicylate, and viewed using a dissecting microscope under transmitted light at various magnifications (10 – 40 x). On each otolith the pairs of opaque and translucent growth zones were counted twice. These counts were two weeks apart.

If reading one and two were the same then the age estimation was accepted, if the readings differed, a third reading was done. After the third reading, those readings that were the same as either reading one or two were accepted. Those readings that differed by up to two were averaged over the three readings and the mean age taken. The readings that differed by more than two were rejected (Figure 3.1).

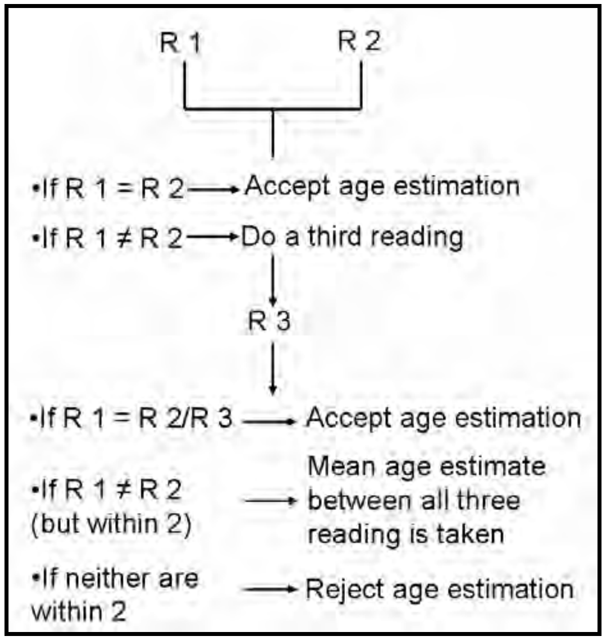

Figure 3.1 Otolith reading protocol, showing the procedure followed to accept or reject otoliths (R 1 = Reading one; R 2 = Reading two; R 3 = Reading three) of *L. aeneus* and *L. kimberleyensis* from Lake Gariep.

The precision of age estimation was calculated using the average percentage error method (Beamish and Fournier, 1981), which is defined as:

$$APE_j = 100\% x \frac{1}{R} \sum_{i=1}^{R} \frac{(X_{ij} - X_j)}{X_j} \qquad \text{(Equation 3.5)}$$

Where X_{ij} is the ith age determination of the jth fish, X_j is the mean age estimate of the jth fish, and R is the number of times each fish is aged. The standard deviation was then substituted for the absolute deviation from the mean age, which is the coefficient of variation (CV) that was calculated as:

$$CV_j = 100\% x \frac{\sqrt{\sum_{i=1}^{R} \frac{(X_{ij} - X_j)^2}{R-1}}}{X_j}$$ (Equation 3.6)

where *CVj* is the age precision estimate for the *j*th fish. The *CV* can be averaged across all fish to produce a mean *CV*. The index of precision (*D*) is then calculated as in Chang, (1982):

$$D_j = \frac{CV_j}{\sqrt{R}}$$ (Equation 3.7)

The percent error in each age was obtained by multiplying the index of precision (*Dj*), by the average age for the *j*th fish.

Due to a distinct spawning season (January 2008), the assumption was made that all fish were hatched in the mode of the spawning season. Age determinations were then back calculated using the previous spawning season. For example, if the spawning season was in January and a fish was caught in May and had four opaque rings, the actual age was calculated as:

4 rings = 48 months – 4 months (May-Jan), and a subsequent final age of 3.4 years was assigned.

Age and growth data were fitted with the von Bertalanffy growth model (VBGF) where:

$$L_t = L_\infty(1 - e^{-K(t-t_0)})$$ (Equation 3.8)

where t_0 is the age at "zero" length; L_∞ is the predicted asymptotic FL and K is the Brody growth co-efficient (Ricker, 1975). For variance estimates the (conditioned) parametric bootstrap resampling method (Efron, 1982) with 1 000 bootstrap iterations was used. Standard errors and 95 % confidence intervals were constructed from the bootstrap data using the percentile method (Buckland, 1984). In order to include ageing error into the VBGF, the Random Effects (RE) methods as proposed by Cope and Punt, (2007) was used. Only the first two readings were included as they had the same number of observations. A likelihood ratio test was used to test for differences in growth rates between sexes at a significance level of $p \leq 0.05$ (Cerrato, 1990).

Mortality

Mortality was estimated for fish sampled using gill nets, and a correction factor was applied to correct for gillnet selectivity. The instantaneous rate of total mortality (*Z*) was estimated by catch curve analysis (Ricker, 1975). A catch curve is constructed by plotting natural logarithms of abundance estimates of a year class at each age (Ricker, 1975). Catch curve analysis involves the calculation in the change in numbers over a change in time (age). This is calculated by the conversion of length frequency distributions to age frequency distributions using a length age key. Catch curve analysis only gives and indication of total mortality (*Z*) and cannot indicate what proportion of the total mortality is as a consequence of fishing (*F*) or natural causes (*M*) (King, 1995). Thus a first approximation of natural mortality (*M*) was obtained using the empirical relationship proposed by Pauly, (1980), where:

$$\ln(M) = -0.0152 - 0.279 \ln L_{\infty} + 0.6543 \ln K + 0.463 \ln T \qquad \text{(Equation 3.9)}$$

where L_{∞} and *K* are the von Bertalanffy growth parameters and *T* is the mean lake temperature (^{o} C). Differences in growth rate between sexes resulted in mortality estimates being separated by sex. Fishing mortality (*F*) was calculated by using the estimates of *Z* and *M* where:

$$F = Z - M \qquad \text{(Equation 3.10)}$$

Selectivity

Gillnet selectivity was estimated for 44, 60, 75, 100 and 144 mm mesh sizes using the Select method (Millar and Holst, 1997). This method was chosen as it was suggested to be a rigorous method of fitting gillnet selectivity to the similar body shaped cyprinid, *Labeo umbratus* (Booth and Potts, 2006). The largest mesh size (144 mm) was excluded for *L. aeneus* as only three fish were caught in it. *Labeobarbus kimberleyensis* were only represented sufficiently in the 100 and 144 mm mesh sizes. In Select, the selectivity of a gillnet with mesh size *i* catching a fish of age *t*, S_t^{GNi}, is described as:

$$S_t^{GNi} = \exp\left(- \frac{\left(t - t_r^{GNi}\right)^2}{2(\delta^{GNi})^2} \right) \qquad \text{(Equation 3.11)}$$

where t_r denotes the age at selection and δ the standard deviation of the gillnet curve or the inverse rate of selection for the logistic ogive.

Age validation

Two methods were used to validate the periodicity of growth increment formation in *L. aeneus* and *L. kimberleyensis* otoliths. The first method was by Marginal Zone Analysis (MZA) and the second by the mark-recapture of chemically tagged captive fish held under the conditions described in Chapter Two.

In MZA, the outer margin of otoliths from fish samples collected on a bi-monthly basis was examined. Growth on the otolith is reflected by the deposition of alternating opaque and translucent zones. On the outer margin of the otolith, the type of zone was noted (i.e. opaque or translucent). The composition of the outer margin was noted and expressed as a percentage of the monthly sample (Figure 3.2).

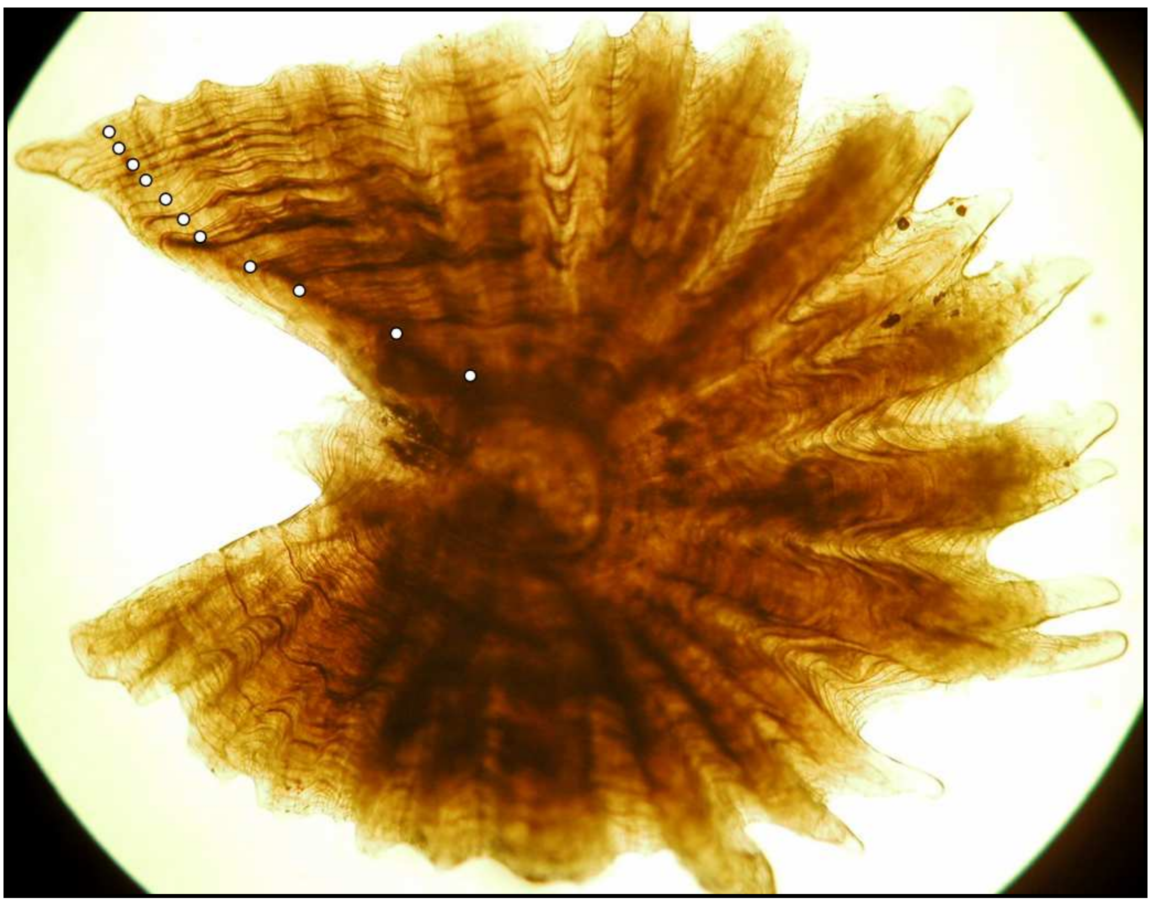

Figure 3.2 An 11 year old, 400 mm FL *L. aeneus* otolith viewed immersed in methyl salicylate under transmitted light at 40 x magnification. Note the translucent margin.

The mark-recapture of chemically tagged fish relies on the assimilation of the calcium binding chemical oxytetracycline-tetrachloride (OTC) at the time of tagging into the otolith (Campana, 2001). Wild-captured individuals were injected with OTC and placed in holding ponds for a minimum period of a year. The result is a fluorescent mark on the growth increment at the time of tagging. The number of rings laid down between the OTC mark and the margin of the otolith are then used to indicate the periodicity of growth increment formation.

Individuals of both *L. aeneus* and *L. kimberleyensis* were captured using rod and line. The fish were then injected with OTC and placed in ponds at low stocking densities. The fish were left in the pond for a minimum of 12 months before being recaptured and the otoliths removed. Otoliths were viewed whole under a compound microscope at 40 x magnification using fluorescent and transmitted light (for specific details see Chapter Two).

3.3. Results

Gillnet species composition

Species composition and relative abundance is summarised in Figure 3.3. Two species dominated (79 %) the experimental gillnet fleet catches from Lake Gariep. *Labeo capensis* (41 %) was the most dominant species, followed by *L. aeneus* (38 %). Of the remaining four species, *L. kimberleyensis*, *Clarias gariepinus*, *Cyprinus carpio* and *Labeo umbratus* contributed 8 %, 7 %, 5 %, 1 % respectively. A single individual of each *Austroglanis sclateri* and *Oncorhynchus mykiss* were caught during the study.

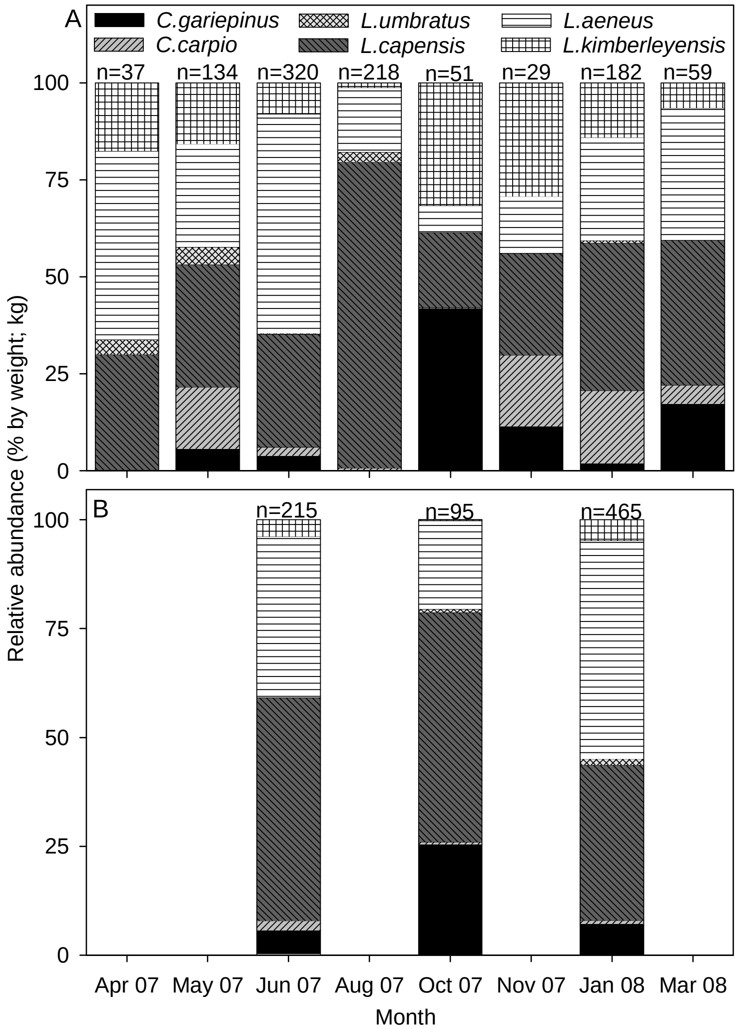

Figure 3.3 Monthly species composition and relative abundance (% by weight) of the six most abundant species from gillnet catches in the Oviston/Venterstad (A) and Gariep Dam (B) regions of Lake Gariep (n = kilograms of fish).

Labeobarbus aeneus

CPUE

Changes in catch per unit effort were used as an indication of whether *L. aeneus* abundance changed seasonally by area (Figure 3.4). *Labeobarbus aeneus CPUE* differed seasonally ($p \leq 0.05$). The *CPUE* of *L. aeneus* displayed seasonal trends when separated regionally for Lake Gariep (Figure 3.4). In the OV region, *CPUE* was highest in the winter (9.02 ± 8.41 $kg.net.night^{-1}$) and lowest the summer (2.42 ± 2.28 $kg.net.night^{-1}$). The opposite trend was observed in the GD region where *CPUE* was lowest in winter and highest in summer (11.66 ± 12.71 $kg.net.night^{-1}$).

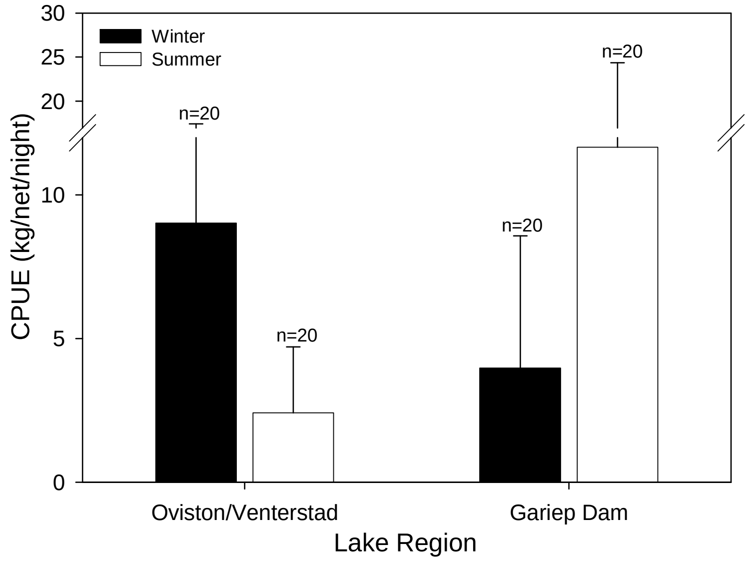

Figure 3.4 Mean seasonal catch per unit effort for *L. aeneus* separated for the Oviston/Venterstad and Gariep Dam regions of Lake Gariep (n=net nights).

Maturity

A total of 925 *L. aeneus* were sexed and assigned a gonad developmental stage during the study period. The sample consisted of 512 females and 413 males. Overall sex ratios for *L. aeneus* differed significantly ($\chi^2 = 27.13$; df = 1; $p < 0.0001$) (Figure 3.5).

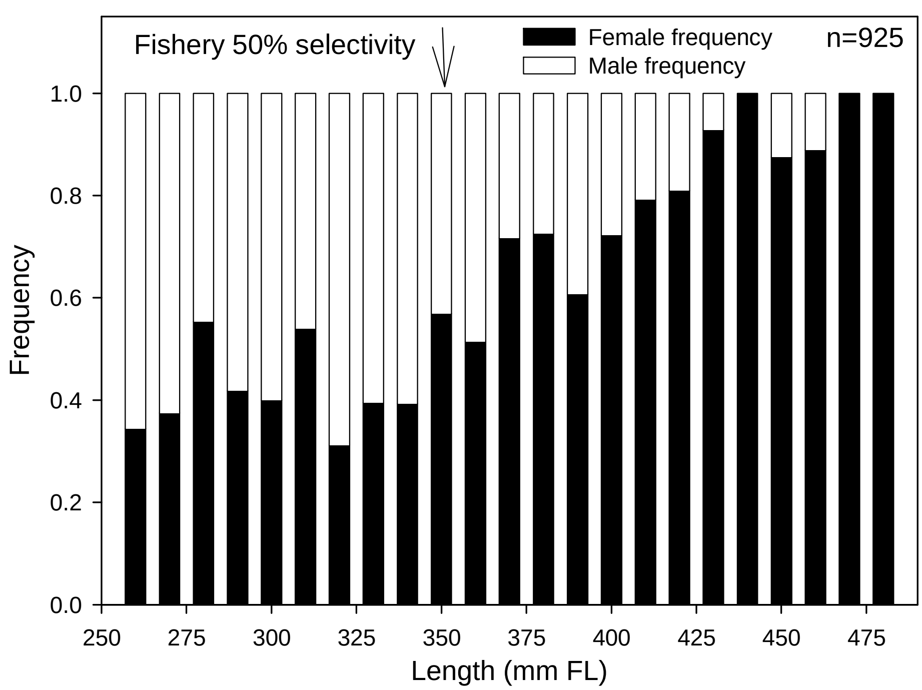

Figure 3.5 Sex ratio changes by 10 mm length classes for male and female *L. aeneus* from Lake Gariep (2007/2008).

The sex ratio between size classes (150-250 mm; 250-350 mm ;> 350 mm FL) also differed significantly ($\chi^2 = 75.42$; df = 2; $p < 0.0001$). When tested against unity, the sex ratio for fish 150-250 mm FL and 250-350 mm FL did not differ significantly. There were significant differences from unity for fish > 350 mm FL in length ($\chi^2 = 97.91$; df = 1; $p < 0.0001$). From significant differences in sex ratio changes with length in *L. aeneus*, it was decided to separate age and growth, maturity and mortality by sex in order to provide separate life history characteristics.

During the spawning season (January 2008), 230 female and 197 male *L. aeneus* were collected and used to determine the length-at-50 % sexual maturity Lm_{50} (Figure 3.6). Length and age at sexual maturity differed between sexes for *L. aeneus*. Males reached Lm_{50} earlier (231 mm FL; 2 years) than females (354 mm FL; 5.5 years).

Gonadal recrudescence followed distinct seasonal trends and is summarised in Figure 3.7 A and B. Gonadosomatic index (GSI) was consistently low during the winter months and highest during the summer months (Figure 3.7 A). At the end of summer and the onset of winter, GSI from June to November decreased. Gonadosomatic index peaked to the highest level during the study period in January and dropped towards June. The spawning season for *L. aeneus* in Lake Gariep therefore extends from January to June. *Labeobarbus aeneus* spawned in the summer.

Visual gonad staging followed similar trends to the GSI (Figure 3.7 B). In July and September, females were predominantly resting (F2) or spent (F5), the gonads began to develop in November (F3) and females were predominantly ripe and running in January (F4). In March and June, there were still reproductively active females sampled from the population, although the largest proportion of females were spent (F5).

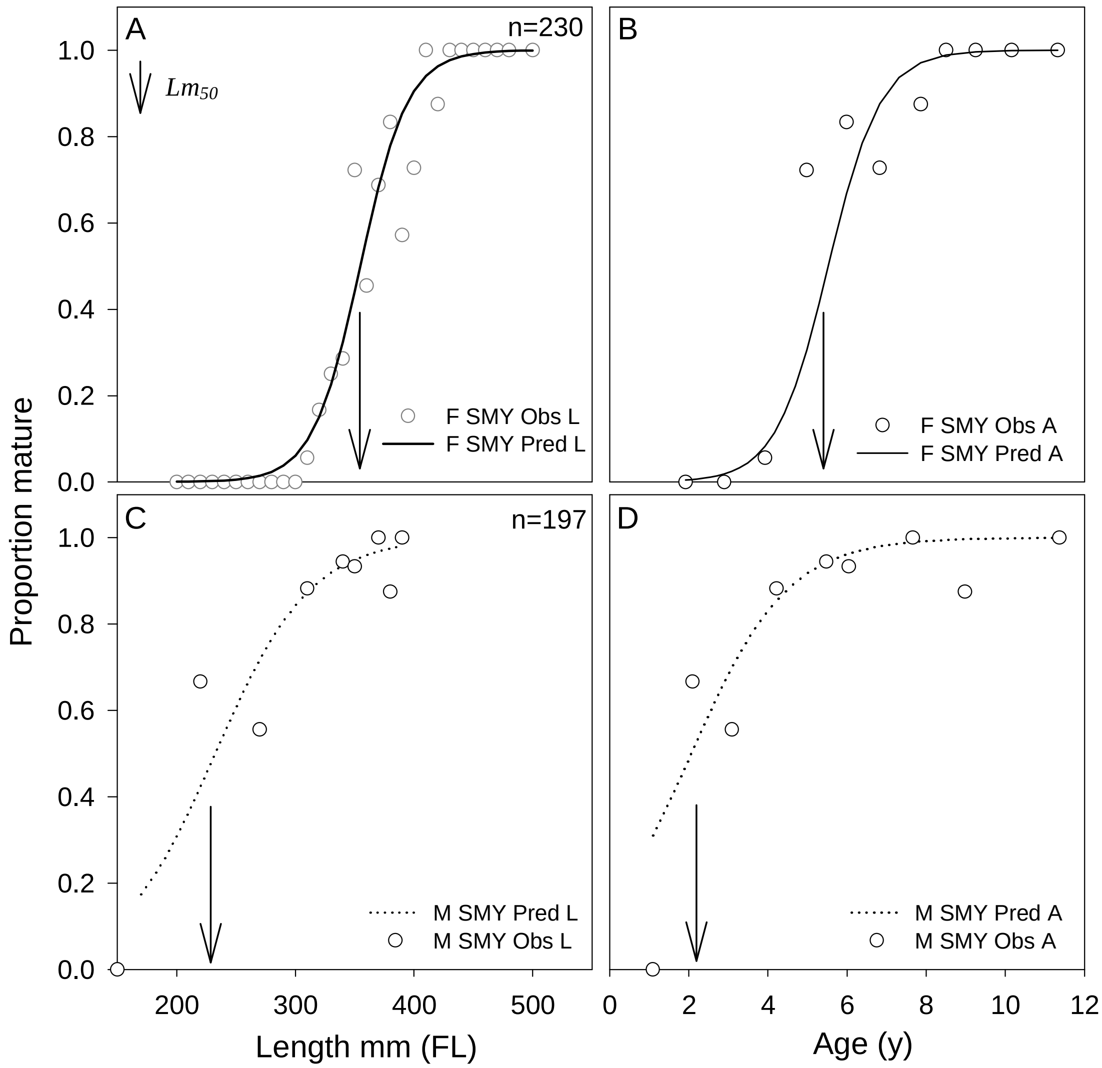

Figure 3.6 Length (A, C) and age (B, D)-at-50 % sexual maturity for *L. aeneus* females (solid line) and males (dotted line) from Lake Gariep (2007/2008).

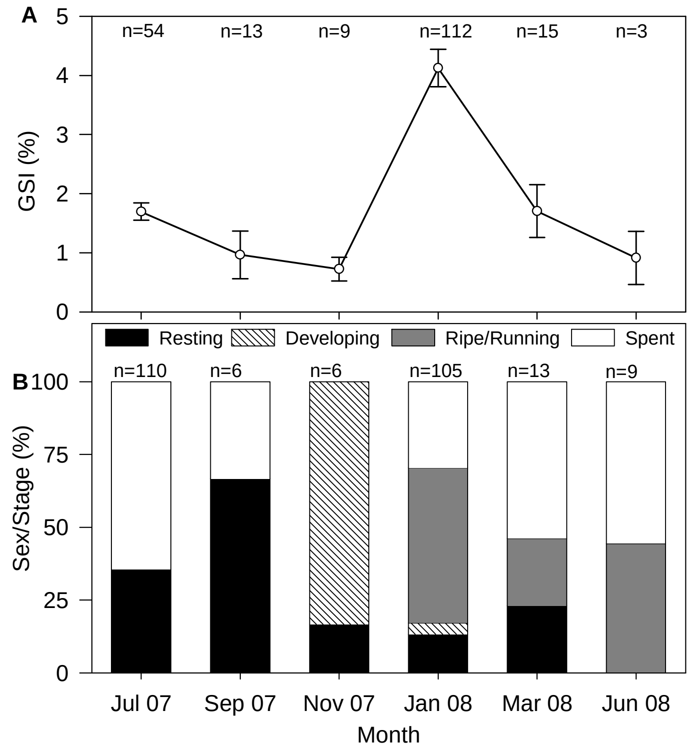

Figure 3.7 (A) Bi-monthly gonadosomatic indices for *L. aeneus* from Lake Gariep (2007/2008). Error bars denote standard error. (B) Proportion of bi-monthly percentages of the visual gonad staging for mature *L. aeneus* (Lm_{50} = 354 mm FL).

Length weight/condition factor

The length/weight relationships for *L. aeneus* is summarised in Table 3.1. Length/weight relationships differed significantly between this study and Hamman, (1981) ($p \leq 0.05$).

Table 3.1 Length/weight relationship comparisons between this study[1] and Hamman, (1981)[2] for whole and gutted *L. aeneus* (separated by sex) and *C. carpio* (Winker et al., unpublished data)[3] from Lake Gariep.

Relationship	Whole mass	r^2	Eviscerated mass	r^2	n
***L. aeneus* (M)**					
Wt (g)[1]	$0.000009 \times FL (mm)^{3.081}$	0.95	$0.000012 \times FL(mm)^{3.014}$	0.91	419
Wt (g)[2]	$0.000146 \times FL (mm)^{2.987}$	0.99		0.99	
***L. aeneus* (F)**					
Wt (g)[1]	$0.000007 \times FL (mm)^{3.119}$	0.97	$0.000011 \times FL (mm)^{3.032}$	0.91	515
Wt (g)[2]	$0.000177 \times FL (mm)^{2.926}$	0.99		0.99	
Both sexes					
Wt (g)[1]	$0.000008 \times FL (mm)^{3.102}$	0.96	$0.000011 \times FL (mm)^{3.023}$	0.91	924
C. carpio					
Wt (g)[3]	$0.00000004 \times FL (mm)^{2.843}$		$0.00000006 \times FL (mm)^{2.791}$		

Table 3.2 Summary of seasonal condition factor for male and female *L. aeneus* from Lake Gariep (2007/2008) (calculated in cm for comparison to historical data).

Sex	Condition Factor	
	Summer	Winter
L. aeneus		
Males	1.47 ± 0.13	1.46 ± 0.18
Female	1.51 ± 0.14	1.50 ± 0.13
All fish	1.47 ± 0.20	

Age validation

Marginal Zone Analysis

Marginal Zone Analysis of *L. aeneus* otolith margins indicated that only one opaque zone is deposited per year (Figure 3.8). The otolith margins were predominantly opaque between May and November 2007, whereafter the percentage of opaque margins decreased and the translucent margins increased in January and March 2008.

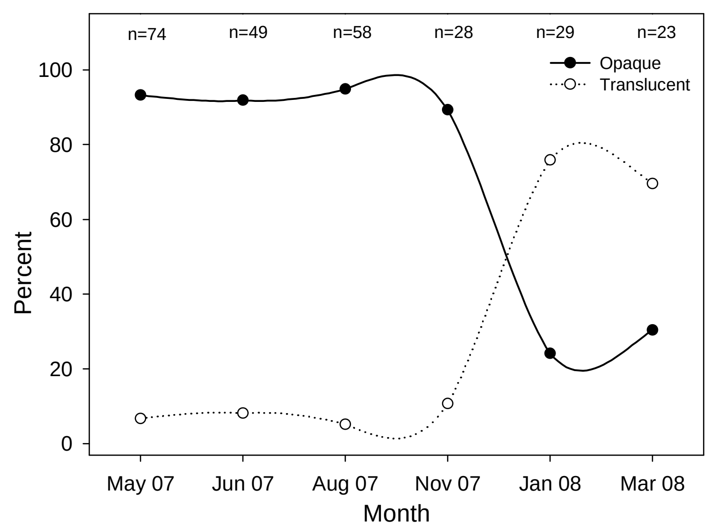

Figure 3.8 The monthly percentage occurrence of opaque and translucent zones on the otolith margin of *L. aeneus* from Lake Gariep (2007/2008).

Mark-recapture of chemically tagged fish

Of the 60 chemically tagged *L. aeneus*, 23 were recaptured from the ponds, after being at liberty for more than a year. The OTC and growth zone deposition before and after the OTC mark on the otoliths of the 23 *L. aeneus* recaptured are summarised in Table 3.3. A single growth zone, comprising one opaque and one translucent zone, was deposited during this time in all otoliths (Figure 3.9). Maximum age recorded from the chemically tagged fish was 14 years. This is older than the maximum recorded age of 12 years for *L. aeneus* caught in gillnets. The fish for the age validation study were caught in the Orange River, and not in Lake Gariep, which may explain the discrepancy in maximum ages.

Table 3.3 Summary of the tag date (TD), years at liberty (YL), recapture date (RD), fork length (FL), sex (m,f), visible fluorescent mark (F), the number of pre-F and post-F growth zones and the estimated total age for OTC marked *L. aeneus* from the mark recapture of chemically tagged fish.

							Growth zones		
Species	**TD**	**YL**	**RD**	**L**	**S**	**F**	**Pre – F**	**Post - F**	**Total**
L. aeneus			17/01/2008	458	f	Y	9	1	10
L. aeneus			17/01/2008	361	m	Y	6	1	7
L. aeneus			08/05/2008	387	f	Y	7	1	8
L. aeneus			08/05/2008	412	f	Y	10	1	11
L. aeneus			08/05/2008	433	m	N	-	-	-
L. aeneus			08/05/2008	400	m	N	-	-	-
L. aeneus	10/03/2007	1.2	08/05/2008	515	f	Y	13	1	14
L. aeneus			08/05/2008	472	f	Y	10	1	11
L. aeneus			08/05/2008	407	f	Y	8	1	9
L. aeneus			08/05/2008	399	m	Y	8	1	9
L. aeneus			08/05/2008	414	f	Y	9	1	10
L. aeneus			09/05/2008	475	f	Y	10	1	11
L. aeneus	10/03/2007	1.2	09/05/2008	480	f	Y	12	1	13
L. aeneus			09/05/2008	420	f	Y	9	1	10
L. aeneus			09/05/2008	385	m	Y	8	1	9
L. aeneus			09/05/2008	421	f	Y	9	1	10
L. aeneus			09/05/2008	400	m	Y	10	1	11
L. aeneus			09/05/2008	425	f	Y	10	1	11
L. aeneus			09/05/2008	407	m	Y	9	1	10
L. aeneus			09/05/2008	442	f	Y	10	1	11
L. aeneus			09/05/2008	440	f	Y	-	1	-
L. aeneus			09/05/2008	405	f	Y	8	1	9
L. aeneus			09/05/2008	416	f	Y	10	1	11
L. aeneus			09/05/2008	467	f	Y	11	1	12
L. aeneus			09/05/2008	416	m	Y	9	1	10

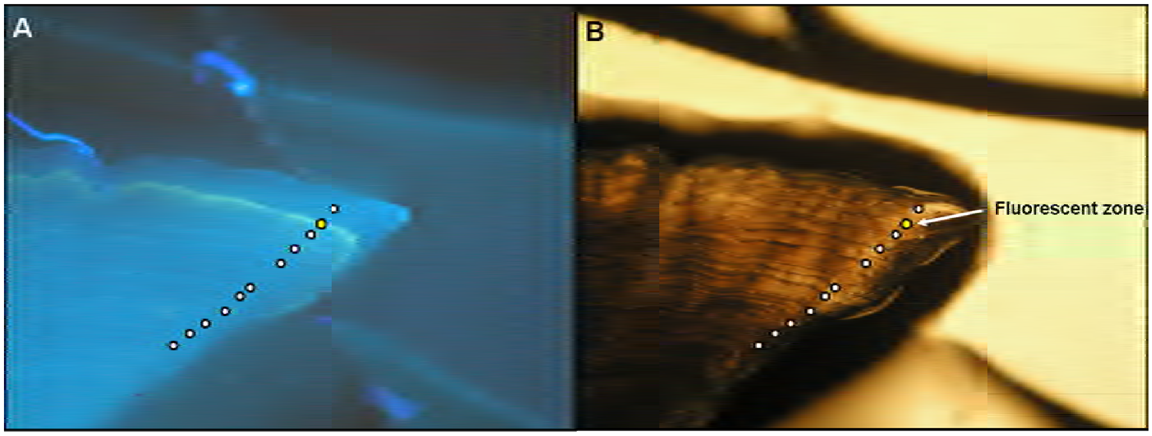

Figure 3.9 (A) *Labeobarbus aeneus* otolith viewed under transmitted light, the yellow dot denotes the fluorescent zone where the OTC was deposited. (B) The same *L. aeneus* otolith as in A, but viewed under fluorescent transmitted light, which makes the OTC band visible.

Age and growth

Otoliths from 388 *L. aeneus* were used for age estimation. Of these, 5.2 % were rejected due to lack of precision between readings. The average percentage error between readings was 6.3 %, the coefficient of variation 3.1 % and an index of precision of 1.8 (Figure 3.10). Growth of *L. aeneus* was described using the von Bertalanffy growth function and the parameters are summarised in Table 3.4. Maximum age and length for *L. aeneus* females was higher than that observed for males (12 years; 496 mm FL and 11 years; 427 mm FL respectively) (Figure 3.11). Growth rate ($p \leq 0.05$) and maximum length ($p \leq 0.05$) differed significantly between sexes (Figure 3.11 D).

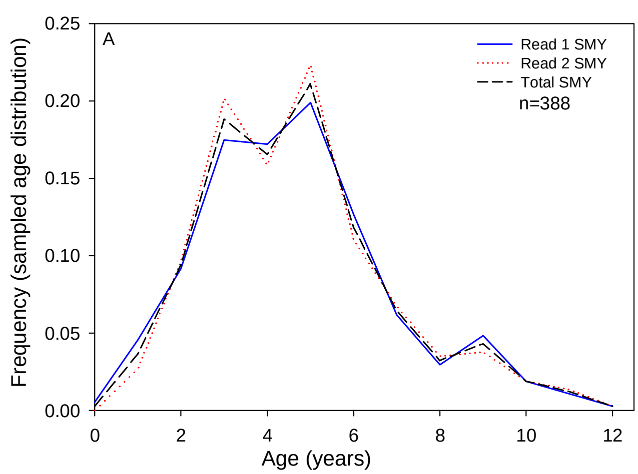

Figure 3.10 The sampled age frequency of otolith reading one and two for *L. aeneus* and, as well as the combined frequency of both readings. The similarity between the two age estimates illustrates the precision between each read.

Table 3.4 von Bertalanffy growth parameters from Lake Gariep for *L. aeneus* males, females, combined sexes and the associated variance estimates (Efron, 1982). Maximum likelihood estimates (MLE), standard errors (SE), upper (UCI) and lower (LCI) 95 % confidence intervals were constructed using the percentile method (Buckland, 1984).

Sex	L_∞	K	t_0
	MLE ± SE [LCI : UCI]	**MLE ± SE [LCI : UCI]**	**MLE ± SE [LCI : UCI]**
Females	491.7 ± 16.2 [465.2 : 528.3]	0.23 ± 0.02 [0.19 : 0.27]	-0.29 ± 0.13 [-0.60 : -0.05]
Males	398.3 ± 16.2 [373.5 : 436.5]	0.33 ± 0.04 [0.25 : 0.41]	-0.34 ± 0.16 [-0.70 : -0.04]
Both sexes	481.8 ± 15.5 [454.0 : 514.6]	0.22 ± 0.02 [0.18 : 0.26]	-0.61 ± 0.15 [-0.93 : -0.34]

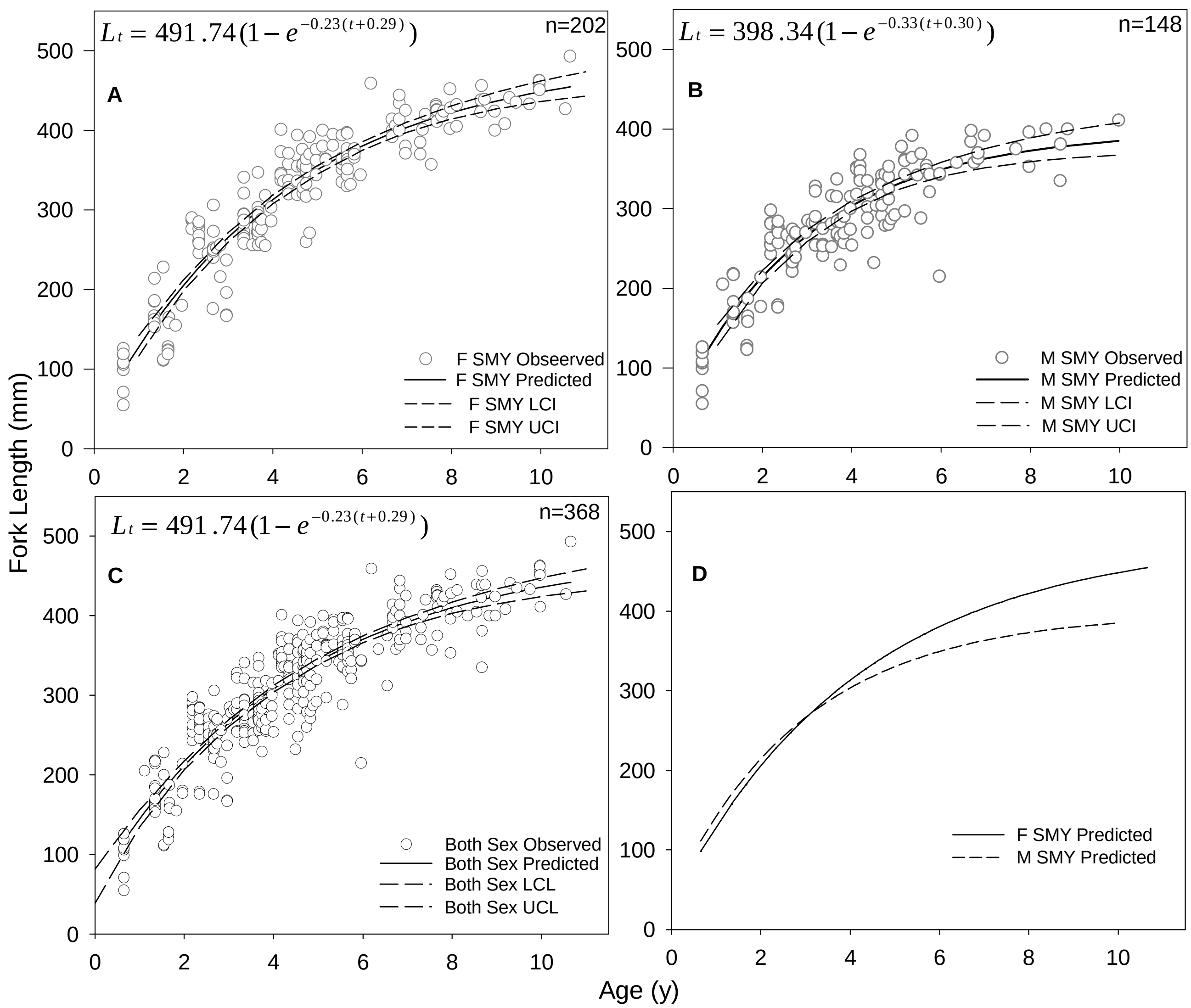

Figure 3.11 *Labeobarbus aeneus* von Bertalanffy growth curves from Lake Gariep (2007/2008) illustrating individual mean lengths at age for females(A), males (B), both sexes (C), and a comparison between male and female predicted curves (D) (Dotted lines denote the 95 % confidence intervals from the bootstrapped predicted lengths at-age).

Mortality

Gillnet selectivity distributions and the numbers at age matrices for *L. aeneus* are presented in Figure 3.12 and Table 3.5, respectively. Few fish were sampled in the zero to five age class as well as from the 10 to 12 age class. Subsequently mortality was estimated by catch curve analysis for age classes five to 10 for both sexes (Figure 3.13). Total mortality (Z) was estimated at 0.54·year $^{-1}$ for female *L. aeneus* and 0.46·year $^{-1}$ for males (Figure 3.13 A and B, respectively). Natural mortality for females was estimated at 0.46·year $^{-1}$. From these values, fishing mortality ($Z – M = F$) for females was estimated to be 0.09·year $^{-1}$.

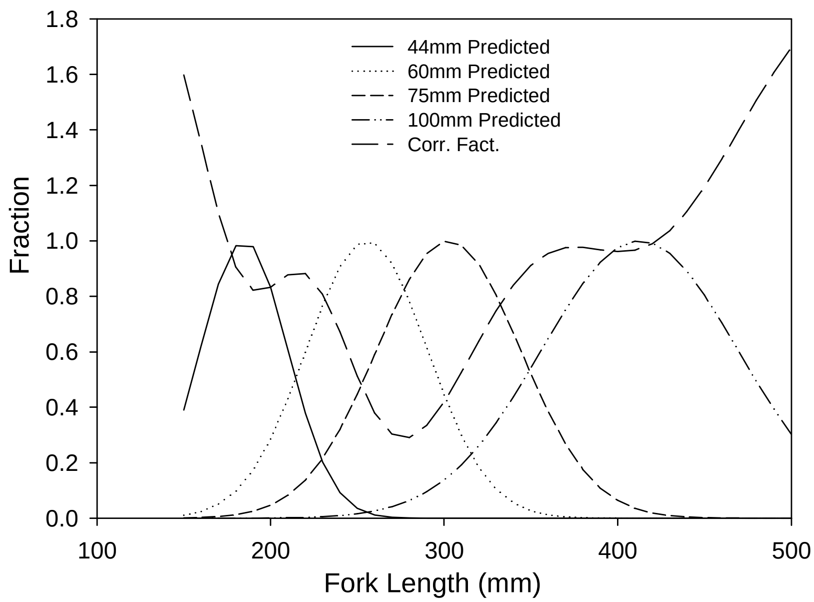

Figure 3.12 Predicted gillnet selectivity and a correction factor by mesh size for *L. aeneus* from Lake Gariep (2007/2008).

Table 3.5 Numbers at age matrix for *L. aeneus* males and females from Lake Gariep (2007/2008).

Length	**Females**											**Males**									
(mm FL)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
141-150	9	7										9	3								
151-160		7											2								
161-170		6	2										4								
171-180		2	3										1	2							
181-190		4											2								
191-200		1	1																		
201-210		1											1								
211-220		5	1			1							4				1				
221-230		1	2	1										2	1						
231-240			4	1										2	1						
241-250			8	2	1									3	1						
251-260			12	13	1									4	8						
261-270			1	9	1									7	4	1					
271-280			9	1	3									3	2	2					
281-290			9	13	3	1								4	7	2	1				
291-300			1	7	2	1								1	1	2	1				
301-310			1	2	3											3					
311-320				4	9		1								3	4					
321-330				3	9	2									2	2	1				
331-340				2	12	3			1						1	6				1	
341-350				2	1	7										5	5				
351-360					1	9	2	2								3	2	2	1		
361-370					6	13	3									1	3	2			
371-380					4	6	3	1									1		1		
381-390						1	2		1									1		1	
391-400					2	7	5	1	3								1	2	1	2	
401-410					1		1	2	2	1											
411-420							3	2		1											1
421-430							1	6	2		1										
431-440							1	1	4	2											
441-450							1		1												
451-460							1	1	1	2											
461-470										2											
471-480																					
481-490																					
491-500											1										
Total	**9**	**34**	**54**	**60**	**59**	**51**	**24**	**16**	**15**	**8**	**2**	**9**	**17**	**28**	**31**	**31**	**16**	**7**	**3**	**4**	**1**

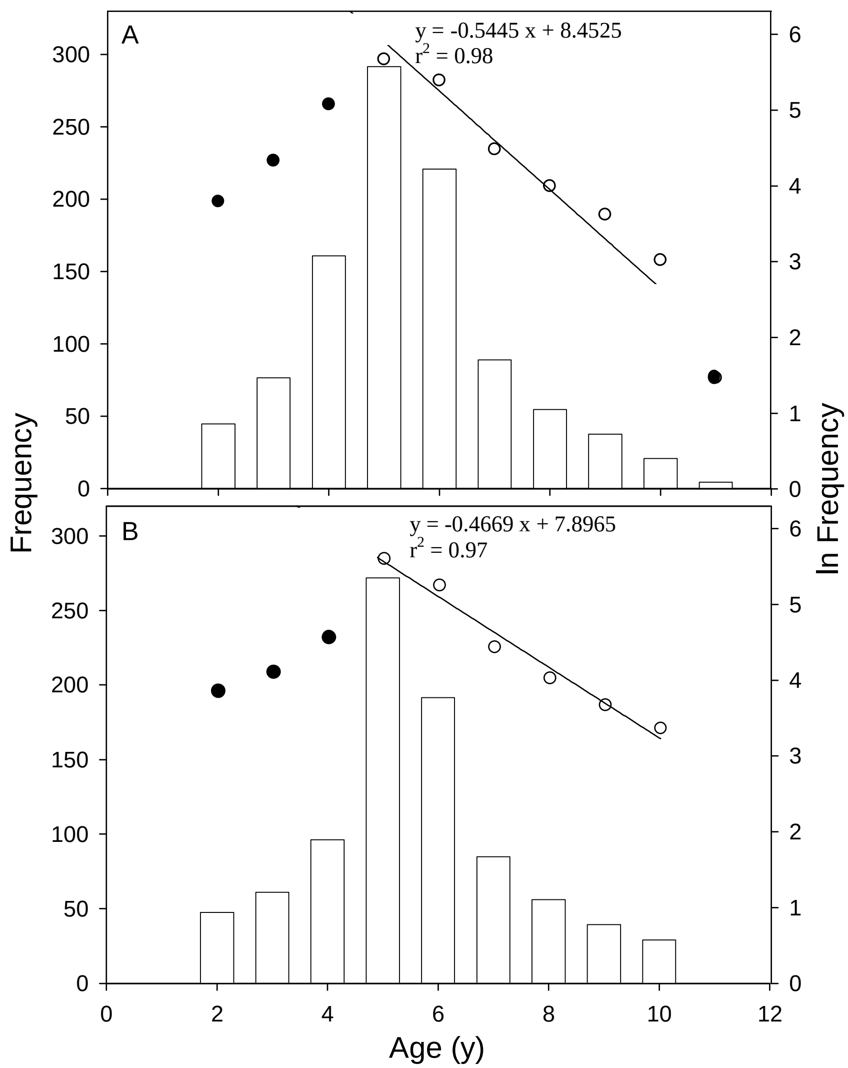

Figure 3.13 Selectivity corrected total mortality (*Z*) estimates for *L. aeneus* females (A) and males (B) from Lake Gariep (2007/2008). Open circles denote ages used for mortality estimates, while closed circles denote those ages not included.

Labeobarbus kimberleyensis

Maturity

Only 6 mature female and 15 mature male *L. kimberleyensis* were recorded during the study period. The smallest mature female was a 390 mm stage four female and the earliest recorded mature male was a 337 mm, ripe running male.

Length weight

Length/weight relationships for *L. kimberleyensis* are summarised in Table 3.6.

Table 3.6 Length/weight relationship comparisons between this study[1] and Hamman, (1981)[2] for whole and gutted *L. kimberleyensis* from Lake Gariep (2007/2008).

Relationship	Whole mass	r^2	Eviscerated mass	r^2	n
L. kimberleyensis					
Both sexes					
Wt (g)[1]	0.000003 x FL (mm)$^{3.275}$	0.98	0.000003 x FL (mm)$^{3.217}$	0.98	61
L. kimberleyensis (M)					
Wt (g)[2]	0.000074 x FL (mm)$^{3.197}$	0.99			
L. kimberleyensis (F)					
Wt (g)[2]	0.000084 x FL (mm)$^{3.162}$	0.99			

Age validation

Marginal Zone Analysis

Marginal zone analysis of *L. kimberleyensis* otolith margins indicated that only one opaque zone is deposited per year, with peak opaque zone deposition occurring between June and November 2007 (Figure 3.14). Sample size was however low, but predicted results are similar to those found for *L. aeneus* from Lake Gariep.

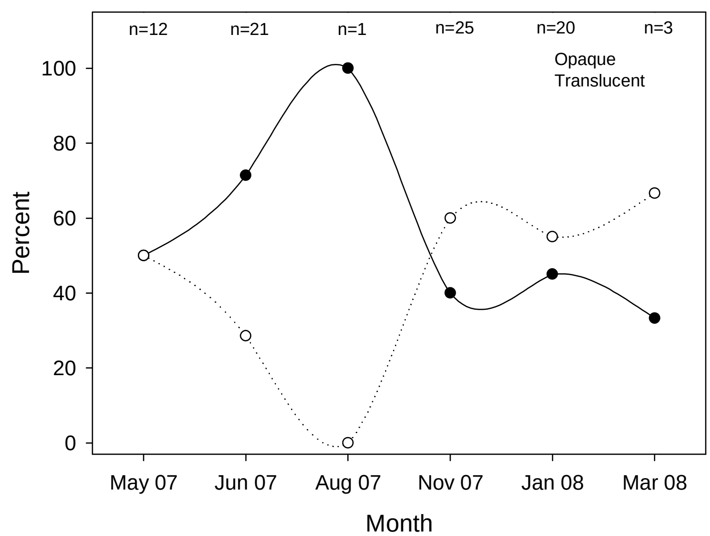

Figure 3.14 The monthly percentage occurrence of opaque and translucent zones on the otolith margin of *L. kimberleyensis* sampled from Lake Gariep (2007/2008).

Mark-recapture of chemically tagged fish

Of the two chemically tagged *L. kimberleyensis*, one was recaptured from the ponds, after being at liberty for more than a year. Eleven growth zones were counted before the fluorescent OTC band, and a single growth zone after the fluorescent band. Marginal Zone Analysis is in agreement with the results from the chemically tagged fish and a single growth zone, comprising one opaque and one translucent zone, was deposited during this time (Figure 3.15).

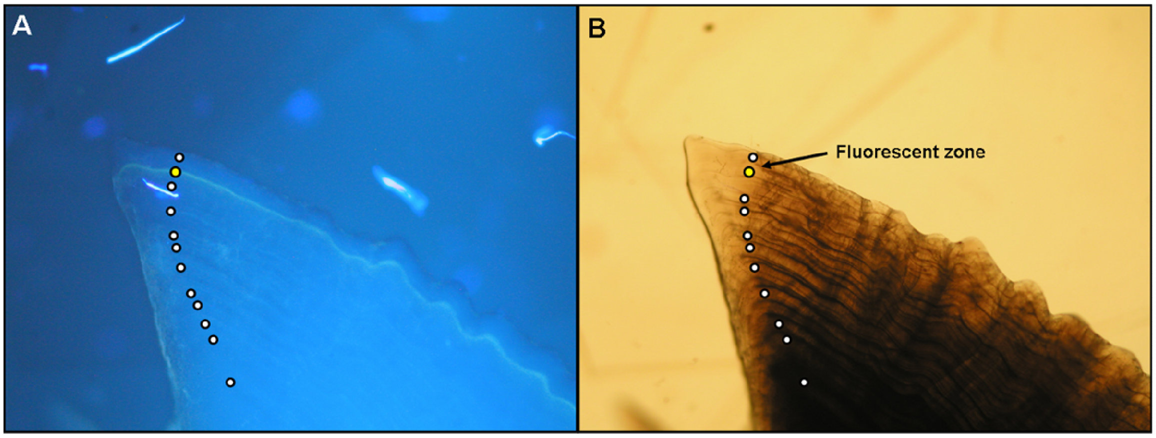

Figure 3.15 (A) *Labeobarbus kimberleyensis* otolith viewed under transmitted light, the yellow dot denotes the fluorescent zone where the oxytetracycline is deposited. (B) The same *L. kimberleyensis* otolith as in A, viewed under fluorescent transmitted light, which makes the fluorescent band clearly visible.

Age and growth

Ninety *L. kimberleyensis* otoliths were used for age estimation. Of these, 1.1 %, were rejected due to lack of precision between readings. The average percentage error between readings was 4.5 %, the coefficient of variation 0.9 % and an index of precision of 0.02 (Figure 3.16). The oldest *L. kimberleyensis* aged during the study period was a 16 year old 690 mm FL female fish (Figure 3.17). The von Bertalanffy growth parameters are summarised in Table 3.7.

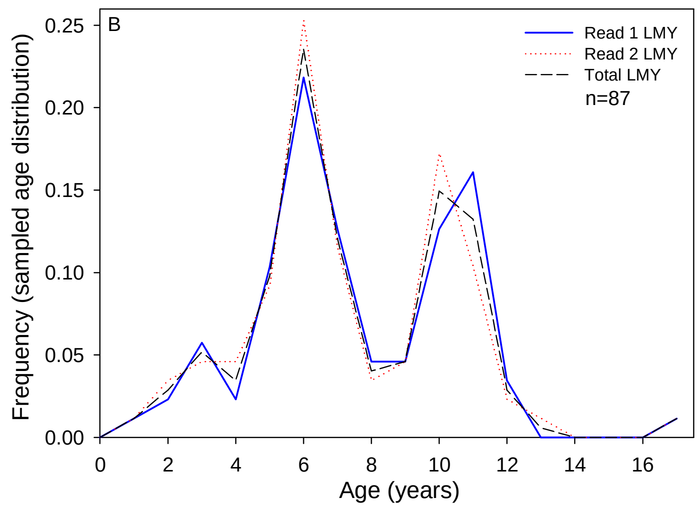

Figure 3.16 The sampled age frequency of otolith reading one and two for *L. kimberleyensis*, as well as the combined frequency of both readings. The similarity between the two age estimates illustrates the precision between each read.

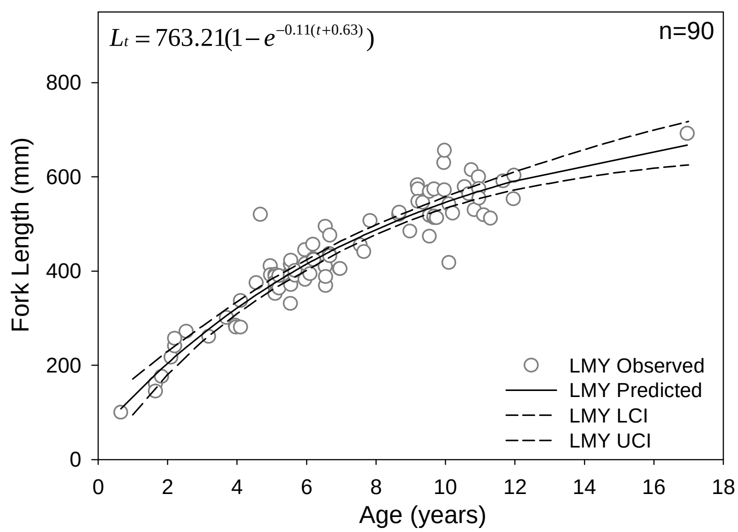

Figure 3.17 *Labeobarbus kimberleyensis* von Bertalanffy growth curve illustrating individual mean lengths at age from Lake Gariep (2007/2008) (Dotted lines denote the 95 % confidence intervals from the bootstrapped predicted lengths at-age) sampled fro Lake Gariep.

Table 3.7 von Bertalanffy growth parameters for *L. kimberleyensis* and the associated variance estimates (Efron, 1982). Maximum likelihood estimates (MLE), standard errors (SE), upper (UCI) and lower (LCI) 95 % confidence intervals were constructed using the percentile method (Buckland, 1984).

Both sexes	L_∞	**K**	t_0
MLE ± SE [LCI : UCI]	763.2 ± 75.2 [667.7 : 958.2]	0.11 ± 0.02 [0.07 : 0.16]	-0.63 ± 0.43 [-1.67 : 0.04]

Mortality

The gillnet selectivity distribution is presented in Figure 3.18.

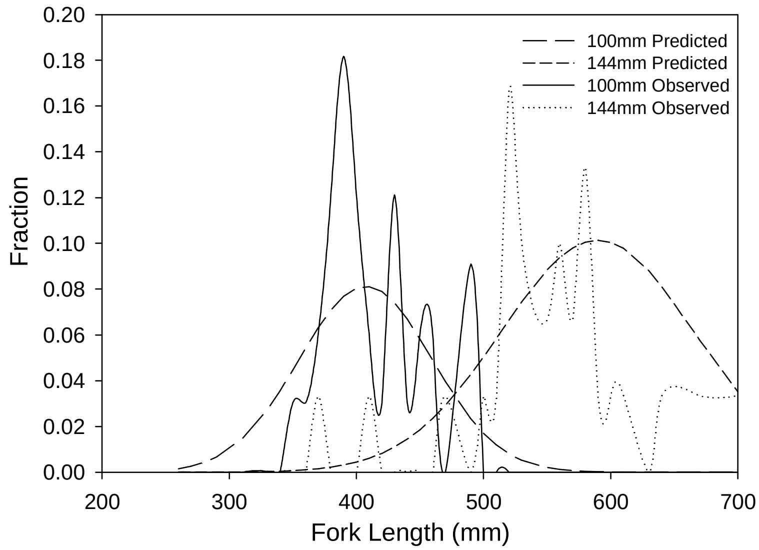

Figure 3.18 Observed versus predicted gillnet selectivity curves for *L. kimberleyensis* from the 100 and 144mm mesh sizes from Lake Gariep (2007/2008).

Only one fish older than 12 years, and few fish younger than six were sampled. Subsequently mortality was estimated by catch curve analysis for age classes six to twelve (Figure 3.19).

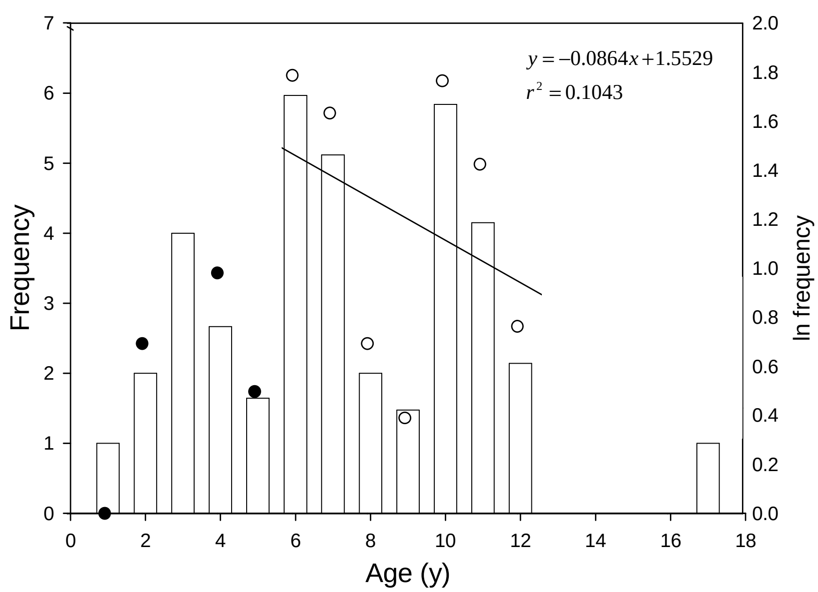

Figure 3.19 Total uncorrected mortality (*Z*) estimates for *L. kimberleyensis* from Lake Gariep (2007/2008). Open circles denote ages used for mortality estimates, while closed circles denote those ages not included.

Total mortality (*Z*) was estimated at 0.08·year $^{-1}$. Due to issue of sample size and selectivity, it was not possible to correct for gillnet selectivity. Numbers at age matrices for *L. kimberleyensis* are summarised in Table 3.8.

Table 3.8 Numbers at age matrix for *L. kimberleyensis* from Lake Gariep (2007/2008).

Length mm(FL)	1	2	3	4	5	6	7	8	9	10	11	12	17
1-100	1												
101-150		1											
151-170		1											
171-220			1										
221-250			1										
251-260			1										
261-270				1									
271-280			1										
281-290				2	1								
291-310				1									
311-340					1	1							
341-360						1							
361-370						2	1						
371-380					1	3							
381-390						4	1						
391-400					1	4	1						
401-410						1	3						
411-420					1	2					1		
421-430						1	2						
431-440							2						
441-450						1		1					
451-460							1	1					
461-480							1			1			
481-490									1				
491-500							1						
501-510								1					
511-520					1				1	4		1	
521-530									1		2		
531-550										2	1		
551-560											1	1	
561-570										1	1		
571-580										3	2		
581-590										1			
591-600											1	1	
601-610												1	
611-620											1		
621-630										1			
631-660										1			
661-700													1
Total	**1**	**2**	**4**	**4**	**6**	**20**	**13**	**3**	**3**	**14**	**10**	**4**	**1**

3.4. Discussion

Labeobarbus aeneus

Labeobarbus aeneus in Lake Gariep attains a maximum age of 12 years (Figure 3.11). Maturity is attained late in life, and 100 % maturity in the population is reached at around two thirds of their lifespan (Figure 3.6). Sexual differences in life history strategies are evident with regards to growth rate, maximum size and maturity. Changes in sex ratio with size have been documented for *L. aeneus* in this study (Figure 3.5) and in the Vaal River System (Mulder, 1973). Male and female growth rates in the initial two years of life are similar but at two years of age, the males reach Lm_{50} whereafter growth slows. During this period, female growth continues until Lm_{50} is reached at age > 5 years, whereafter female growth then also begins to slow down. Not only is the growth between sexes variable but the maximum length differed significantly between sexes (Figure 3.11 D). In Lake Gariep, maximum size of female *L. aeneus* was 496 mm FL, which was larger than that for males (427 mm FL).

Total mortality estimates for *L. aeneus* males and females were 0.46·year $^{-1}$ and 0.54·year $^{-1}$, respectively (Figure 3.13), and similar to estimates for *L. aeneus* in other South African reservoirs (Hamman, 1981; Richardson et al., in review; Tómasson, 1983; Weyl et al., in press) (Table 3.9). The difference between the mortality estimates for male and female *L. aeneus* may be a result of the skewed sex ratio in favour of females for fish >350 mm FL. The size at 50 % selectivity in anglers catches was 350 mm FL resulting in anglers catches being dominated by female fish (see Chapter Five). If the fishing mortality (*F*) is subtracted from the total mortality (*Z*) for females, the result is a similar estimate of natural mortality between sexes. Estimates of the total harvest of *L. aeneus* were estimated to be 6.5 tons annually (see Chapter 5). The surface area of Lake Gariep is 35 490 ha. Thus < 6 kg/ha of *L. aeneus* are harvested from Lake Gariep annually and fishing mortality (*F*) can be considered negligible. Estimates of *M* for both sexes were 0.46 year $^{-1}$. The lower Z in males may thus be a result of decreased fishing mortality.

The von Bertalanffy growth parameters of *L. aeneus* populations from both native and introduced systems have been summarised in Table 3.9 (Weyl et al., in press). The *L. aeneus* population in Lake Gariep displays similar life history characteristics to other *L. aeneus* populations in South Africa, although changes in Lm_{50} and maximum size are evident. The

Lake Gariep male *L. aeneus* reach Lm_{50} earlier than all other populations. While female *L. aeneus* in Lake Gariep, however, reach maturity later than all other populations.

Changes in the age and length at maturity for *L. aeneus* between the original studies on Lake Gariep (Hamman, 1981), seem to be small with the most marked increase, however, being female Lm_{50}. Different ageing techniques have been identified as possible causes of different age estimates for the same species (Boxrucker, 1986). In a study comparing age estimates from scales and otoliths, the average percent error and coefficient of variation of the scale age estimates was approximately seven times greater than for the otoliths (Boxrucker, 1986). Differences in the estimated age at maturity, given the different lengths at maturity, are probably not as a result of different ageing techniques for *L. aeneus* between the two studies, with Hamman, (1981), ageing fish using scales, not otoliths as in this study. A comparison between using otoliths or scales for ageing *L. aeneus* indicated that age estimates usually agree between the two methods (Tómasson, 1983).

Although comparing age-at-50 % maturity may be inconclusive because of differences in ageing techniques, the changes in Lm_{50} are comparable. Changes in length at maturity for a number of species have been associated with either unstable conditions or overexploitation (Dieckmann and Heino, 2007; Olsen et al., 2004). Both of these phenomena have caused species to mature earlier in order to compensate for unsuitable conditions (Dieckmann and Heino, 2007; Olsen et al., 2004). A variety of studies have indicated that a possible cause of phenotypic plasticity in age and length at maturity may be a response to high levels of fishing pressure (Jennings et al., 1999). This is not true for the Lake Gariep fishery, where estimates of Z for male and females are $0.46 \cdot year^{-1}$ and $0.54 \cdot year^{-1}$ respectively. Fishing mortality was estimated to be $0.09 \cdot year^{-1}$. *Labeobarbus aeneus* also contributes a small percentage to overall anglers catches (see Chapter Five). Thus changes in Lm_{50} may not be directly attributed to overexploitation.

Table 3.9 Summary of von Bertalanffy growth parameters of South African *Labeobarbus aeneus* populations (Weyl et al., in press). L_{mat} = length at maturity; A_{mat} = age at maturity; ω = KL_∞; VGBF = Von Bertalanffy growth function; L_∞ = asymptotic length; K = Brody growth coefficient; t_0 = age at zero length; *M* = Natural mortality; [1]Koch, 1975; [2]Hamman, 1981; [3]This study; [4]Weyl et al., (under review); [5]Mulder, 1973; [6]Tómasson, 1983; [7]Straub, 1972; [8]Richardson et al., (under review).

	Maturity		VBGF Parameters			Natural mortality
Location	L_{mat}	A_{mat}	L_∞	K	t_0	M
Males						
Boskop Reservoir[1]	-	-	345	0.195	-0.07	-
Lake Gariep[2]	210	3	676	0.110	-0.09	-
Lake Gariep[3]	231	3	398	0.330	-0.34	0.46 $year^{-1}$
Glen Melville Reservoir[4]	297	4	407	0.193	-0.20	-
Great Fish River[4]	247	3	374	0.403	-0.06	-
Vaal River[5]	280	4	1115	0.059	-0.48	-
Lake van der Kloof [6]	-	3	603	0.190	0.52	-
Females						
Boskop Reservoir[1]	-	-	1560	0.031	-0.53	-
Lake Gariep[2]	310	5	684	0.120	-0.20	-
Lake Gariep[3]	354	5	491	0.236	-0.29	0.46 $year^{-1}$
Glen Melville Reservoir[4]	327	6	13259	0.001	-6.85	-
Great Fish River[4]	333	4	516	0.235	-0.15	-
Vaal River[5]	340	5	1221	0.051	-0.51	-
Lake van der Kloof [6]	300	4	710	0.160	0.47	-
Combined sexes						
Glen Melville Reservoir[4]	-	-	650	0.066	-4.23	0.96 $year^{-1}$
Barberspan Reservoir[7]	-	-	1281	0.036	-1.15	-
Xonxa Reservoir[8]	-	-	276	0.250	-0.63	0.30 $year^{-1}$
Lake van der Kloof[5]	-	-	465	0.234	0.369	-
Great Fish River[4]	-	-	498	0.230	-0.37	0.56 $year^{-1}$
Vaal River[5]	-	-	765	0.150	0.11	-

Tómasson et al., (1984) observed that *L. aeneus* Lm_{50} was phenotypically plastic, and that it would change in relation to the success of the previous years recruitment or environmental conditions. Interestingly enough, the female *L. aeneus* in Lake Gariep are maturing later than in the original study (Hamman, 1981). Reasons for this may include that the previous study was conducted just after impoundment, and the conditions for *L. aeneus* may have been different to present conditions. In a study on a pioneer population of vendace (*Coregonus albula* (Linnaeus, 1758)), the population drove development towards a new life history pattern, by increasing relative fecundity and decreasing the size at maturation when invading a new environment (Bohn et al., 2004). *Labeobarbus aeneus* may have been exposed to similar unstable conditions just after impoundment resulting in a smaller Lm_{50}.

Body form and weight at length for Lake Gariep *L. aeneus* differed between the original study (Hamman, 1981) and present (Table 3.1). In a length weight relationship in the form of $W = aL^b$, the variable *b* represents the form of a fishes body, and values of $b > 3$ indicate a more compressed body form while those $b < 3$ are indicative of a more elongate body form (Froese, 2006; Hile, 1936). In Hamman, (1981), and this study, the value of *b* was 2.98 and 3.08 for male and 2.92 and 3.11 for female *L. aeneus* respectively. This change in the value of *b* may indicate a change in form from a more elongate, to a more compressed form, and changes in weight at length.

In the Great Fish River, a system invaded by *L. aeneus* via inter-basin water transfer in 1977, a study eight years after invasion (Laurenson et al., 1989) showed that a viable population of *L. aeneus* had still not established itself, however, 30 years later, a viable population has been established (Weyl et al., in press). Currently, 38 years after impoundment in Lake Gariep, conditions may favour for *L. aeneus* more than just after impoundment as is indicated by their increase in weight at length and the value of *b*. There is also evidence from this study that suggests that *L. aeneus* may be spawning in the lake.

Contrary to findings in other studies on *L. aeneus*, the Lake Gariep population appears not to undergo a spawning migration to the inflowing rivers but in the opposite direction toward the lake wall (GD region). During the peak spawning season (January 2008) the abundance of *L. aeneus* in Lake Gariep did not decrease, as has been eluded to by other authors when *Labeobarbus* species undergo spawning migrations (de Graaf et al., 2005 ; Tómasson et al., 1984). This evidence indicates that *L. aeneus* may be utilising the lake for spawning. This was substantiated by the seasonal changes in *L. aeneus* abundance within the lake. During the winter sample (June 2007), *L. aeneus* was more abundant in the OV than GD region of Lake Gariep. In the summer sample (January 2008), *L. aeneus* was most abundant in the GD region of the lake, which is furthest from the inflowing rivers. This increase in abundance in the GD region in summer also coincided with a peak in GSI. Two factors may influence the increased abundance of *L. aeneus* in the GD region of the lake. Lake Gariep is a hydroelectric impoundment, consequently the release of water from the impoundment may create currents in the GD region and *L. aeneus* may be able to spawn on gravel beds in this region of the lake. Currents as a result of discharging water from the Tunhordfjord and Palsbufjord hydroelectric impoundments have been documented to elicit a migratory response in char (*Salvelinus* *alpinus* (Linnaeus, 1758)) (Aass, 1970). The summer sample also coincided with lower turbidity in the GD region of the lake than the OV region.

Tómasson et al., (1984), in Lake le Roux (now Lake van der Kloof) reported that during the spawning season, *L. aeneus* moved into the inflowing Orange River to spawn. Tómasson et al., (1984) argued that the presence of juveniles in the littoral zone surrounding the lake were as a result of good dispersal from the inflowing Orange River. Although this may have been the case, there have also been angler reports of *L. aeneus* using gravel beds on wave-washed shorelines to spawn in Sterkfontein Dam (Impson, 2007). The ability to spawn in a lacustrine environment has also evolved in other members of this genus in Lake Tana, Ethiopia (de Graaf et al., 2005). It has to, however, be noted that the Lake Tana *Labeobarbus* species flock is highly evolved to the lacustrine environment and congregation by *L. aeneus* near the lake wall is most likely related to water currents over suitable spawning habitat.

Seasonal changes in abundance of *L. aeneus* in Lake Gariep may also be related to seasonal turbidity gradients experienced within the lake. During the winter, catches of *L. aeneus* were significantly higher in the OV region of the lake than in the GD region. During the summer months, however, the converse was true. The turbidity (secchi depth) in Lake Gariep was higher in the OV than the GD region of the lake (see Chapter Two; Figure 2.5 A) and this may have resulted in the increased abundance of *L. aeneus* in the GD region.

During the summer months, the silt laden Orange River floods after the first rains of the season (Keulder, 1979). *Labeobarbus aeneus* relies heavily on visually selecting zooplankton and has been reported to favour less turbid conditions (Dorgeloh, 1995; Eccles, 1986; Gaigher and Fourie, 1984). In Lake Le Roux, the abundance of *L. aeneus* increased from low abundance at the inflowing river to increased abundance nearest the dam wall. This was postulated to be as a result of a turbidity gradient between the inflowing river and the dam wall (Tómasson et al., 1985). Turbidity has been suggested to be a severe bottleneck in the success of *L. aeneus* populations in shallow turbid impoundments (Dorgeloh, 1995; Eccles, 1986; Gaigher and Fourie, 1984). As a result of evidence pointing toward changes in the life history characteristics of *L. aeneus* between studies just after impoundment and this study, further research on the adaptations of *L. aeneus* to a lacustrine environment need to be investigated, as it was beyond the scope of this study.

Labeobarbus kimberleyensis

The growth rate of *L. kimberleyensis* in Lake Gariep is slow with a maximum age of 17 years recorded in this study at a length of 690 mm FL (Figure 3.17). This is similar to other studies on *L. kimberleyensis* in both the Vaal River (Mulder, 1973) and Lake le Roux (Tómasson, 1983) (Table 3.10). For a species that attains 82.5 cm and 22.7 kg (Skelton, 2001), a theoretical projected maximum age must be well over the observed 17 years. The largest *L. kimberleyensis* ever recorded was an individual of 27.5 kg found at the confluence of the Caledon and Orange Rivers, just above the inflow to Lake Gariep (Jubb, 1970). Maturity for *L. kimberleyensis* in Lake Gariep is reached late, with first male maturity at 337 mm FL and 4 years, and female first maturity at 390 mm FL and 6 years of age. Of the 71 *L. kimberleyensis* sexed and staged during the study period, only 6 mature females and 15 mature male *L. kimberleyensis* were recorded. This corresponds to a large size and old age before Lm_{50} is reached for the species.

Table 3.10 Summary of South African von Bertalanffy growth parameters for *L. kimberleyensis* ([1]Mulder, 1973; [2] Hamman, 1981; [3] Tómasson, 1983; [4]This study).

Location	**Maturity**	**VBGF Parameters**		
	L_{mat} (minimum)	L_∞	K	t_0
Males				
Vaal River[1]	350 mm	667 mm	0.12	0.27
Lake Gariep[2]	400 mm	1108 mm	0.06	0.08
Lake van der Kloof[3]	-	541 mm	0.17	0.20
Females				
Vaal River[1]	460 mm	1039 mm	0.12	0.27
Lake Gariep[2]	440 mm	1141 mm	0.06	0.20
Lake van der Kloof[3]	-	614 mm	0.14	0.22
Both Sexes				
Vaal River[1]	-	-	-	-
Lake Gariep[2]	-	-	-	-
Lake van der Kloof[3]	-	1073 mm	0.09	0.48
This study[4]	390 mm	763 mm	0.118	-0.634

Do the life history traits of *L. aeneus* and *L. kimberleyensis* make them vulnerable to exploitation?

King and MacFarlane, (2003) advocated five broad life history categories (opportunistic strategists, periodic strategists, equilibrium strategists, salmonic strategists, intermediate strategists) that indicate the resilience or threat that a species may face as a result of exploitation (Table 3.11). The following life history parameters were used to classify the five categories: size at maturity, maximum size, growth rate, fecundity, maximum age, egg size and parental investment (King and McFarlane, 2003). *Labeobarbus aeneus* is relatively long lived (10-20 years), late maturing (2/3rds of its lifespan) and has fairly high natural mortality rates (0.46. year^{-1}). According to this characterisation, *L. aeneus* is an intermediate strategist. Exploitation of intermediate strategists should be conservative, as they are vulnerable to overfishing (King and McFarlane, 2003). The recommendation by King and MacFarlane (2003) for the management of intermediate strategist stocks was to maintain a critical spawning biomass.

Table 3.11 Life history categories and suggested management targets to ensure sustainable utilisation of fish used as a comparison to estimate effects of exploitation on *L. aeneus* and *L. kimberleyensis* from Lake Gariep, taking into account their life history characteristics (King and McFarlane, 2003).

Strategy	Characteristics	Management
Opportunistic	Short generation time, low individual fecundity, variable habitats, high resource energy, high abundance	Maintain critical spawning biomass
Periodic	Slow growing, long lived, late maturing, variable recruitment, low variability in abundance	Maintaining appropriate age structure, spatial refuges, maximum size limit
Equilibrium	Low fecundity, late maturity, low intrinsic rate of increase	Low harvest rates
Salmonic	Relatively short lived, fast growing, large sized	Increased understanding of population drivers
Intermediate	Mid range life history strategy, life span of 10-20 years, variable abundance	maintain critical spawning biomass

From a summary of biological data for *L. kimberleyensis*, it is clear that the species is slow growing, late maturing and has moderate to low fecundity (Mulder, 1973; Tómasson et al., 1984); unfortunately sufficient data were not available for a complete picture of its life history. Although this is the case, *L. kimberleyensis* displays the characteristics of the "equilibrium" species as classified by King and MacFarlane, (2003). Management of the equilibrium species recommends low harvest rates due to the vulnerability of stock collapse as a result of overexploitation (King and MacFarlane, 2003). Sport anglers predominantly target large individuals. In *L. kimberleyensis* populations, these large individuals would predominantly be made up of females as a result of a sex ratio skewed toward females in the larger size classes (Mulder, 1973). Removing large female fish from a population can have dire consequences for the exploited species (Birkeland and Dayton, 2005). It has been shown that large females display a number of traits, such as increased fecundity, better egg quality and larval survival and increased spawning frequency, which makes their removal problematic (Birkeland and Dayton, 2005; Froese et al., 2008).

Evidence also suggests that the Lake Gariep *L. aeneus* population may utilise the lake to spawn, with fish aggregating near the lake wall. *Labeobarbus* spawning migrations have been documented elsewhere (de Graaf et al., 2005 ; Tómasson et al., 1984), and at these times the migrating fish become vulnerable to fishing (de Graaf et al., 2004). Although the Lake Gariep spawning aggregations were not actively targeted during the study period, identifying these aggregations and their vulnerability to overexploitation may help ensure that they are not targeted in the future. The overexploitation could also be avoided by the implementation of closed areas or closed seasons during the *L. aeneus* spawning season.

CHAPTER 4: Characterising and describing the Lake Gariep fishery

4.1. Introduction

The actions of fishermen are at the centre of understanding fisheries resources and open access commons (St Martin, 2001). Not just fishermen actions, but understanding why the fishermen act the way they do, may go a long way toward effective management (Arlinghaus and Mehner, 2004). Race, gender and motivation to fish add dimensions to fisheries management that may not necessarily directly effect fish stocks, but may affect the way fish stocks are exploited. Subsistence fishing is a consumptive practice, as the fishers rely on the resource as a livelihood (Allan et al., 2005). Recreational angling is seen as less consumptive, although recently recreational angling has been identified as a causal factor in the global fish crisis (Cooke and Cowx, 2004). Identifying different sectors using the resource may help understand the threats that face the exploited species. The situation is no different in the South African context, where the focus of inland fisheries research has all but ignored the human dimension of fisheries.

Historically, inland fisheries research in South Africa has predominantly focused on biological information of the fisheries (Dorgeloh, 1994, Hamman, 1980, Schramm, 1993, Tómasson et al., 1984) and largely ignored the human dimension (Cadieux, 1980). In a study on the Mutshindudi River catchment in Limpopo Province, Van Der Waal, (2000) documented subsistence fishing and the contribution of fish to the livelihoods of local fishers, although a formal definition or characterisation of fishers was not made. In an appeal to establish awareness on the need for inland fisheries policy in South Africa, Weyl et al., (2007) recognised the need for stakeholder analysis in inland fisheries development but this only included a rough separation by user groups. To date no inland fisheries surveys have documented the resource user groups in post-apartheid South African impoundments (Andrew et al., 2000). Lake Gariep provides an ideal opportunity to document the human dimension of South African inland fisheries on the countries largest impoundment. The main objective of this chapter was to provide the first description of the resource users of an inland fishery in South Africa.

4.2. Materials & Methods

Questionnaire survey

A questionnaire survey was conducted together with a Roving Creel Survey (for specific methods see Chapter Two). During these interviews the following socio-economic information was recorded:

- Origin of the fisher/fishers
- Angler demographics (race/gender/age)
- Primary motivation for fishing (sale/recreation/subsistence)
- Means of transport used to get to the lake
- Employment
- Whether they have been interviewed previously

See Chapter Two, Figure 2.7 for questionnaire. One question was added, asking anglers whether or not they had been interviewed before so that only information from the first interview of a specific angler (first time interview) was chosen for analysis. The characteristics of local anglers can be over-emphasised in socioeconomic analysis if a single angler is interviewed and identical information recorded multiple times.

Lake Gariep hosts national, provincial and informal angling competitions. Because access to the lake is controlled by Free State Nature Conservation and the Eastern Cape Parks Board, the dates of the competition as well as contact details of competition organisers were obtained. All competitions during the sample year (October 2006 - December 2007) were attended regardless of whether they fell within the standard bi-monthly samples or not. Competition anglers were classified according to the same criteria as recreational anglers, as their motivations to fish were very similar.

<u>**Key –informant and other data sources**</u>

Key-informant interviews were conducted during the exploratory survey, and predominantly used to ascertain logistical aspects of the fisheries surveys as well as the perceptions of the anglers within the region. Throughout the sampling period informal interviews were conducted with key informants, where questions arose that surveys could not answer.

National census data were analysed for comparison with Lake Gariep findings (Stats SA, 2002).

Statistical analysis

Socio-economic data were tested for independence between regions and user groups using χ^2 contingency tables at a significance level of $p \leq 0.05$.

4.3. Results

Six hundred and twenty one angler interviews were conducted between October 2006 and December 2007. Only first time interviews were included for socio-economic analysis. In GD 145 first time interviews were conducted while in OV 212 first time interviews were conducted.

Exploratory data analysis was used to define the sectors utilising Lake Gariep using the following socio-economic information: (1) Permanent employment/occupation; (2) Fate of fish; (3) Mode of transport; (4) Distance travelled; (5) Fishing gear. Participants could be separated into two user groups; subsistence and recreational anglers (Figure 4.1).

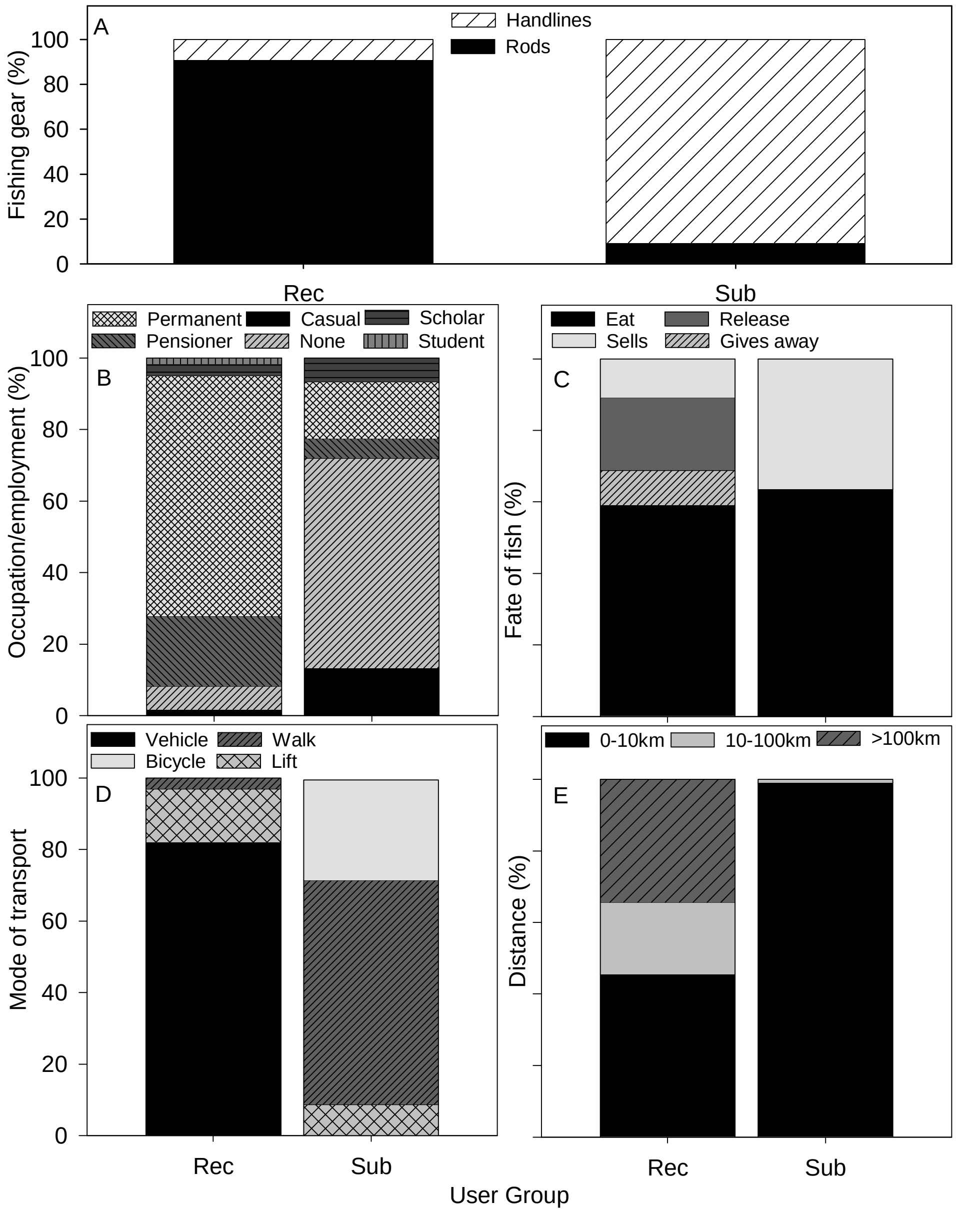

Figure 4.1 Five characteristics used for user group classification on Lake Gariep (2007/2008): (A) Fishing gear; (B) Angler occupation and employment; (C) The fate of the anglers fish; (D) The mode of transport used to access Lake Gariep; (E) The distance anglers travelled to Lake Gariep from their origins (Rec = recreational anglers; Sub = subsistence anglers).

Subsistence fishers

Lake Gariep subsistence fishers are individuals that live on or near the lake, use basic transport methods to access the lake (walk, bicycle, and lift), predominantly use artisanal type gear (handlines), and the primary motivation to fish is as a source of food. A subsistence fisher is an individual who is reliant on the resource as a primary or supplementary source of income.

Fishing is primarily done with a handline (Figure 4.2). This consists of a flexible wire with a large diameter (> 0.30 mm) nylon line attached to it. The wire is lodged into the ground. The line is cast with a swinging circular motion overhead and then released. This is then attached to the wire and a bell is attached to the line. The bells are mainly constructed of a sawn off aerosol can with a rattle within. When a fish ingests the bait, the wire bends with the pull and the bell sounds. The fish is then pulled in very carefully by hand.

Figure 4.2 Subsistence fishers from the Oviston/Venterstad region of Lake Gariep fishing on an island at low lake levels. Note the handlines in the background with a bell, wire and large diameter (> 0.30 mm) monofilament line.

Recreational anglers

Definition

Recreational anglers utilise the resource primarily for leisure purposes but may sell some of their catch. They access the resource by vehicle and sometimes lift; they have permanent employment, use high technology gear, and may consume or sell a portion of their catch (Figure 4.1).

Recreational anglers (Figure 4.3) predominantly use high technology gear consisting of a fibreglass or graphite rod, and a multiplying or spinning reel.

Figure 4.3 Lake Gariep recreational anglers. Note the use of a vehicle to access the resource and the high technology spinning reels and graphite fishing rods.

Lake Gariep

Utilisation patterns and user group characteristics differed by area and are therefore discussed separately. Lake Gariep anglers socio-economic characteristics are summarised in Table 4.1.

Table 4.1 Lake Gariep angler characteristics separated by user group and region (2007/2008).

		RECREATIONAL			SUBSISTENCE			
CHARACTERISTICS		**GARIEP**	**OVISTON/VENTERSTAD**	**ALL**	**GARIEP**	**OVISTON/VENTERSTAD**	**ALL**	**ALL USERS**
RACE (%)	White	60.5	72.3	63.4	0.0	0.0	0.0	41.7
	Coloured	34.0	25.3	31.9	87.3	84.5	84.9	50.2
	Black African	5.5	2.4	4.7	12.7	15.5	15.1	8.1
GENDER (%)	Male	76.8	75.9	76.6	73.0	85.7	83.5	83.5
	Female	14.9	21.7	16.4	12.7	9.4	10.0	10.0
	Children<10	8.3	2.4	7.0	14.3	4.9	6.5	6.5
AGE (%)	0-20 yrs	21.5	0.0	18.7	19.0	21.5	24.1	21.0
	20-40 yrs	32.2	38.9	33.1	28.6	32.2	31.3	32.5
	40-60yrs	38.8	22.2	36.7	28.6	38.8	30.4	33.7
	> 60 yrs	7.4	38.9	11.5	23.8	7.4	14.3	12.7
ORIGIN (%)	<10	32.7	84.8	45.5	95.5	100.0	99.0	78.6
	10-100km	24.8	6.1	20.1	4.5	0.0	1.0	8.3
	>100km	42.6	9.1	34.3	0.0	0.0	0.0	13.1
TRANSPORT (%)	Vehicle	76.0	100.0	82.0	0.0	0.0	0.0	33.1
	Lift	20.0	0.0	15.0	33.3	2.5	8.7	11.2
	Walk	4.0	0.0	3.0	64.1	63.0	62.8	38.6
	Bicycle	0.0	0.0	0.0	2.6	34.4	28.6	17.0
EMPLOYMENT (%)	None	3.1	19.2	6.6	40.0	63.5	58.7	38.7
	Casual	1.0	3.8	1.6	10.0	14.1	13.3	8.8
	Permanent	78.1	26.9	67.2	30.0	12.2	15.8	35.5
	Pensioner	12.5	46.2	19.7	17.5	2.6	5.6	11.0
	Student/Scholar	5.2	3.8	4.9	2.5	7.7	6.6	6.0
FATE OF FISH (%)	Eat	61.0	50.0	59.1	80.0	59.4	63.5	61.6
	Release	24.7	0.0	20.4	0.0	0.0	0.0	8.7
	Sell	10.4	43.7	10.8	20.0	40.6	36.5	25.6
	Give Away	3.9	6.3	9.7	0.0	0.0	0.0	4.1
TOTAL (%)		**73.9**	**26.1**	**38.7**	**19.6**	**80.4**	**61.3**	**100.0**

Gariep Dam

Resource utilisation

Of all anglers interviewed, 71 % were recreational anglers, whilst the remainder, were subsistence fishers (Table 4.1). Forty eight percent of recreational users originated from within 50 km from the resource. Sixty seven percent of recreational anglers were not resident while 11 %, 12 % and 7 % originated from GD, Hydropark and Norvalspont respectively. Of all subsistence fishers, 51 % were from Hydropark, 39 % from Norvalspont and 11 % from GD.

Transport

Transport characteristics are summarised in Table 4.1. Walking was the most frequent mode of transport for subsistence fishers (64 %). Lifts made up a substantial portion of mode of transport in the subsistence sector (33 %). Only 2.5 % of subsistence fishers used a bicycle. The recreational fishery was slightly different with 76 % of recreational users accessing the Lake with their own vehicle, 20 % caught a lift and 4 % walked.

Employment & fate of fish

Employment and the fate of anglers catches are summarised in Table 4.1. In GD 40 % of subsistence fishers were unemployed, while 30 % of fishers had a permanent job. A large percentage of subsistence fishers were pensioners (17 %). Casual workers made up a small percentage of subsistence fishers (10 %). The remainder was made up of students and scholars. Recreational anglers were predominantly employed (78 %), with a further 12 % being pensioners. Employment was dependant on user group (χ^2 test of independence: $\chi^2 = 43$, df = 3, $p \leq 0.05$). The fate of anglers catches was dependant on user group (χ^2 test of independence: $\chi^2 = 16$, df = 3, $p \leq 0.05$).

Within the subsistence sector no fishers released or gave their catches away. Subsistence fishers predominantly only ate their catch (80 %). Only 20 % of subsistence fishers sold some of their catch. A large percentage of recreational anglers only consumed the fish they caught (61 %). A reasonably high percentage of recreational anglers released their fish (24 %), while only 3 % sold a portion of their catch (Table 4.1).

Fisher demographics

The demographic characteristics of the GD region are summarised in Table 4.1 and Figure 4.4. Race was dependant on user group (χ^2 test of independence: $\chi^2 = 66$, df = 2, $p \leq 0.05$). Of the recreational anglers, Whites were the dominant user group (60 %), followed by Coloureds (33 %), with Black Africans only making up a small portion of recreational anglers. Subsistence users were only represented by Coloureds (87 %) and Black Africans (13 %). The majority of subsistence fishers were males (74 %), 12 % were females and 14 % children under the age of ten. Recreational angling was also dominated by men (76 %) with women and children making 14 % and 8 % respectively.

Anglers in the recreational sector were fairly evenly distributed between the ages of 20 and 70 years old, with anglers between 40 and 60 years old being the dominant group. Subsistence fishers had two dominant age classes, those anglers between 18 and 30 years old with an older class between 45 and 75 years old also being dominant (Table 4.1).

Oviston/Venterstad

Resource utilisation

Subsistence fishermen were the dominant user group in the OV area (83 %). In the OV district only 15 % of recreational anglers originated from other areas, whilst 53 % were from Oviston and 30 % from Venterstad. Venterstad had a higher percentage of subsistence users (81 %) than Oviston (19 %). In the region, recreational anglers originated predominantly (90 %) within a 50 km radius of the resource. Within the subsistence sector all users originated locally (< 15 km). The recreational sector was similar with > 80 % of anglers originating within 20 km of the region

Transport

Transport characteristics are summarised in Table 4.1. Subsistence fishers predominantly walked to access the resource (62 %), the second most important mode of transport was a bicycle and the least used being a lift (2.5 %). The recreational sector was different with all recreational anglers accessing the lake with their own vehicle.

Employment & fate of fish

Employment and the fate of anglers catches are summarised in Table 4.1. Unemployment rates were much higher in the subsistence than recreational sectors. Employment was dependant on user group (χ^2 test of independence: χ^2 = 259, df = 2, p $\leq$ 0.05). Subsistence fishers had high unemployment rates (63 %), and a further 14 % having only casual work (taking part-time jobs when available). Only 12 % of subsistence fishers had some sort of stable employment. Pensioners and scholars made up a small percentage of subsistence fishers (2 % and 7 % respectively). Employment was also low in the recreational sector (26 %), although anglers were predominantly pensioners (46 %), with a small percentage having no employment (20 %). Fate of fish was dependant on user group (χ^2 test of independence: χ^2 = 6.5, df = 2, p $\leq$ 0.05). A large proportion of recreational anglers only consumed the fish they caught (50 %). No recreational anglers released their entire catch. A large proportion (43 %) of the recreational anglers sold a fraction of their catch. Subsistence fishers predominantly only ate their catch (59 %) and 40 % sold a portion of their catch. Within the subsistence sector no fishers released or gave their catches away.

Fisher demographics

The demographic characteristics of the OV region are summarised in Table 4.1 and Figure 4.4. Racial makeup in the OV region is dependant on user group (χ^2 test of independence: χ^2 = 259, df = 2, p $\leq$ 0.05). Recreational users were dominated by White (72 %) and Coloured users (25 %) and a small percentage of Black African recreational anglers. Subsistence fishers were dominated by Coloured fishers (84 %), with the remainder comprising of Black African fishers. Subsistence fishers were predominantly male (86 %), with a small proportion being female (9 %) and the remainder being children younger than 10 years old. Subsistence fishers were dominated by anglers between 20 and 30 years old, fisher frequency peaked again between 40 and 60 years old. The frequency of anglers between 50 and 70 years old was constant, with no anglers being recorded over 80 years old. The recreational sector was dominated by anglers between 55 and 80 years old, while 40 % of anglers were aged approximately 40 years old.

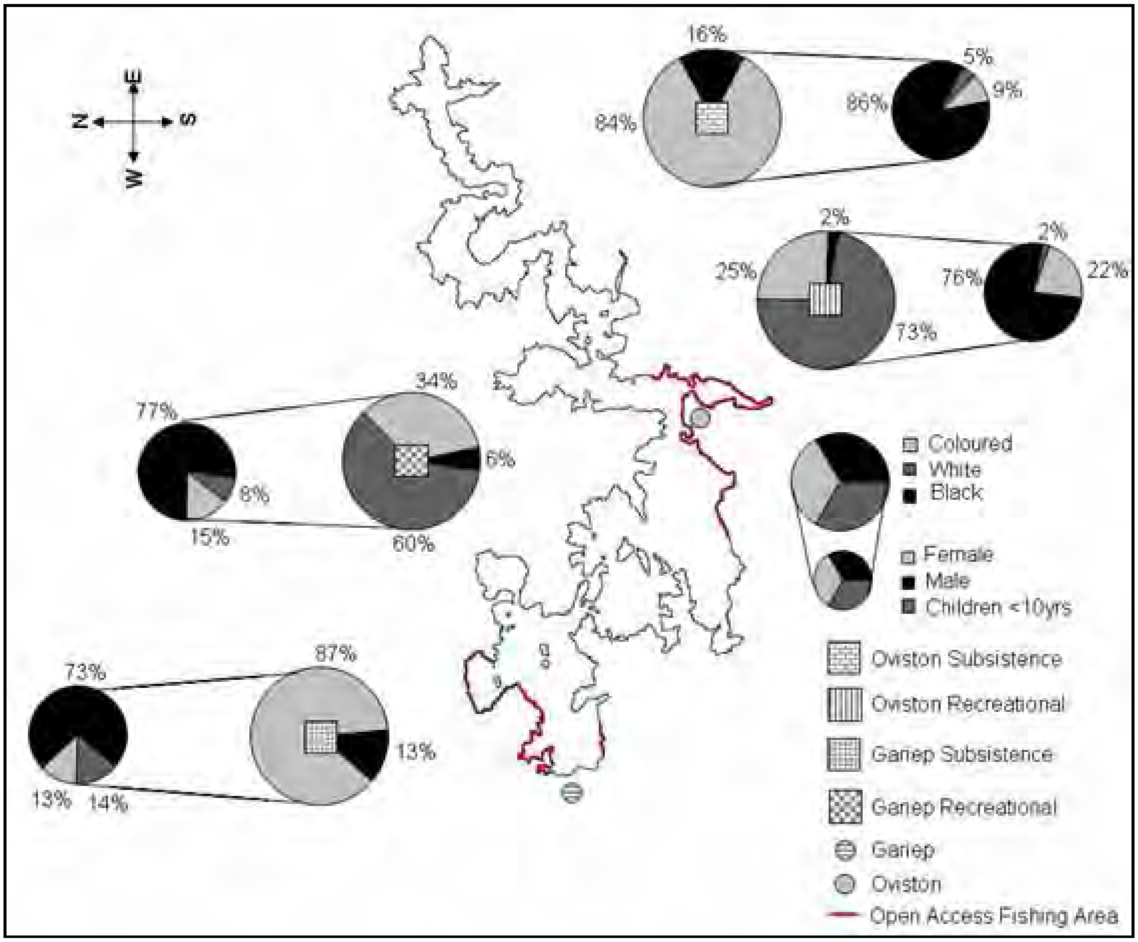

Figure 4.4 Angler demographics, separated by user group for the two major regions situated on the Lake Gariep shore sampled between October 2006 and December 2007.

4.4. Discussion

The complexity of the Lake Gariep fishery was highlighted by the diversity of user groups, races and origins of anglers using the lake (Table 4.1). Overall the Lake Gariep fishery was dominated by subsistence fishers (61 % of all users) during the study period (Table 4.1). Large regional differences were evident in user group dynamics and their associated characteristics. Although this may be the case there was a difference between user group abundance by region. The GD region was dominated by recreational anglers and the OV region by subsistence anglers.

This is the first documentation and characterisation of subsistence angling on a South African impoundment. Our definitions are similar to those used for marine subsistence fishers, which were first legally recognised as a formal fishing sector in South Africa in 1998 with the promulgation of the Marine Living Resources Act No. 18 (1998). Branch et al., (2002) characterised subsistence fishers according to poverty, harvest for self-use (whether by consumption or sale to meet basic needs of food security), and the use of low-technology gear.

In the context of Lake Gariep, subsistence fishers were defined according to five similar characteristics, these were gear types, how they accessed the lake (walk, vehicle, bicycle etc.), angler origins, employment, and the fate of the fish they caught. This differs from the only other case study on inland subsistence fishing, that was in the Mutshindudi catchment in the Limpopo province, where the primary motivation for subsistence fishers was for protein in the form of fresh fish (van der Waal, 2000). On Lake Gariep, fishing was done as there was a need, either for food, or as a source of income by selling the fish. Subsistence fishing is seen in many instances as a last resort activity, practiced by the poorest people (Smith et al., 2005). Subsistence fishers are able to utilise the resource because of easy accessibility and the low cost of subsistence fishing, which makes it available as a last resort activity when all else fails. Entry into the fishery costs little with the total cost of gear being approximately 20 rand (100 metres of line = R 10, wire= R 2, 5 hooks = R 8).

The use of low cost transport to access the resource is ubiquitous with subsistence fisheries worldwide (Branch et al., 2002; Brown and Toth, 2001). Subsistence anglers utilising Lake Gariep predominantly either walked, rode a bicycle and very few caught lifts. This highlights the accessibility and affordability of Lake Gariep as a protein source.

The age structure of fishers in both the OV and GD subsistence sector indicates a predominance of fishers between the ages of 18 and 40 years old. This is considered within the working age-bracket in South Africa (Stats SA, 2001). The age structure indicates that in this sector there is a shortage of employment and the workforce is utilising Lake Gariep as a last resort activity. The GD recreational sector has a similar age structure to that of the subsistence fishers, yet the opposite is true for this sector, the anglers are all employed and are utilising the lake for social/recreational reasons and not as a livelihood. The OV recreational sector age structure is typical of a retirement village where the anglers are predominantly over 60 years of age and fish for recreational purposes. Reasons for the large subsistence sector on the lake maybe related to > 60 % unemployment rate in the small towns on the lakeshore (see Chapter Two, Table 2.2).

The interview data supports this with unemployment rates being much higher in the subsistence than recreational sectors (Figure 4.1 B). A large proportion of the GD and OV subsistence fishers had no employment. A further portion had only casual work. With the high unemployment rates in the both regions, fishing was relied upon by those individuals that were unable to find alternative employment. Fishing is also seen as an alternative activity when informal employment was not available.

Although the recreational anglers were employed or retired, a large proportion of recreational anglers from both regions consumed a portion of their catch. Not only were divisions among sectors evident, but regional intersectoral differences may also be evident in recreational fisheries (Arlinghaus and Mehner, 2004). The only difference between the two regions' recreational anglers was that recreational anglers from OV never released their catch, while in GD catch and release was commonplace. This may have been because a large proportion of the OV recreational anglers sold a fraction of their catch. Reasons for selling catch as a recreational angler lie in the fact that the recreational anglers from OV are predominantly retired and hence the catch may be sold to subsidise fuel and tackle expenses.

No fishermen encountered during the survey period sold their entire catch. The predominant trend was that if anglers caught surplus to what their household needs were, the excess was sold. In the GD region however, the subsistence anglers predominantly only consumed the fish they caught. Most subsistence fishers in the GD region also had access to freezing facilities and thus did not need to sell their excess catch, instead freezing it and only fishing when necessary. The consumption of caught fish and the revenue provided by selling fish are import commodities in rural communities (Neiland et al., 2000). Although in many instances worldwide subsistence fishing is carried out in conjunction with other agricultural activities (Cerdeira et al., 2001), the situation is not the same on Lake Gariep.

In the Lake Gariep area, fishers originate in township communities where there is no surrounding community agricultural land, thus without employment the lake is a means of livelihood. Subsistence fishers from both areas predominantly only ate their catch, although more only ate their catch in GD than in OV. In GD a smaller percentage of subsistence fishers sold their catch than OV. Reliance on the resource as a source of primary and supplementary income is evident in OV, while in GD the resource is predominantly used as a supplementary source of food and income. In GD unemployment rates are less than in OV, which further explains the dependence of subsistence fishers in the OV region on the lake.

In the recreational sector, ascertaining whether the desirability or draw of the resource is primarily local or from further afield may reveal the sphere of influence the lake has. Of all the recreational anglers using Lake Gariep, the majority originate within 50 km from the resource. Within the OV region, the recreational sector is predominantly older retired individuals. Oviston and Venterstad are not well recognised tourism venues with Oviston being distinctly considered a retirement village (H. Carey Estate Agent, pers. comm.). The GD region however, was dominated by recreational anglers with a small subsistence sector present. The large recreational sector in GD may be attributed to two major factors. Firstly, the GD region is focused on tourism with a large number of guesthouses and a well established resort (Lake Gariep Tourism Association). Secondly, with there being jobs available in the town, the surrounding communities may not depend on the lake as heavily as in the OV region. Increasingly, the socio-economic benefits for both anglers and the wider communities from inland recreational fisheries are being recognised (Peirson et al., 2001). The tourism in the GD region of Lake Gariep may provide local communities with income that originates indirectly from Lake Gariep such as employment through guesthouses, hotels similar unstable conditions just after impoundment resulting in a smaller Lm50.

In South Africa there is a general perception that fishing is not a traditional activity practiced by the indigenous people on inland waters (Andrew et al., 2000). This also appears to be the case at Lake Gariep where Black Africans fished less than Coloureds, even though they had the same access opportunities as other users. Coloureds were the dominant racial group among Lake Gariep subsistence fishers (84 %), with Black Africans only forming a minor portion of the subsistence fishery (15 %). This is not in accordance with local census data (see Chapter Two, Table 2.2) where Black Africans (59 %) are the dominant racial group in both regional municipalities. In the future, if their fishing activities increase, because they are the predominant racial group in the region (see Chapter Two, Table 2.2), fishing effort could increase greatly with associated effects on the fishery.

Synthesis

The large subsistence sector on Lake Gariep also brings to light the contribution of fish to local economies and food security within the rural communities surrounding the lake. Lake Gariep subsistence fishers are highly reliant on the resource. Such levels of reliance can be expected to have an impact on the fish that are exploited. Lake Gariep subsistence fishers are highly reliant on the resource for food and as a result effort limitations are not likely in the future. Recreational anglers also used the resource consumptively. Increasingly the focus in fisheries management is shifting toward the management of people and not fish (Ditton and Hunt, 2001). Once an understanding of why users utilise the resource, actual catch and effort data can then be used to provide an indication of exploitation rates on the various fishes of the lake and what effect this exploitation has on the fishes, particularly *L. aeneus* and *L. kimberleyensis*.

CHAPTER 5: A quantitative assessment of the Lake Gariep fishery

5.1. Introduction

The main aim of any fishery assessment is to determine the status of the resource and establish safe levels for sustainable exploitation (King, 1995). Catch and effort surveys give a good indication of what is removed from a resource by anglers, which can subsequently be used to determine how the fish population responds to harvest (Reid and Montgomery, 2005). The species, sex and size composition of anglers catches also reflect what impact angling has, or may have on the exploited populations in the future (Almodovar and Nicola, 2004).

In a study on *L. aeneus* and *L. kimberleyensis*, Mulder, (1973) indicated that with the increase in angling pressure on both species, a critical situation may be reached in the future. Fisheries surveys on South African reservoirs have focused on estimating fish biomass and the fisheries potential of a variety of inland reservoirs. There is no available information on angling effort or catch per unit effort (*CPUE*) or size and species selectivity for South African impoundments.

The aim of this chapter was to provide an initial assessment of the catch, effort and yield in Lake Gariep. Specifically the objectives were: (1) Assess seasonal catch and effort. (2) Determine total yield from the fishery. (3) Ascertain what proportion of the catch is made up of *L. aeneus* and *L. kimberleyensis*, and what effect the exploitation rates may have on the species.

5.2. Materials & Methods

Creel surveys

To estimate seasonal catch rates, and angler effort, randomly stratified Roving Creel Surveys (RCS) were conducted on a bi-monthly basis between March 2007 and December 2007. The RCS consisted of angler interviews to determine species composition, size selectivity and the

CPUE for Lake Gariep anglers. To determine fishing effort, counts of fishers in the sampling region were conducted. On each sampling day, all fishers in each stratum were counted twice daily. Each count consisted of an instantaneous count of fishers within that stratum (anglers/day). For specific details on RCS design and methods see Chapter Two.

Catch per unit effort

To estimate mean *CPUE*, procedures outlined by Pollock et al., (1994) were followed. Catch per unit effort was estimated using the equation:

$$\overline{CPUE} = \frac{\sum_{i=1}^{n} \left(Ci/Ei \right)}{n}$$

(Equation 5.1)

Where *Ci* is the catch on day *i* and *Ei* is the effort on day *i*. Due to monthly and regional differences in catch rates, *CPUE* was calculated by month for each of the two regions of Lake Gariep.

Catch per unit effort data were not normally distributed and the dataset contained many zeros. This is a common problem in biological statistics (Fletcher et al., 2005). Recent approaches to dealing with skewed data with many zeros is to use Generalized Linear Models (GLMs) to model predictor variables against catch (Fletcher et al., 2005; Johnson and Omland, 2004). To investigate monthly and regional trends in anglers catches the following approach was followed:

Two datasets were created: (1) A binomial dataset, indicating the presence or absence of catch (1 or 0 respectively). This allows for estimating the probability of capture (PC) of fish in the catch. (2) A dataset of the log transformed *CPUE* for catches containing fish.

(1) To investigate the influence of month, user group and area on the probability of capture (PC), generalized linear models (GLMs) were applied. To find the optimal combination of parameters, the fit of the different models were assessed using the Akaike Information Criterion (AIC) in the form of:

$$AIC = -2ln[L(\theta p|y)] + 2p,$$ (Equation 5.2)

where p is the number of free parameters, and $L(\theta|y)$ is the likelihood of model parameters given the data y (Johnson and Omland, 2004). The model building function was then used to ascertain the best explanatory variables for changes in PC.

The presence/absence data (1 or 0 respectively) was then modeled against explanatory variables. For the presence/absence model, because the distributions were binomial, the logit link function was used for the binomial distribution (Mccullagh and Nelder, 1995), where:

$$f(p) = log(p/(1-p)),$$ (Equation 5.3)

p is the underlying continuous probability of the binary dependent variable, ranging from 0 to 1. The presence/absence data was modeled using logistic regression. To model the influence of sampling month, region and user group against catches, GLMs were used in the form of:

$$log(p(PC))/(1-p(PC)) = \beta_0 + \beta_1(Month) + \beta_2(Region) + \beta_3(UserGrp) + \varepsilon$$ (Equation 5.4)

(2) Non-zero, log transformed data were tested for normality using Quantile-Quantile Plots (Statistica 8.0). The data were normally distributed and tested for differences between month and region with a Multi-Factorial ANOVA. All statistical analysis was done using STATISTICA 8.0, StatSoft®.

Lake Gariep anglers generally spend an extended period of time fishing on any particular day. The more hours spent by an angler fishing, the more chance an angler has of catching a fish. Roving Creel Survey data were used to model the probability of capturing a fish from the onset of angling, at the start of the day, to the end of each fishing day. To estimate the PC at the end of the fishing day, the PC over time was fitted with a von Bertalanffy function. This was then modified for the probability of capture in the form of:

$$PC_t = PC_\infty(1 - e^{-K(PC - PC_0)})$$ (Equation 5.5)

Where PC_0 is the probability of capture at “zero” time fished; PC_∞ is the predicted asymptotic *PC* and *K* is the Brody co-efficient, describing the increasing probability of capturing a fish as trip length increases on any given day.

At the average day length for any particular month, the PC was obtained from the growth function and calculated by parametric bootstrapping using the mean product of 1000 iterations within the confidence intervals at the average day length obtained from the von Bertalanffy function.

Effort

Average daily effort was calculated using the equation:

$$\hat{E} = Mean\left(\sum_{j}^{n} \frac{\sum A_{i,j}}{n_{i,j}}\right) \qquad \text{(Equation 5.6)}$$

where $\hat{E}$ represents the expected number of anglers during any time of the fishing day, $A_{i,j}$ is the number of observed anglers in on the *i*th day in stratum *j* and $n_{i,j}$ is the number of instantaneous counts on the *i*th day in stratum *j*.

The length of the fishing day for all anglers was obtained from angler interviews.

Total catch

Significant differences between the catch rates in regionally and temporally resulted in separating the total catch (TC) monthly and into two regions, GD and OV. Total catch was calculated by Monte-Carlo Simulation (Davies and Hinkley, 1997) using the mean product of 1000 iterations of angler effort (anglers. $hour^{-1}.day^{-1}$) and positive *CPUE* (kg. $man^{-1}.hr^{-1}$) drawn from raw data with replacement and raised by mean monthly angling day length and the probability of capture at mean day length for each month and number of days in assessment period.

$$TC_i = \hat{E}_i \times \overline{CPUE_{pos}} \times DL_i \times PC_i \times D_i, \qquad \text{(Equation 5.7)}$$

where TC_i represents the total catch (t. period^{-1}), $\hat{E}_i$ represents the expected number of anglers during any time of the fishing day during sampling period i, $CPUE_{pos}$ is the catch per unit effort for positive catches (kg.man^{-1}.hr^{-1}), DL_i is the average day length during sampling period i, PC_i is the probability of capturing a fish at the average day length (DL_i) during sampling period i and D_i is the numbers of days during each sampling period.

The total catch of *L. aeneus* was calculated as the percentage of anglers catches and expressed as a percentage of total catch of all species (t. period^{-1}).

Results from a number of angling competitions held on Lake Gariep were added to the total catch to obtain an estimate of the total catch from Lake Gariep. Absolute catch data for these competitions was obtained from the organizers (B. Fritz, unpublished data) therefore the total catch represented is the absolute catch from all competitions during the study period.

Species composition & length frequency

Species composition

The relative abundance of the five species present in Lake Gariep anglers catches was calculated as the percentage of the monthly catch composition for each species by weight (kg). The relative abundance of species was tested for significant differences by region using a χ^2 test of independence.

Length frequency

To best describe the length distribution of *L. aeneus* from anglers catches, length frequency was modeled using methods Punt et al., (1996).

Parameter estimates for selectivity are obtained by maximum likelihood methods. The proportion of fish caught per length class (ψ) by fork length (L) was fitted with the logistic curve:

$$\psi = \frac{1}{1 + e^{-(L - Lm_{50})/\delta}}, \qquad \text{(Equation 5.8)}$$

where L_{50} is the mean fork length at selectivity and δ is the width of the logistic ogive. A logistic ogive was used as the population structure from gillnetting indicated that fish on the right hand side were not selected against and that a gamma distribution did not adequately represent the angler hook and line selectivity.

Potential yield

As no historical fisheries data exist for Lake Gariep yields were compared to, a ball-park estimate of the potential fish yield was calculated using two morphoedaphic models to obtain an estimate of exploitation. (1) The global, temperature-adapted morphoedaphic index (MEI) (Schlesinger and Regier, 1982) calculated as:

$$LOG.10\ \text{Yield}\,(\text{kg.hectare}^{-1}\text{year}^{-1}) = 0.44xT + LOG.10\left(\frac{TDS}{MD}\right) + 0.021, \qquad \text{(Equation 5.9)}$$

and (2) the Marshall and Maes, (1994) model, specifically formulated for small southern African water bodies as:

$$(\text{Yield})\text{kg.hectare}^{-1}\text{year}^{-1} = 23.281\,\text{x}\left(\frac{EC}{MD}\right)^{0.447}, \qquad \text{(Equation 5.10)}$$

where T is the mean annual water temperature in º C, TDS is the total dissolved solids (mg.l^{-1}), EC is electrical conductivity (µS.m^{-2}) and MD is the mean depth of the reservoir when full in metres (see Chapter Two). The two models give a first indication of what the lake can potentially yield compared to current levels of harvest.

5.3 Results

Five hundred and eight creel survey interviews were conducted between March and December 2007. Slightly more interviews were conducted in the OV (291) than the GD (224) region (the distribution of the interviews and angler effort along the shoreline within each region is shown in Figure 5.1).

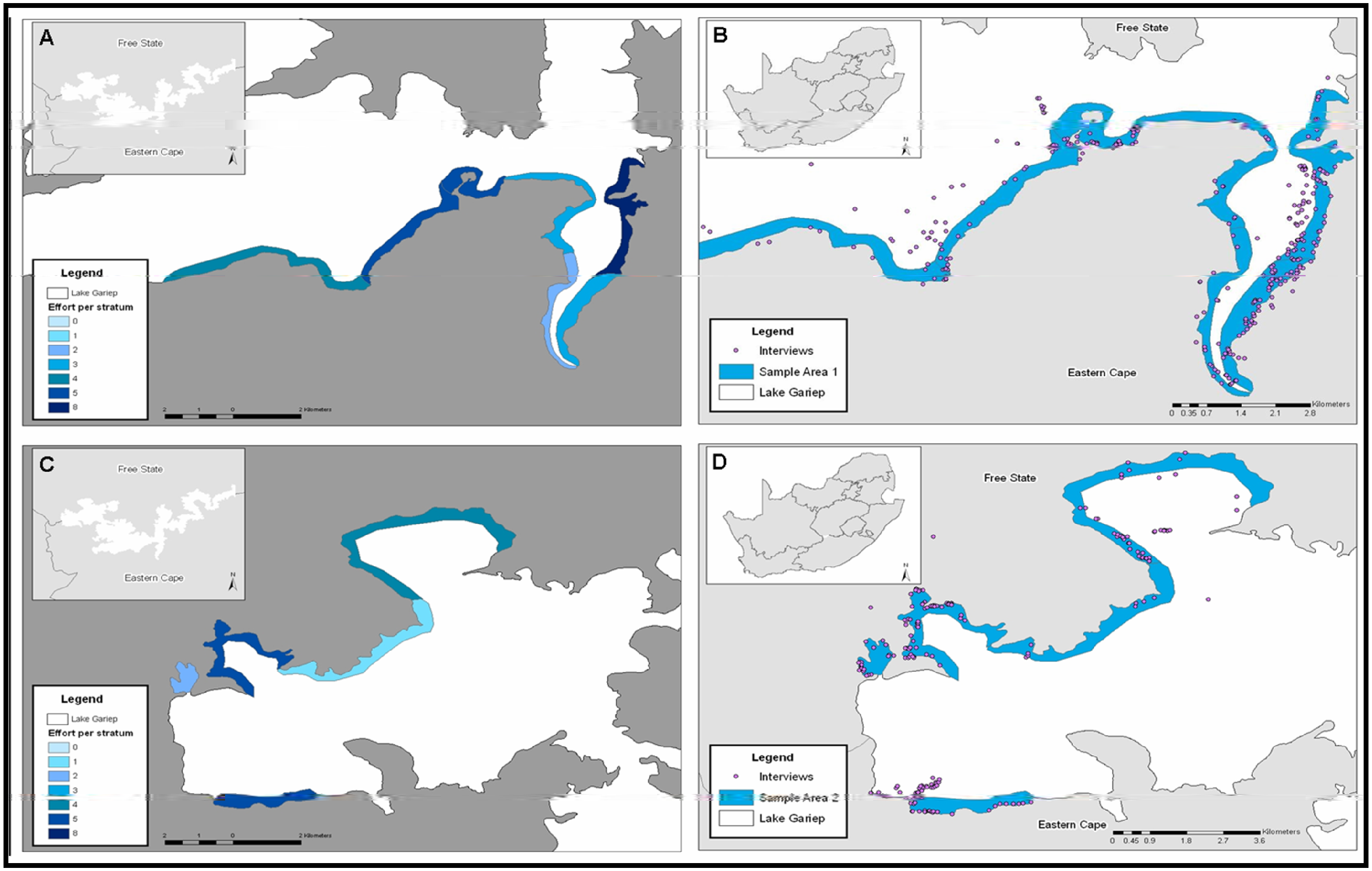

Figure 5.1 Spatial distributions of angler interviews within the Oviston/Venterstad (A) and Gariep Dam (C) regions October 2006 and December 2007 on Lake Gariep. B) Mean daily fishing effort for each stratum within Oviston/Venterstad (B) and Gariep Dam (D). The points that appear to be situated in the lake were interviews conducted at low lake levels.

Species composition

Five species were recorded in anglers catches; carp (*Cyprinus carpio*), Orange River mudfish (*Labeo capensis*), smallmouth yellowfish (*Labeobarbus aeneus*), largemouth yellowfish (*Labeobarbus kimberleyensis*) and the African sharptooth catfish *Clarias gariepinus* (Table 5.1). Numerically and by weight, carp dominated the catch composition, contributing 72 % to total numbers, *L. aeneus*, *L. capensis* and *C. gariepinus* each contributed *ca*. 7 %. The contribution of *L. kimberleyensis* to catches by number and weight was < 0.5 %. The relative abundance of species differed by area (χ^2 test of independence: $\chi^2 = 182$, df = 4, $p \leq 0.05$). Although the proportion of the dominant species *C. carpio* was similar between areas (76 %; 82 %), the catches of the catches of *L. aeneus* (13 %; 2 %), *L. capensis* (9 %; 4.5 %) and *C. gariepinus* (2 %; 12 %) differed between GD and OV respectively (Table 5.1).

Table 5.1 Lake Gariep fishery species composition and contribution to anglers catches by numbers and weight (GD = Gariep Dam; OV = Oviston/Venterstad).

Species	Oviston/Venterstad		Gariep Dam		Total	
	Number (1127)	Weight (989)	Number (1213)	Weight (1150)	Number (2340)	Weight (2139)
***Cyprinus carpio* (%)**	75.8	81.7	68.7	75.7	72.1	78.5
***Clarias gariepinus* (%)**	13.2	12.0	2.6	2.3	7.7	6.8
***Labeo capensis* (%)**	8.4	4.4	14.3	9.2	11.5	7.0
***Labeobarbus aeneus* (%)**	2.2	1.6	14.3	12.7	8.5	7.5
***Labeobarbus kimberleyensis* (%)**	0.4	0.4	0.2	0.2	0.3	0.3

Length frequency & angling selectivity

Length frequency histograms for the five dominant species in anglers catches is summarised in Figure 5.2. Anglers 50 % selectivity of *L. aeneus* (L_{50}) is 350 mm FL.

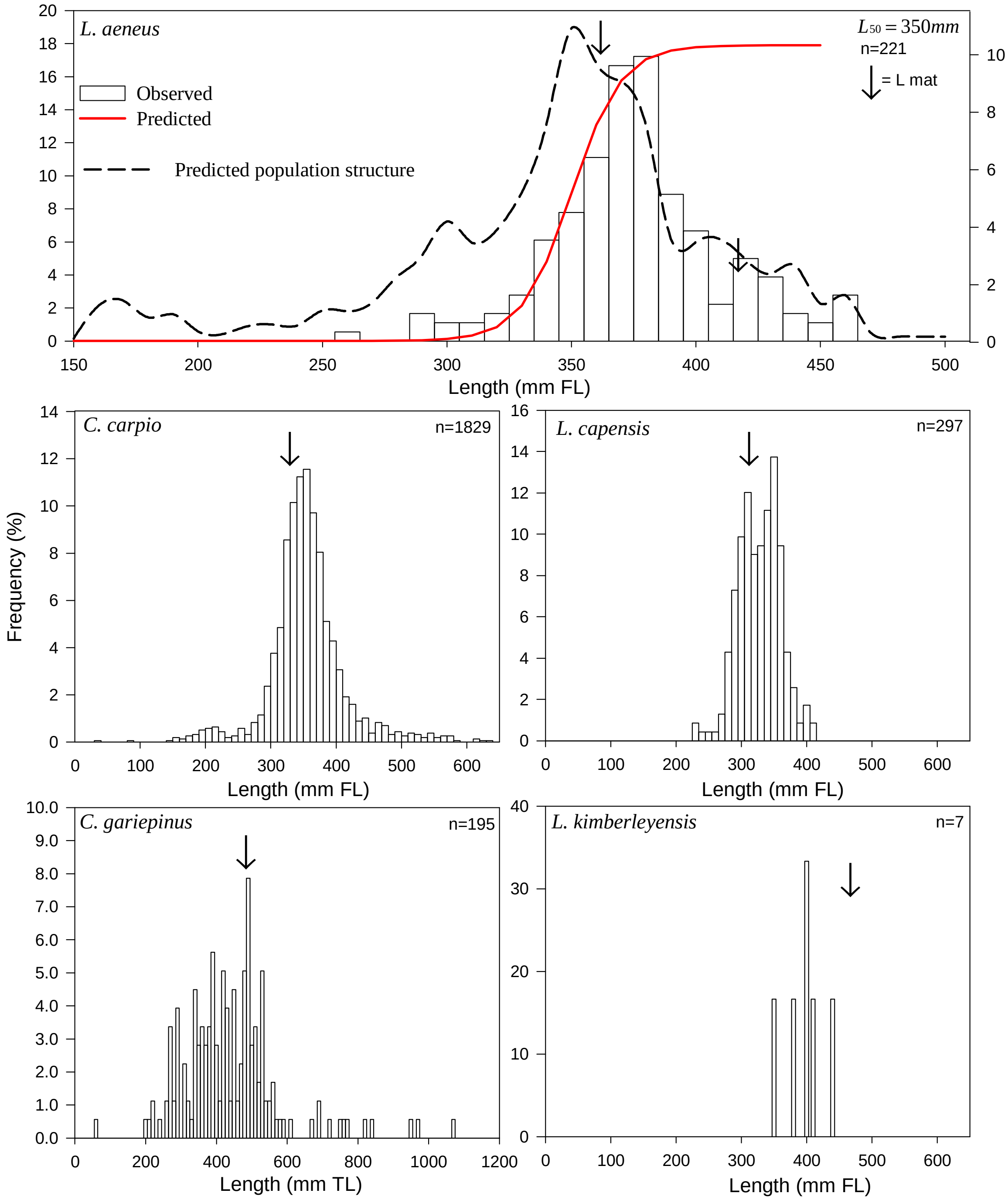

Figure 5.2 Length frequency distributions for the five species documented in anglers catches from Lake Gariep between October 2006 and December 2007 (Arrows indicate length-at-50% maturity; L_{50} = length at 50% selectivity). *Labeo capensis* and *C. carpio* Lm_{50} was obtained from Tómasson, (1983) and *C. gariepinus* Lm_{50} from Quick and Bruton, (1984). For *L. kimberleyensis* the arrow indicates first length at maturity from this study. The corrected population structure (for methods see Chapter Three) and predicted selectivity (logistic ogive) are shown for *Labeobarbus aeneus*.

Probability of capture

On any sampling day the most significant predictor of the PC for all species was time fished (Wald $X^2(1) = 7.169$, $p = 0.007$). Within the first three hours of angling, PC rose almost linearly from 0 to 0.65, after which it flattened out between four and ten hours to a maximum of 0.81 (Figure 5.3 A). There were no significant differences in PC for all species between region (Wald $X^2(1) = 0.021$, $p = 0.882$) or month (Wald $X^2(5) = 8.210$, $p = 0.145$). The probability of capturing *L. aeneus* differed significantly between month (Wald $X^2(5) = 20.690$, $p = 0.000$) and region (Wald $X^2(3) = 46.755$, $p = 0.000$) (Figure 5.3 B). The probability of capturing *L. aeneus* in the OV region was consistently low throughout the year. In the GD region PC for *L. aeneus* followed seasonal trend, ranging from zero in March to 0.46 [95 % CI = 0.32:0.61] in October.

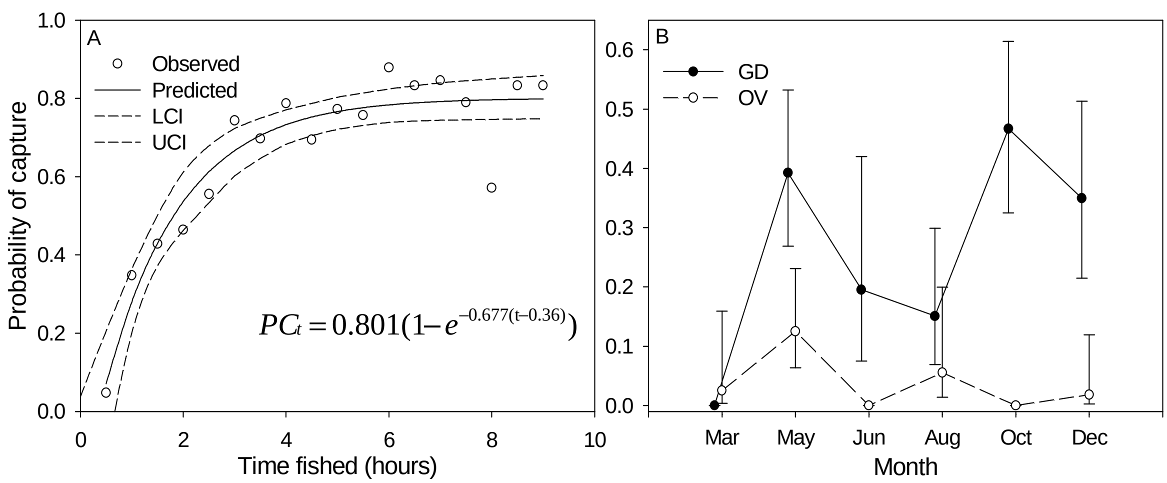

Figure 5.3 (A) The probability of capturing a fish on any particular day for all Lake Gariep anglers (Dotted lines denote the 95 % confidence intervals from the bootstrapped predicted lengths at-age). (B) Mean monthly probability of capture (standardised over all months) of *L. aeneus* in Gariep Dam (GD) and Oviston/Venterstad (OV) from all angler catches on Lake Gariep (error bars denote 95 % confidence intervals).

Effort

Regional and temporal trends in effort are summarised in Figure 5.4 A. There were no significant differences between weekday and weekend total effort (Kruskall-Wallis non parametric Analysis of Variance). This resulted in an average daily effort for all days. Week and weekend effort differed between subsistence and recreational anglers (Factorial ANOVA, $p \leq 0.05$). Subsistence users predominantly fished during the week, and effort (anglers/day) decreased on the weekend. The opposite was true for recreational anglers, whose numbers were low during the weekdays and increased on weekends. Because *CPUE* did not differ significantly between the two sectors, differences in user group effort were therefore negligible when calculating total catch. Total daily effort did not differ between weekdays and weekends. Thus total effort was calculated as an average daily effort for each month, but separated by area because of the difference in catch rates by area.

Effort during the sampling period is summarised in Figure 5.4 A. Average monthly effort in GD and OV followed similar monthly trends. In March, the OV region (17 ± 3 anglers/day) had lower mean daily effort than the GD region (25 ± 6 anglers/day). Angler activity peaked in May, and similar numbers of anglers were observed in OV and GD (45 ± 9; 41 ± 8 anglers/day respectively). Angler activity then decreased in June and August to 18 ± 4; 19 ± 4 anglers/day and 6 ± 1; 13 ± 3 anglers/day in OV and GD respectively. In October and December angler activity increased to 29 ± 4; 28 ± 5 in GD and 13 ± 3; 20 ± 2 in OV respectively.

Catch Per Unit Effort

Regional and temporal trends in mean *CPUE* is summarised in Figure 5.4 B. Many zero observations resulted in non-zero, log abundance positive catches being used to indicate regional and temporal trends in *CPUE*. The single best predictor of differences in non-zero, log abundance positive *CPUE* was region (Factorial ANOVA $p \leq 0.05$), followed by an interaction between sample month and region (Factorial ANOVA $p \leq 0.05$). Mean monthly *CPUE* followed seasonal trends in both regions. Catches in the GD region were consistently higher than the OV region. Catches in GD were highest in March (1.17 ± 0.24 $kg.man^{-1}.hr^{-1}$) and October (0.98 ± 0.15 $kg.man^{-1}.hr^{-1}$) and lowest in June (0.48 ± 0.12 kg. $man^{-1}.hr^{-1}$) and August (0.42 ± 0.10 kg. $man^{-1}.hr^{-1}$). In the OV region, catch rate was lowest during March (0.21 ± 0.06 kg. $man^{-1}.hr^{-1}$), June (0.30 ± 0.05 kg. $man^{-1}.hr^{-1}$) and August (0.28 ± 0.7 kg.man^{-}

$^{1}.hr^{-1}$), and highest in October (0.67 ± 0.11 kg. $man^{-1}.hr^{-1}$) and December (0.82 ± 0.11 $kg.man^{-1}.hr^{-1}$).

Total catch

The total catch from the Lake Gariep fishery during the sampling period (March to December 2007) was estimated to be 86.0 [95 % CI = 40.4:154.8] t. $period^{-1}$. Regionally GD had the highest TC estimate of 46.0 [95 % CI = 15:102.6] t. $period^{-1}$ while the estimate for OV was 40.0 [95 % CI = 13.9:89.6] t. $period^{-1}$. Competitions contributed a further 7.5 t over the sampling period.

Estimates of TC varied temporally in both areas, although they showed similar monthly trends. Total catch in both regions was highest in May (OV = 12.9 [95 % CI = 0.7:47.6] t. $year^{-1}$; GD = 15.2 [95 % CI = 0.5:64.0] t. $period^{-1}$). Total catch then decreased in both regions during June to a low in August of 3.8 [95 % CI = 0.1:13.6] t. $period^{-1}$; 3.1 [95 % CI = 0.2:13.4] t. $period^{-1}$ in GD and OV respectively (Figure 5.4 C).

The total catch of *L. aeneus* was estimated to be 6.5 t. $period^{-1}$.

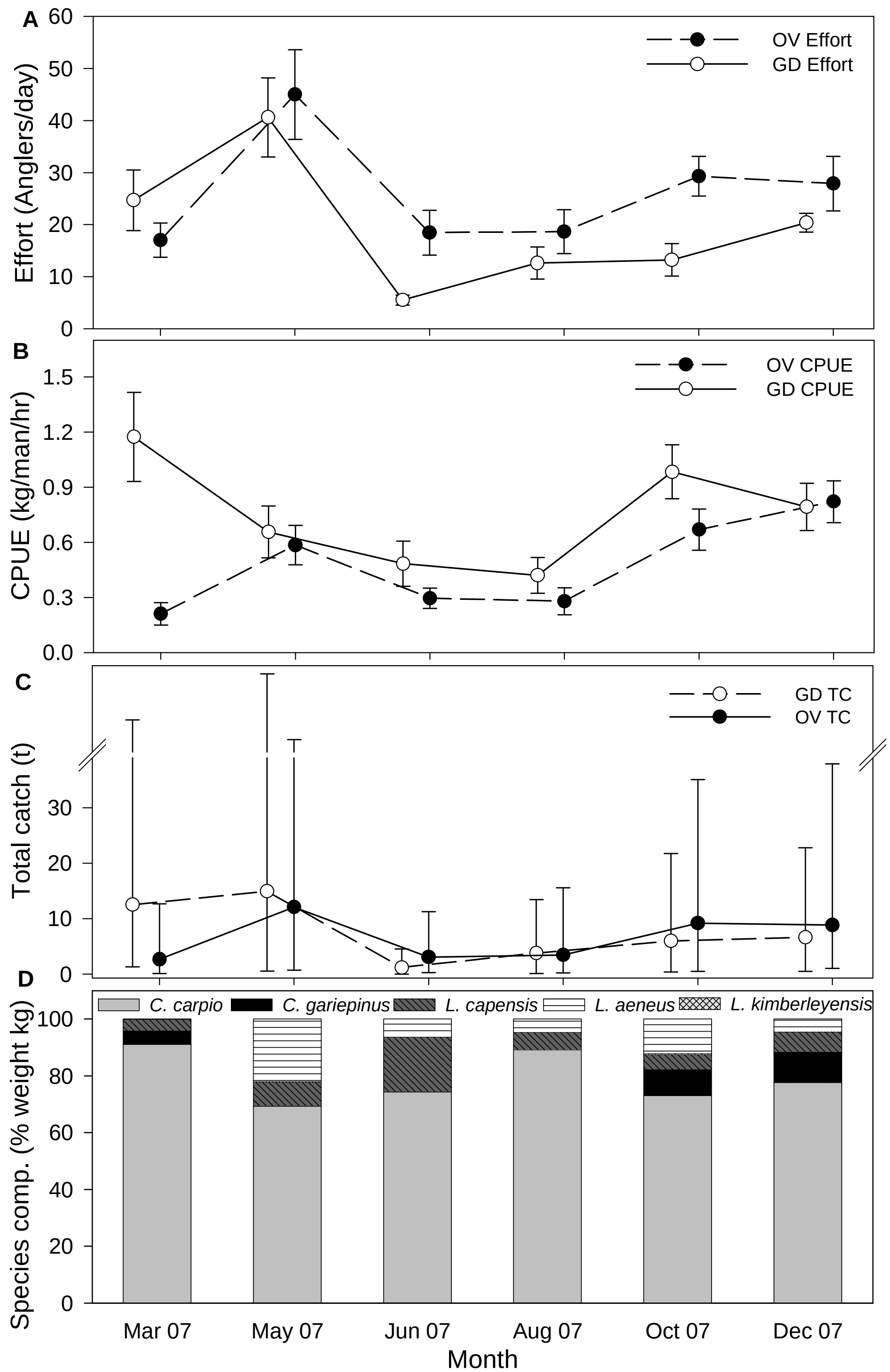

Figure 5.4 (A) Average daily angler effort (anglers/day) between March and December 2007 (± SE). (B) Mean *CPUE* (kg. $man^{-1}.hr^{-1}$) for all anglers (± SE). (C) Total catch (t) for both regions of Lake Gariep (2007/2008) (error bars denote 95 % CI). (OV = Oviston/Venterstad; GD = Gariep Dam). (D) Monthly relative species abundance.

Angler bag frequencies

Of the 85 angler catches containing *L. aeneus*, 17.3 % and 30.3 % of recreational and subsistence anglers had bag limits over the legal limit of two respectively (Table 5.2).

Table 5.2 Frequency of yellowfish in anglers bags and the percentage of bags over the specified bag limit for Lake Gariep anglers (2007/2008).

	Recreational (%)	Subsistence (%)	N
Bags containing *L. aeneus*	61.2	38.8	85
Bags over 2 fish limit	17.3	30.3	19

Potential yield

The potential yield for Lake Gariep ranged from 11.5 kg. hectare^{-1} year^{-1} (Schlesinger and Regier, 1982) to 64.1 kg. hectare^{-1} year^{-1} (Marshall and Maes, 1994). The surface area of Lake Gariep is 35 490 ha. The total potential yield for Lake Gariep was estimated at 412 t^{-1} year^{-1} (Schlesinger and Regier, 1982) and 2275 t^{-1} year^{-1} (Marshall and Maes, 1994) for all species at full capacity.

5.4 Discussion

Lake Gariep anglers catches consisted of five species, four of which are indigenous to the Orange/Vaal River system (*L. aeneus*, *L. kimberleyensis*, *L. capensis* and *C. gariepinus*), and the fifth, *C. carpio* is an alien invasive species (Skelton, 2001). Although the most dominant species in anglers catches was the common carp *C. carpio*, at times *L. aeneus* did contribute up to 20% of monthly catches (Figure 5.4 D). Overall *CPUE* varied between the two regions of Lake Gariep, with GD having significantly higher catch rates than the OV region (Figure 5.4 B). In both regions the PC and *CPUE* was seasonal, with the lowest PC in the winter and the highest during the summer months. Certain fish species are known to have decreased metabolism and feeding during winter and thus decrease the probability of capture (Cooke et al., 2003). In studies on largemouth bass (*Micropterus salmoides*), fish had decreased or ceased feeding, reduction in activity and are caught infrequently by anglers in winter (Cooke et al., 2003; Keast, 1968; Keast and Welsh, 1968).

The contribution of *C. carpio* to catches in both regions was very similar, although the relative contribution of the other three species differed by region. The catches of the less abundant species *L. aeneus* and *L. capensis* contributed to this increased catch rate in the GD region as they were significantly more abundant in anglers catches than in the OV region.

In both the fisheries independent survey and anglers catches in Lake Gariep, longitudinal differences in catch rates of *L. aeneus* were noted seasonally, with increased *CPUE* toward the lake wall (also see Chapter Three). Similar differences were noted in a nearby lake on the Orange River, Lake van der Kloof (Tómasson et al., 1985). These differences were attributed to a decrease in water turbidity from the inflowing river toward the lake wall (Tómasson et al., 1985). The longitudinal differences in catch rates may be related to the reliance of *L. aeneus* on a zooplanktivorous diet, with increased abundance correlating with increased phytoplankton productivity and the resultant zooplankton yield, due to decreased turbidity in the lower reaches of Lake van der Kloof (Eccles, 1986). Similar causes may explain the increased abundance of *L. aeneus* in the GD region of Lake Gariep.

Angler activity was highest during the summer months, peaking just before the onset of winter in April/May. The increased angler activity during this period was a result of a number of public holidays and a long weekend in which there was a large influx of tourists into the GD region. The OV region on the other hand, is not considered to be a popular tourism venue (H. Carey, estate agent, pers. comm.), and is dominated by subsistence fishers that may have been attracted by the prospect of an increased probability of capturing a fish during this period. Interestingly angler activity trends are similar to those of PC, and angler activity is highest when the PC is highest. In the Mutshindudi catchment in the Limpopo province, angler activity followed similar seasonal trends (van der Waal, 2000).

On Lake Gariep, angler activity was related to the probability of capturing a fish and angler activity was highest when the PC was highest. Anglers are increasingly motivated to fish if his chances of catching a fish are high, specifically as the Lake Gariep fishery is dominated by subsistence fishers (see Chapter Four), who fish for food.

The catch by subsistence fishers was estimated to be 55 t. period^{-1}. Thus the contribution of fish to the livelihoods of subsistence fishers is significant. Taking into account the estimated 577 subsistence households (Stelzhammer, unpublished data) that utilise the resource as a primary or supplementary source of income, the resource is extremely important to the communities surrounding the resource. The average daily catch of a Lake Gariep subsistence angler is 5.8 kg, in the Mutshindudi River catchment in Limpopo province, mean daily catch is 0.162 kg (van der Waal, 2000). While the average fishing day length for Lake Gariep anglers was double that of Mutshindudi River anglers, the Lake Gariep anglers *CPUE* was > 30 times higher than the *CPUE* of Mutshindudi River anglers (van der Waal, 2000). Mutshindudi River anglers were also satisfied with their catches and considered their daily catches to be sufficient (van der Waal, 2000). The discrepancy between areas may be that catches in the Mutshindudi River may be generally low as a result of overexploitation and anglers are not motivated to fish more than to meets their everyday needs (van der Waal, 2000).

The current estimated yield of 86.0 [95 % CI = 40.4:154.8] t. year^{-1} from the fishery and 7.5 t. year^{-1} from competition angling for Lake Gariep, is well below the estimated potential yield of between 412 t^{-1} year^{-1} (Marshall and Maes, 1994) and 2275 t^{-1} year^{-1} (Schlesinger and Regier, 1982) using predictive models. Empirical estimates of MEI have been widely criticised, but in data limited situations provide some estimate of potential yield (Ryder, 1982). Although the yield from the fishery is low compared to even the conservative empirical estimate of Schlesinger and Regier, (1982). These models cannot account for species specific differences in potential yield and fishing has various other deleterious effects including effects on the population structure, particularly the size and age at maturity of an exploited population (Stergiou, 2002).

The population structure of fish species in anglers catches indicates that for two of the indigenous fish species, *C. gariepinus* and *L. kimberleyensis*, L_{50} was smaller than the length at maturity for that particular species. As *C. gariepinus* is not a high conservation priority species, and the exploitation of large *C. gariepinus* populations in reservoirs has been recommended (Andrew et al., 2000; Weyl et al., 2007), in Lake Gariep, selecting this species at small sizes poses little threat to the sustainability of the resource.

Despite contributing 8 % to gillnet species composition (see Chapter Three), *L. kimberleyensis* formed a small portion of anglers catches and consequently may not be under threat under current conditions.

The remaining three species all enter the fishery after they reach maturity. If fish are targeted after maturity has been reached, individuals may at least be given a chance to spawn successfully, thus reducing the chance of stock failure (Almodovar and Nicola, 2004). The length frequency distribution for *L. aeneus* from Lake Gariep is not as a result of the available population structure. The lack of or complete absence of fish smaller than a certain size for *L. capensis* and *L. aeneus* may be as a direct result of hook selectivity. Various studies on hook selectivity have reflected gape size as a primary predictor of hook selectivity in fishes (Punt et al., 1996; Stergiou and Erzini, 2002). The gape size in *L. capensis* and *L. aeneus* is smaller than that of *C. carpio*, of which there were individuals selected for well below the size selected for in *L. aeneus* and *L. capensis*. Not only does hook selectivity play a role, but selectivity on a species specific basis may affect the relative abundance of species in anglers catches. *Labeobarbus aeneus* and *L. capensis* were the two most dominant species in the gillnet catches from Lake Gariep (see Chapter Three) and *C. carpio* formed a relatively small portion of gillnet catches. Therefore anglers may specifically select what species they prefer to target through bait and habitat selection.

Recreational and subsistence anglers reasons for fishing differ, thus the species targeted may vary between sectors, although with gear (hook and line) and bait types being similar, species composition and abundance between user groups did not differ. The common carp is favoured by subsistence anglers as it yields a good ratio of flesh : body size and so the gear is predominantly rigged to target carp. The catch of other species is predominantly incidental, although all species are utilised by the subsistence fishers. Although the African sharptooth catfish, *C. gariepinus* attains 1.4 m SL and 59 kg (Skelton, 2001), this species is mostly avoided by subsistence fishers as it may snap their handlines, potentially causing the loss of their gear. *Cyprinus carpio* is a favoured target of recreational anglers in other areas of South Africa (Cadieux, 1980), and Lake Gariep is no exception.

The largemouth yellowfish *L. kimberleyensis* has high conservation priority, and is IUCN redlisted as near threatened (IUCN, 2008). This species is a no-take species in South Africa (Nature Conservation Ordinance, No.8 of 1969). Low angler catches from Lake Gariep (< 0.5% of TC) seem to pose little threat to the species. *Labeobarbus aeneus* on the other hand forms a larger proportion of anglers catches, there is also defiance of bag limits for the species from both recreational and subsistence anglers. Thus angling may have an impact on *L. aeneus*. Although this may be the case, L_{50} is at least above the legal size limit.

Evidence from catch rates, size structure and the biological characteristics of *L. aeneus* and *L. kimberleyensis* suggests that both the *L. aene*us and *L. kimberleyensis* populations are not currently under threat. Although this may be the case, further investigation using stock assessment tools is required.

Chapter 6: General discussion and management recommendations based on per-recruit analysis

The demographics of the Lake Gariep fishery highlight the complex nature of the fishery. The fishery is dominated by subsistence anglers, although recreational angling does form a substantial part of the fishery. This study has documented the existence of the large subsistence sector on Lake Gariep that relies on the lake to provide a source of food, income or supplementary income. The recreational anglers are not reliant on the resource as a livelihood, and release a greater proportion of their catches than do subsistence anglers. The large informal subsistence sector evident on Lake Gariep raises the question as to how much the sector relies on *L. aeneus* and *L. kimberleyensis* as a target species.

Lake Gariep angler catches are dominated by an alien fish species, *C. carpio*. At current harvest rates the populations of indigenous fishes, especially the *L. aeneus* and *L. kimberleyensis* are currently not forming an important proportion of the fish harvested from Lake Gariep. No long-term monitoring data were available for Lake Gariep, and so to make assumptions on the state of the fish stocks in the lake directly from catch rates is very difficult (Caddy, 2002). Relating the size structure of fish targeted in the fishery and linking this to the life history traits of the species may indicate whether angling is likely to cause a decline of the fish stocks of Lake Gariep (Punt et al., 1996).

From a summary of biological data for *L. kimberleyensis*, it is clear that the species is extremely slow growing and late maturing and has moderate to low fecundity. *Labeobarbus kimberleyensis* displays the characteristics of the "equilibrium" species as classified by King and MacFarlane (2003). Management of an equilibrium species recommends low harvest due to the vulnerability of stock collapse as a result of overexploitation (King and McFarlane, 2003). These life history characteristics classify *L. aeneus* as an intermediate strategist (King and McFarlane, 2003). The recommendation by King and MacFarlane (2003) for the management of intermediate strategist stocks was to maintain a critical spawning biomass.

Not only are the effects of the current fishery on the status of the *Labeobarbus* stock important, but documenting current exploitation levels has far-reaching consequences for future fisheries development. The expansion of South African inland fisheries is imminent

(Andrew et al., 2000, Richardson et al., in review, Weyl et al., 2007), specifically in Lake Gariep, where community fisheries projects are currently being investigated and a quota of 200 t has been issued as a means of providing an income to the local communities surrounding the lake (J. Carey. Oviston Nature Reserve Manager pers. comm.). The proposed fishery is not a hook and line fishery, and a new suite of problems may face the species, specifically as its life history characteristics appear to make it vulnerable to fishing. Therefore an assessment of the response of the *L. aeneus* stock to fishing is necessary.

In data limited situations, such as the Lake Gariep fishery, where no long term fisheries data exists, per-recruit models have been suggested to give an indication of the effect of exploitation on the spawning stock biomass of a species (Booth and Buxton, 1997; Butterworth et al., 1989; Punt et al., 1996). Specifically, indicators or biological reference points (*BRPs*) are derived, which provide an indication of how much fishing effort it takes to compromise the biological sustainability of the fish stock (Allan et al., 2005; Mace, 1994; Sparre and Venema, 1997). Because the principal aim of this assessment was to ascertain biological sustainability of harvest, and not to maximize yield, a spawner biomass-per-recruit (*SBR*) approach was chosen to assess the response of *SBR* to different levels of fishing mortality (*F*) and age at selection.

There has been much debate in literature about how much *SBR* can be reduced without having deleterious effects on the fish stock (Clark, 1991; Deriso, 1987; Gabriel et al., 1989; Mace, 1994; Quinn et al., 1990; Sissenwine and Shepherd, 1987). For the Cyprinid, *Labeo cylindricus* Peters, 1852, which is fast growing and early maturing, Booth and Weyl, (2004) investigated two *BRPs*, F_{SB35} and F_{SB50}. A specific approach was taken to estimate *BRPs* for Cichlids by taking into account their life history strategies (long lifespan, low fecundity, parental investment) and F_{SB40} was recommended as a conservative approach to sustainaing the livelihoods of the fishers utelising Cichlids (Booth, 2004). In many cases, *BRPs* are chosen as they are a trade off between maximum yield and sustainable harvest levels (Booth, 2004; Booth and Buxton, 1997; Booth and Weyl, 2004) and not specifically geared toward formulating reference points for the conservation of the species. Although the definition critical spawning biomass is vague, it is considered somewhere between 20 % and 50 % of pristine spawning stock biomass (King, 1995). The rationale behind assigning a critical spawning biomass of between 20 % and 50 % the pristine levels is that at these values of *SBR*, the population may not able to maintain sufficient recruitment (Booth and Buxton, 1997;

Clark, 1991; Deriso, 1987; Gabriel et al., 1989; King, 1995; Mace, 1994; Quinn et al., 1990; Sissenwine and Shepherd, 1987; Weyl et al., 2007).

In order to assess the spawning stock biomass of *L. aeneus*, biological input parameters for the spawner biomass-per-recruit analysis were obtained from Chapter Three and hook and line selectivity from Chapter Five. The input parameters chosen were from female *L. aeneus* as they formed the predominant portion of anglers catches (see Chapter Three, Figure 3.5). These input parameters are summarised in Table 6.1. Spawner biomass-per-recruit models assume that recruitment is constant and that there is a steady state stock structure (the fish stock under consideration is at equilibrium) (Butterworth et al., 1989; Sparre and Venema, 1997). Spawner biomass-per-recruit as a function of fishing mortality *F* and selectivity at age *t* S_t, was calculated as:

$$SBR(F,S_t) = \sum_{t=0}^{max} W_t \tilde{N}_t \psi_t$$

(Equation 6.1)

where *Wt* is weight of fish at age *t*, *ψt* is the maturity at age *t* and *max* is the age of the oldest aged fish in the population. The relative number of fish at age *t*, *t N~*, is calculated as:

$$\tilde{N}_t = \begin{cases} 1 & if \cdot t = 0 \\ \tilde{N}_t e^{-M - S_{t-1}F} & if \cdot 0 < t < \max \\ \dfrac{\tilde{N}_{\max-1} e^{-M - S_{\max-1}F}}{1 - e^{-M - S_{\max}F}} & if \cdot t = \max \end{cases}$$

(Equation 6.2)

A conservative approach was taken when investigating *BRPs* because of the high conservation priority of *L. aeneus*. Two *BRPs* were investigated. These were F_{SB80} and F_{SB50} (those fishing mortalities that correspond to reduction of *SBR* to 80 % and 50 % of pristine levels, respectively. Fisheries managers are increasingly advocating erring on the side of caution, and so any *SBR* < F_{SB50} was chosen as an indicator of critical levels of *SBR*.

The variability of the reference point estimates was assessed by Monte-Carlo simulation using 1000 iterations. For each simulation, a random normally-distributed variate was drawn and both *BRP*s estimated. Natural mortality was assumed to be normally distributed around the mean natural mortality rate with a *CV* of 15%, such that for *L. aeneus* M_{La} ~ $N\left(0.46(0.46x0.15)^2\right)$. Confidence intervals from the resultant *BRP* vectors were calculated using the percentile method (Buckland, 1984).

Table 6.1 Biological and fisheries input parameters and the chapters from this thesis where the parameters were obtained and used for the application of spawner biomass models for *L. aeneus* from Lake Gariep (2007/2008).

Parameter	Value	Chapter
L_∞ (asymptotic length)	491.71 mm FL	Chapter 3
K (brody growth coefficient)	0.24 year^{-1}	Chapter 3
t_0 (age at zero length)	-0.29 years	Chapter 3
a (length weight parameter)	0.000012	Chapter 3
b (length weight parameter)	3.03	Chapter 3
ψ (age-at-50% maturity)	5.5 years	Chapter 3
$\delta\psi$ (width of logistic ogive)	0.6	Chapter 3
t_r (age-at-50% selection)	5.3 years	Chapter 5
δt_r (standard deviation of selectivity curve)	0.7 years	Chapter 5
M (natural mortality rate)	0.46 year^{-1}	Chapter 3
max (max age considered)	12 years	Chapter 3

Stock response

The response of *L. aeneus SBR* to increasing *F* is summarised in Figure 6.1 and the isopleth diagram showing the response of *SBR* to different age-at-selectivity and *F* in Figure 6.2. Results of the estimated *BRP*s that included random variation in the assumed natural mortality rate are summarised in Table 6.2. Current *F* (0.09 year^{-1}) reduces *SBR* by approximately 7%. The first precautionary *BRP* (F_{SB80}) was reached at *F* of 0.27 year^{-1} and 16 times increase of current *F* is required to reduced *SBR* to F_{SB50} (*F* = 1.44 year^{-1}). At ages of selection below four years, *SBR* was depleted to below F_{SB50} (Figure 6.2). At current *F*, *SBR* cannot be depleted below F_{SB50} at any age at selectivity. At ages below four, the F_{SB50} is reached at or below a four times increase in *F*.

Table 6.2 Biological reference points and their associated estimates of variability derived from Monte-Carlo simulation using 1000 iterations of the CV (15%) around the mean natural mortality for *L. aeneus* from Lake Gariep (2007/2008).

Species	t_r	BRP	MLE	CV (%)	95% CI
L. aeneus	5.30	F_{SB80}	0.27	32.81	[0.16, 0.52]
		F_{SB50}	1.44	62.38	[0.64, 3.77]

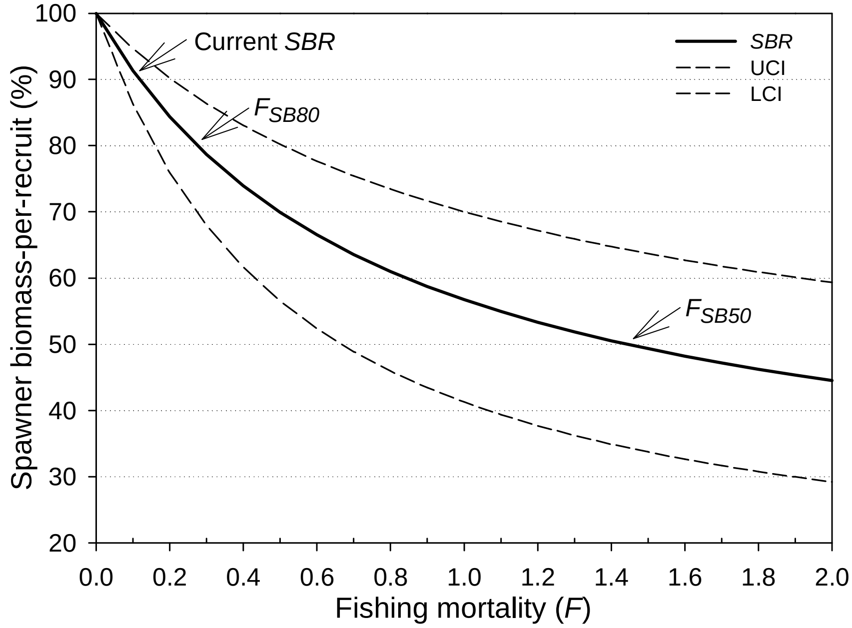

Figure 6.1 Spawner biomass-per-recruit (%) as a response to increased fishing mortality for L. aeneus from Lake Gariep (2007/2008) indicating the levels of *F* that reduce *SBR* to the investigated *BRPs*, F_{SB50} and F_{SB80} (F). (Dotted lines denote the 95 % confidence intervals from the bootstrapped values around the mean natural mortality rate with a CV of 15 %).

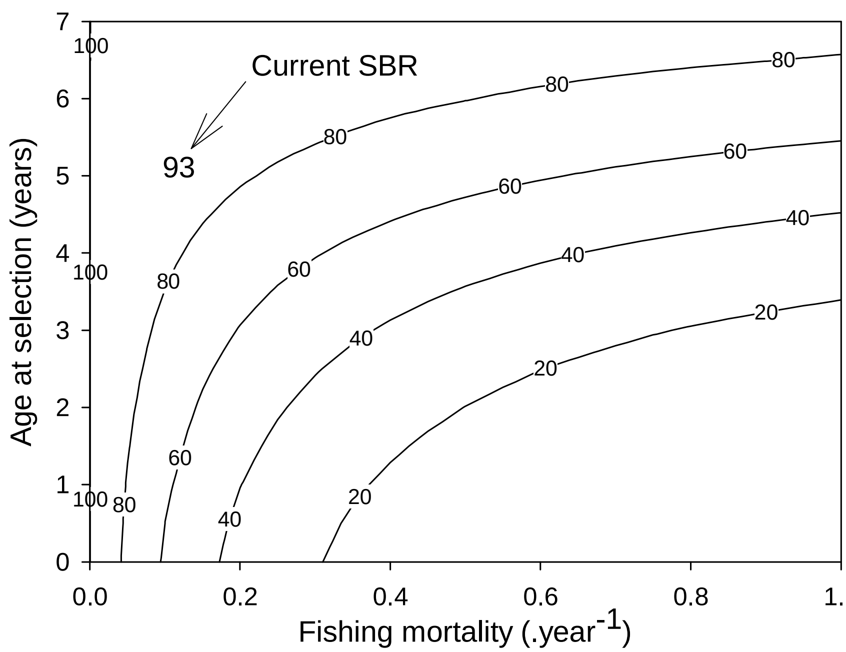

Figure 6.2 Isopleth diagrams describing the response of Lake Gariep *L. aeneus* spawner biomass-per-recruit for under different combinations of fishing mortality and age at selection. Current *SBR* (*F* = 0.09; age at selection = 5.3) is indicated by the arrow. Contours represent the proportion of pristine spawner biomass-per-recruit.

Per-recruit simulations provide estimates of how much current *F* is reducing the *SBR* of the exploited species. On Lake Gariep, current *F* reduces female *L. aeneus SBR* by approximately 7 % (Figure 6.1), therefore current exploitation rates can be considered sustainable (*SBR* > F_{SB80}).

There are a number of characteristics of the Lake Gariep fishery that may explain the maintenance of biologically sustainable exploitation of *L. aeneus*. The *L. aeneus* population of Lake Gariep were selected for at age-at-50 % maturity (am_{50}), allowing individuals an opportunity to spawn successfully before entering the fishery (Almodovar and Nicola, 2004). Booth and Weyl, (2004) indicated that selecting *Labeo cylindricus* above am_{50} using selective gillnets (i.e. above am_{50}) did not deplete the *SBR* to F_{SB50}, even when *F* was doubled. If however, unselective seine nets were used and fish of all sizes were harvested, F_{SB50} was reached rapidly (Booth and Weyl, 2004).

Current *F* (0.09 year^{-1}) has little impact on the *L. aeneus* stock in Lake Gariep, but changes in the age at selection and mortality (*M*) for *L. aeneus* depleted the spawning stock biomass (Table 6.3; Figure 6.2). If fishing effort more than doubled, and the age at selection for *L. aeneus* decreases by two years, the *SBR* rapidly approaches SBR_{50} (Figure 6.2). At current age at selection however, the fishery can increase by ten times without dropping the *SBR* to the precautionary *BRP*, SB_{50}. Caution should be taken to ensure that this age at selection does not decrease.

Although angling effort on Lake Gariep is generally low (20-90 anglers/day; see Chapter Five), anglers also have restricted access to the shoreline, with approximately 70 % being closed to fishing. This inadvertently creates a situation where effort is greatly limited for the system. Closed areas have been proposed by a number of authors as at least a partial solution to decreasing fishing effort (Botsford et al., 2003; Gell and Roberts, 2003; Hilborn et al., 2004). Generally, there is a perception that closed areas provide more protection to less mobile species, affording highly mobile or migratory species little protection (Gell and Roberts, 2003; Hilborn et al., 2004). According to Hilborn et al., (2004) closed areas have a range of benefits other than limiting only effort, these are by; (1) increasing fishery yields through the spill over of fish from closed areas; (2) closed areas are a buffer against uncertainty such as stock assessment errors; (3) reduced collateral impacts by reducing the effect of fishing on not only fish, but other organisms as well; (4) by protecting sedentary organisms; (5) protecting multi-species fisheries and; (5) improving scientific knowledge using closed areas as controls to fished areas. Although *L. aeneus* is a highly mobile species (Tómasson, 1983), the more closed area there is, as is the situation at Lake Gariep, the less probability an individual has of encountering an angler and the more protection it gains.

Concluding remarks

The effect of angling on *L. aeneus* and *L. kimberleyensis* is summarised in Figure 6.3. The life history characteristics of *L. kimberleyensis* and *L. aeneus* make them vulnerable to exploitation through slow growth and late maturity and low rates of natural mortality.

There is a large subsistence sector that is highly reliant on Lake Gariep as a source of food. Lake Gariep anglers use the resource consumptively (when caught, they are kept). *Labeobarbus aeneus* is target species in the fishery, while *L. kimberleyensis* is caught as by-catch. Although angling practices are consumptive, both species contribute a small portion to anglers catches from Lake Gariep.

The spawning stock of *L. aeneus* is considered pristine and *SBR* was > 90 % of pristine levels. Spawner biomass-per-recruit for *L. aeneus* was sensitive to changes in age at selection and mortality. The biological sustainability of *L. aeneus* and *L. kimberleyensis* in Lake Gariep is not under threat at current levels of exploitation (Figure 6.3).

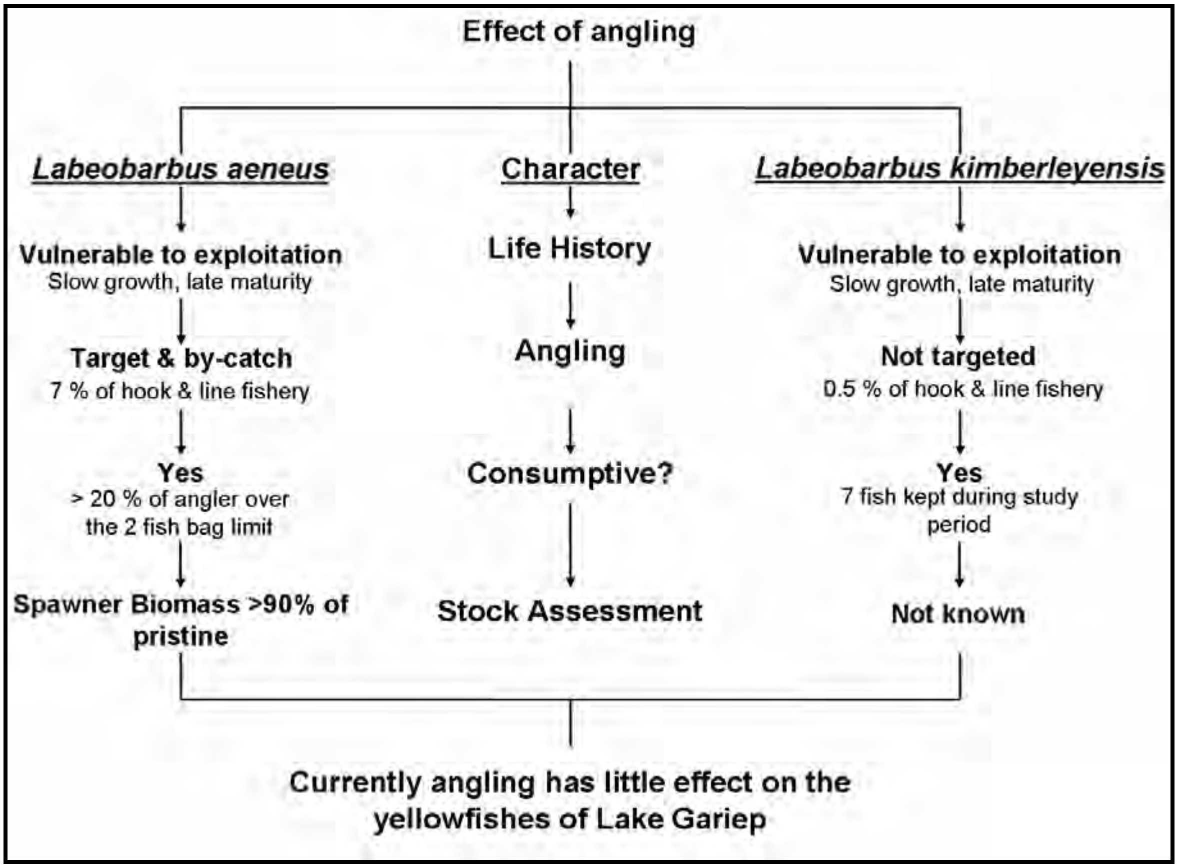

Figure 6.3 Summary of the effect of angling on *L. aeneus* and *L. kimberleyensis* in Lake Gariep by assessing the life history characteristics, angling characteristics and a stock assessment model.

Management recommendations

The Lake Gariep fishery relies predominantly on *C. carpio*, an alien fish species, that also provides an important livelihood to local subsistence fishers. As there is a high degree of reliance on Lake Gariep as a source of food, effort limitations on the subsistence sector in the future is unlikely was the fishery to expand. Under the current situation on the lake, 70 % of the shoreline is closed to fishing, access is limited to between 06h00 and 18h00, *L. aeneus* has a 300 mm FL size limit and two fish bag limit and *L. kimberleyensis* is a no take species. It is recommended that in terms of placing limitations on users, the fishery remain unchanged.

As has been mentioned before, South African inland waters have been identified as vehicles for development in the future. Should an alternate fishery develop, such as a gillnet fishery, protocols should be put into to place to ensure sustainable use. The fishery should be monitored bi annually to asses for changes in *CPUE* and the size composition of the catch.

For *L. aeneus,* the age at selection should be above the am_{50} for the species. There is circumstantial evidence of *L. aeneus* spawning aggregations in Lake Gariep. Should such aggregations be actively targeted, a closed season during the peak spawning season (January to June) of *L. aeneus* should be implemented. *Labeobarbus kimberleyensis* can be assumed to be as vulnerable as *L. aeneus*, and should not be actively targeted in the fishery. Continued monitoring and reassessment of the fishery is important to establish whether utilisation patterns change over time, and to make changes to the management strategy for the fishery accordingly.

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