

**AN ASSESSMENT OF THE INVASION STATE AND
FISHERIES SUITABILITY IN FOUR DAMS AND A
NATURAL LAKE IN THE WESTERN CAPE, SOUTH AFRICA**

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“I am aware of the University’s Policy on Plagiarism. All of the work is my own. I have not included ideas, phrases, passages or illustrations from another person’s work without acknowledging their authorship.”

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Signed:

A handwritten signature in black ink, appearing to read "Bred", enclosed within a hand-drawn circle.

ABSTRACT

Despite more than a century of introductions, fish invasions are poorly understood in South Africa. This thesis aims to: (1) provide baseline information on the fish fauna in five inland water bodies (four dams: Theewaterskloof, Clanwilliam, Quaggaskloof, and Voelvlei and a natural lake, Groenvlei) in the Western Cape; (2) determine which species were established and provide a baseline of abundance and size structure for monitoring and, (3) make preliminary recommendations for a fishery. First, criteria for determining establishment were developed by undertaking a full biological assessment of bluegill *Lepomis macrochirus*, a data-poor species in South Africa. This included the assessment of growth rate using validated estimates of age derived from otoliths in two dams (Clanwilliam Dam: $L_t = 335.9(1 - e^{0.113(t+1.06)})$; Groenvlei: $L_t = 287.2(1 - e^{-0.171(t+0.54)})$). Length at 50% maturity was similar for males (146 mmFL) and females (147 mmFL). Length frequency analysis combined with data on the age and growth and reproduction demonstrated that established populations of bluegill contained several age cohorts as well as mature and juvenile fishes.

A meta-analysis was conducted to: (1) compile a list of initial stocking dates for all alien fishes in each waterbody and (2) use angler tournament data to assess for additional species and persistence over time. Data from the meta-analysis was combined with ichthyological survey data to determine establishment success. These data demonstrated that nine non-native species had established in the five water bodies. Clanwilliam Dam had the largest number (7) of non-native species established, Groenvlei (5) and Theewaterskloof, Brandvlei and Voelvlei the lowest with four species. The state of invasion of each species in the province showed that all nine species are categorised as invasive.

This information on establishment was then integrated into a framework for rapidly determining what type of fishery would be most suitable for the 5 waterbodies. Potential yield was estimated using morphoedaphic models, were 260 t/yr for Theewaterskloof Dam, 93 t/yr for Voelvlei, 81 t/yr for Brandvlei, 59 t/yr for Groenvlei and 55 t/yr for Groenvlei. The CPUE for Groenvlei was the highest in gill nets with 1.32 ± 1.94 kg/h, then Voelvlei 1.05 ± 1.34 kg/h followed by Brandvlei (0.84 ± 1.48 kg/h), Clanwilliam (0.71 ± 1.55 kg/h) and lastly Theewaterskloof (0.36 ± 0.41 kg/h). Only Theewaterskloof could produce in excess of 100 t/yr but less than 400 t/yr of fish making it suitable for a small scale fishery. The CPUE values of Theewaterskloof were the lowest and a gill net fishery on this water body may not produce sufficient fish for the fishery. All water bodies had a high recreational angling usage, the opening of a small scale fishery could be detrimental to this industry. Subsistence and recreational anglers should be promoted with the possibility of a long line industry targeting *Clarias gariepinus*.

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CHAPTER 1: GENERAL INTRODUCTION

Intentional as well as unintentional introductions have made fish one of the world's most introduced aquatic animals (Gozlan *et al.* 2010). Intentional introductions occurred to establish food fishes, create new fisheries, restore depleted fish stocks, and control plants, invertebrates, and other fishes, while accidental introductions include escapees from aquaculture and the ornamental fish trade (Ellender and Weyl 2014, Weyl *et al.* 2014). The consequences of introductions include: a decline in the native macro-invertebrate community, reduction in water quality, loss of native genetic transcriptions through hybridization, behavioural changes in native species, community changes in the form of species extinction and food webs and alterations in the ecosystem by means of ecological engineering (Cucherousset and Olden 2011, Vilizzi 2012).

Globally, the impacts of these introductions may not be entirely harmful as Gozlan (2008) refers to the development of aquaculture and sport fishing of alien fish as supplementing the local and national economy through employment opportunities and income generation. In the United States for example, sport fishing generated US\$69 billion in 2005 (Pimentel *et al.* 2005, Blaine 2013). These figures do not include the use of the resource by subsistence fishers and societal benefits (Pimentel *et al.* 2005). Although not all the impacts appear to be negative, the negative impacts do appear to be substantial. Financially, in the US, the conservative losses due to alien fish was US\$5.4 billion annually. Cambray and Bianco (1998) estimated that 3000 of the 10 000 known freshwater fish could become extinct in the next 30 years and that one of the main causes after habitat degradation is alien fish introductions (Cambray 2000).

South Africa

Introductions of fish into South Africa started as early as the 18th century (Skelton *et al.* 1984). Many of the early fish to be introduced into South African waters were for angling and food purposes because early settlers into the Cape Province found few native fish species that would meet either of these needs. Introductions started with *Carassius auratus* in 1726 for ornamental purposes followed by *Cyprinus carpio* in 1859 (Ellender and Weyl 2014). The Cape Piscatorial Society then aided in the introduction of *Oncorhynchus mykiss* and *Salmo trutta* in 1897 and 1892, respectively (Weyl *et al.* 2014). With the arrival of these species the state-funded Jonkerhoek hatchery was established for primary propagation and by the 1930's numerous trout hatcheries had been established (Ellender and Weyl 2014). This facilitated the introduction of other species such as *Tinca tinca* in 1896 and three *Micropterus* species and *Lepomis macrochirus* by 1939 (Weyl *et al.* 2014). Government initiatives of stocking and introducing non-native fishes was terminated in the 1990's as awareness of the impacts caused by non-native fishes changed the attitude of conservation authorities. By this time at least 20 non-native fish species had been propagated and introduced into South African waters with four of these species in the worlds 100 worst invasive species (Lowe *et al.* 2000, McCafferty *et al.* 2012, Weyl *et al.* 2014).

The Cape Floristic Region (CFR)

Introduced predatory species such as *Micropterus salmoides* and *Micropterus dolomieu* have the largest impacts on native species and as the Cape Floristic Region (CFR) is a biodiversity hotspot the effects of introduced species is likely to have a significant impact on the native species (Myers *et al.* 2000). The CFR has 24 native fish species with 17 of these at least near threatened and two critically endangered according to the IUCN (Gaigher *et al.* 1980, Weyl *et al.* 2014). While impacts in streams and rivers are fairly well documented, little is known on

the impacts, development, spread and potential fisheries of non-native fishes in South Africa (Ellender and Weyl 2014). For example, it is often assumed that the lower reaches of South Africa's Rivers and impoundments are fully invaded (Van Rensberg *et al.* 2011). However, there are few data available to support this assumption. In the Western Cape, the last survey of impoundments was in 1978 (McVeigh 1979). In addition, the only gear used in this survey was gill nets, reducing the possibility of sampling small species. As a result, species compositions in impoundments have not been recently assessed in this region. This not only impacts on our understanding of the spread of alien fishes but also constrains the development of fisheries.

Inland fisheries

There is increasing interest to develop inland fisheries in South Africa by government and small scale fisheries (Britz *et al.* 2015). It is therefore likely that provincial management authorities such as Cape Nature, will need to make decisions on fisheries development and management in inland water bodies. Decision making is however constrained by a lack of even the most basic data on the suitability of inland water bodies for fisheries development.

As a result of such constraints Weyl *et al.* (2007) proposed the use of rapid assessment data including a productivity analysis, species composition, stakeholder consultation and personal observations to make preliminary recommendations for fisheries development. In the absence of monitoring data many assessments in South Africa are based on presence/absence data (e.g. Leprieur *et al.* 2008, Marr *et al.* 2009). Such assessments are only suitable for initial assessments of potential suitability because ultimately, fisheries can only be based on fully established, self-sustaining populations. This is important because for some fishes impoundments could act as sinks for river-spawned species which might make up a large proportion of catches in a virgin fishery but, as a lack of internal recruitment processes are

unlikely to sustain fisheries. An example is the failure of many upper Zambezi River species such as *Labeo* spp. in Lake Kariba (Zengeya and Marshall 2008). It is therefore important that information on establishment be included into the Weyl *et al.* (2007) framework to provide a more comprehensive and concise framework to support the development of inland fisheries in South Africa.

1.1 Thesis outline

This thesis was conceptualised to: (1) provide baseline information on the fish fauna in five inland water bodies (four dams: Theewaterskloof, Clanwilliam, Quaggaskloof, and Voelvlei and a natural lake, Groenvlei) in the Western Cape; (2) determine which species were established and provide a baseline of abundance and size structure for monitoring and, (3) make preliminary recommendations for a fishery. To do this, the thesis is organised in 6 Chapters.

After the general introduction (Chapter 1), Chapter 2 describes the study areas, physical characteristics of these water bodies, prior information on the fish species that are expected to occur in these water bodies and the general sampling methods adopted to attain the samples.

In Chapter 3, bluegill *Lepomis macrochirus* are used as a model species to illustrate how the establishment success of invasive species should be evaluated using an evidence-based framework. In this case the Blackburn *et al.* (2011) framework. As there is no biological information on bluegill in South Africa, this chapter will contribute towards the better understanding this invader in South Africa. Using appropriate criteria for establishment developed in Chapter 3, Chapter 4 evaluates the invasion state and establishment success of all non-native fishes sampled from the five water bodies in the study area. Having done this, the Weyl *et al.* (2007) framework was applied to undertake a fisheries suitability analysis to make

recommendation regarding what type of fishery might be appropriate in each of the five water bodies. Finally the general discussion in Chapter 6 explores the changes in the fish fauna over time and makes recommendations for future research.

CHAPTER 2: STUDY AREA AND GENERAL SAMPLING

METHODS

2.1 Study area

The five water bodies selected to be surveyed are a natural lake Groenvlei (Lake Pleasant) and four dams, namely Theewaterskloof, Voelvlei, Greater Brandvlei and Clanwilliam Dam (Figure 2.1).

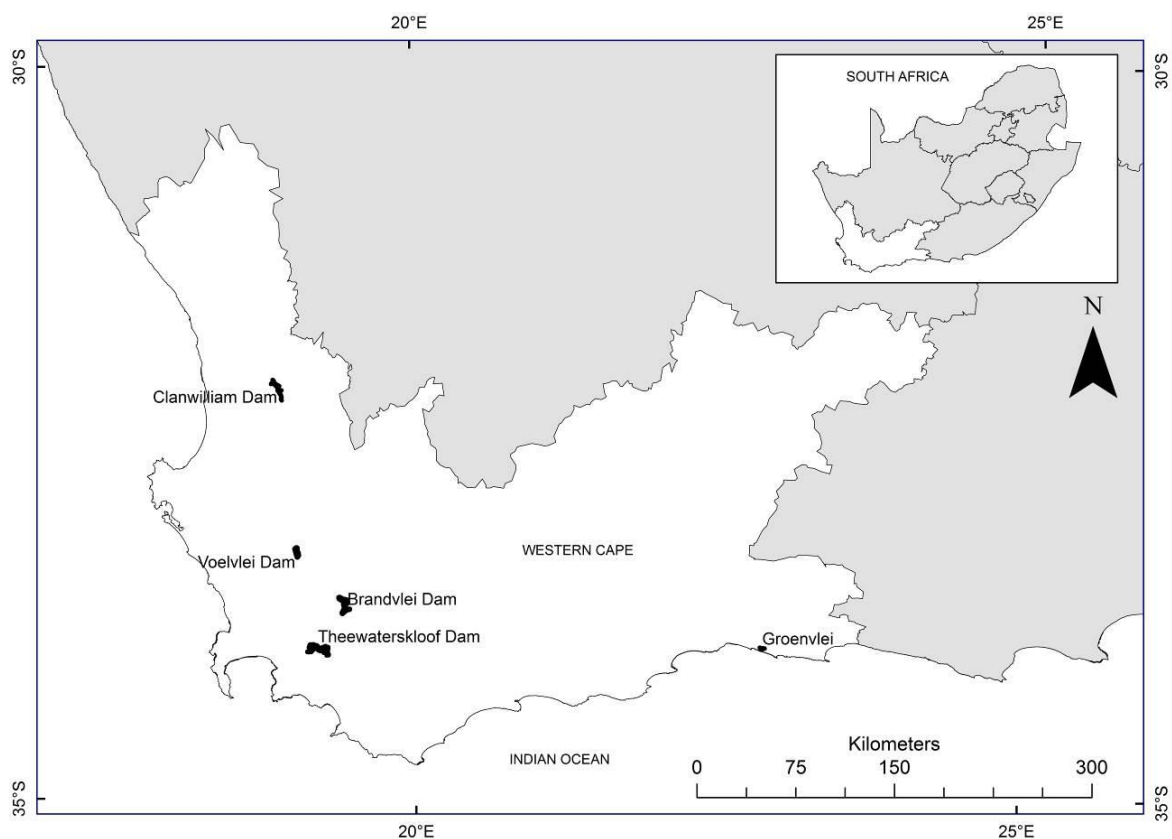


Figure 2.1. A map of the Western Cape Province with the locations of the five water bodies.

2.1.1 Groenvlei

Groenvlei ($34^{\circ}01'34.81''S$, $22^{\circ}51'00.94''E$) is located on the southern coast of South Africa, 5 km east of Sedgefield (Figure 2.2). This lake, one of five lakes is separated by sandy ridges between Wilderness and Knysna (Martin 1960). It was named after the green colour of the

water in the Vlei and was formed some 6 000 years ago. Groenvlei was connected to Swartvlei, a lake 5 km west of it until 8 000 years ago, over the next 2000 years wind-blown sand deposits separated Groenvlei from the ocean (Parson 2008). It was this early connection to the ocean and salt spray blown over the dunes that gives Groenvlei its brackish nature (Parson 2008).

Groenvlei, situated in the Goukamma nature reserve, is 4 km long, has a maximum width of 1 km and covers approximately 250 hectares (Parson 2009). Water in the lake is dependent on rainfall, spring flow, evaporation and seepage as there is no outlet nor influent rivers (Parson 2009). Ground water is supplemented by an annual rainfall of approximately 780 mm which falls predominantly during the winter months (Parson 2009).

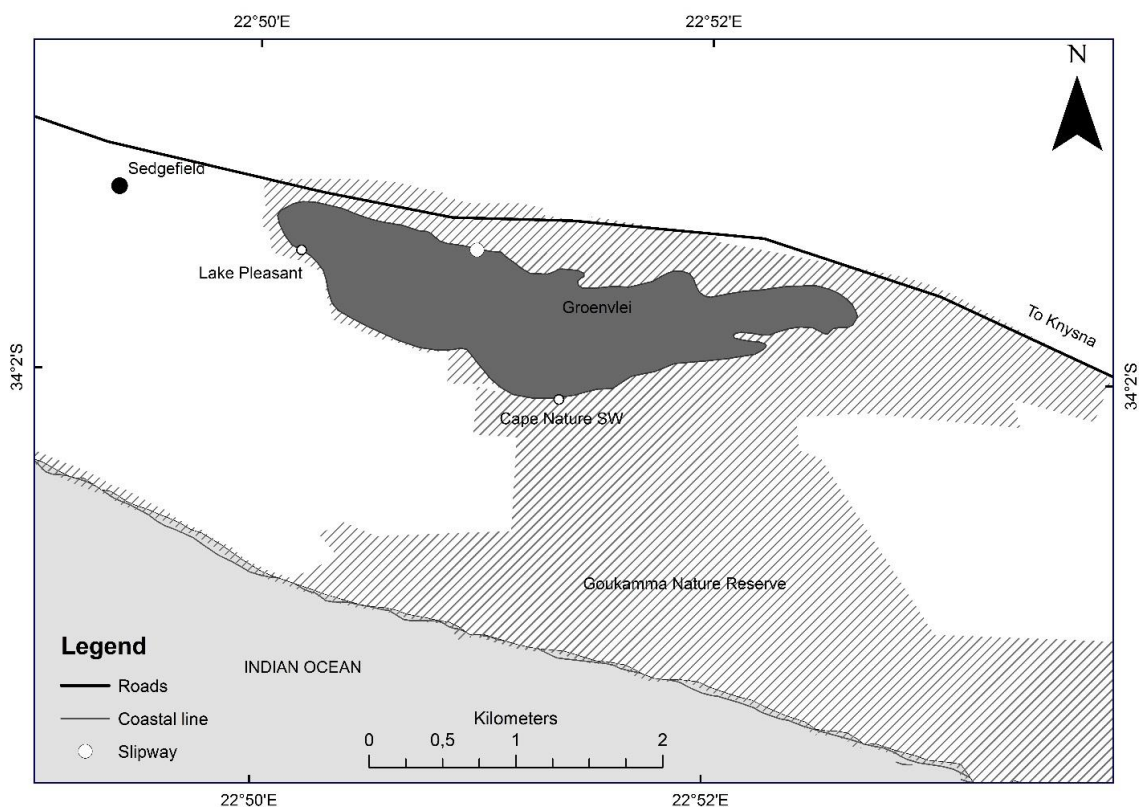


Figure 2.2. A map of Groenvlei showing the surrounding Goukamma Nature Reserve, slipways and locations Sedgefield.

Native and non-native fish introductions

This lake was chosen in the early 1900's as an ideal site for the introduction of non-native recreational fish species such as largemouth bass, *M. salmoides* and bluegill sunfish, *L. macrochirus* (Harrison 1952). In assessing the status of fish stocks prior to the non-native introductions, early sampling resulted in only one species of indigenous fish being identified, this being estuarine round herring, *Gilchristella aestuaria*. Subsequent surveys identified a second indigenous species, the cape silverside, *Atherina breviceps* (Ratte 1989). The lack of freshwater fish was attributed to the isolation of the lake and by 1989 Ratte (1989) found these two indigenous species to be sufficiently divergent from other specimens in the region to suggest they receive priority conservation status. Further studies on these two species found that they only utilized a narrow component of the available resources in the lake so introductions of non-native species would increase the use of the lake (Coetzee 1982).

Largemouth bass were introduced in 1934 to boost the recreational fishery and for harvesting purposes as this lake had no suitably sized fish (Jubb 1973, Harrison 1952). Only 15 fingerlings were stocked into Groenvlei from Jonkershoek hatchery in Stellenbosch and by 1973 they had successfully invaded the lake (Jubb 1973). This successful introduction led to further legal introductions of fish species including: bluegill sunfish *L. macrochirus*, Mozambican tilapia *Oreochromis mossambicus* and western mosquitofish *Gambusia affinis*. Since these legal introductions, one illegal introduction of the common carp, *Cyprinus carpio* has occurred. All five non-native species of fish appear to be breeding successfully but the effects of the common carp introduction are still to be seen.

Water quality and hydrology

Data collected by Department of Water Affairs (DWA), from 1978 – 2012 shows Groenvlei has an average pH of 8.55 ± 0.47 (DWAF 2014). Water temperature in Groenvlei ranges from 11.3 to 30.2 between 1988 and 1998 (DWAF 2014).

2.1.2 The Greater Brandvlei Dam (Brandvlei and Quaggaskloof)

Situation

The Greater Brandvlei dam (33°41'41.15"S, 19°25'38.79"E) is located 15 km south of Worcester (Figure 2.3). This dam is comprised of Quaggaskloof and Brandvlei dam which are separated by a small divide during times of low water levels but conjoined as water levels rise (DWA 1988). As there are no suitable storage sites on the Breede River, these off-channel storage dams were constructed. Greater Brandvlei has a capacity of 444 million m³ which is fed by a feed canal from Smalblaar with a capacity of 45 m³/s (DWA 1988). This earth-filled dam was constructed primarily for irrigation purposes and for water supply to nearby towns. The construction of Greater Brandvlei Dam was completed in 1983 (DWA 1988).

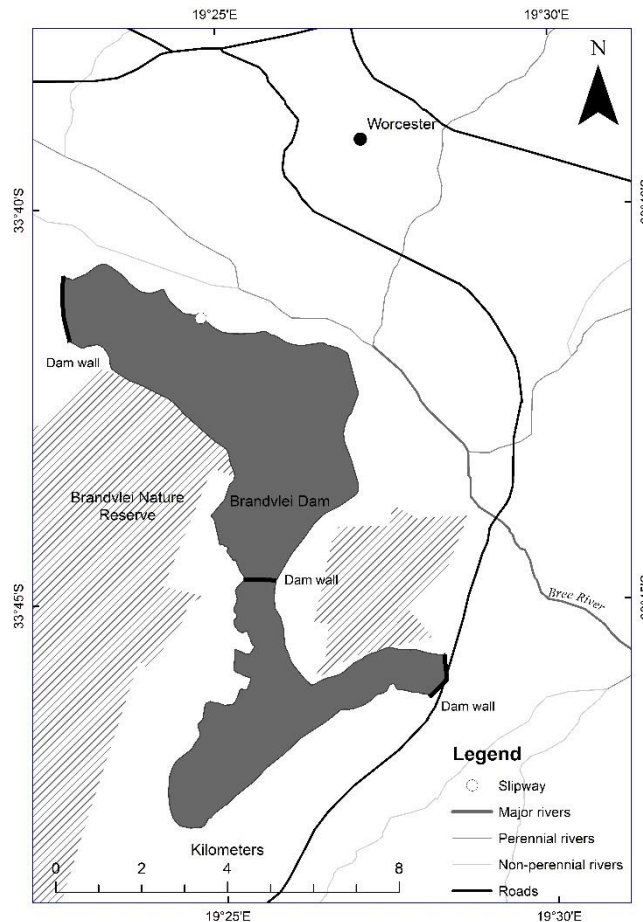


Figure 2.3. A map of the Greater Brandvlei dam showing surrounding nature reserves, dam walls and the town of Worcester.

Native and non-native fish introductions

Brandvlei is an important dam in the conservation of the endangered whitefish, *Barbus andrewi*. This fish is endemic to the Western Cape and is threatened by predatory alien fish species and by the unsustainable use of riverine habitat (Impson *et al.* 1998). Populations of whitefish are abundant in Brandvlei and Impson *et al.* (1998) recommended using this stock to repopulate the depleted Berg River population. Should this stock of fish collapse it could have serious implications for the survival of this species. There are numerous alien fish species within the dam including: *M. salmoides*, *M. dolomieu*, *C. carpio*, *B. andrewi*, *C. auratus*, *G. aestuaria* and *L. macrochirus* (McVeigh 1979).

Water quality and hydrology

The greater Brandvlei dam has a neutral pH of 6.58 ± 0.91 when averaged over the period 1972 – 2011 and from 2001 – 2012 it received an average annual rainfall of 298.3 ± 104.4 mm. (DWAF 2014)

2.1.3 Voelvlei

Situation

Voelvlei dam ($33^{\circ}21'54.69''S$, $19^{\circ}02'35.17''E$) is situated 100 km north east of Cape Town and south of Gouda (Bradlow 1963; Figure 2.4). On the eastern side of Voelvlei rise the Elandskloof Mountains which form part of the Drakensberg range that continue to spread south. Voelvlei runs from the dam wall in the north for 7 km south and is nearly 2 km wide.

Originally known as Vogel vlei or Vogel valley which in English means Bird Lake due the abundance of water birds in the winter months, it was renamed as Voelvlei once the dam was built (Bradlow 1963). Early accounts of Vogel vlei were made in the 1700's when early explorers passed the vlei to ascend a pass through the Elandskloof Mountains (Bradlow 1963). Since this time, there was little development to the lake until after the Second World War. Construction of the dam around the vlei was commenced in 1948 and was completed by 1952 (Bradlow 1963). A canal was constructed from the Klein Berg River for additional water and an outlet into the Great Berg River was created. The construction of the dam was for agricultural, industrial and domestic use and by the late 1960's the demand on the water from Voelvlei exceeded the capacity and in 1971 the dam wall was raised to accommodate this demand (DWAF 2004)

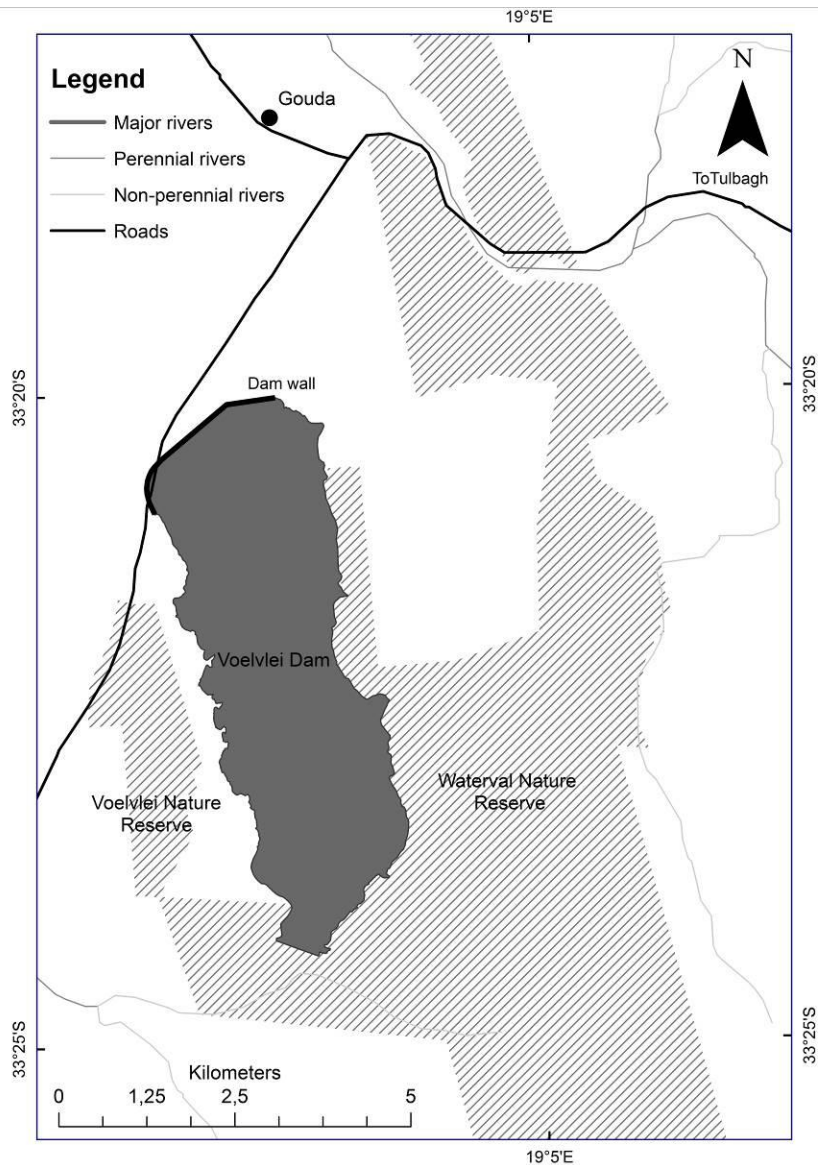


Figure 2.4. A map of Voelvrei showing surrounding nature reserves, the dam wall and Gouda town.

Native and non-native fish introductions

Voelvrei, being a natural Vlei would frequently dry up during the summer months and by mid-winter would become a swamp (Bradlow 1963). These fluctuations in water levels meant no native fish would survive in the lake. Only once the dam wall was constructed were fish able to invade and become established in the lake. Small mouth bass, *Micropterus dolomieu* appear to have been one of the first to invade along with Berg-Breede Rivier witvis, *B. andrewi* and rainbow trout, *Oncorhynchus mykiss* (Bradlow 1963). The witvis is the only indigenous fish to

the region while the other two were introduced into rivers in the region. Bluegill sunfish, *L. macrochirus* were introduced later (1952) as a bait fish for the *M. dolomieu* which rapidly became established (Bradlow 1963).

Fishing was opened to the general public in 1955 and quickly drew the attention of many anglers because of the great quantity of smallmouth bass. The dam was closed to the general public 1958 but opened again in 1962 and has stayed open ever since. Records of anglers catching up to 12 *M. dolomieu* a day with some exceeding 3lbs (1.35 kg) were documented in 1962 (Bradlow 1963).

Recent introductions of non-native invasive fish in this dam appear to be having large effects on the water quality in the dam. The two species thought to be responsible are the common carp, *C. carpio* and sharp tooth catfish, *Clarias gariepinus*. The increase in numbers of carp have been linked to the decline in water clarity which was reported as potentially detrimental to the lucrative recreational bass fishery (DWAF 2004, Drenner *et al.* 1997, Impson 2006, Roberts *et al.* 1995).

Water quality and hydrology

According to DWAF (2014), Voelvlei has a neutral pH of 7.21 ± 1.1 over the period 1969 – 2012 and for the same period has received an annual rainfall of $523.33 \text{ mm} \pm 112$. Secchi readings were taken from 1990 – 2014 and show a reduction in water clarity (Table 2.1). Water temperature in Voelvlei ranges from 12.5 °C to 27.7 °C during the period 1993 – 1998, data was not available from 1999 to 2014 (DWAF 2014).

Table 2.1 Secchi depths in Voelvlei from 1990 to 2014 (DWAF 2014).

Year	Secchi depth (cm)
1990	116 ± 24
1991	116 ± 47
1992	108 ± 27
1993	59 ± 36
1994	106 ± 45
1995	105 ± 76
1996	67 ± 49
1998	285
1999	95
2014	26 ± 2.8

2.1.4 Theewaterskloof dam

Situation

Theewaterskloof dam (34°01'59.95"S, 19°15'05.61"E) situated on the Riviersonderend, Waterkloof, du Toit and Elands rivers is the largest dam in the Western Cape with a perimeter of 82 km and a surface area of 5059 ha (Swanepool *et al.* 2006; Figure 1.5). The dam wall is on the far south-eastern side of the dam and extends nearly 17 km in a north-westerly direction towards the Hottentots Holland nature reserve and mountains (Google Earth 2013).

Theewaterskloof dam formed part of a larger water scheme, the Riviersonderend-Berg River Project which planned on linking the catchments so excess surface winter run-off could be stored in a central dam. This water could then be gravity fed through tunnels between the two river systems known as the Inter-Basin Transfer scheme (IBT) to where it was needed during the dry summer months (Hugo 2011). Water from this scheme would be for irrigation, industrial and municipal use (Hugo 2011).

Preliminary investigations into the design and construction of Theewaterskloof dam were undertaken in 1929 and the provisional design was completed in 1952 (Hugo 2011). By 1970 the construction of Theewaterskloof was underway and was completed by 1978. Since the construction of Theewaterskloof dam further water storage capacity was needed and in 2005 the Berg dam was built. This dam then eliminated the need for the IBT and so these tunnels were closed off.

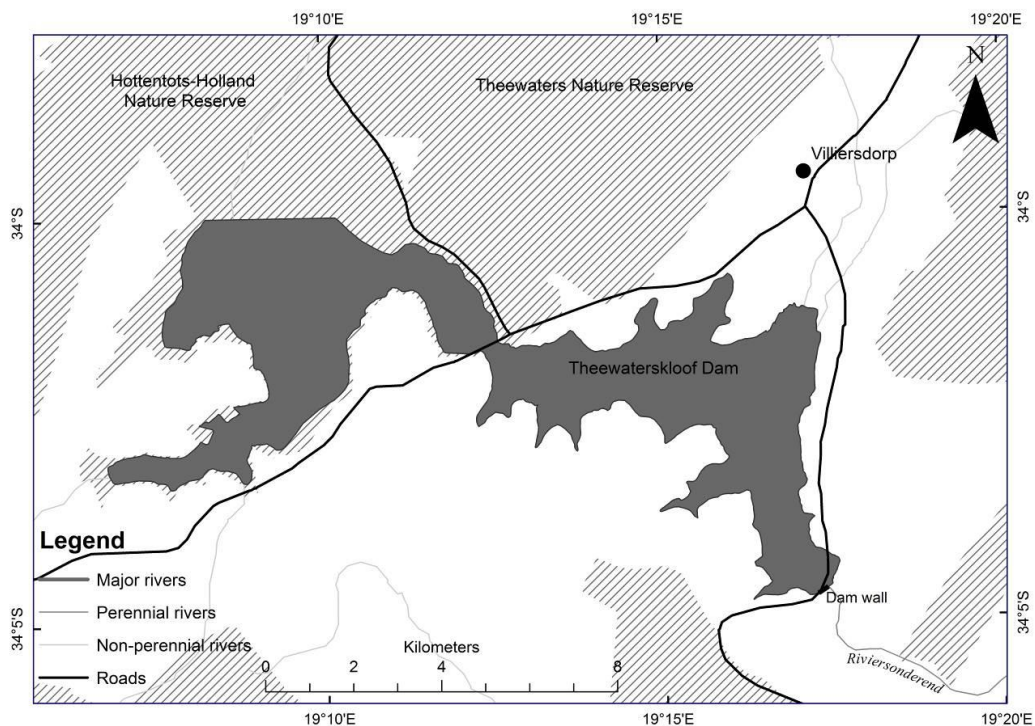


Figure 2.5. A map of Theewaterskloof dam showing surrounding nature reserves, the dam wall and the town of Villiersdorp.

Native and non-native fish introductions

Theewaterskloof dam has been known for many years as a hot spot for *M. salmoides* angling in South Africa (Impson 2006). While there is little literature on the stocking of non-native fish into Theewaterskloof dam it is thought that many of the non-native fish reached the dam through influent rivers and the IBT. By the mid 1990's the dam was dominated by *M. salmoides*, which contained high numbers of *L. macrochirus*, but small numbers of *C. carpio* and *O. mykiss* (Impson 2006). *Clarias gariepinus* has been caught recently, suggesting an

illegal introduction of this fish species directly into the dam or quite possibly through the IBT scheme.

The numbers of native fish species originally found in the influent river systems appear to have been reduced greatly by predatory non-native species especially *O. mykiss* and *M. salmoides*. The possibility of cape kurper, *Sandelia capensis* a small native species surviving in the dam is minimal but given sufficient cover in macrophytes there is a possibility that small numbers of this fish could still survive in the dam (Impson 2006).

Water quality and hydrology

Data collected by Department of Water Affairs (DWA), from 1980 – 2013 shows Theewaterskloof has an average pH of 6.78 ± 0.83 (DWA 2014). Water temperature in Theewaterskloof ranges from 10 °C to 23 °C during the period 1988 - 1998.

2.1.5 Clanwilliam Dam

Situation

Clanwilliam dam (33°12'06.82"S, 18°53'01.94"E) is situated just southwest of Clanwilliam town on the Olifants river (Figure 2.6). It was originally built for irrigational use, but also supplies the surrounding towns with municipal water (Holtzhausen 2006). The dam is long, nearly 22 km but less than 1 km at its widest.

This dam, that supplies water to the surrounding towns and through canals to local farmers for irrigation is situated on the Olifants river and has a capacity of 122 million m³ (Holtzhausen 2006). Originally completed in 1935, the dam wall was raised in 1969 by 6m and plans to raise the wall another 13m which will yield a further 69.5 million m³ per annum are underway

(Holtzhausen 2006, Anon 2015). This dam which is of major significance to the recreational bass anglers, specifically small mouth bass, *M. dolomieu*, appears to have had an invasion of the alien species *C. gariepinus* and *C. carpio* which appear to be affecting the bass fishery (Holtzhausen 2006).

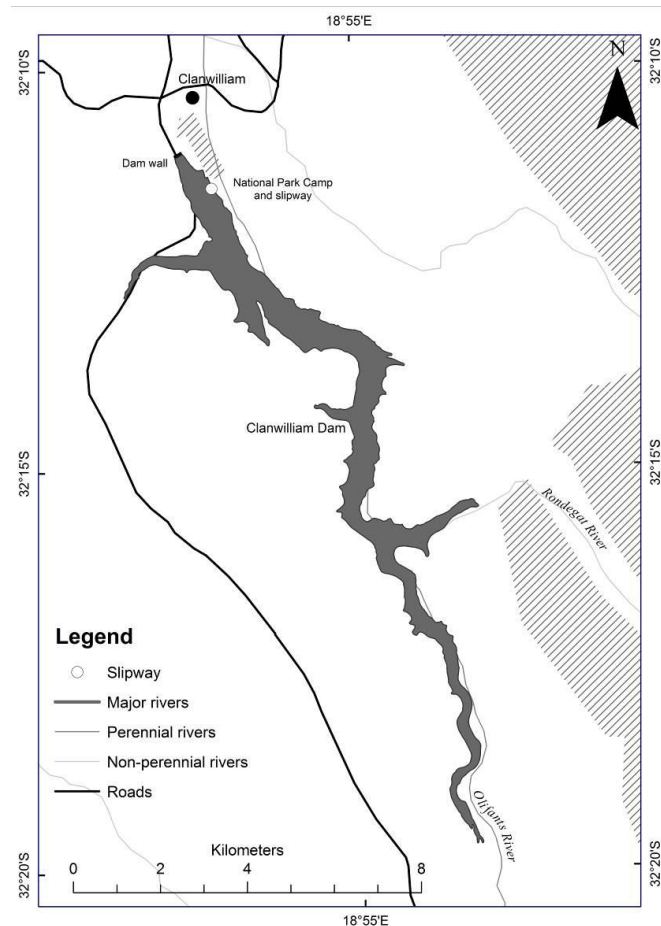


Figure 2.6. A map of Clanwilliam showing the dam wall, National Park Camp and slipway and influent rivers.

Native and non-native fish introductions

The Olifants River, on which Clanwilliam dam is situated, has ten native fish species, two from the family Bragidae, seven Cyprinids and one Galaxiid (Gore *et al.* 1991). Two of these fish are considered endangered, another two are vulnerable and four are rare. Eight of these species are endemic to this river system and therefore are of extreme conservation importance (Gore *et al.* 1991).

The Clanwilliam yellowfish, *Labeobarbus capensis*, was one of the first freshwater fish to be scientifically described in South Africa and was illustrated in early expeditions of exploration in 1686 (Skelton 2000). This fish was valuable to the indigenous inhabitants and was noted as an out-standing angling species to the early settlers. Unfortunately, to improve the angling of the Olifants River, alien fish, including three *Micropterus* species, were introduced into the system from the 1930's onwards (Skelton 2000). The impact of these introductions and the construction of impoundments were implicated in the decline of the Clanwilliam yellowfish and other endemic species (Skelton 2000).

In 1978, McVeigh (1979) undertook a survey on Clanwilliam dam, he found seven fish species. Three of these were indigenous, *Labeobarbus capensis*, *Barbus serra* and *Labeo seeberi* while the remainder were alien species. Clanwilliam Dam has since become one of the top recreational *M. dolomieu* fisheries in country, with the record fish captured there. A large active recreational fishery for *M. dolomieu* in the dam has created a positive economic impact on the town of Clanwilliam. It is therefore necessary to consider the future of both the native fishes and the recreational fishery on the dam.

Water quality and hydrology

Clanwilliam has had an average rainfall of 246.89 ± 79.28 mm over the last 40 years and a fairly neutral pH of 6.83 ± 0.71 .

2.2 General sampling methods

2.2.1 An assessment of the fish diversity and relative abundance

The survey was conducted between March 2013 and May 2014 and focussed on four dams and one natural lake in the Western Cape Province (WCP) ranging in size from 234 ha to 5059 ha. To include seasonal trends, dams were surveyed during September 2013 and in April 2014. During each survey, the dam was mapped according to its depth profile, its substrate, aquatic macrophytes, tributaries and any other factors that could influence fish distribution. The reservoir habitats were then categorised into sites suitable for experimental fishing and potential sampling sites were chosen at random. Six fishing gears were used during the survey. These were: (1) multifilament nylon gill nets consisting of 5 panels (5 m each) with stretched mesh sizes of 44 mm, 60 mm, 75 mm, 100 mm and 144 mm; (2) a 30 m long x 2 m deep beach seine net with a stretched mesh size of 10 mm; (3) long lines constructed of 12 mm rope with ten hooks (size 9/0) baited with fish heads and intestines at 2 meter intervals; (4) electro fishing; (5) fyke nets; (6) angling. In each dam four fyke nets and three long line sites were selected, and all gears were set overnight. Four gill nets were set on each dam with a set period varying on catches with a minimum of 2 hours on Brandvlei and overnight on Clanwilliam. The number of sites chosen for seine netting and electro fishing varied depending on the size of the dam and the number of suitable sites available. At each site, water temperature, turbidity, conductivity and pH were measured directly, using hand held instruments. All fish caught during experimental fishing were identified to species level, measured to the nearest mm total length or fork length, depending on species, and weighed to the nearest gram.

2.2.2 Field sampling and analysis

The water bodies were sampled using a seasonally and geographically stratified sampling design for a period of 12 months (April 2012 - April 2013). Sampling was conducted during

two sampling periods April - May (autumn) and October - November (early summer). These are essentially biodiversity surveys and for this reason six different gear types were used to sample as great a size range of fish over as wide of a range of habitats as possible. The number of net nights for each gear per water body can be seen in Table 2.1.

Electro fishing

Electro fishing was undertaken using a backpack electro fisher. This was conducted in 5 x 50m long littoral areas in each dam (where conductivity allowed) to assess for small fish species and sample more complex habitats than can be sampled using the seine net.

Seine nets

A 30m long x 2m deep (mesh size 10mm) seine net was used to assess the littoral fish community. The seine net was used during the day and either set using a boat or by walking it out as described by Olds (2012).

Fyke nets

Four double-ended fyke nets (8 m guiding net, first-ring diameter of 55 cm, 10 mm mesh size at the cod end) were set in each of the water bodies per night. The nets were set for 33 nights in Clanwilliam, 30 in Groenvlei, 20 in Quaggaskloof, 24 in Theewaterskloof and 27 nights in Voelvlei.

Fyke nets are considered a passive gear type and were set in water approximately 1 - 1.5m deep. All fyke nets were fitted with an "otter guard" comprising plastic mesh with openings no larger than 10 cm x 10 cm to prevent Cape clawless otters, *Aonyx capensis*, from entering the nets. Although the use of these otter guards can influence the maximum size of fish that could

enter the nets, their use is considered critical to avoid bycatch. All fyke nets were set in the evening (between 16:00 and 18:00) and lifted the next morning (between 06:00 and 08:00) with an average soak time of 16 hours. All the fyke nets were set and collected in the same sequence as to minimize variance in soak time (Olds 2012).

Gill nets

A set of four multi-meshed gill nets each measuring 35 m x 2.75 m with stretch meshes of 44, 60, 75, 100 and 144 mm (5 m per mesh size) were set in the dams (Olds 2012). The nets were deployed for four nights on each water body per survey. Gill nets were deployed at sunset and set for an average soak time of three hours; the nets were manned at all times to reduce mortality and incidental bycatch. A total of 32 net nights were undertaken in Clanwilliam, 27 in Groenvlei and Quaggaskloof, 24 in Theewaterskloof and 28 in Voelvlei.

Hook and line sampling

The sampling results were supplemented with angling, both bank and from boats.

Long lines

Three long lines were set with ten hooks each (1 hook every 2 metres) and these were baited with flesh baits. This is a passive gear and remained over-night once set. A total of 17 net nights were undertaken in Clanwilliam, 11 in Quaggaskloof, 11 in Theewaterskloof and 14 in Voelvlei.

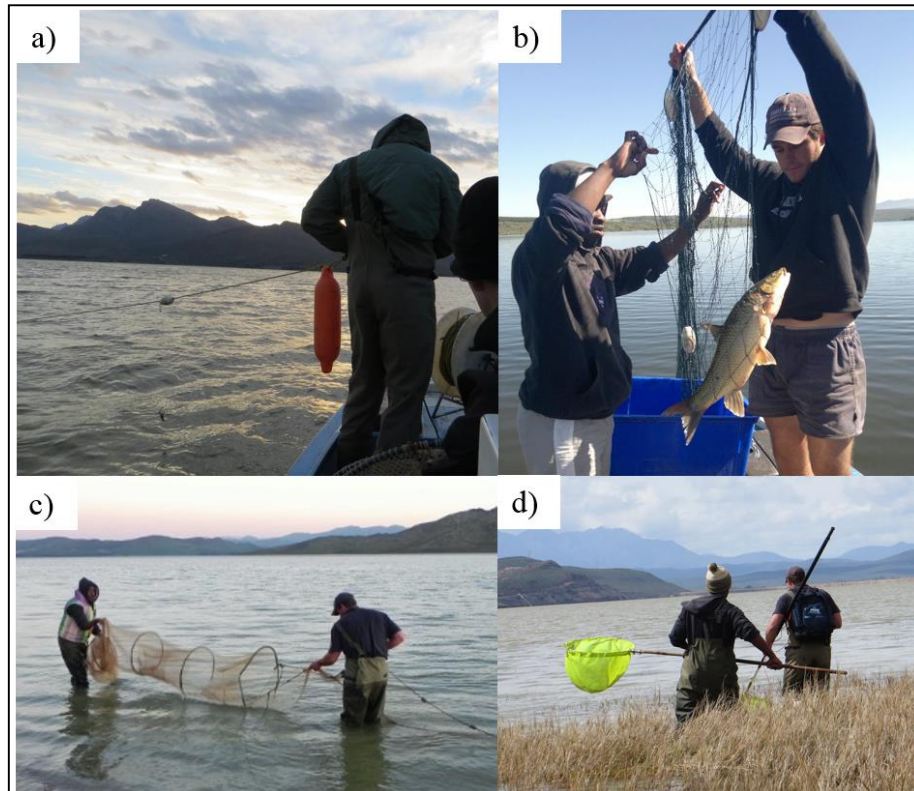


Figure 2.7. Gear used during survey: a) long lines being set at Quaggaskloof; b) a large *Labeobarbus capensis* being removed from a gill net at Clanwilliam; c) Fyke net being set in Quaggaskloof; d) electro fishing in the shallows in Quaggaskloof.

Table 2.2. Number of gears set in each water body.

Dams	Number of gear set				
	Electro fishing	Fyke nets	Gill nets	Long line	Seine nets
Brandvlei	3	20	27	11	6
Clanwilliam	3	33	32	17	4
Groenvlei	-	30	27	-	3
Theewaterskloof	2	24	24	11	6
Voelvlei	3	27	28	14	3

2.2.3 Tournament data

Data were collected from art-lure and bank angling tournaments held on the water bodies. These data were used to identify species not caught during the survey and to identify trends in fish species abundance. Tournaments included: Western Province Bass Divisionals, Southern Cape Bass Angling Association Divisionals, Western Province Artificial Lure Angling Society (WPALA), WPALA Coarse, Western Province Coarse league, Western Cape Bass Angling Association (WCBA), South African Bass Angling Association (SABAA), Clanwilliam Winter Classic, WPFSA (Western Province Freshwater Angling Association).

Environmental parameters

Detailed limnological information was collected to correlate biological parameters to variable limnological variables. These parameters are turbidity (NTU), secchi depth, temperature, conductivity and pH.

CHAPTER 3: ASSESSING ESTABLISHMENT OF BLUEGILL SUNFISH, *LEPOMIS MACROCHIRUS*

3.1 Introduction

The lack of large native angling species upon which to base inland sport fisheries in the Western Cape Province (WCP) led to the introduction of 20 non-native species (Marr *et al.* 2012; Weyl *et al.* 2014). Although the distribution of the larger sport fishes is well researched (De Moor and Bruton, 1988) most research to date has used presence/absence data to infer establishment (e.g. Leprieur *et al.* 2008; Marr *et al.* 2009). Reliance on such presence data, which are often temporally disjunct, complicates the development of fisheries recommendations because presence does not necessarily infer establishment. Richardson *et al.* (2000) and Williamson *et al.* (1996) developed frameworks and definitions as basis for invasions but use of two different frameworks and definitions led to scientists describing invasions differently. To aid in such assessments, Blackburn *et al.* (2011) proposed a framework for biological invasions to evaluate the invasion state of organisms by combining the two frameworks (Figure 3.1). This framework depicts the stages of invasion that a species has reached, the barriers imposed, terminology and the management for the species for the various stages.

This framework is based on six barriers to invasion (see Figure 3.1), where failure at each barrier would lead to a failure to establish. Firstly the alien species needs to be transported into a new area, this geographical barrier is the primary source of invasion, once overcome, the species needs to pass the captivity or cultivation barrier. This barrier is man-made such as quarantine in cultivation and restricted access to the natural environment in cultivation. The categorisation of these invasion are levels B1 and B2 respectively while B3 bypasses the

cultivation and captivity barrier. The next barrier is survival, this describes a species as present in the natural environment while not reproducing. C1 represents casual introduced species that is surviving but not reproducing. C2 describes a species that started to reproduce but not at a sustainable level. If the alien species reproduces but is maintained in one region it becomes a category C3. The dispersal from the point of original introduction is the next barrier, here the species either spreads far from the origin of invasion without reproducing (D1) or can reproduce (D2). Crossing this dispersal barrier is the first stage of becoming an invasive species. The final barrier to establishment is the environment. Species that overcome this barrier are fully invasive with numerous individuals dispersing, reproducing at multiple sites (E).

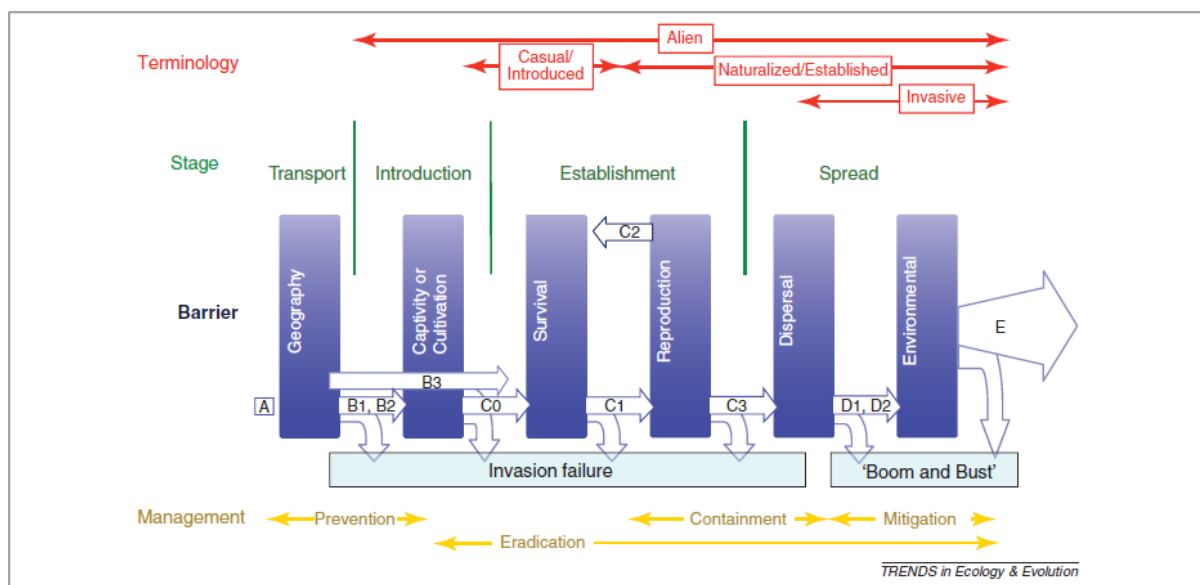


Figure 3.1. The proposed unified biological invasion framework (Blackburn *et al.* 2011)

In South Africa, this invasion framework has been applied at a national level (Ellender and Weyl 2014) and at local scales (e.g. Makinen *et al.* 2013; Jones *et al.* 2015). Makinen *et al.* (2013) for example identified the first introduction of Giant pangasius, *Pangasius*

sanitwongesi, in the Breede River. These species is part of the pet trade as part of the Blackburn *et al.* (2011) framework it is classified ‘C1: Individuals surviving in the wild in the location where introduced, but no (current evidence of) reproduction’. In contrast, Jones *et al.* (2015) demonstrated that Vermiculated sailfin *Pterygoplichthys disjunctivus*, which were introduced in 2004 via the pet trade are reproducing and have currently spread between two systems are now classified as ‘D2 invasion: ‘self-sustaining population in the wild, with individuals surviving and reproducing a significant distance from their original point of introduction’ in the Blackburn *et al.* (2011) unified framework.

According to Blackburn *et al.* (2011) establishment is attained once a species is surviving and reproducing in the environment in which it resides. The presence of a full length-age population structure can be an indication of reproduction with multiple cohorts depicting spawning. To develop this population structure the age at length of the species needs to be known. No previous studies have been undertaken for this analysis on *L. macrochirus* in Africa.

Assessments of fish species establishment in impoundments are important to fishery development as fisheries based on poorly established species may collapse. Previous research evaluating the success of fishes in South African environments have used reproductive success, and growth rate as indicators (Weyl *et al.* 2009). In this study, the use of biological indicators as a measure for establishment success is evaluated for bluegill *L. macrochirus*.

Lepomis macrochirus are native to the United States of America east of the Rocky Mountains from coastal Virginia to Florida, west to Texas and northern Mexico, and north to western Minnesota and western New York (Page and Burr 1991). They have been introduced in at least 24 countries globally (Welcomme 1988). They were introduced into South Africa in

1938 for angling purposes and as a prey species for largemouth bass *M. salmoides* (Harrison 1962, Weyl *et al.* 2014). They have since been spread into a further 10 African countries (Welcomme 1988). This fish reaches a maximum length of 200mm with the largest caught specimen is 1.9 kg (Ross 2001). Anecdotal accounts of the invasive impacts of *L. macrochirus* in Southern Africa include overpopulation, predation on juvenile fish and competition with indigenous fish for food (Bruton *et al.* 1982, De Moor and Bruton 1988, Jubb 1959, Jubb 1964). Although this invasive species has been in Africa for over seven decades, little is known about the biology of this fish, the impacts on native ichthyofauna nor the establishment in WCP water bodies (Weyl *et al.* 2014).



Figure 3.2 Bluegill sunfish, *Lepomis macrochirus*.

The main objective of this chapter is to use *L. macrochirus* as a model species to illustrate how the establishment success of invasive species should be evaluated using an evidence-based framework. In this case the Blackburn *et al.* (2011) framework. As there is no biological information on bluegill in South Africa, this chapter will also contribute towards better

understanding this invader in South Africa and develop appropriate criteria with which to determine establishment in Chapter 4.

3.1.1 Aims and objectives

The aim of this chapter is to assess what stage of establishment and invasion *L. macrochirus* is currently at according to Blackburn *et al.* (2011) framework in four Western Cape dams and a natural lake.

This aim will be achieved through three objectives:–

- 1) Determining the age and growth of this species in a non-native habitat through edge analysis (EA) of otoliths collected.
- 2) Biological analysis of the species in these water bodies will be undertaken to determine at what stage is sexual maturity reached.
- 3) Using the results of the biological analysis and age and growth studies with the population structure from the survey results to determine if the criteria for establishment and invasion have been met.

3.2 Methods and materials

Study area

Fish were sampled during surveys from Groenvlei (34°01'34.81"S, 22°51'00.94"E), the greater Brandvlei (Quaggaskloof) (33°41'41.15"S, 19°25'38.79"E) Voelvlei (33°21'54.69"S, 19°02'35.17"E) Theewaterskloof (34°01'59.95"S, 19°15'05.61"E) and Clanwilliam dam (33°12'06.82"S, 18°53'01.94"E) were sampled in September 2013 and April 2014. Monthly samples for the validation of the periodicity of the deposition of growth zones were collected from Settlers Dam near Grahamstown (33°24'47.30"S, 26°30'17.30"E). Fish were collected

with a combination of: (1) multifilament nylon gill nets consisting of 5 panels (5 m each) with stretched mesh sizes of 44 mm, 60 mm, 75 mm, 100 mm and 144 mm; (2) a 30 m long x 2 m deep beach seine net with a stretched mesh size of 10 mm; (3) electro fishing; (4) fyke nets and (5) angling. Survey methods are described in Chapter 2.

Biological analysis

After capture, *L. macrochirus* were sacrificed, weighed to the nearest 0.1 g, measured to the nearest millimetre fork length (FL), sexed and the developmental stage of the gonads macroscopically staged according to the criteria presented in Table 3.1. The sagittal otoliths were removed and stored dry for later analysis.

Table 3.1 Macroscopic criteria for assessing gonadal recrudescence in *L. macrochirus* (adapted from Weyl and Hecht, 1999).

Stage	Macroscopic appearance
Juvenile	Gonads discernible as thin white bands. Sex not distinguishable
Resting	Testes appear as a thin white band while ovary is pale white-red in appearance and granular when cut open
Developing	Testes thicker and milky coloured. Ovary larger, red with a rough appearance externally. Individual ova are visible
Ripe	Testis white and sperm can be extruded from a cut testis, or later (ripe running) by applying pressure to the abdomen. Ovary red to yellow, individual ova clearly visible and can be separated from the ovary when opened. Later (ripe running) by applying pressure on the abdomen of the fish.
Spent	Ovary and testes flaccid, sac like and appear bruised. Some remaining ova may be visible in the ovary

Condition factor

The condition of *L. macrochirus* populations in Clanwilliam and Groenvlei was calculated

using Fulton's condition factor CF using the equation: $CF = \left(\frac{mass}{length^3} \right) 10^5$, (Ricker, 1975).

As was used by Neff and Clare (2008), to compare between the populations.

Age and growth

Fish were aged using sagittal otoliths using the procedures described in Weyl and Hecht (1999). Sagittal otoliths were used because these were the largest otoliths and easiest to interpret. Otoliths were viewed whole, submerged in methyl-salicylate under reflected light at varying magnifications ($\times 10 - 40$). Exploratory analysis showed that otoliths from fish larger than 200 mm FL could not be read whole and required sectioning. Otoliths from large fish were therefore set in clear polyester casting resin; sectioned transversely through the nucleus (thickness 0.3 mm) using a double bladed diamond edge saw and mounted on a glass slide using DPX mountant. As was the case for whole sagittal otoliths, sectioned otoliths were examined under a binocular microscope using transmitted light at variable magnification (10-40 \times).

Growth zones were visible as alternating translucent and opaque zones and can be seen in Figure 3.3. Growth increments were counted twice on otoliths that were randomized, such that each reading was undertaken without prior knowledge of fish FL, sampling month or sex and without knowledge of the counts from previous readings. If the counts from the two readings were the same the count was accepted. If the readings differed, a third count was made. If this resulted in two identical counts, then this was accepted as the final estimate. If the three readings differed by two (e.g. 2, 3, 4) then the median estimate was accepted if the readings differed by more than two (e.g. 1, 2, 4), then the otolith was rejected from the dataset. Readings were made by a single reader.

Because validation is an essential requirement for ageing studies (Campana *et al.* 2001) the periodicity of increment formation was assessed by Edge Analysis (EA) using the procedures described by (Campana 2001). In EA the optical composition of the margin of the otolith (opaque or translucent) was expressed as a function of time, using otoliths collected monthly

from Settlers Dam between April 2013 and March 2014. This demonstrated that a single growth zone was deposited each year (Figure 3.3) and all subsequent analyses were conducted under the assumption of the deposition of one growth increment per year.

Length-at-age, L_t , was described by the von Bertalanffy growth function (VGBF) of the form: $L_t = L_\infty(1 - e^{-K(t-t_0)})$, where L_t is the length at age t , L_∞ is the predicted asymptotic length, K is the Brody growth coefficient, and t_0 is the age at zero length (Ricker, 1975). The parameters were estimated by minimising the binomial negative log-likelihood (LL) function using: $-LL = n \ln(\hat{\sigma})$, where $\hat{\sigma}$ is the maximum likelihood estimate of the model standard deviation described as: $\hat{\sigma} = \sqrt{\frac{\sum_i (L_i - \hat{L}_i)^2}{n}}$, and \hat{L} is the predicted total length-at-age, L_i is the observed length-at-age and n is the total number of observations. The variability of the parameters was estimated using the conditioned parametric bootstrap resampling technique described by Efron (1980). For each of the two sampling sites, sex-specific and combined sex models were fitted. In the sex specific datasets, age data for unsexed juveniles were included in the data from unsexed fish. Therefore, for the combined sex models, only one set of unsexed juvenile data were included in the analyses.



Figure 3.3. *Lepomis macrochirus* otolith showing translucent and opaque zones.

Reproductive biology

To determine the length-at-50% maturity, the proportion of sexually mature individuals (ripe and spent) by 10mm FL class, collected during the spawning season, was fitted with a logistic curve of the form $\psi(l) = (1 + e^{-(l-\phi)/\sigma})^{-1}$, where $\psi(l)$ is the proportion of mature fish of length l , ϕ is the length-at-50%-maturity and σ the inverse steepness of the maturity function. As all fish in the sample were aged using sagittal otoliths, age at 50% maturity was estimated by fitting the same ogive to data where fish were grouped by observed age class instead of length. Parameters were estimated by non-linear minimisation of a negated Binomial log-likelihood function.

3.3 Results

Population structure

In total, 435 fish were sampled. A summary of the population length structures of *L. macrochirus* in the four water bodies where they were found is presented in Figure 3.4. Groenvlei and Clanwilliam indicate established populations with peaks in the 60-80mm size classes. The presence of juvenile and adult fish indicates these fish are spawning and reproducing. The population structures in Theewaterskloof and Voelvllei show numerous juvenile fish with few adults in a single cohort. The fairly high abundance of *L. macrochirus* in Groenvlei and Clanwilliam Dam resulted in subsequent analyses focusing on these two localities.

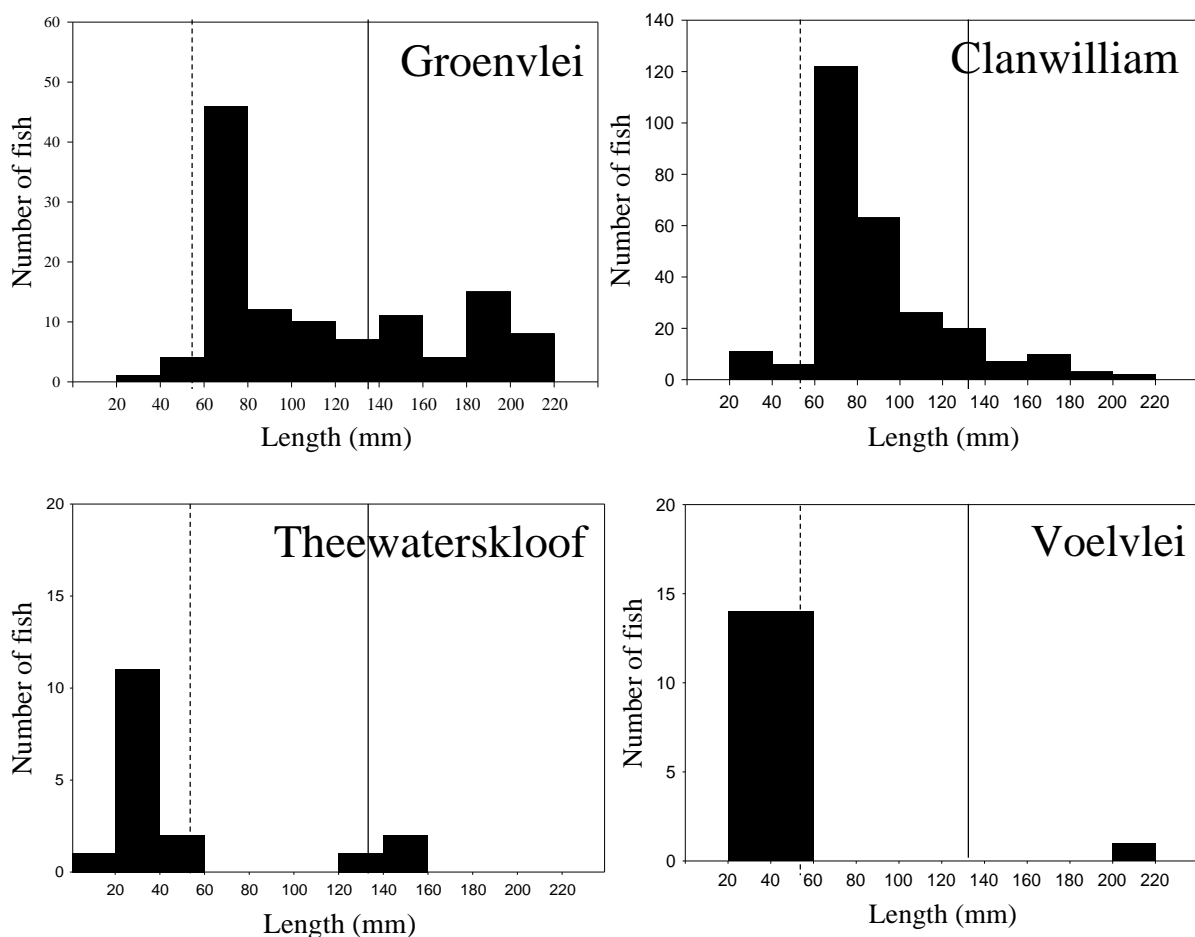


Figure 3.4. Length frequency for *L. macrochirus* sampled between April 2013 and March 2014 in four different water bodies using fork length. *L. macrochirus* were absent from Quaggaskloof. The dashed

line represents fish at one year and solid line is fish at 50 % maturity (Peterson *et al.* 2010),(Groenvlei n= 118, Clanwilliam n = 271, Theewaterskloof n= 17, Voelvlei n= 29).

Condition factor

Analysis demonstrated that condition factor (CF) different between juveniles 0-100mm FL and fish larger than 200mm FL (ANOVA $p < 0.050$) and that there were differences between CF of adult and juvenile fish, but was similar for all groups in Clanwilliam Dam. Juvenile CF was higher in Clanwilliam while adult CF was higher in Groenvlei as can be seen in Figure 3.5.

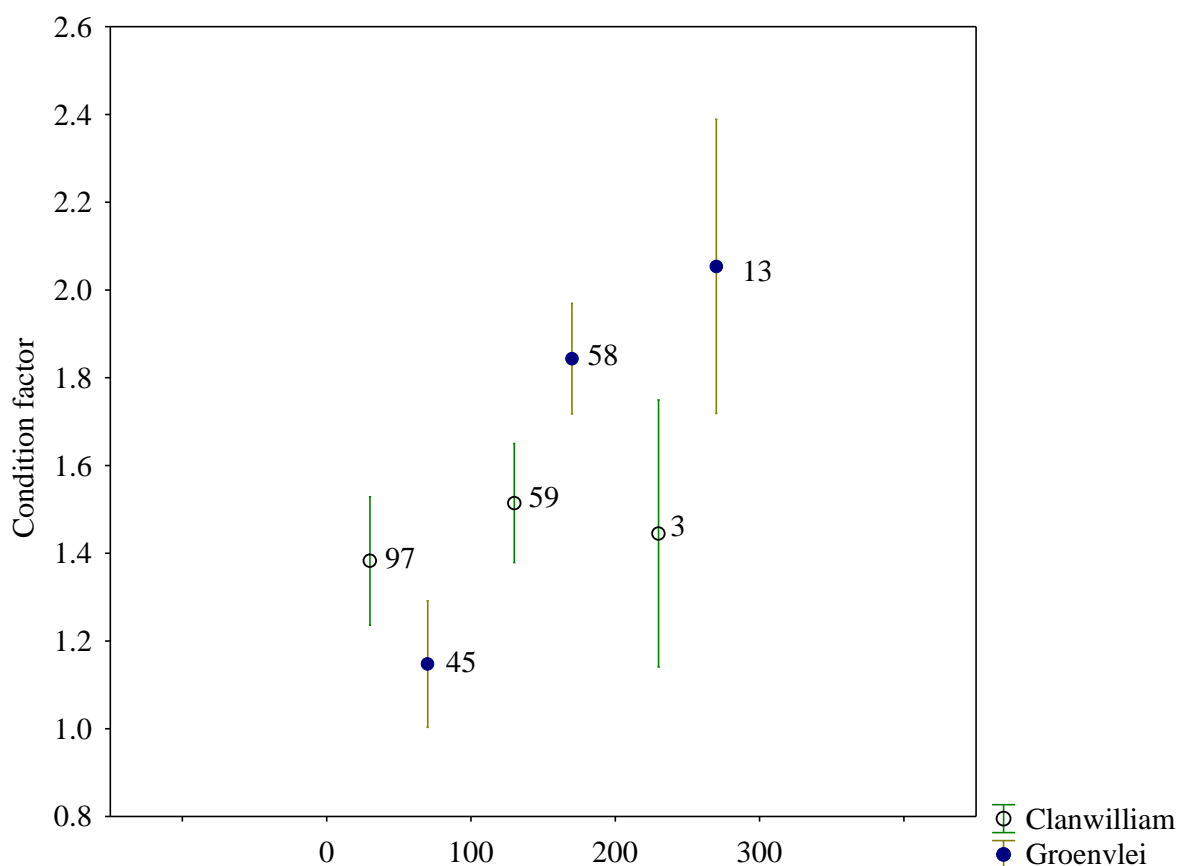


Figure 3.5 The relationship between condition factor and length with mean \pm 95% CI for fish <100 mm, 101-199 mm, >200 mm sampled from Clanwilliam and Groenvlei in the Western Cape, South Africa between April 2013 and March 2014. Numbers denote sample size.

Age and growth

For validation, EA was done on a total of 191 otoliths were sampled from Settlers Dam. The monthly proportions of otoliths with an opaque edge was unimodal and therefore growth zone

deposition rate was validated as annual (Figure 3.6). Age was estimated for a total of 89 otoliths sampled in Groenvlei and 132 in Clanwilliam with the plots of age and length for individual fish in Clanwilliam and Groenvlei in Figure 3.7 and 3.8 respectively. The relationship between age and length and the fitted VBGFs are shown in Figure 3.7 and 3.8 with combined sex, von Bertalanffy growth functions for Groenvlei and Clanwilliam populations shown in Table 3.2.

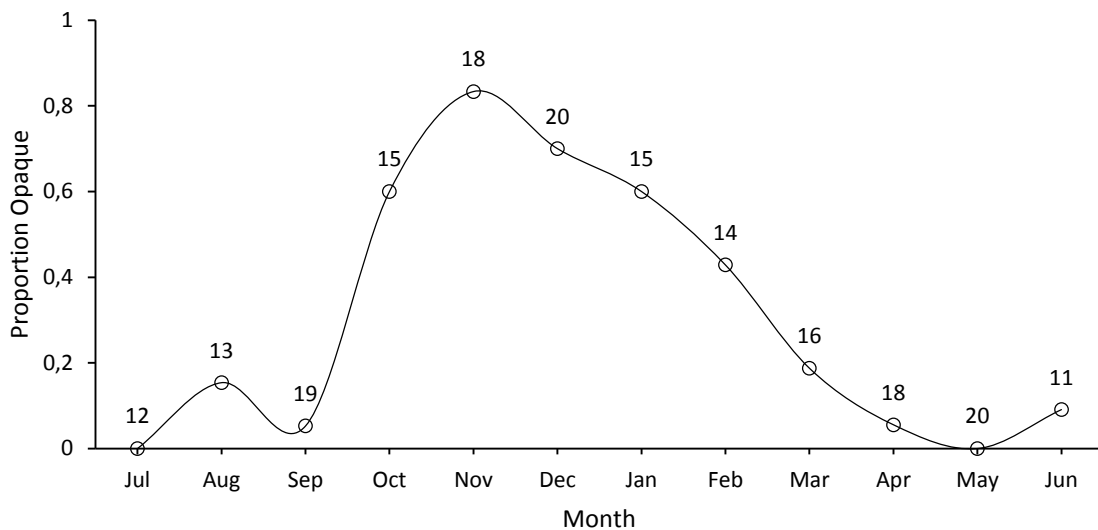


Figure 3.6. Edge analysis showing the proportion of *L. macrochirus* sagittal otoliths with an opaque margin sampled between April 2013 and March 2014 in Settlers Dam, Eastern Cape, South Africa. Numbers denote sample size.

Table 3.2 Parameters estimates for von Bertalanffy growth function (VBGF) model fitted to combined sexes of *Lepomis macrochirus* in Groenvlei and Clanwilliam dam, South Africa and their native range in the United States of America (Willis *et al.* 2001).

Parameter	Clanwilliam dam (n=132)	Groenvlei (n=89)	Native range (n=490)
L_{∞}	335.9	287.2	231
K	-0.113	0.171	0.41
t_0	-1.06	-0.54	0.27

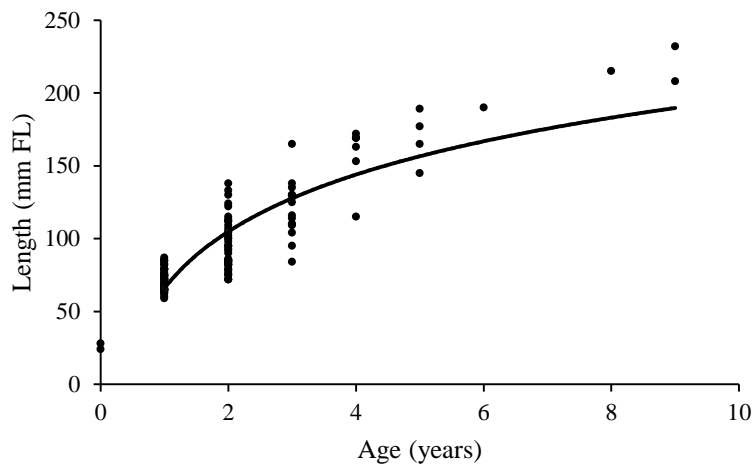


Figure 3.7. Age at length plots for *L. macrochirus* caught in Clanwilliam Dam between April 2012 and September 2013.

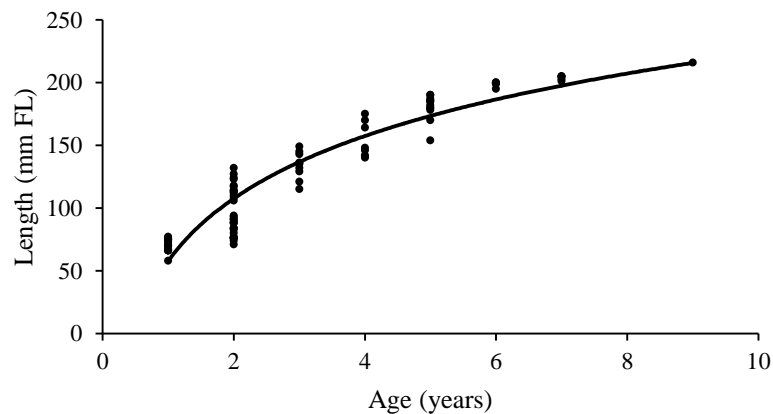


Figure 3.8. Age at length plots for *L. macrochirus* caught in Clanwilliam Dam between April 2012 and September 2013.

Maturity

Length-at-50% maturity (ϕ) was calculated at 147 mm FL and 3+ years for females and 146 mm and 3+ for males sampled from Clanwilliam and Groenvlei (Figure 3.9.). Showing that maturity of both sexes was reached at a similar size. Using this length at maturity, there was evidence for both spawning capable and juvenile fish from the four localities.

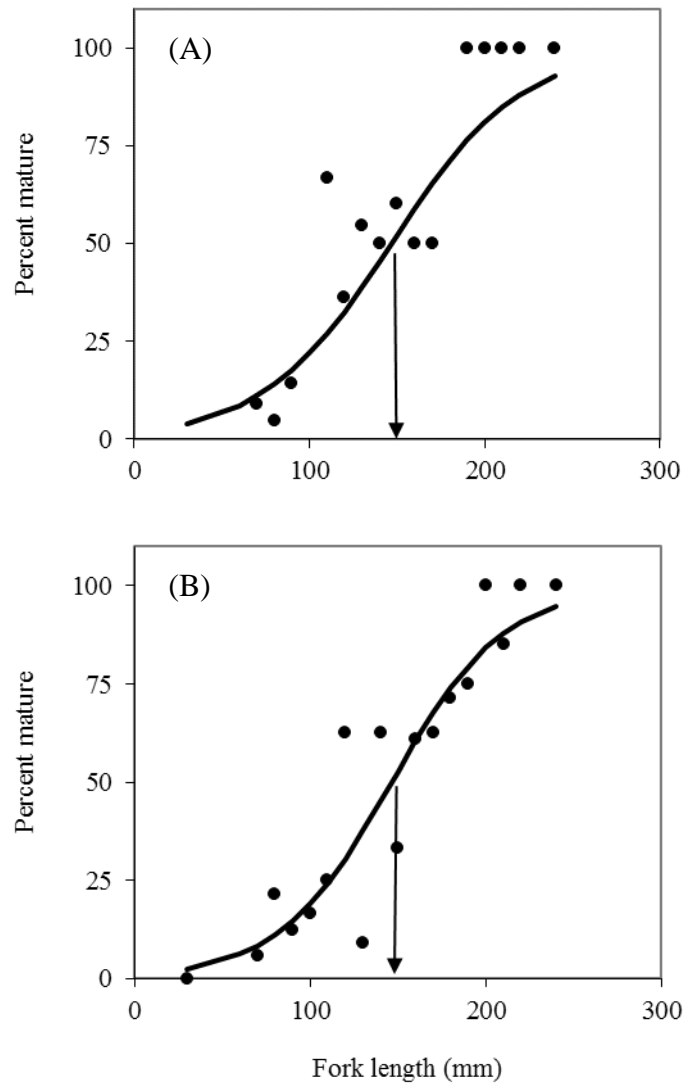


Figure 3.9 *Lepomis macrochirus* female (A) and male (B) at maturity expressed as a percentage of ripe and spent fish in Groenvlei and Clanwilliam dam, Western Cape, South Africa. Arrows denote length at 50% maturity. Sample size: males (163); females (100).

3.4 Discussion

After it was transported to South Africa in 1938 from the United States of America, *L. macrochirus* was introduced into many water bodies (DeMoor and Bruton, 1988) including all the assessed water bodies: Groenvlei in 1940, Clanwilliam in 1951, Voelvlei in 1952, Theewaterskloof in 1978 and Quaggaskloof in 1983, by the Cape Piscatorial Society as fodder for predatory *M. salmoides* (de Moor and Bruton, 1988, Bradlow, 1963). Applying the

(Blackburn *et al.* 2011) framework, it is obvious that the geographical and captivity barriers to introduction of the species were overcome by late 1938 and that survival and reproduction barriers to establishment were breached with human assistance. A survey by McVeigh (1979) undertook a gill net survey on dams in the Western Cape demonstrated that *L. macrochirus* were present in Clanwilliam, Voelvlei, absent in Quaggaskloof, while Theewaterskloof and Groenvlei were not surveyed. The current survey demonstrated that the species was still absent from Quaggaskloof but present in the other four localities, where it appears to have persisted for between 75 and 37 years since its first introduction into Groenvlei and Theewaterskloof respectively.

To evaluate the success of the species, the age and growth and length at maturity in the invasive populations were compared to populations in its native range. Age analysis of *L. macrochirus* had not been undertaken in Africa and because growth deposition rates can differ between regions, validation of the growth zone formation rate was necessary. Results showed that one opaque band was deposited each year. This was consistent with findings for another centrarchid *M. salmoides* (Taylor *et al.* 2012) and is consistent with studies in their native range (Reiger 1962, Schramm 1989). Due to its importance as a fisheries species in the USA there are excellent data available for its native range (Jackson *et al.* 2008). On comparison with growth data for 146 populations of *L. macrochirus* from 26 different states or provinces of the United States and Canada (Jackson *et al.* 2008) the fish in SA impoundments grew at comparable rates. This data were compiled to formulate one VBGF for these populations.

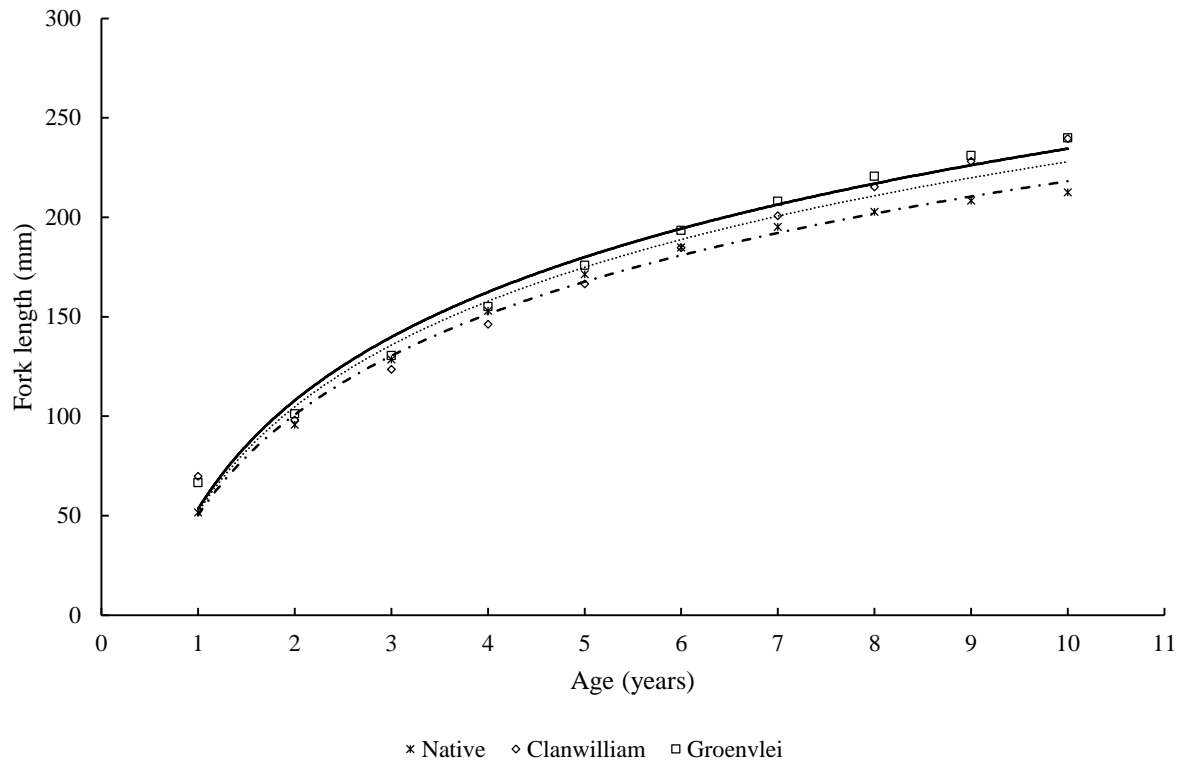


Figure 3.10 von Bertalanffy growth functions for *L. macrochirus* sampled in Clanwilliam Dam and Groenvlei compared to their native range.

The VBGF showed a comparable length at age in Clanwilliam dam, Groenvlei their native range suggesting a similar growth pattern as seen in (Figure. 3.10.). While *L. macrochirus* had a similar length at age to their native range, Fultons condition factor of the species in Clanwilliam dam (1.42 ± 0.65) and Groenvlei (1.59 ± 0.6) appeared superior to its native range of North America (0.73 ± 0.2) (Peterson *et al.* 2010, Neff and Clare, 2008). The superior CF in the invaded waterbodies when compared to their native range can be due to factors such as ecology with different species that *L. macrochirus* predate upon, or environmental where water characteristic may be dissimilar. Simpkins and Hubert (1996) showed that there can be a difference in CF caused by lotic or lentic systems and these factors need to be further analysed. VBGF and condition factor show that the species is capable of feeding and growing at rates that are comparable to those observed in its natural range.

The assessment of the reproductive biology of *L. macrochirus* showed that male and female fish reached a length-at-50% maturity of 14.6 cm FL and 14.7 cm FL respectively. Similar to the findings presented here, Peterson *et al.* (2010) found no significant difference of the rate to maturity between sexes and therefore length at maturity was directly comparable. Using the VBGF for both Groenvlei and Clanwilliam demonstrates that age-at-50% maturity is attained at three years. In its native range the length at maturity varies considerably between areas, e.g. age-at-50% maturity of 2 years in South Dakota, 3 to 5 years in Utah and 5 to 7 years in Ontario (Peterson *et al.* 2010, Drake *et al.* 1997). *Lepomis macrochirus* maturity was therefore similar to native range populations. The presence of fish in excess of three years exhibits the potential for reproduction of the species in these water bodies. This presence of adult fish that could spawn does not necessarily confirm that this is the case as certain conditions are needed for spawning to occur. To confirm spawning has occurred over a period of time, the length and age structure of a population can be a useful indicator.

Lepomis macrochirus were introduced into all five water bodies but by 1978 they were absent from Quaggaskloof. The survey undertaken in 2013/2014 found populations of *L. macrochirus* in four of the remaining four water bodies (McVeigh 1979). If there have been no further introductions, this would suggest that the species had been able to reproduce over time. The population structures of *L. macrochirus* in Theewaterskloof and Voelvlei appear similar, with a population spike of juveniles 60 mm FL, less than a year old, and few adult fish indicating recruitment failures. As these water bodies are all at similar latitudes and temperatures (range 12.8 – 26.7°C) as in the native north American range of *L. macrochirus*, differences in success may be either environmental or biological (Piper *et al.* 1989, Engelhardt and McCarty 1990). Environmentally these water bodies differ considerably, survey results showed secchi depths

of 159 ± 32.6 cm in Groenvlei and 138.2 ± 25.9 cm in Clanwilliam, while Theewaterskloof and Voelvlei were 52.8 ± 5.1 cm and 26.1 ± 2.9 cm respectively, and most recently the introduction of *C. gariepinus* in the presence of *C. carpio* could further alter these environments (Cambray 2003, Drenner *et al.* 1997, Bruton 1979, Vitule *et al.* 2006, Vitule *et al.* 2009). The need for further research into the environmental demands of *L. macrochirus* is necessary to determine the invasion status and risks of further spread of this alien species.

Weyl *et al.* (2009) using yellowfish *L. aeneus* demonstrated how various factors needed to be considered to determine the establishment of a fish species. The most important factors are a) reproduction and b) time in the water body. Blackburn *et al.* (2011) in their unified framework found that even if a species is reproducing the invasion may be a failure due to the rate of reproduction being slower than the mortality rate; this is where time in the water body becomes an important factor. The condition factor, growth and maturity of *L. macrochirus* in South Africa appears similar to its native range showing that this species has adapted well to this invaded region. The population structures of this species in Groenvlei and Clanwilliam show that it is well established with a full size range and multiple cohorts. This species is now categorised as 'D2 invasion: "self-sustaining population in the wild, with individuals surviving and reproducing a significant distance from their original point of introduction' according to the Blackburn *et al.* (2011) framework. Further research is necessary to determine which factors may be driving establishment success.

CHAPTER 4: INVASION STATE OF NON-NATIVE FISHES IN FIVE LENTIC BODIES IN THE WESTERN CAPE

4.1 Introduction

The Cape Province of South Africa has 36 native freshwater fish species, of these 17 are endemic, 10 are listed as endangered and 3 vulnerable (Table 4.1, Weyl *et al.* 2014). It is due to this diversity that the CFR is known as a biodiversity hotspot (Myers *et al.* 2000). Freshwater ecosystems are at the source of nearly all aspects of human society and support a rich diversity of biological life (Cucherousset and Olden 2011). The human demands which include private, industrial and agriculture water supply; recreational use; economic and food security, place increasing pressure on these scarce resources (Cucherousset and Olden 2011, DAFF 2014). The pressure on the natural biological diversity of these systems is further increased through the introduction of non-native fish species. Twenty non-native fish species have been introduced into the Western Cape Province (Marr *et al.* 2012, Weyl *et al.* 2014) with 12 of these species having been introduced into the five water bodies surveyed. Species introduction dates into the water bodies can be seen in Table 4.2. Many of these introduction were over half a century ago, providing time for these species to impact the ecological system.

Ecological impacts of these fish in South Africa cover numerous levels of the biological organisation: non-native fishes are five-fold from genetic hybridization, to a change in individual behaviour traits of native fish, to population effects such as transmission of pathogens and diseases, through to community and ecosystem changes (Cucherousset and Olden 2011; Ellender and Weyl 2014).

Impoundments constructed primarily for water storage on natural systems are known to frequently support multiple invaders and can act as a source of invasion into rivers systems (Johnson *et al.* 2008). Elton (1958) listed three abiotic environmental attributes that could lead to the success of exotic introductions, these were (a) habitat connectivity and propagule pressure, (b) disturbance and environmental variability, and (c) species diversity and biotic interactions. The construction of impoundments has altered the attributes of the environment such as; changes in the magnitude and flow of rivers, reduce sediment loads, create barriers to fish migration and convert stream habitats into standing water, hereby aiding in the to the success of exotic species (Malmqvist *et al.* 2002). This alteration in habitat has led to the extirpation of native fish, especially those relying on shallow waters and riffles, whilst allowing for non-native fish to thrive and spread between impoundments like “stepping stones” (Havel *et al.* 2005).

Public impoundments in the Western Cape were last surveyed in the late 1970’s (McVeigh, 1979) and therefore, the current invasion state of these impoundments is unknown nor has the invasion status of many of the species introduced into the Western Cape been formally assessed. Information of the invasion status of introduced species is therefore necessary. To aid in the process of defining invasive species Blackburn *et al.* (2011) proposed an invasion framework. This framework was outlined in Chapter 3 and the applicability of this framework to define invasion state of fishes was tested on bluegill sunfish, *L. macrochirus* was discussed.

Table 4.1 The five water bodies surveyed with the influent river system into each. Native fish species to each water body are shown. Water bodies on each river system are; Brandvlei on Berg, Clanwilliam on Olifants, Theewaterskloof on Riviersonderend and Voelvlei is on the Berg.

Native species	River Systems	IUCN Status
<i>Austroglanis barnardi</i>	Olifants	Endangered
<i>Austroglanis gilli</i>	Olifants	Vulnerable
<i>Barbus anoplus</i>	Olifants	Least concern
<i>Barbus andrewi</i>	Breede, Riviersonderend, Berg	Endangered
<i>Barbus calidus</i>	Olifants	Vulnerable
<i>Barbus erubescens</i>	Olifants	Critically Endangered
<i>Barbus serra</i>	Olifants	Endangered
<i>Galaxias zebratus</i>	Breede, Olifants, Riviersonderend, Berg	Not assessed
<i>Labeobarbus capensis</i>	Olifants	Vulnerable
<i>Labeo seeberi</i>	Olifants	Critically Endangered
<i>Pseudobarbus burchelli</i>	Breede, Riviersonderend	Critically Endangered
<i>Pseudobarbus burgi</i>	Berg	Endangered
<i>Pseudobarbus phlegethon</i>	Olifants	Not assessed
<i>Pseudobarbus skeltoni</i>	Breede, Riviersonderend	Not assessed
<i>Sandelia capensis</i>	Breede, Riviersonderend	Not assessed

(Clark *et al.* 2009, Chakona and Swartz 2013, IUCN 2015)

Table 4.2. Summary of alien fish introduction dates into each of the five water bodies.

Species	Groen-vlei	Theewaters-kloof	Brand-vlei	Voelvlei	Clanwilliam
<i>Clarias gariepinus</i>		About 1990 ²	About 2000 ²	About 1990 ²	About 2000 ²
<i>Cyprinus carpio</i>	1990 ²	1978 ⁶	1983 ⁶	1952 ¹	1935 ⁶
<i>Gambusia affinis</i>	1938 ⁵				
<i>Lepomis macrochirus</i>	1940 ⁶	1978 ⁶	1983 ⁶	1952 ¹	1951 ⁶
<i>Micropterus dolomieu</i>		1978 ⁶	1983 ⁶	1952 ¹	1943 ⁶
<i>Micropterus punctulatus</i>				1952 ⁶	1945 ⁴
<i>Micropterus salmoides</i>	1934 ³	1978 ⁶	1983 ⁶	1952 ⁶	1936 ⁶
<i>Oncorhynchus mykiss</i>				1951 ⁶	
<i>Oreochromis mossambicus</i>	1950 ⁶			1979 ⁵	1969 ⁶
<i>Salmo trutta</i>				Before 1935 ⁶	
<i>Tilapia sparmanii</i>			1983 ⁶	1979 ⁵	1961 ⁶
<i>Tinca tinca</i>			Before 1935 ⁶		

¹ Bradlow (1963); ² Olds *et al.* (2011); ³ Jubb (1973); ⁴ Harrison (1964, 1965); ⁵ Clark *et al.* (2009); ⁶ de Moor and Bruton (1988); ⁷ Impson (2006)

The determinants of invasion success or failure in the Blackburn *et al.* (2011) framework were six barriers. These were; geographical, captivity or cultivation, survival, reproduction, dispersal and finally if the species survived and reproduced in a dispersed range. From this the criteria for invasion success are age and growth, condition, maturity, reproduction and population structure. Using these criteria to define invasion status of non-native fishes in the Western Cape by using data from ichthyological surveys conducted on four dams and a natural lake.

4.1.1 Aims and Objectives

The aim of this chapter is to determine the establishment of non-native fish species found in each water body using the Blackburn *et al.* (2011) framework. To do this the following hypotheses were tested:

Hypothesis 1: H_0 = Species composition in the five water bodies was representative of the native riverine fish fauna; H_i = Species composition was not representative of the native fish fauna but was dominated by alien species.

Hypothesis 2: H_0 = Fish fauna in the water bodies is representative of direct stocking records in each water body (from meta data analysis); H_i = Fish fauna is not a result of direct formal stocking and is more representative of the alien fish fauna in the province in each water body (therefore alien fish invaded via the catchment or by illegal introductions).

Hypothesis 3: H_0 = all species that were introduced established in the water bodies; H_i = establishment success varies between species with documented invasion failures following establishment (or e.g. goldfish – failure after being sampled).

4.2 Methods and materials

4.2.1 Meta-analysis

Fish surveys were undertaken in the Cape Region from 1976 to 1979. These surveys were summarised by Gaigher (1980), the results were used to compare the difference in relative abundance of fishes and presence or absence of certain species in the different water bodies. The gill net mesh, number of nets set and soak times are presented in Table 4.3. Species results from the McVeigh (1979) survey for Voelvlei are available but no specifications on the gill nets used are available. A literature review of the introduction dates for species into the five impoundments was undertaken to determine the period of time that each species has been in the water body.

Table 4.3. The gear used in the McVeigh (1979) survey showing gill net mesh size (mm), total soak time for all the nets and the number of nets set in Brandvlei and Clanwilliam Dams.

Dams	Gill net mesh (mm)	Total soak time (h)	No. of nets set
Brandvlei	45,50,57,76,95,102,114	not reported	not reported
Clanwilliam	35,45,57,73,93,118,150	156	7

4.2.2 Angler tournament data

Tournament data were used to identify species not caught during the survey and to identify trends in fish species abundance over time. These data can determine first the initial introduction of new species and the increase in abundance of these new species.

Tournament data were collected from WPALA (Western Province Artlure Association), WPFSA (Western Province Freshwater Angling Association), SABAA (South African Bass Angling Association) and WCBAA (Western Cape Bass Angling Association). WPALA,

SABAA and WCBAA use art lures in their competitions and occur over a two day period with eight to ten hours of angling a day. Competitors use is limited to two people per team and must use boats for angling. All fish to be weighed must be over a minimum size limit of 300 mm total length with penalties for “short” fish. Organised bass anglers in South Africa maintain a strict catch and release policy, with fish stored in oxygenated wells during the competition. WPF AA focuses on bank angling with a maximum of 15 people per team and a spread of 30 m between anglers. No artificial lures are to be used with only organically digestible food baits. Keep nets need to be used in order to keep fish alive. The number of angling competitions for each event and the years of data collected are available in Table 4.4.

Table 4.4. The competitive angling events held annually at Brandvlei, Clanwilliam, Groenvlei, Theewaterskloof and Voelvlei, showing the duration of data available and the number of annual events. The competitions were: WPALA (Western Province Artlure Association); WPF AA (Western Province Freshwater Angling Association); SABAA (South African Bass Angling Association) and WCBAA (Western Cape Bass Angling Association).

Dams	Competition							
	WPALA (bass and coarse)		WPF AA		SABAA		WCBAA	
	Years	No. of Annual Events	Years	No. of Annual Events	Years	No. of Annual Events	Years	No. of Annual Events
Brandvlei			2007-2012	4	2002-2012	1	2003-2012	2
Clanwilliam					1999-2013	1	2002-2013	2
Groenvlei					2004-2012	1		
Theewaterskloof			2007-2012	4	2000-2013	1	2003-2013	2
Voelvlei	2001-2008	12						

Analysis of angler tournament records

A descriptive analysis of the catch information was used to determine species caught in each water body and the time period for which each species has been caught. Changes in species caught will be recorded to determine first introduction of or last occurrence of a species. Statistically, catch records will be analysed to determine the CPUE of individual species and total fish in water bodies to compare between the five water bodies and species. Occurrence of species and CPUE in angler tournament data will be incorporated into survey results in determining the establishment of a fish species.

4.2.3 Sampling

Fish were sampled using multi-mesh gill nets, fyke nets, long lines, seine nets, electro fishing and angling as describe fully described in Chapter 2, fish sampled in all gears were identified to species level, measured to the nearest mm FL and fish killed for biological analysis were weighed to the nearest gram.

4.2.4 Length Frequency

The length-frequency of all non-native species surveyed was determined and these lengths compared with known age and growth data found in Table 4.5 to estimate the number of age classes represented by the length data.

4.2.5 Criteria for establishment

The methods used in Chapter 3 for assessing the establishment of *L. macrochirus* were used to determine the establishment of fishes in all the water bodies. These criteria of invasion success are age and growth, condition, maturity, reproduction and population structure. The success of an invasion will therefore be determined based on data collected during the survey by using

the length frequency of species caught. Historical surveys and angler tournament data will be used to verify the occurrence of the species in an impoundment and period of time since the introduction of the species. Length frequencies or population structures can be necessary in determining establishment of a fish species (Weyl *et al.* 2009).

Table 4.5. Estimated length at age and Von Bertalanffy Growth Function (VGBF) parameters for fishes sampled during the current study.

Species	L _{max} (cm)	T _{max} (y)	VGBF			Length at age (mm)					
			L _∞	K	t ₀	1	2	3	4	5	6
<i>C. carpio</i> ^{1,2}	68	7	625.8	0.39	0.16	175	321	420	486	531	561
<i>C. gariepinus</i> ^{1,3}	130	8	931.7	-0.15	-2.43	375	452.3	519.1	576.5	626	669
<i>G. affinis</i> ¹	6	-	-	-	-						
<i>M. dolomieu</i> ^{1,7}	50	18	498.6	0.229	0.141	89	173	240	293	335	368
<i>M. punctulatus</i> ⁶	35	11	350	0.511	0.33	102	201	261	297	318	331
<i>M. salmoides</i> ^{1,4}	60	14	598	0.28	-0.52	207	303	375	430	471	502
<i>O. mossambicus</i> ^{1,5}	39	11	266.06	0.7904	-0.269	12	17	21	23	24	25
<i>T. sparmanii</i> ¹	23	-	-	-	-						

¹ Weyl *et al.* (2014); ² Winker *et al.* (2010); ³ Wartenberg *et al.* (2013); ⁴ Taylor (2012); ⁵ Weyl and Hecht 1998; ⁶ Olmsted and Kilambi (1978); ⁷ Impson (2006)

Studies have previously used population structure as a determinant of establishment (Orlova *et al.* 2004, Weyl *et al.* 2007, Jude *et al.* 1992). Full population structures, with multiple cohorts or size classes are representative of reproduction, growth and age of fishes. Therefore population length structure will be used as the basis for determining the establishment of a species through multiple cohorts and reproductive maturity.

4.3 Results

4.3.1 Meta-analysis

An assessment of the literature revealed introduction records/occurrences for 12 species in the five water bodies. Dates of introduction (or first report of presence) are summarised in Table 4.2 with the exception of *C. auratus* as this species was part of the pet trade. These data demonstrate the persistence of many introduced species over decades.

4.3.2 Angler tournament data

Tournament data for each of the five dams were collected to analyse trends in catches and was used to confirm fish presence if not caught during either of the surveys. Bass and coarse angling tournament data were collected going back historically as far as possible to assess for historical catches.

Results from the South African Bass Anglers Association (SABAA) whom target only Black bass species are summarised in Table 4.6. These show a history of black bass catches from 1999 to 2013 in Clanwilliam, Groenvlei, Brandvlei and Theewaterskloof. Catches of bass in the Greater Brandvlei SABAA tournaments shows that they have been present for over a decade, therefore established, although not sampled during the surveys, possibly due to low numbers.

Table 4.6 Summary of available South African Bass Angling Association (SABAA) Divisional catch per unit effort (CPUE) data for Western Cape for Clanwilliam Dam, Groenvlei, Brandvlei and Theewaterskloof 1999-2013.

Year	Clanwilliam			Groenvlei			Brandvlei			Theewaterskloof		
	Fish/day	S.D.	n	Fish/day	S.D.	n	Fish/day	S.D.	n	Fish/day	S.D.	n
1999	4.5	1.0	58									
2000										3.5	1.4	38
2002	2.3	1.3	55				2.9	1.6	68			
2003	3.6	1.5	79				2.7	1.3	31	2.6	1.7	16
2004				2.5	2.2	75				1.7	1.1	10
2005	2.5	1.4	90	3.4	1.7	70	3.2	1.6	46			
2006	2.1	1.2	33	4.4	1.4	93	3.6	1.5	174			
2007							3.2	1.6	37			
2008	4.7	0.8	79	4.3	1.6	70	4.2	1.4	35			
2009	4.4	1.1	84	3.9	1.6	102	4.9	0.5	45	3.6	1.6	69
2010	4.1	1.4	81	3.4	1.6	73	4.3	1.3	39			
2011	4.6	1.0	96	3.5	1.7	133	3.7	1.8	66	2.2	1.5	60
2012	4.5	1.0	87	4.2	1.3	69	2.8	1.5	74	2.4	1.2	49
2013	4.4	1.2	74							1.6	1.5	38
Mean	3.9	1.5	816	3.7	1.75	685	3.5	1.6	615	2.7	1.7	280

The Western Province Freshwater Angling Association (WPF AA) targets primarily common carp and has separate tournaments on Brandvlei and Quaggaskloof although when the two dams are full they are a single water body (see Chapter 2). CPUE in Theewaterskloof and Brandvlei have remained fairly constant since 2007 while there has been a steady increase in CPUE since 2010 in Quaggaskloof (Table 4.7).

Table 4.7. Summary of available Western Province Freshwater Angling Association (WPF AA) catch per unit effort (CPUE) data for Western Cape for Brandvlei, Quaggaskloof and Theewaterskloof.

Year	Brandvlei			Quaggaskloof			Theewaterskloof		
	Fish/day	S.D.	n	Fish/day	S.D.	n	Fish/day	S.D.	n
2007				1.93	2.83	103	1.62	4.26	113
2008				2.72	4.07	125	1.47	3	72
2009	3.32	2.6	151	5.9	4.9	253	.55	1.6	26
2010	2.16	2.43	79	3.01	3.06	115	1.62	2.83	89
2011	1.92	2	74	8.36	5.11	291	2.02	2.46	99
2012	2.92	2.35	140	8.02	5.56	385	1	1.33	47
Average	2.58	2.33	111	4.99	4.25	212	1.38	2.58	74

On comparison of bass angling data from Voelvlei from the Western Province Art Lure Association (WPALA) with those from coarse fishing (*C. carpio* and *C. gariepinus*) WPFSA results show an interesting trend for Voelvlei (Table 4.8). WPALA originally focused on targeting *M. dolomieu* in 2001 but by 2003 catches had started to decline and by 2006 the CPUE had dropped so significantly that the tournament was converted to coarse angling, focusing on different species of fish. It was in the same year that the bass league ceased that the coarse anglers started to use Voelvlei as a competitive angling venue with consistent catches since 2006 (Table 4.8).

4.3.3 Historical surveys

The results from the gill net survey undertaken in 1978 by McVeigh (1979) in the Western Cape between 1976 and 1979 can be seen in Table 4.9. Soak times for the gill nets in Brandvlei are not known so only relative abundance of fish caught can be calculated, whilst in Clanwilliam the CPUE can be calculated, these data can be seen in Table 4.9.

Table 4.8. Summary of available Western Province Artlure Angling Society (WPALA) Bass and WPALA Coarse catch per unit effort (CPUE) data for Western Cape for Voelvlei 2001 - 2012.

Year	Bass Angling		Coarse Fishing	
	Fish/angler	n	Fish/angler	n
2001	2.84	375		
2002	3.7	458		
2003	1.82	319		
2004	1.06	131		
2005	0.29	23		
2006	0.1	3	6.73	85
2007			4.28	176
2008			8.43	67
2009			6.04	294
2010			3.58	356
2011			5.16	192
2012			7.1	152

Table 4.9. Summary of catches from the gill net surveys undertaken between 1976 and 1979 (McVeigh 1979) showing species abundance in Brandvlei and Clanwilliam and Catch Per Unit Effort (CPUE) for species caught in Clanwilliam in gill nets.

Species	Brandvlei	Clanwilliam	
	Abundance (%)	Abundance (%)	CPUE/gill net h
<i>Barbus andrewi</i>	73.1		
<i>Carassius auratus</i>	3.4		
<i>Cyprinus carpio</i>	23.4		
<i>Labeobarbus capensis</i>		18.5	10.9
<i>Barbus serra</i>		45.6	26.9
<i>Lepomis macrochirus</i>		14.1	8.3
<i>Labeo seeberi</i>		1.1	0.6
<i>Micropterus dolomieu</i>		17.4	10.3
<i>Micropterus salmoides</i>		2.2	1.3
<i>Oreochromis mossambicus</i>		1.1	0.6

The results from angler data and previous surveys for species occurrences in the five water bodies are summarised in Table 4.10. Cape Nature undertook gill net surveys on Groenvlei using eight nets with mesh sizes of 100,145 and 178 mm from June to October 2014. The length frequency of *C. carpio* from these surveys is shown in Figure 4.1.

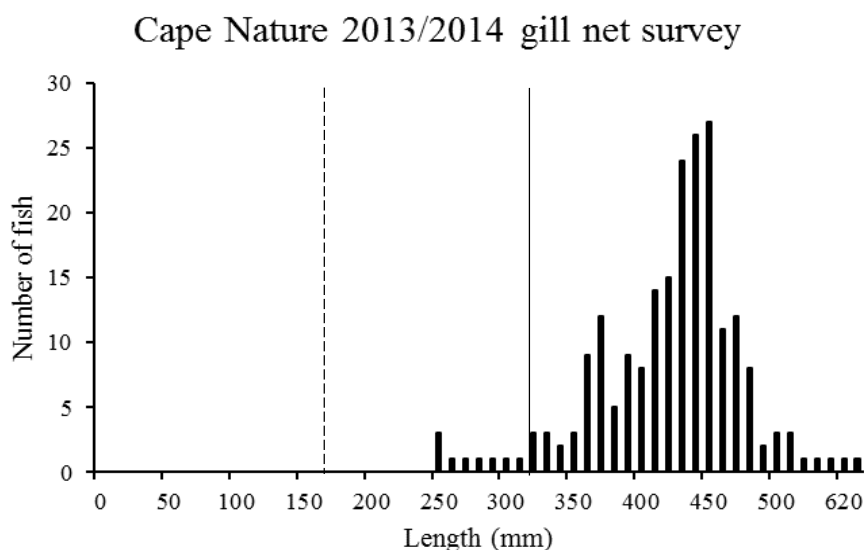


Figure 4.1. *Cyprinus carpio* catches from Cape Nature gill net survey undertaken in 2013/4, the dashed line represents the length at age one and solid line represents the length at 50% maturity (Hasley 2014 (unpublished)).

Table 4.10. Historical species data from A= McVeigh 1978 survey, B= Bass angling 1999-2013, C= coarse angling 2000-2012 in Brandvlei, Clanwilliam, Groenvlei, Theewaterskloof and Voelvlei dams. 1 represents the presence of a species in each data set and an empty block the absence of the species.

Species	Brandvlei			Clanwilliam			Groenvlei			Theewaters-kloof			Voelvlei		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
<i>A. breviceps</i>															
<i>B. andrewi</i>	1		1											1	
<i>B. serra</i>				1		1									
<i>C. auratus</i>	1														
<i>C. carpio</i>	1		1						1			1	1		
<i>C. gariepinus</i>			1									1			
<i>G. aestuaria</i>	1														
<i>L. capensis</i>				1		1									
<i>L. macrochirus</i>	1		1	1					1			1	1		1
<i>L. seeberi</i>				1											
<i>M. dolomieu</i>		1	1	1	1						1		1		1
<i>M. punctulatus</i>					1										
<i>M. salmoides</i>	1	1	1	1	1			1			1				
<i>O. mossambicus</i>	1			1											
<i>O. mykiss</i>														1	1
<i>O. mossambicus</i>				1											
<i>S. trutta</i>														1	
<i>T. sparmanii</i>				1											

4.3.4 Survey results

Population structure

The length frequency of native and non-native fish sampled during the survey is presented in Figures 4.2 - 4.7. These show number of fish caught and their corresponding lengths. The number of fish by size can be skewed due to the gears used, for example in Voelvlei numerous juvenile *O. mossambicus* were caught in seine nets. The littoral areas of Voelvlei, being void of structure, make the use of a seine net easier than the other water bodies surveyed. Fish caught in all gears used are shown to represent the entire population structure.

Labeobarbus capensis was only caught in Clanwilliam Dam. There is a skewed population structure with the smallest fish caught at 300mm (Figure 4.2). The lack of age to length data for *L. capensis* and *B. andrewi* means neither ages nor maturity of these species can be calculated. The population *B. andrewi* caught in Brandvlei was skewed to the smaller fish. This species reaches 600mm but none over 320mm were caught however this could be attributed to the gear used (Skelton, 2001).

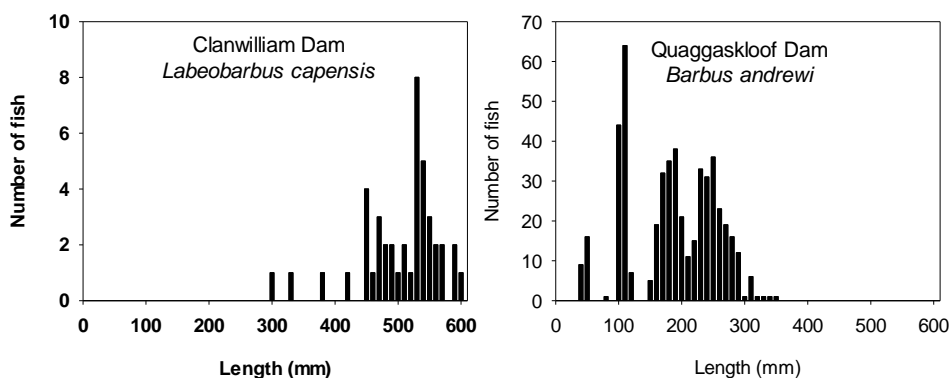


Figure 4.2. Length frequency of *Labeobarbus capensis* and *Barbus andrewi* using fork length sampled from Clanwilliam Dam and Brandvlei during ichthyological surveys conducted during September 2013 and March 2014)(Clanwilliam n = 43, Quaggaskloof n = 498).

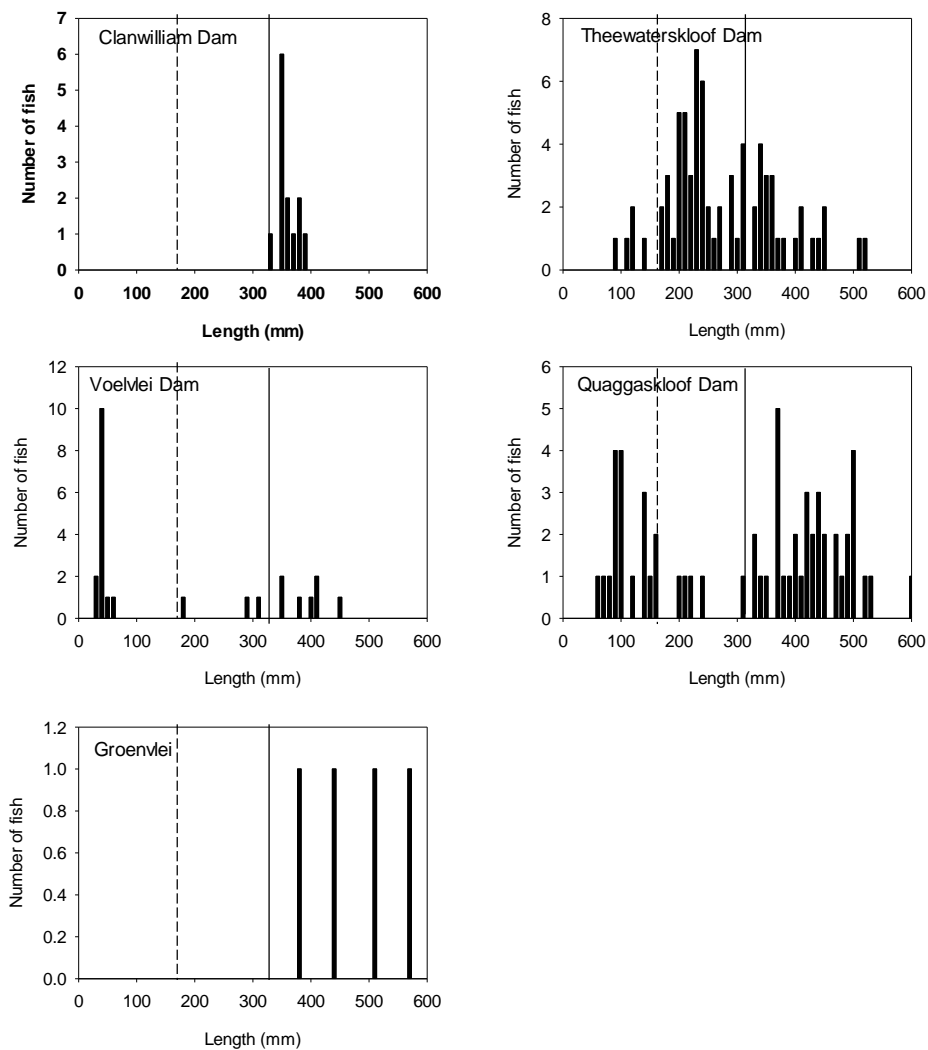


Figure 4.3. Length frequency distributions of common carp *Cyprinus carpio* using fork length sampled from five water bodies in the Western Cape, South Africa, during surveys conducted from April 2013 - May 2014, the dashed line represents fish at one year and solid line is fish at 50 % maturity (Winker *et al.* 2010),(Clanwilliam n = 13, Groenvlei n = 4, Quaggaskloof n = 24, Theewaterskloof n= 73, Voelvlei n= 58).

Cyprinus carpio was caught in all of the five water bodies. In both Groenvlei and Clanwilliam all fish caught were older than one year and mature (Figure 4.3). Only 2-3 year old fish were caught in Clanwilliam showing a single cohort. When supplemented with gill net data from a Cape Nature survey undertaken in 2013/2014 a full population of juvenile and mature fish were caught (Figure 4.1). In the remaining three water bodies a full population structure can be seen, showing juveniles and adults.

Black bass (*Micropterus* spp.) population structures for Clanwilliam, Groenvlei, Theewaterskloof and Brandvlei can be seen in Figure 4.4. As the catches for *M. dolomieu*, *M. salmoides* and *M. punctulatus* were collated together a generalised maturity of 300 mm FL based on the maturity of *M. salmoides* (Weyl *et al.* 1998). These graphs still show multiple cohorts of fish in Clanwilliam, Groenvlei and Theewaterskloof. These species were grouped together as they were seen as a species that has fairly similar predatory traits and rates of growth.

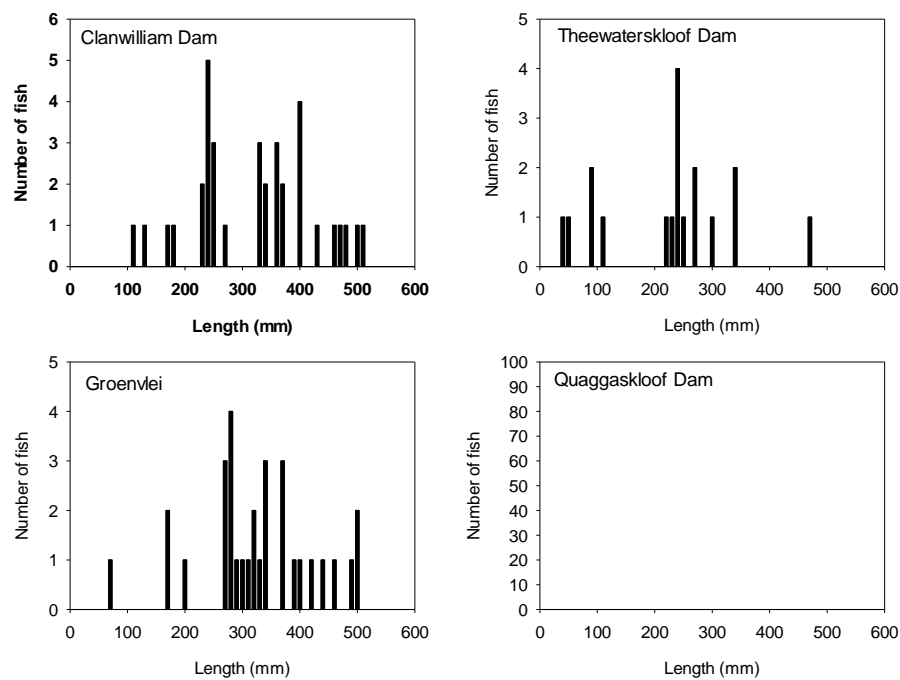


Figure 4.4. Length frequency distributions of Black Bass (combined *Micropterus dolomieu*, *M. salmoides* and *M. punctulatus*) sampled from four water bodies in the Western Cape, South Africa, during surveys conducted from April 2013 - May 2014. Data were combined from all gears used. (Clanwilliam n = 35, Groenvlei n = 28, Quaggaskloof n = 0, Theewaterskloof n = 15).

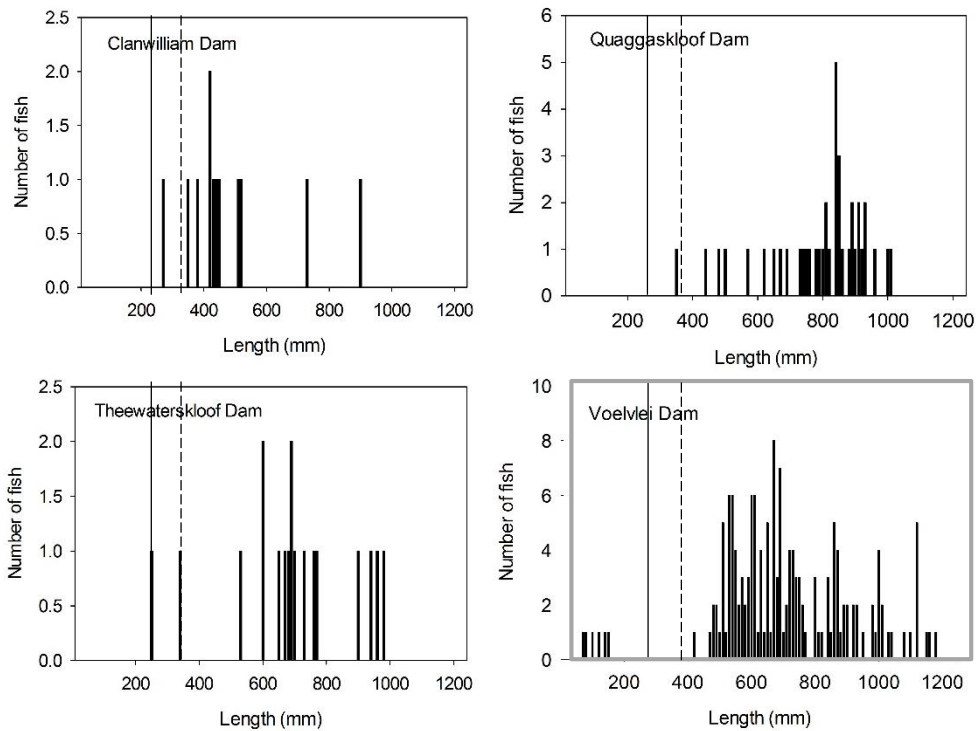


Figure 4.5. Length frequency distributions of African sharp-tooth catfish *Clarias gariepinus* using total length sampled from four water bodies in the Western Cape, South Africa, during surveys conducted from April 2013 - May 2014, the dashed line represents fish at one year and solid line is fish at 50 % maturity (Legendre *et al.* 1992)(Clanwilliam n = 12, Quaggaskloof n = 54, Theewaterskloof n = 18, Voelvlei n = 159).

Clarias gariepinus were only caught in four of the five water bodies with none caught in Groenvlei as can be seen in Figure 4.5. Few specimens were caught in Clanwilliam Dam with only one juvenile, when compared to the other three water bodies there are far fewer fish. Brandvlei and Theewaterskloof also have very few juvenile fish but due to the young age of maturity of this species the sampling period may have influenced this. Only Voelvlei had numerous juveniles which were caught in seine nets.

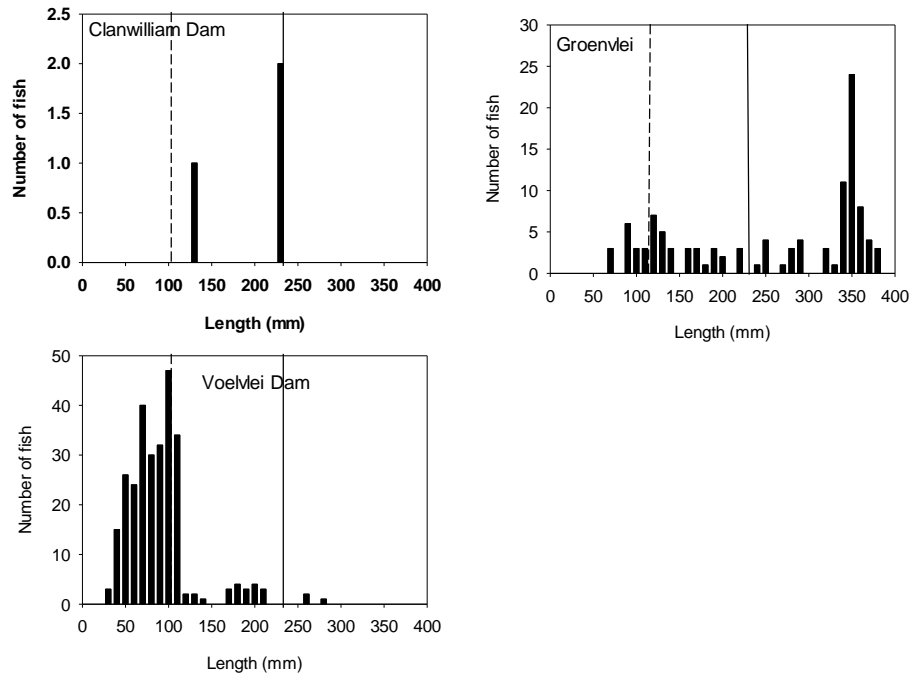


Figure 4.6. Length frequency distributions of Mozambique tilapia, *Oreochromis mossambicus* using fork length sampled from three water bodies in the Western Cape, South Africa, during surveys conducted from April 2013 - May 2014, the dashed line represents fish at one year and solid line is fish at 50 % maturity (Weyl *et al.* 1998)(Clanwilliam n = 3, Groenvlei n = 112, Voelvlei n= 278).

Oreochromis mossambicus were caught in three of the five water bodies. Only three specimens were caught in Clanwilliam dam. These fish were over a year old but had not reached maturity (Figure 4.6). The population structure in Voelvlei shows many juveniles under the one year old mark then a sudden drop off after a year old. Even though there is a dramatic drop off there is still a population which is mature. The numerous juvenile fish were caught in seine nets set in late March 2014 possibly after summer spawn (Weyl *et al.* 1998). Groenvlei showed a full population structure with numerous cohorts, juvenile and adult fish.

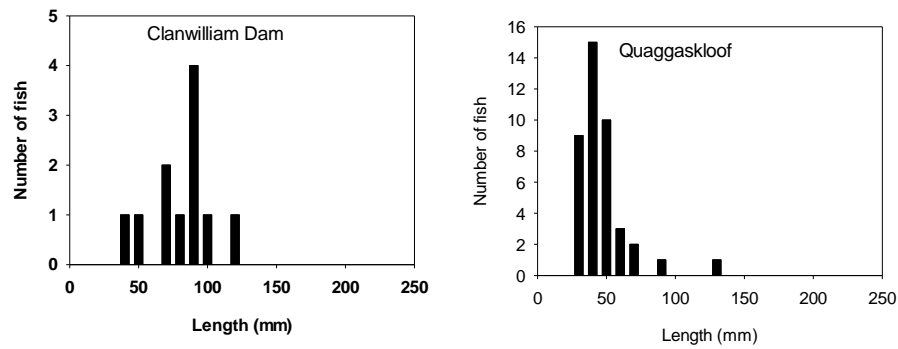


Figure 4.7. Length frequency distributions of Banded tilapia, *Tilapia sparmanii* sampled from four water bodies in the Western Cape, South Africa, during surveys conducted from April 2013 - May 2014, the dashed line represents fish at one year and solid line is fish at 50 % maturity (Clanwilliam n = 11, Quaggaskloof n = 41).

Tilapia sparmanii populations were found in Clanwilliam and Quaggaskloof. Little information is available on length at age and the maturity of the species (Figure 4.7). As 230mm TL is the maximum length of this species it would appear that the population comprises juveniles and adults (Skelton, 2001).

4.3.5 Statistical analysis

The fish species composition of fish that were stocked into the five water bodies were compared to what is currently in them. The results of a chi-square analysis of fish originally stocked into the water bodies and present fish species are shown in Table 4.12. These show that there was no significant difference in each dam of original fish introductions when compared to the current presence or absence of each species. A Student's t-test was undertaken to determine if there was a difference between fish species that were stocked to what was present in all dams combined, it showed a significant difference between the stocking and present species ($p < 0.05$). Table 4.11 shows the species that were stocked and species still present.

Table 4.11. Fish stocked into each water body and the current present or absence in 2013/2014. Presence or absence is shown by the 0 = absent, 1 = present. The first number represents fish stocked and the second the presence or absence of the species in 2013/2014.

Species	Water body				
	Groenvlei	Theewaterskloof	Brandvlei	Voelvlei	Clanwilliam
<i>C. gariepinus</i>	0/0	1/1	1/1	1/1	1/1
<i>C. carpio</i>	1/1	1/1	1/1	1/1	1/1
<i>G. affinis</i>	1/1	0/0	0/0	0/0	0/0
<i>L. macrochirus</i>	1/1	1/1	1/0	1/1	1/1
<i>M. dolomieu</i>	0/0	1/1	1/1	1/0	1/1
<i>M. punctulatus</i>	0/0	0/0	0/0	1/0	1/1
<i>M. salmoides</i>	1/1	1/1	1/1	1/0	1/1
<i>O. mykiss</i>	0/0	0/0	0/0	1/0	0/0
<i>O. mossambicus</i>	1/1	0/0	0/0	1/1	1/1
<i>S. trutta</i>	0/0	0/0	0/0	1/0	0/0
<i>T. sparmanii</i>	0/0	0/0	0/0	1/0	1/1
<i>T. tinca</i>	0/0	0/0	0/0	0/0	0/0
<i>C. auratus</i>	0/0	0/0	0/0	0/0	0/1

Table 4.12. Chi square results for fish stocked into each of the five dams when compared to what was present during the 2013/2014 survey.

Water body	χ^2	deg. freedom	P value
Brandvlei	1.66	5	0.89
Clanwilliam	1.75	7	0.97
Groenvlei	0	3	1
Theewaterskloof	0.875	3	0.83
Voelvlei	4.2	9	0.9

When fish stocked into each dam was compared to currently established fish species, the chi square results for each impoundment showed that in each impoundment fish that were stocked

became established (Table 4.14.), although when the student t-test was undertaken over all dams, it showed that fish stocked did not necessarily become established ($p < 0.05$). Data from Table 4.13 were used in the Chi square analysis. T-test results showed that there was a significant difference ($p < 0.05$) between fish that were stocked and establishment of these fish in each water body.

Table 4.13. Fish stocked into each water body and the current establishment of each species in 2013/2014. Stocked or not stocked is shown by the 0 = not stocked, 1 = stocked. The first number represents fish stocked and the second the establishment (1) or non-establishment (0) of each species in 2013/2014.

Species	Water body				
	Groenvlei	Theewaterskloof	Brandvlei	Voelvlei	Clanwilliam
<i>C. gar</i>	0/0	1/1	1/1	1/1	1/1
<i>C. car</i>	1/1	1/1	1/1	1/1	1/0
<i>G. affinis</i>	1/1	0/0	0/0	0/0	0/0
<i>L. macrochirus</i>	1/1	1/1	1/0	1/1	1/1
<i>M. dolomieu</i>	0/0	1/0	1/1	1/0	1/1
<i>M. punctulatus</i>	0/0	0/0	0/0	1/0	1/1
<i>M. salmoides</i>	1/1	1/1	1/1	1/0	1/1
<i>O. mykiss</i>	0/0	0/0	0/0	1/0	0/0
<i>O. mossambicus</i>	1/1	0/0	0/0	1/1	1/1
<i>S. trutta</i>	0/0	0/0	0/0	1/0	0/0
<i>T. sparmanii</i>	0/0	0/0	0/0	1/0	1/1
<i>T. tinca</i>	0/0	0/0	1/0	0/0	0/0
<i>C. auratus</i>	0/0	0/0	0/0	0/0	1/0

Table 4.14. Chi square results when comparing the establishment currently when compared to fish that were stocked in each dam.

Water body	χ^2	deg. freedom	P value
Brandvlei	7.01	7	0.99
Clanwilliam	0.97	7	0.99
Groenvlei	0	3	1
Theewaterskloof	0	3	1
Voelvlei	4.2	9	0.426

4.4 Discussion

The assessment presented in this chapter was able to contribute towards testing the three proposed hypotheses. The first hypothesis, that species composition in the five water bodies was representative of the native riverine fish fauna could not be supported by data. Although a total of 16 species were sampled using all gears from the five water bodies, data demonstrate that few native fishes have been able to establish in impoundments with native large cyprinids only being sampled from Clanwilliam Dam and Quaggaskloof. Interestingly, where they were present these two species dominated gill net catches. The *L. capensis* population in Clanwilliam Dam comprised of only adult fishes with limited recruitment. The population was therefore categorised as casual with recruitment most likely dependent on the influent rivers such as the Rondegat River (Weyl *et al.* 2014). This differs from the full population structure of *B. andrewi* in Brandvlei which demonstrates that this is a self-sustaining population driven by internal recruitment processes. In other localities the composition of survey catches was generally dominated by non-native *C. gariepinus*, *O. mossambicus*, *C. carpio* and black bass *Micropterus* spp. *Clarias gariepinus* were sampled from all four dams but not from Groenvlei. This demonstrates the alternative hypothesis and was therefore failed to be rejected, as species composition was not representative of the native fish fauna but was dominated by alien species.

The second hypothesis that “the fish fauna in the water bodies is representative of direct stocking records in each water body (from meta data analysis)” was only partly proven. While most alien fishes captured were formally introduced into the dams or influent river systems prior to 1980, *C. gariiepinus* is an exception. This species was not formally introduced but appeared as a result of illegal stocking in Voelvllei and Theewaterskloof in 1990 and Brandvllei and Clanwilliam around 2000 (Bradlow 1963, Jubb 1973, Harrison 1964, Clark *et al.* 2009, de Moor and Bruton 1988). In addition *Cyprinus carpio* was found in Groenvlei from about 1990 (Olds *et al.* 2011). This shows that the majority of alien fishes in these water bodies have been around for at least 25 years but that despite a cessation of formal stocking in 1980 (see Weyl *et al.* 2014) additional introductions appear to be caused by illegal introductions, most likely by anglers. Thus the fish fauna in dams is not always a result of direct formal stocking and is more representative of the alien fish fauna present in the region (therefore alien fish invaded via the catchment or by illegal introductions).

The final hypothesis, that all species that were introduced established in the water bodies also appears to be supported with some exceptions, (e.g. *L. macrochirus* disappearing from Brandvllei and *M. dolomieu* from Voelvllei). At least one *Micropterus* species was found in three of the five water bodies during the survey, from the age and growth of these species cohorts caught ranged from 1 year up to 4 years. *M. dolomieu* and *M. salmoides* were introduced into Voelvllei in 1952 (Bradlow 1963). Angler data shows that *M. dolomieu* were being caught until 2006 but have now completely disappeared from catches whilst in Brandvllei both species are being caught showing that these fish are still present and appear to be established. In Theewaterskloof, *M. dolomieu* is still occasionally caught by anglers, but does not appear to be present in large numbers as it was not caught during the survey, its’ presence

is therefore considered to be casual. The presence of this species years after initial introduction could be due to numerous reasons such as multiple stockings, maturing fish in the population with few juveniles and recent changes to water parameters such as turbidity.

Cyprinus carpio were caught in all five of the water bodies surveyed. This was one of the first invasive fish species to be introduced into South Africa and into the water bodies other than Groenvlei where it was only found in the mid to late 1990s (Olds *et al.* 2011). Results from the surveys indicate that this species is abundant in Theewaterskloof, Voelvlei and Brandvlei with representatives in most of the age and size classes showing it is well established. The results from the 2013/2014 survey show only four *C. carpio* were caught in Groenvlei, but angler catch data and Cape Nature gill net survey results show that these fish are numerous and could therefore be classified as fully established. In Clanwilliam Dam few fish were caught and the *C. carpio* population was represented by fishes between 330 and 380 mm FL. These fish are between two to three years old, with a lack of juveniles and full grown fish this species is currently classed as casual in Clanwilliam. The mesh sizes used during the survey could be a reason for the lack of large *C. carpio* caught in Clanwilliam. Further surveying of this water body is therefore needed to assess the establishment of these fish but until such time they remain as casual invaders.

Clarias gariepinus although only introduced into the dams from the 1990's onward had cohorts corresponding to ages of one year all the way through to at least six years (Legendre *et al.* 1992). Data from this survey demonstrates just how rapidly this species appears to invade dams and how it is spreading through river systems. For example, in Clanwilliam Dam this species appears to be in an early stage of invasion. Although in the early stages of invasion in Clanwilliam Dam, this species has been shown to be a successful aquatic invader (Booth *et al.*

2010). This can be attributed to the species ability to adapt to different environments through eurytopic physiology, it is highly fecund and grows quickly (Booth *et al.* 2010). *Clarias gariepinus* has had numerous negative impacts on indigenous species and further studies are important to monitor the establishment of this species (Cambray 2003).

Similar states of establishment were observed for other species. *Oreochromis mossambicus* was sampled from three water bodies, Groenvlei, Clanwilliam and Voelvlei. Large numbers from different cohorts were found in both Voelvlei and Groenvlei whilst three fish were caught in Clanwilliam Dam of two different length classes. Anglers do not target this species in Clanwilliam Dam and due to the low numbers caught, this species is either a casual invader or establishing in this locality. *Tilapia sparmanii* was sampled only from Clanwilliam Dam and Brandvlei. This fish is known to occur in the influent systems into both dams, the Olifants and Breede respectively (De Moor and Bruton 1988). Unfortunately little is known on the growth rates of this species although they are known to reach 230 mm TL (Skelton 2001). The largest specimen caught was in Brandvlei at 130mm, but due to the various size classes and the period of time since this fish was introduced it is considered to be established in both water bodies. *Gambusia affinis* was only found in Groenvlei and in large numbers. This fish was first introduced into the lake in 1938 and has remained ever since making it an established species (Clark *et al.* 2009).

The invasion state at a provincial level was based on how many water bodies an alien species was found in. If present and established in more than one water body it was considered to spread from the point of introduction into the country (Jonkershoek Hatchery, in Stellenbosch) and could thus be classified as a stage E invader according to the Blackburn *et al.* (2011)

framework. A summary of the invasion status of each fish species in each water body and level of invasion in the province is presented in Table 4.15.

Table 4.15. Fish species sampled from the five water bodies during 2013 and 2014 surveys showing the total establishment of the species in the water body and invasiveness in the province.

Species	Groen-vlei	Theewaters-kloof	Brand-vlei	Voel-vlei	Clan-william	State in the Province
Native						
<i>Labeobarbus capensis</i>	A	A	A	A	C	Native
<i>Barbus andrewi</i>	A	A	E	A	A	Native
<i>Atherina breviceps</i>	E	A	A	A	A	Native
<i>Gilchristella aestuaria</i>	E	E	E	A	A	Native
Alien						
<i>Micropterus salmoides</i>	E	E	E	A	E	Invasive
<i>Micropterus dolomieu</i>	A	C	E	A	E	Invasive
<i>Micropterus punctulatus</i>	A	A	A	A	E	Invasive
<i>Lepomis macrochirus</i>	E	E	A	E	E	Invasive
<i>Cyprinus carpio</i>	E	E	E	E	C	Invasive
<i>Clarias gariepinus</i>	A	E	E	E	E	Invasive
<i>Oreochromis mossambicus</i>	E	A	A	E	E	Invasive
<i>Tilapia sparmanii</i>	A	A	E	A	E	Invasive
<i>Gambusia affinis</i>	E	A	A	A	A	Invasive
Total	7	5	7	4	9	

Established (E) = self-sustaining population with evidence of multiple age cohorts including both spawning capable adults and juveniles present in the population or evidence from multiple years of angling data; Casual (C) = present but no evidence for self-sustaining populations with no juveniles sampled; Absent (A) = not sampled.

The fish originally stocked into each dam when compared to species currently present were shown to have become established, although when assessing all dams combined, fish originally stocked did not become established ($p < 0.05$). Therefore not all fish species that were stocked became established. Results showed that the fish fauna in each dam is representative of direct stocking although when assessing all water bodies combined there appears to be a significant difference between fish originally stocked what is currently present in the water body. Among the established species are *O. mossambicus*, *C. carpio*, *M. salmoides* and *C. gariepinus*, fishes which have a proven ability to sustain recreational, subsistence and commercial fisheries (Weyl *et al.* 2007). As a result, there is potential scope for the development of fisheries based on alien fishes in these dams. Which fishery development options might be suitable is explored in Chapter 5.

CHAPTER 5: FISHERIES SUITABILITY ANALYSIS

5.1 Introduction

Global inland fisheries in 2012 was estimated at 11.6 million tons, which is 12.7% of total global fish production (Welcomme 1997). This has increased from 10.9% in 2006 (FAO 2012) and demonstrates a higher demand for fresh water fish. While this demand is rising for capture fisheries, the growth in recreational fisheries especially in developed countries such as North America and Europe has offset the economic viability of capture fisheries (FAO 2012). This can be seen by the lack of growth in inland fisheries in Europe and the Americas when compared to the 3.5% per year growth in Africa from 1950 – 2009 (FAO 2012). This increased growth is important in developing countries where the role of inland fisheries is increasingly seen as a vehicle for rural development, poverty reduction, food security, livelihood provision and regional economic development (McCafferty *et al.* 2012).

In South Africa, increasing interest in inland fisheries has been driven by the development of national policies to address food security, economic empowerment, and optimal economic benefit from water and poverty eradication (DAFF 2014). The lack of policy on inland fisheries in South Africa has slowed down the implementation of these national policies (Weyl *et al.* 2007). In the development of these fishery policies it is necessary to take into account the dynamic nature of the current users of these resources, biodiversity concerns and sustainable harvest rates (McCafferty *et al.* 2012).

Current users of freshwater fish resources are mainly subsistence and recreational anglers (Weyl *et al.* 2007, Ellender *et al.* 2009). Recreational anglers primarily utilize the resource for leisure purposes, use high technology gear and release, consume or sell a portion of their catch

(Ellender *et al.* 2009). They generally have permanent employment while subsistence anglers live within 15 km of a lake, use basic transport, artisanal gear and are reliant on the resource for food and as a primary or supplementary source of income (Ellender *et al.* 2009). Initially alien fish were introduced to South Africa for recreational angling. The establishment of these fish led to the development of a billion rand recreational fishery (Ellender and Weyl 2014). Economic input by recreational anglers into local economies is aligned with certain national policies including economic empowerment and poverty eradication. Subsistence fishing in South Africa is considered low but increasing. Weyl *et al.* (2007) attributed this low participation in subsistence fisheries to a lack of angling tradition, and the absence of an institutional framework to facilitate managed and sustainable access to fish resources in inland waters. The lack of legal reforms on subsistence fishing could be hampering the development of this fishery but water management authorities are beginning to tolerate and in some cases promote subsistence fishing leading to the slight increase in this fishery (McCafferty *et al.* 2012).

The third user of freshwater fish resources is commercial fisheries. ‘A commercial fishery is operated by a private individual who is granted access at provincial level to harvest a pre-determined yield from a dam. The enterprise is profit- oriented, striving to minimise production costs and to maximise efficiency in production’ (Weyl *et al.* 2007). Commercial inland fisheries are under developed in South Africa as a result of a history of limited access to resources, low demand for freshwater fish, the lack of an inland fisheries policy and unclear fisheries management objectives (Weyl *et al.* 2007). Numerous attempts to develop small-scale commercial fisheries in South Africa have largely failed post initial project interventions for various reasons but primarily because commercial viability is marginal. (McCafferty *et al.* 2012). Commercial fishers are likely to conflict with other resource users and the employment

gains in this fishery could be offset against the losses from tourist sites where recreational fishing is established (McCafferty *et al.* 2012, Ellender *et al.* 2010).

Developing fisheries recommendations requires understanding the dynamic nature of the users. Inland fisheries have been cited as important in rural development and poverty reduction (Marshall and Maes 1994) but this requires the harvest of fish which may clash with recreational anglers who often utilise catch and release procedures (Ellender *et al.* 2010). The over development of the resource may also lead to the collapse of the fishery while inappropriate development could increase friction between the users (McCafferty *et al.* 2012, Ellender *et al.* 2010).

The Western Cape is currently exploring opportunities for managing fisheries in its dams. Options include subsistence, recreational and small scale commercial fishers. In addition, the province intends to initiate experimental fisheries on at least three water bodies including Voelvlei, Brandvlei and Theewaterskloof Dams. Since recreational fisheries contribute towards the provincial economy, while subsistence and commercial fisheries contribute to food security, management needs to ensure sustainable utilisation of fish stocks over time. Therefore the economic and social well-being of fishers (Hilborn and Walters 1992) should therefore be a top priority for provincial administration.

Provincial administration needs to determine what fishing pressure for the water body is sustainable. Complex pressures on fisheries can lead to declines in catches from previously thought sustainable levels, these factors are numerous and include; pollution, altered flow, habitat degradation and non-native species introductions (Allan and Flecker 1993). Overfishing and depleted populations of fresh water fish stocks may not be able to recover as they could be

increasingly vulnerable to disturbances (Allan *et al.* 2005). It is therefore essential to maintain sustainable fishing levels which will not lead to depletion in the population.

An important starting point is an assessment of the current state of the fish stocks in each dam. Unfortunately there were no data available on species composition and relative abundance of individual fishes in major dams prior to this study. Having established that suitable fish species are established, data on their relative abundance are essential for decision making regarding resource use and for monitoring the impacts/state of the fishery. In addition, fisheries independent baseline surveys that are independent of fisheries catch data are an important monitoring tool as they allow for an assessment of the “impact” of management interventions.

5.1.1 Aims and Objectives

The aim of this chapter is to make recommendations that are relevant for the provincial conservation authority, Cape Nature, to develop a fisheries management policy for five water bodies in the Western Cape. The main objectives are to assess species composition and relative abundance of fishes as well as the current uses and users of the five water bodies to determine the economic and social benefits that can be derived. To assist in such assessments Weyl *et al.* (2007) developed a decision making framework based on the productivity analysis, species composition, stakeholder consultation and personal observations. Productivity analysis uses the morpho-edaphic index MEI to predict fish yields by taking into account numerous variables such as lake fertility and mean depth. The species composition of the lakes is determined by gill net survey undertaken while stakeholder consultation is undertaken both formally and informally. This framework covers numerous aspects of the fishery and using a standard framework in South Africa over numerous water bodies is useful in standardising data collection and the use of this data.

5.2 Methods and materials

Preliminary recommendations for fisheries development in the five water bodies were developed using the decision making approach presented in Weyl *et al.* (2007) to recommend four management categories: community-managed subsistence fishery (CMSF); commercial fishery (CF); recreational fishery (RF) or open-access equilibrium (OAE) (Table 5.1). The basis for decision making in each case the potential yield from the resource, species composition, current utilisation of the resource and personal observations.

5.2.1 Potential yield

To obtain a first-estimate of the potential fish production in each dam, models using a morphoedaphic index (MEI) as a predictor of fish yield were applied. These models take into account lake fertility through conductivity or Total Dissolved Solids (TDS) and lake depth. Ryder *et al.* (1974) found that these models were useful in predicting the total annual yield from dams. While these models are useful providing a base line yield, they have been criticised. Downing *et al.* (1990) showed a stronger correlation to primary productivity than to the MEI while Jackson *et al.* (1990) found shortcomings in the functions used such as mean depth. These shortcomings have not prevented numerous researchers from using the MEI in determining the yields and are still shown to be useful (Ryder 1982, Weyl *et al.* 2007). This study is aligned with South African norms of establishing a first-estimate of potential fish production and whilst MEI has been criticised it is useful in standardising results across numerous water bodies and can be used in recommendations for development of new fisheries. Two empirical models were applied:

(1) the Schlesinger and Regier (1982) global, temperature-adapted MEI model:

$$\text{LogYield} \left(\frac{\text{kg}}{\text{ha}} \right) / \text{yr} = 0.044T + 0.482 \left[\text{Log} \frac{\text{TDS}}{\text{MD}} \right] + 0.021;$$

where T is temperature in °C, TDS is the total dissolved solids in mg/l and MD is the mean depth of the reservoir in meters, and;

(2) the Marshall and Maes (1994) model developed for African reservoirs was:

$$Yield \left(\frac{kg}{ha \cdot yr} \right) = 23.281 * \left[\frac{MD}{CON} \right]^{-0.447}$$

and CON is the mean conductivity measured in $\mu S.m^{-2}$.

Temperature and MD data were collected from the Department of Water Affairs (DWA) while TDS and CON data were collected during field surveys (DWAF 2014) to be fitted into these models. Temperature was calculated on a yearly average and MD when the dam was at maximum capacity. Of the two MEI models chosen, the Schlesinger and Regier (1982) model was the more conservative. However, since MEI based models are only an indication of the total productivity of a dam, the results from both models are indicative of the range of potential yields attainable from the dam.

5.2.2 Species composition

Methods used for the species composition of each water body are found in Chapter 4. Although six gears were used, only results from gill nets and long lines will be used for CPUE as these are potentially useful gears for commercial fisheries.

Table 5.1. Definitions of fisheries sectors (Weyl *et al.* 2007)

Fisheries development options (after Weyl *et al.* 2007)

Subsistence fishery (SF)

This type of fishery is managed by a local community to maximise sustainable yield, food security and employment. The fishery is managed primarily through input controls such as closed seasons, gear limitations and limited access. Allowable gears in this fishery include long lines and hook and line fishing. A SF was recommended in areas where (1) models predicted fishery yields of > 50 t/yr; (2) no IUCN red data book listed species were present and the species composition was dominated by *Clarias gariepinus*, *Oreochromis mossambicus* and *Cyprinus carpio*; (3) community land bordered the dam; (4) there was a pre-existing subsistence fishery; (5) there were no pre-existing tourist facilities and the dam was is not conducive for tourism development for scenic or safety reasons.

Commercial fishery (CF)

A commercial fishery is operated by a private individual who is granted access at provincial level to harvest a pre-determined yield from a dam. The enterprise is profit- oriented, striving to minimise production costs and to maximise efficiency in production. Gears permissible for commercial use include gill nets, long-lines and beach seine nets and the fishery is managed on maximum yield strategy. A commercial fishery was recommended in areas where: (1) predicted fishery yields > 100 t/yr; (2) Species composition was dominated by *Clarias gariepinus*, *Oreochromis mossambicus* and *Cyprinus carpio*; (3) No IUCN red data book listed species were present; (4) There was limited community access to and use of the resource; and (5) Limited recreational and subsistence use of the fishery was observed.

Recreational fishery (RF)

In a recreational fishery the resource is used exclusively for recreation by anglers using hook and line. Users are neither dependent on the resource for survival, nor for economic gain. These fisheries can be managed for maximum participation through output controls such as daily bag limits and through catch-and-release (where recreational anglers return caught fish to the water alive) fishing. An RF was recommended where: (1) models predicted yield lower than those capable of sustaining either a CMF or a CF; (2) there was a history of recreational use; (3) the dam was bordered by nature reserve, private land or community land; (4) pre-existing tourist facilities were present or showed potential for the development of tourist facilities; (5) the community expressed an interest in tourism development.

Open access equilibrium (OAE)

In OAE fisheries no management recommendations are set and the dam is maintained as a common, open-access resource. An OAE was recommended in dams where predicted yields were lower than those capable of sustaining either a CMF or a CF and the potential for the establishment of tourist facilities was limited.

5.2.3 Stakeholder Consultation

The primary stakeholders for the development of the fishery in the five water bodies were identified with the help of the local Cape Nature official. Informal and semi-structured interviews were conducted with the various stakeholders to determine the nature of their use of the resource, and whether they had any recommendations or suggestions to improve the fishery potential of the water body. These stakeholders included fishers on the water bodies, the local authorities in charge of each water body and local residents who reside near the water body or provide accommodation and services to individuals interested in using the resource.

5.3 Results

5.3.1 Productivity

Input parameters for MEI models and the resultant estimated yield and potential total annual yield for each dam are shown in Table 5.2. Due to their depth and low high conductivity and TDS all dams exhibited low productivity, with a possible annual yield not exceeding 60 kg/ha/yr for either, the Schlessinger and Regier (1982) or the Marshall and Maes (1994) models. The exception was Groenvlei which, as a result of its relatively high TDS and shallow depth was predicted to be more productive. In terms of total yield, only Theewaterskloof was likely to be capable of yielding in excess of 100 t/yr.

Table 5.2. Summary of physical characteristics of four dams, potential production and annual yield obtainable from five water bodies in the Western Cape. Ranges in potential yield are the result of either

applying the conservative Schlesinger and Regier (1982) or the optimistic Marshall and Maes (1994) model. Mean temperature was mean air temperature and maximum gross value of harvests was estimated assuming a price of R8/kg (C. Welgemoed, Fusion Speciality Foods, South Africa, pers. comm).

Dam	Size (ha)	Mean depth (meters)	Cond. $\mu\text{S}\cdot\text{m}^{-2}$	TDS (mg/l)	Mean Temp ($^{\circ}\text{C}$)	Potential Yield		Max value (R '000s)
						kg/ha/yr	t/yr	
Voelvlei	1573	10	80	54	16	12-59	19-93	744
Clanwilliam	1126	11	67	45	16	10-52	12-59	472
Brandvlei	1687	11	56	38	17	11-48	18-81	648
Theewaterskloof	5059	9	53	36	17	11-51	58-260	2080
Groenvlei	234	4	718	481	16	53-237	12-55	440

5.3.2 Species composition

Illustrated in Table 5.3 is the experimental gill net and long line CPUE data. In dams containing catfish, long line CPUE varied between 0.06 ± 0.25 fish/10 hook/night at Clanwilliam to 4.35 ± 2.50 fish/10 hook/night at Voelvlei. In addition, gill net CPUE ranged from 0.38 ± 0.56 fish/net/h at Theewaterskloof to 3.15 ± 3.06 fish/net/h at Brandvlei. It is shown that gill nets catch a variety of species in the water bodies while long lines only caught *C. gariepinus*. Native species of concern were caught in gill nets for example in *B. andrewi* in Brandvlei and *L. capensis* in Clanwilliam Dam. Therefore the use of gill nets may not be suitable in these water bodies, while long lines that only target alien *C. gariepinus* may be useful.

Table 5.3. Mean \pm S.D of Catch Per Unit Effort (CPUE) of fish species captured in gill nets and long lines during surveys conducted in the Western Cape. Effort was number of fish per one hour per gill net, and number of fish per 10 hook/h for long lines. Long line sample size: Clanwilliam = 16, Groenvlei = 0, Brandvlei = 9, Theewaterskloof = 11, Voelvlei = 14).

Species	CLAN	GROEN	BRAND	THEE	VOEL
Gill net					
<i>Barbus andrewi</i>			2.88 \pm 2.39		
<i>Cyprinus carpio</i>	0.06 \pm 0.14	0.05 \pm 0.15	0.08 \pm 0.19	0.27 \pm 0.33	0.06 \pm 0.11
<i>Clarias gariepinus</i>	0.01 \pm 0.03		0.19 \pm 0.47	0.05 \pm 0.11	0.29 \pm 0.32
<i>Labeobarbus capensis</i>	0.23 \pm 0.65				
<i>Lepomis macrochirus</i>	0.01 \pm 0.04	0.14 \pm 0.19			0.01 \pm 0.03
<i>Micropterus spp.</i>	0.13 \pm 0.2	0.02 \pm 0.09		0.06 \pm 0.12	
<i>Oreochromis mossambicus</i>		0.93 \pm 1.45			0.02 \pm 0.05
Total	0.44 \pm 1.06	1.14 \pm 1.88	3.15 \pm 3.06	0.38 \pm 0.56	1.09 \pm 0.5
Long line					
<i>Clarias gariepinus</i>	0.06 \pm 0.25		3.33 \pm 1.87	0.64 \pm 1.23	4.35 \pm 2.50

The total soak times for the nets in each water body varied according to the number of nets set and the period of time each net was set for, this is seen in Table 5.4 along with CPUE for each dam. Groenvlei had the highest CPUE of gill nets at 1.32 ± 1.94 kg/h and Theewaterskloof had the lowest at 0.36 ± 0.41 kg/h. In dams containing catfish, long line CPUE ranged between 0.01 ± 0.05 kg/10 hook/h at Clanwilliam dam to 1.48 ± 0.9 kg/10 hook/h at Voelvlei Dam.

Table 5.4. Total number of gill nets set on each water body and the soak times, weight of all fish caught in the nets and the Catch Per Unit Effort (CPUE) by weight for each water body.

Water body	Gill nets			Long lines	
	Gill net sets	Soak time (h)	CPUE (kg/h)	Long line sets	CPUE (kg/h)
Clanwilliam	32	188	0.71 \pm 1.55	16	0.01 \pm 0.05
Groenvlei	26	81	1.32 \pm 1.94		
Brandvlei	27	117	0.84 \pm 1.48	9	0.87 \pm 0.71
Theewaterskloof	23	228	0.36 \pm 0.41	11	0.14 \pm 0.34
Voelvlei	28	192	1.05 \pm 1.34	14	1.48 \pm 0.90

In gill nets, species composition varied between dams and between mesh sizes. The overall CPUE by mesh size is shown in Figure 5.1. In all the dams 144mm mesh size had the highest catch rates with a similar pattern between dams appearing of reduced catches as the mesh size decreases except in Brandvlei. In Brandvlei, 144mm mesh had the highest proportion of the catch in the dam although the 44mm had a far higher proportion of the catches when compared to other water bodies.

The percentage catch of fish in the five water bodies is presented in Table 5.5. This depicts four fish species most common in the water bodies. These being *C. carpio*, *C. gariepinus*, *M. salmoides* and *L. macrochirus*, while *O. mossambicus* make up the majority of catches in Groenvlei. These species are all non-native and can be used for subsistence and recreational purposes.

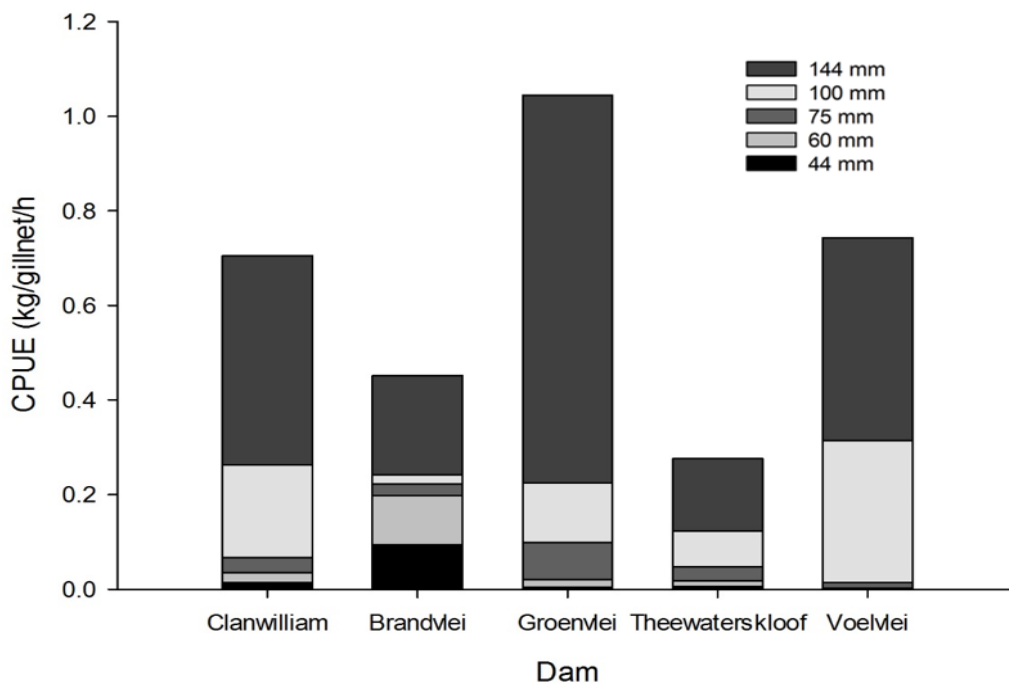


Figure 5.1. CPUE of gill nets set per hour in the five water bodies surveyed by mesh size (144mm, 100mm, 75mm, 60mm and 44mm mesh sizes).

Table 5.5. Percent (%) species composition by weight of experimental gill net catches in five water bodies in the Western Cape. The overall resource status, expressed as conservation status of each species as (T) threatened native; or (A) alien. Potential utilisation of each species is either for (S) subsistence; (C) commercial; or (R) recreational use. Dams Brandvlei, Clanwilliam, Groenvlei, Theewaterskloof and Voelvlei.

Species	Resource Status			Species composition (%)			
	Status	Uses	Brand-vlei	Clan-william	Groen-vlei	Thee-waterskloof	Voel-vlei
Tilapia <i>O. mossambicus</i>	A	SCR			86		1
Spotted bass <i>M. punctulatus</i>	A	SR		1			
Largemouth bass <i>M. salmoides</i>	A	SR		1	2	7	
Smallmouth bass <i>M. dolomieu</i>	A	SR		14			
Bluegill <i>L. macrochirus</i>	A	SCR			2		
Clanwilliam yellowfish <i>L. capensis</i>	T	R		74			
Common carp <i>C. carpio</i>	A	SCR	11	9	10	46	14
African catfish <i>C. gariepinus</i>	A	SCR	65	1		46	85
Whitefish <i>B. andrewi</i>	T	R	24				

Gill net catches in Brandvlei show that as the mesh size increases the catches of the native *B. andrewi* decrease until a mesh of 100m when they increase slightly (Figure 5.3). *Clarias gariepinus* catches increase after 100mm but stay below the levels of *B. andrewi*. The fall in native fish CPUE with an increase in mesh size could be due to the smaller size of the species of 600mm (Skelton 2001) and with mesh sizes of larger than 145mm, few *B. andrewi* may be caught. The use of gill nets as a harvesting gear could therefore impacts negatively on endangered native fishes but further research on the use of larger mesh sizes could however be useful.

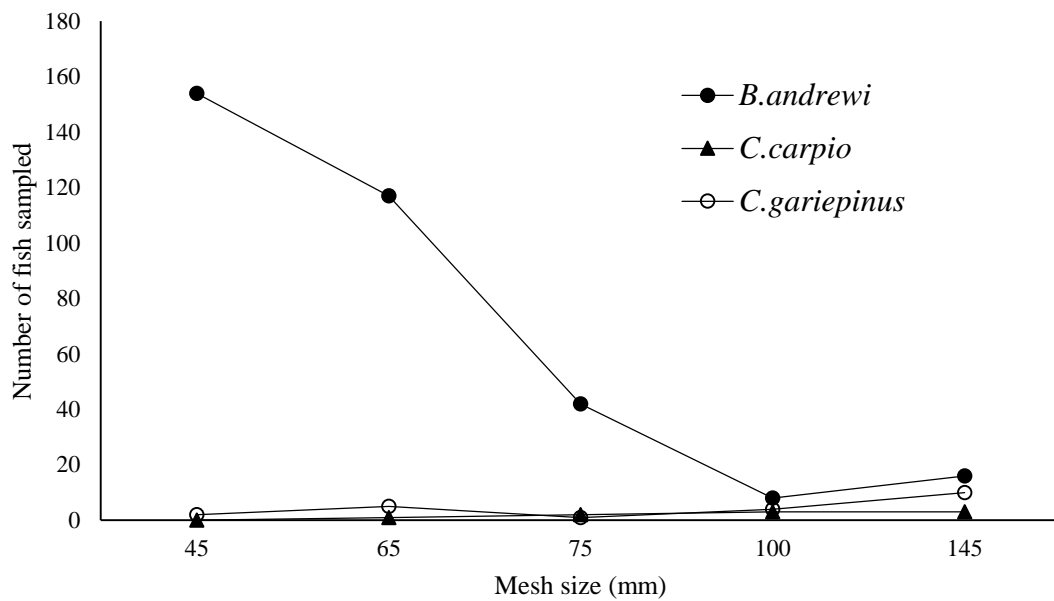


Figure 5.2. Catches in gill nets from Brandvlei showing the number of fish caught per species in the five mesh sizes (45mm, 65mm, 75mm, 100mm and 145mm).

In Clanwilliam there are very few native fish caught in the small mesh sizes but from 75mm onwards there was a marked increase. Bass CPUE appear relatively constant with an increase in mesh size while carp catches increase only in the 145mm mesh (Figure 5.3). Gill nets in Clanwilliam dam are therefore not a suitable gear of harvested alien fish species as the larger mesh sizes will have a large impact on native species.

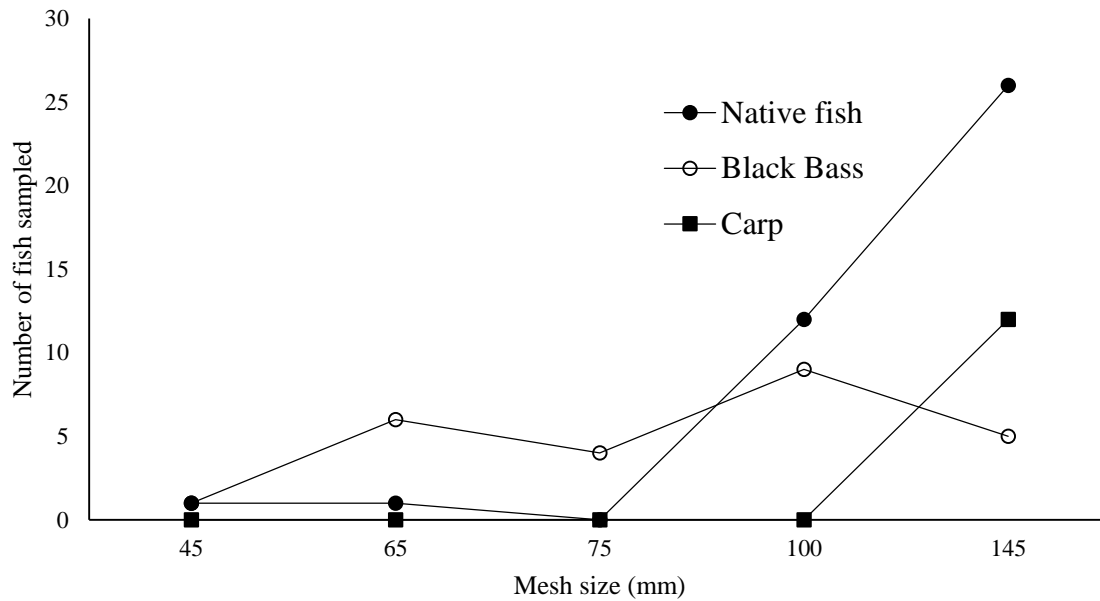


Figure 5.3. Catches in gill nets from Clanwilliam showing the number of fish caught per species in the five mesh sizes (45mm, 65mm, 75mm, 100mm and 145mm).

5.3.3 Stakeholder consultation

The results from stakeholder consultations and personal observations by the survey team are summarised in Table 5.6. The pattern of utilisation of the five water bodies is dominated by recreational use (Table 5.6). In addition, many of the dams are currently used for recreational activities such as angling and boating. In all dams accessible by local communities an interest was expressed to develop both a capture fishery and tourist facilities.

Table 5.6. Summary of productivity analysis, species composition, stakeholder consultation and personal observations leading to recommendations for potential use of each of five dams surveyed in the Western Province of South Africa.

Parameter	Voelvlei	Clanwilliam	Brandvlei	Theewaterskloof	Groenvlei
Size (ha)	1573	1126 ¹	1687	5059	234
MEI Yield (kg/ha/yr)	12-59	10-52	11-48	11-51	53-237
Potential Yield (tons/yr)	19-93	12-59	18-81	58-260	12-55
Commercial species	Yes	Yes	Yes	Yes	Yes
Species of conservation concern	No	Yes ²	Yes ³	No	No
Nature Reserve	Yes ⁴	No	No ⁵	Yes ⁶	Yes ⁷
Private land shoreline	Yes	Yes	Yes	Yes	Yes
Community access to shoreline	Yes	Yes	Yes	Yes	Yes
Tourist facilities (yes/no)	Yes	Yes	Yes	Yes	Yes
Recreational boating	Yes ⁸	Yes	Yes	Yes	Yes ⁹
Recreational angling	Large ¹⁰	Large ¹¹	Large ¹¹	Large ¹¹	Large ¹¹
Subsistence angling	Small ¹²	Large ¹³	Small	Small ¹³	Small ¹⁴
Commercial fishing	No	No	No	No	No
Illegal gill netting	No	No	No	No	No
Tourist value	Minimal ¹⁵	High	High	High ¹⁶	High ¹⁶
Local interest to develop capture fishery	Yes ¹⁷	No	Yes ¹⁸	Yes ¹⁷	No
Recommendation	RF/SF	RF	RF	RF/SF/CF	RF/SF

¹ raising of the dam wall will increase the capacity; ² Clanwilliam yellowfish listed as vulnerable; ³ Berg-Breede River Whitefish listed as endangered; ⁴ Voelvlei and Waterval Nature Reserves; ⁵ while nature conservation areas do not border Brandvlei Dam the Brandvlei prison restricts access to a major part of the shoreline; ⁶ Theewaterskloof Nature Reserve and Hottentots-Holland Nature Reserve; ⁷ Goukamma Nature Reserve; ⁸ sailing is available but only electric motors are permitted; ⁹ canoes and boats can be hired, but only electric motors are permitted; ¹⁰ changes in recreational angling from small-mouth bass to common carp and sharptooth catfish; ¹¹ regular angling competitions take place; ¹² local communities, access to the dam limits the pressure; ¹³ local communities and farm labourers adjacent to the dam; ¹⁴ local community that is authorised to make use of the eastern end of the lake; ¹⁵ dam is not aesthetically appealing and falling fish catches; ¹⁶ this fishery has potential for up-market utilisation; ¹⁷ experimental commercial fishing license issued; ¹⁸ no permit issued. RF = recreational fishery, OAE = open access equilibrium, CF = commercial fishery

5.4 Discussion

When making recommendations for fisheries development four aspects need to be taken into account (Weyl *et al.* 2007). These include; productivity analysis, species composition, current utilisation and development. Productivity analysis of a water body is necessary to determine whether a fishery is sustainable. South Africa is a water scarce country with few large impoundments suitable for harvest fisheries. According to Britz *et al.* (2015), yields of between 100 to 400 t/yr are necessary for small scale commercial fisheries and only dams that can potentially produce >400 t/yr are theoretically viable for larger scale commercial fisheries.

Of the five water bodies assessed in the Western Cape, only one of these water bodies produced in excess of >100 t/yr, this being Theewaterskloof. While this dam had the highest yield it would still yield less than 400t/yr, making it suitable for a small scale fishery but not large scale. When these yields were added to 10 dams in the North West Province, only one dam in each province could sustain a small scale fishery, no dams could sustain large scale fisheries. In Table 5.7, a harvest fishery on Theewaterskloof can employ 36 people, based on the assumption fish could be sold at R8/kg, and with minimum annual wage of R 29 045/yr (Department of Labour 2015). As the yields in this table are based on the Marshall and Maes (1994) morphoedaphic index which is the upper bound of the potential yields, sustainability would not be possible at these harvest levels but rather slightly lower. The development of subsistence fisheries would not provide economic benefit but food security for the fishers.

Table 5.7. Estimated annual yield in tons, based on the Marshall and Maes (1994) morphoedaphic index, estimated total value of the fish assuming a price of R8/kg and the total number of people that could be employed at minimum rural wage of R 29 045 per year in the five water bodies in the Western Cape Province. Employment is estimated under the assumption of a 50% operating cost.

Water body	Yield (tons)	Value (R '000s)	Employment (no. of persons)
Brandvlei	81	648	11
Clanwilliam	59	472	8
Groenvlei	55	440	8
Theewaterskloof	260	2080	36
Voelvlei	93	744	13
Total	842	6736	232

The gross value derived from the potential yield indicates that a commercial fishery on even the largest dam would be relatively small value (maximum gross value = R 2,080 million/year). This figure appears large enough to sustain a fishery but operation costs have not been included here and these are likely to be at least 50% of the total value of the fishery (Andrew *et al.* 2000). Given this relatively low value, and the high likelihood of conflicts with recreational and

subsistence users management for subsistence and recreational angling is likely to be the more appropriate (Weyl *et al.* 2007).

In Clanwilliam Dam and Brandvlei, native fishes of conservation concern made up 52% and 91% of all fishes sampled in gill nets respectively by number of fish. *Labeobarbus capensis* is the largest indigenous fish species in the CFR. Once widespread this species is now limited to the Olifants-Doring River systems and classified as vulnerable (Impson *et al.* 2007). This flagship species of the CFR draws awareness to the plight of the other fish in the CFR which require special monitoring and research (Impson *et al.* 2007). *Barbus andrewi* which are found in Brandvlei have undergone a rapid decline in both population numbers and geographical distribution in the province and are now considered critically endangered (Impson 2007). Due to the vulnerability of these species to fishing gears that target numerous species of fish such as gill nets, any harvest fishery would require gears that are selective for a target species to maintain these populations of indigenous fish. In the other water bodies, potentially commercial species contributed 85% to the CPUE by number in Theewaterskloof, 86% in Groenvlei and 98% in Voelvlei. These fish can be used for both subsistence and recreation. *Clarias gariepinus* in South Africa is common but in the Western Cape more specifically this species is extra-limital and is considered a pest by many anglers and would therefore be suitable for directed harvesting (Cambray 2003, Vitule *et al.* 2006, Kadye *et al.* 2012).

Current usage of the water bodies shows that there is a high recreational value in the water bodies, including both boating and angling. Tourist facilities at all the water bodies expedite these recreational activities and these activities could be aided by nature reserves bounding all the water bodies except Brandvlei and Clanwilliam. Interviews indicate that only in Clanwilliam is there a large subsistence angling usage with the remaining water bodies having a small

demand. Local interest has been shown to develop capture fisheries on Voelvlei and Theewaterskloof as experimental commercial fishing licenses have been issued, and in Brandvlei although no license has been issued. Given the results of the current surveys, it is unlikely that these commercial ventures will be economically viable.

Evaluation of harvesting methods

The biodiversity survey used various gears to target as many different species of fish as possible in various habitats. Due to the specifics of each gear they showed differing results in size of the fish caught and species. When developing fishery recommendations, the gear to be used is essential. Currently in South Africa there is a lack of inland fishery policy and due to this the development of small scale commercial and subsistence fisheries is under developed (Britz *et al.* 2015, McCafferty 2012). As this policy is developed, the use of various gears in fisheries needs to be assessed. International uses of gears are useful as a comparison. The use of selective gears such as trot lines (long lines) and bush hooks (lines attached to tree limbs overhanging the water) used in Florida to target catfish for subsistence use (FFWCC 2014) could for example be considered as suitable gear in the Western Cape as the results from the current survey suggest limited bycatch. As these gears are selective and target catfish (*C. gariepinus*) which can be used for both subsistence and commercial purposes they could be useful to reduce the conflict between recreational anglers targeting black bass species, and limiting the number of indigenous species affected by fishery activities (Quinn 1993).

5.4.1 Fisheries Recommendations

Voelvlei

Yield estimates range between 12 and 59 kg/ha per year depending on the model used this equates to a total obtainable yield of between 19 and 93 tons per year. The dam contains three species *C. gariepinus*, *C. carpio* and *O. mossambicus* with commercial potential and the fish species composition is entirely comprised of fishes that are alien to the system and there are no fishes of conservation concern. As a result, the dam has some potential for commercial fisheries development. However, the western side of Voelvlei Dam is bordered by Voelvlei Nature Reserve while the south and eastern edges are bordered by the Waterval Nature Reserves, while the northern and north-east is comprised of private land. As a result there is limited access for local communities.

This private land provides accommodation facilities to the public, although, the camp site on the northern end of the dam, near the dam wall, is exclusively used by fishing club members. Public access to the dam is found near the dam wall with parking facilities on the north-eastern side. Silwerfontein guest house provides accommodation and access to the dam. The only boat launch site is at the yacht club, although launching of smaller boats is possible from the banks, with only electric motors permitted on the dam. The yacht club is still active with occasional sailing events on the water body.

Voelvlei, with a once thriving recreational smallmouth bass fishery, has in recent years, become a *C. gariepinus* and *C. carpio* dominated recreational fishery, with recreational angler catches of smallmouth bass becoming non-existent. Subsistence anglers also target these species, but due to the limited public access on this water body their effort appears to be focused on the north-western side of the dam.

In terms of yield this dam appears marginal for the long term development of a commercial fishery. One experimental fishing permit has however been issued by the Department of Water Affairs (DWA) on this water body primarily to target *C. gariepinus* and *C. carpio* which are now both well established. The yield of this fishery should be monitored and catch rates adjusted to ensure long term sustainability. Our overall assessment is that such a fishery does not conflict with conservation goals but may conflict with recreational use of the dam. Managers should therefore be aware of potential conflicts. As a result of the negative publicity of gill nets, the commercial fishery should focus on the use of long line to target *C. gariepinus* or on seine nets to target *C. carpio*.

Clanwilliam Dam

The yield estimates for this water body range between 10 and 52 kg/ha per year depending on the model used, this equates to a total obtainable yield of between 12 and 59 t/yr. The dam contains three species *C. gariepinus*, *C. carpio* and *O. mossambicus* with commercial potential. These species however currently make up a very small proportion of the fish population and gill net catches were dominated by *Labeobarbus capensis* a species of conservation concern. *Labeobarbus capensis* is endemic to this system and is listed under vulnerable on the IUCN redlist. For this reason a commercial gill net fishery is not a viable option for this dam.

The dam is not bordered by any nature reserves but rather private land, although a municipal campsite does border the dam near the dam wall providing accommodation and boat access to the dam. Accommodation in the form of camping and self-catering can be found around the dam. Water sports are common in the summer months, including water skiing and jet-skiing. The dam is considered important for recreational angling, with anglers targeting small and large-mouth bass. Several bass competitions are held on the dam throughout the year, with the

summer and winter bass classics being held here. There are also a large number of subsistence anglers who fish along the banks. Many of these anglers grew up fishing this water body and continue to do so. These anglers gain access to the dam between the private properties and walk along the edges. As a result of the low yield, existent subsistence and recreational angling interests and considerable tourist value of this dam, it is recommended that this dam be managed to maintain the current recreational and subsistence fishing *status quo*.

Brandvlei

Yield estimates range between 11 and 48 kg/ha per year depending on the model used, this equates to a total obtainable yield of between 18 and 81 tons per year. The dam contains two species *C. gariepinus* and *C. carpio* with commercial potential. There is one species of conservation concern, *Barbus andrewi* as it is listed as endangered on the IUCN redlist (Skelton 2001).

No nature reserves border Brandvlei although the Brandvlei prison restricts access to a major part of the shoreline. Private land makes up the majority of the shoreline with municipal land making up the rest. Communities access the water body on the north western and north eastern where the majority of the subsistence fishing occurs. The Brandvlei yacht club and Worcester yacht club provide camping facilities and self-catering cottages. Tourists frequently use these facilities to access the dam for water and jet skiing, while kite surfing and wind surfing during high winds is becoming a further attraction. The dam is still used as a recreational bass fishing dam with tournaments still being held during the year. There has been local interest in developing a capture fishery on the dam targeting *C. gariepinus*. As a result of *B. andrewi* dominating catch compositions gill nets are not a viable harvest strategy. Further research on larger mesh size gill nets could be valuable to determine the catch rates of *B. andrewi*. A long

line fishery could be considered if any commercial fishery were to be developed. This would however need to be carefully monitored to avoid potential conflicts with recreational users of the dam.

Theewaterskloof

Yield estimates range between 11 and 51 kg/ha per year depending on the model used, this equates to a total obtainable yield of between 58 and 260t/yr. The dam contains two species *C. gariepinus* and *C. carpio* with commercial potential. The fish species composition is entirely comprised of fishes that are alien to the system and there are no fishes of conservation concern.

Theewaterskloof dam is bordered by two nature reserves, the Theewaters Nature Reserve and Hottentots-Holland Nature Reserve on the northern and north western shores. The remainder of the shore line is comprised of private land. Communities access the shoreline through the nature reserves. Tourist facilities on the dam are provided for by the Theewaterskloof sports club and other private sites. Sailing and water sports are undertaken on Theewaterskloof, predominantly from the sports club especially in the summer months. Recreational angling for large-mouth bass is large, with regular tournaments being held. Coarse anglers also make use of the dam targeting *C. carpio* and *C. gariepinus*. Subsistence anglers, predominantly farm labourers and local communities also fish in the dam but this is considered to be small. An experimental commercial fishery has been issued with a license to start operating on the dam to target *C. carpio* and *C. gariepinus*. Tourist value is considered high due to the water sports undertaken and the recreational fishing value of the dam. Due to its large size this dam it is capable of yields that might sustain a small scale commercial fishery. Such a fishery should however be developed in consideration of the considerable tourist value of the dam.

Groenvlei

Groenvlei is a 234 ha dam situated 5 km east of Sedgefield. Yield estimates range between 53 and 237 kg/ha/yr depending on the model used, this equates to a total obtainable yield of between 12 and 55 t/yr. The dam contains *C. carpio* which has commercial potential. No fishes of conservation concern occur in this water body. This nature lake is surrounded by the Goukamma Nature Reserve, with private shoreline at the Lake Pleasant chalets and lodges on the western edge. Communities access the lake from the N2 highway at an authorised location, due to the nature of the lake fishing from the shoreline is limited and the community makes use of small row boats to fish off. Tourist facilities are available at Lake Pleasant and through the nature reserve. Hiking trails around the lake, canoeing and birding are available through the nature reserve. Boating with only electric motors are permitted on the lake. Recreational bass and carp anglers both make use of this lake, with the Outeniqua bass masters holding an annual tournament. Subsistence anglers make use of the eastern slipway to go fishing but this fishing pressure is considered to be small with a maximum of up to four small row boats being used.

In summary, this water body is simply too small to sustain a commercial fishery. Recreational anglers have for a long time been actively using this venue with yearly bass competitions (Anon 1956). For this reason recreational and subsistence angling should be promoted.

CHAPTER 6: GENERAL DISCUSSION AND RECOMMENDATIONS FOR FUTURE WORK

6.1 General discussion

Developing inland fisheries in South Africa has become an important issue that was not addressed during the apartheid era (Weyl *et al.* 2007, McCafferty *et al.* 2012). A lack of legislation and governance has driven the need for research to develop sustainable inland fisheries. The latest report on inland fisheries in South Africa has exposed necessary steps and specific research essential to developing these fisheries. Britz *et al.* (2015) in their report to the WRC (Water Research Commission) identified knowledge gaps requiring attention. The first was the need for a comprehensive survey and monitoring programme. This thesis has contributed the knowledge base needed to guide inland fisheries development in the Western Cape by targeting specific knowledge gaps by estimating potential yields, determining establishment success of various fish species, identifying social issues and by determining which fisheries might be suitable in each of five major water bodies in the province. In addition, the thesis also took the opportunity to determine important biological information for *Lepomis macrochirus*, an invasive fish that has never been studied in Africa.

This thesis started out by assessing the biology of *L. macrochirus* (Chapter 3) including the use of monthly samples for validating the periodicity of growth zone formation using edge analysis. *Lepomis macrochirus* in South Africa appeared to grow longer than the average of 10 populations in their native range. This coupled with the higher CF shows that the species appears to be very successful in the invaded range. The ecology of the water bodies and fish histology and diet could be factors in the success of this species. The biological data of this

species were used to demonstrate that length structure of fish populations was an adequate measure for establishment. This criterion was then used to evaluate establishment of other fishes (Chapter 4) in a rapid assessment of the five water bodies. Initial stocking dates for each species in each dam was identified, with angler tournament data and historical surveys to determine trends over time with the current 2013/2013 survey used to identify the current species compositions and population structures. These data showed only two large native species of fish were caught in the five water bodies, these being *L. capensis* and *B. andrewi*. There were nine alien species; *M. salmoides*, *M. dolomieu*, *M. punctulatus*, *L. macrochirus*, *C. carpio*, *C. gariepinus* and *O. mossambicus* which were invasive and two which were established in single localities. This shows a trend that many of the native species previously found in the influent river systems to the dams are not present whilst in each dam fish originally stocked were found to be established but when all the water bodies were compared these stockings were not significantly related to establishment. Authorities need to consider the effects of further dam construction on river systems with endangered fish species and the impact that these dams could have. Dams could play an even greater role in the spread of alien fish species as they can be used as a source of invasion further into influent streams. This study did not assess the influent streams as this could be a further area of concern as many of the endangered fish species still surviving in South African freshwaters are found in head waters (Weyl *et al.* 2014).

Developing the fisheries in Chapter 5 required the information from the previous chapters and it determined the potential yield and productivity of the water bodies. This is crucial in calculating what the sustainable fishing yields were from the water body (Weyl *et al.* 2007). A morphoedaphic index (MEI) was used to determine the potential yield. While these models are useful providing a base line yield, they have been criticised. Downing *et al.* (1990) showed a

stronger correlation to primary productivity than to the MEI whilst Jackson *et al.* (1990) found shortcomings in the functions used such as mean depth. These shortcomings have not stopped numerous researchers from using the MEI in determining the yields and are still shown to be useful (Ryder 1982, Weyl *et al.* 2007). This study presented a first estimate of yields for the waterbodies and MEI was useful as standardised method which has been used in other waterbodies around the country. The results indicated Theewaterskloof had the highest potential yield of the five water bodies (260 t/yr) with the second highest being Voelvlei (93 t/yr). The value of these fisheries when calculated at R8/kg could employ 72 and 26 people respectively at a minimum wage. MEI models were used to calculate yields but as stated are known to overestimate fish yields and sustainable levels could be far lower. Other costs involved in the fishery such as cost to market for the fish, packaging and transport were not included, these costs could reduce the profits by up to half. This further reduces the profits to these industries. As Africa contributes 23.48% (6.9 mill tonnes) of global inland fisheries production and is ranked second highest by continents, the development of sustainable fisheries is essential in maintaining and improving this production. Africa is divided into nine regional groupings based on climate and geography (Welcomme 2011). The Southern region in which South Africa falls catches 1.1 million tonnes or 4.72% of Africa's catches whilst the largest region, Great Lakes catches 8.98 million tonnes or 37.08%. The fisheries in the Great Lakes are primarily based on *Lates niloticus* and *tilapia* spp. This region relies heavily on fish as a source of protein since as much as 66% of the protein consumed is from freshwater fish (Welcomme 2011). The growth in African inland fisheries has been limited with only 3 regions, Great Lakes, West Coastal and Northern showing a growth over 1% with the Southern Region a growth of only 0.54% (Welcomme 2011). Many of these inland fisheries are small scale or subsistence fishers providing income for over 2 million people but who are often overlooked (de Graaf and Garibaldi 2014, Britz *et al.* 2015). The lack of recognition for these fishers is

seen through policies that do not include them as they do not appear to be adding to the GDP. Recreational, non-harvest fishers who clearly contribute to the GDP seek after the larger of a fish species may conflict with local fishers if a lack of management regulations and policy is not formulated. In South Africa, case studies show that most of the fishing on inland waters is recreational and small-scale fisheries. Most of the small-scale fisheries use hook and line and cast nets as their main gear whilst on Nandoni, Makuleke and uPhongolo Dam, gill nets are used (Britz *et al.* 2015). According to current legislation only hook and line are legal gears due to their ability to target individual species. Policy regulations need to be considered for the use of gears such as trot lines (long lines) which can target *C. gariepinus*.

Theewaterskloof when considered as the only possible dam for a small scale fishery, had high tourist and recreational fishing value and opening a fishery could be detrimental to these industry. *C. gariepinus*, which is not focused on as a recreational species was only caught in low numbers. Subsistence fishing and recreational fishing was proposed for the remaining water bodies whilst including additional gear to target *C. gariepinus* such as trot lines used in Florida could be useful (FFWCC 2014, Quinn 1993).

6.2 Recommendations for future work

The current surveys should be viewed as a first assessment of the fishery and proper management of fisheries requires better knowledge on the biology and ecology of the fishes as well as of the fisheries. For this reason there is considerable scope for future research. Chapter one presented an invasive species that had no previous assessment performed on. Histology of this species could be undertaken in greater detail to determine the spawning season and potential fecundity. Fultons Condition Factors (CF) in the invaded water bodies was nearly

double that of the native range, providing scope for future research on the ecology and biology, especially diet of this species in the invaded range.

Ongoing surveys are required to monitor changes in native fish communities and the development of populations of recently introduced fishes in the water bodies such as Clanwilliam Dam. The recent introductions of *C. gariepinus* could impact the species compositions in these water bodies. If harvest fisheries were to be developed, the impacts of these fisheries must be monitored carefully to ensure they remain sustainable with changing species compositions (Cambray 2003). These surveys could provide information to determine if newly introduced species such as *C. gariepinus* and historically introduced species are still established and changes in establishment.

Britz *et al.* (2015) stated that it was necessary to do fish surveys on water bodies around the country to develop and create sustainable utilisation of inland fisheries. A replicate of this survey on an increased number of water bodies around the country will increase the national knowledge on the inland waters of South Africa and in so doing provide answers for which policy can be formed to develop the water bodies.

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