BLACK BASS (*MICROPTERUS* SPP.) IN THE OLIFANTS- DOORN RIVER SYSTEM: DISTRIBUTION, DISTRIBUTION BARRIERS, PREDATORY IMPACT AND MANAGEMENT

by

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DECLARATION

I, Johannes Adriaan van der Walt, declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed	**Date**

ABSTRACT

In the Cape Floristic Region the Olifants- Doorn River (ODR) system is a known biodiversity hotspot in terms of endemic freshwater fish. Eight of the 10 described native freshwater fish species are endemic to this river system. One of the main threats to these fish is predation by introduced predatory fishes. Three species of alien invasive black bass (*Micropterus salmoides, Micropterus dolomieu* and *Micropterus punctulatus*) were introduced into the ODR system during the 1930s but prior to this study, their distribution and impacts had never been quantified on a system-wide basis. This study aimed to clarify the current distribution, distribution barriers, predatory impact and best management options for black bass in the ODR system. This was achieved by conducting a system-wide survey of 578 km of stream covering 41 tributaries in the ODR system. Black bass presence was tracked upstream within each tributary to its uppermost distribution point where physical barriers preventing further spread were identified and described. Fish species composition, abundance and size were recorded directly above and below these barriers to quantify black bass impact on the native fish.

This research demonstrated that since introduction, natural and human assisted dispersal has facilitated not only the establishment of black bass in the Olifants and Doring main streams but also facilitated the invasions into 22 tributaries. Based on survey results it was estimated that 81.5 % of the ODR system that was previously occupied by native cyprinids is now invaded by black bass. Assessments of native fish abundance and size distribution above and below black bass invasion barriers demonstrated that in invaded tributaries only adults of larger cyprinids (*Labeo seeberi, Labeobarbus capensis* and *Barbus serra*) were able to co-occur with black bass species. Smaller fish such as juvenile *L. seeberi, L. capensis* and *B. serra* and native minnows (*Barbus calidus, Pseudobarbus phlegethon* and *Barbus anoplus*) were absent from the black bass invaded reaches. The findings of this catchment scale study are consistent with findings from other studies in the region. As a result, most native fishes are now restricted to streams above the natural barriers that limit the upstream invasions of black bass. Black bass eradication from invaded reaches is therefore necessary for habitat

restoration. Effective eradication will however depend on the presence of barriers to prevent re-invasion from downstream sources.

To better understand what constitutes the nature of such barriers, this study characterised the natural barriers that inhibited black bass invasions in 17 tributaries. Natural barriers comprised of 15 waterfalls, two cascades and one chute ranging in height from 0.49 m to 3.5 m with an average vertical drop of 1.21 ± 0.67 m. These findings suggest that black bass have poor jumping abilities and the recommended height of artificial barriers as part of a black bass management program should be between 80 and 100 cm depending on the size of the tributary. As a result, the presence of natural barriers or the construction of artificial barriers to prevent black bass invasions is considered a vital component of native fish conservation projects.

Finally, the study assessed the feasibility of black bass eradication from the 22 invaded tributaries in the ODR system based on eight criterion covering aspects of biological, physical, anthropogenic and logistical importance. This assessment showed that effective eradication was most likely only feasible in seven tributaries. Prioritisation of these seven tributaries for black bass eradication based on the threatened status of the resident native species, the land-use in the respective catchments and the tributary length available for rehabilitation indicate that the Breekkrans, Biedouw and Thee Rivers should receive the highest priority.

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DEDICATION

I would like to dedicate this thesis to my wife Marika and our three children, Franzelle, Adriaan and Zani.

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GLOSSARY

CAPE	Cape Action for People and the Environment
CapeNature	Provincial Conservation Authority, Western Cape, South Africa
CFR	Cape Floristic Region
DENC	Department Environment and Nature Conservation, Northern Cape
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
FL	Fork length
MAP	Mean annual precipitation
ODR	Olifants- Doorn River
SAIAB	South African Institute for Aquatic Biodiversity
SL	Standard length
TL	Total length

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction and impact of alien invasive freshwater fish

Worldwide, freshwater fish have been introduced outside their native ranges, where they have been classified as invasive due to their ability to establish, spread and cause negative impacts on the receiving environment (Blackburn *et al.* 2011). It was reported by Gozlan (2008) that 624 freshwater fish species have been globally introduced outside their native range and this introduction of invasive alien fish into freshwater ecosystems is universally regarded as a threat to natural systems (Malmqvist & Rundle 2002). According to Gozlan (2008), the social drivers for fish introductions are for food (51 %), the pet trade (21 %), sport fishing (12 %) and fisheries (7 %). Alien fish introductions have been spread further by anglers to lotic and lentic systems without regard to the impact of native biota (Cambray 2003). Globally, rivers are already impacted by a number of anthropogenic influences and with the addition of invasive fish it can alter the natural balance of the lotic ecosystem (Malmqvist & Rundle 2002). Gozlan *et al*. (2010) also noted that there are eight freshwater fish species on the IUCN list of 100 worst alien invasive species, while Cowx (2012) listed invasive fish as the main threat to freshwater fish. Freshwater ecosystems have lost more species due to anthropogenic impacts than terrestrial ecosystems, or the oceans (Abell *et al*. 2008). The endemism of fish species in freshwater systems are often high with a lot of yet undescribed species (Abell *et al*. 2008), which implies that a number of species not known to science might already have been lost. Estimates suggest a global loss of up to 3000 freshwater fish species over the next 25 to 30 years (Cambray 2003). The effect of introduced freshwater fish is not limited to loss of species, but could also lead to hybridization and disruption of ecosystem function (Britton *et al*. 2010), disease (Gozlan 2008), behavioural changes and trophic cascades (McDowall 2006), as well as fragmentation of native populations (Swartz 2000).

South Africa has not escaped the global trend of fish introductions with 55 freshwater fish species introduced into non-native areas between 1726 and 2012 (Ellender & Weyl 2014). The consequence of this is that South Africa is listed as one of six global fish invasion hotspots (Leprieur *et al*. 2008). Of the 55 introduced species, 28 are native South African species that have been introduced outside their historical range and they are regarded as extralimital species (Ellender & Weyl 2014). The impacts of these species in South Africa are similar to those demonstrated elsewhere. In a review, Ellender & Weyl (2014) summarised existing impacts to demonstrate that alien fish impact on native biota at all organisational levels. These impacts include hybridisation with native biota, introduction of parasites and disease, habitat alteration, as well as competition with, and predation on, native biota (Ellender & Weyl 2014). Invasions of South African aquatic ecosystems by alien fish are therefore of concern, particularly when they are in sensitive or unique biomes such as the Cape Floristic Region (CFR), a known biodiversity hotspot with high endemism (Linder *et al*. 2010). The rivers of the CFR are known for their unique and largely endemic fish fauna that rates among the most important in terms of freshwater fish endemism in Africa (Darwall *et al*. 2009; Linder *et al*. 2010). Within the CFR the endemic freshwater fish exist within very restricted ranges (Skelton 2001). Nineteen endemic freshwater fish species are associated with the CFR of which 15 are threatened with extinction, primarily due to the impacts of invasive alien sport fish species and habitat degradation (Impson *et al*. 2002; Tweddle *et al.* 2009). The Olifants- Doorn River (ODR) system is home to ten native freshwater fish of which eight are endemic to this river system. Current genetic studies indicates that the genera *Pseudobarbus, Galaxias* and *Sandelia* represent species complexes rather than single species which will increase the number of endemic fish even further (Swartz 2005; Swartz *et al*. 2009; Chakona *et al*. 2013).

Significantly, 20 non-native freshwater fishes that have been introduced into the CFR have established (Weyl *et al*. 2014). Recent studies on the effect of alien fish on native fish in the CFR indicates that they affect the behaviour and composition of the native fish assemblages (Woodford & Impson 2004; Woodford *et al*. 2005; Shelton *et al*. 2008) as well as the lower trophic levels, including aquatic invertebrates and algae (Lowe *et al*. 2008). Eleven of the 20 invasive alien fish introduced into the CFR are also present in the ODR system. Of particular concern are invasions by predatory sport fishes such as black bass species which, in the ODR, include largemouth *Micropterus salmoides* (Lacepede, 1802), smallmouth *Micropterus dolomieu* Lacepede, 1802 and spotted bass *Micropterus punctulatus* (Rafinesque, 1819) (Weyl *et al*. 2014).

1.2 Introduction and spread of black bass

1.2.1 Global

Black bass (*Micropterus* spp.) are predatory freshwater fish, native to North America that have been widely introduced to promote recreational fishing opportunities (Loppnow *et al*. 2013). There are currently eight described black bass species (Near *et al*. 2003). The two most popular angling species, *M. dolomieu* and *M. salmoides* have been introduced extralimital all over the United States (Brown *et al*. 2009a; Brown *et al*. 2009b). For example, the first introductions into the state of California started as early as 1874 where *Micropterus* spp. have been responsible for the decline in native minnow species (Loppnow *et al*. 2013) which included three chub species (*Gila* spp.) (Iguchi *et al*. 2004). The introduction of black bass into California and Arizona has also been responsible for the decline in populations of threatened amphibians (Iguchi *et al*. 2004).

Black bass have also been introduced to other continents outside N. America as sport fish. Casal (2006) reported that *M. salmoides* has been introduced into 72 countries and this is the black bass species that is listed as one of the 100 worst invaders globally (Lowe *et al*. 2000). According to Loppnow *et al*. (2013), *M. dolomieu* has been introduced to 24 countries. Since their initial introduction, many black bass populations have expanded their range by intentional and accidental stocking and climate-mediated habitat expansion (Jackson 2002; Rahel & Olden 2008). As a result of these expansions and because of their associated impacts, *Micropterus* spp. are considered invasive in many countries (e.g. Lowe *et al.* 2000; Iguchi *et al*. 2004; Ellender & Weyl 2014).

Impacts from *Micropterus* spp. are mainly linked to predation effects. In Japan, introduced black bass reportedly had a severe impact on the native fish assemblages that did not evolve with large, diurnal, carnivorous freshwater fish. This provided an ecological vacuum that was exploited by the black bass (Iguchi *et al*. 2004). In Guatemala *M. salmoides* was reported to be a contributing factor in the extinction of a freshwater bird, the Atitlan grebe *Podilymbus gigas* Griscom, 1929 (Iguchi *et al*. 2004). Other reported impacts of bass on native species are from Spain (Elvira & Almodovar 2001) and Canada where predation by *M. dolomieu* and *M. salmoides* in introduced lakes had a severe impact on the native minnow populations (Findley *et al*. 2000).

1.2.2 South Africa

Four species of black bass has been introduced into South Africa to boost recreational angling namely *M. salmoides*, Florida bass *Micropterus floridanus* (Lesueur, 1822), *M. punctulatus* and *M. dolomieu* (Ellender & Weyl 2014). *Micropterus salmoides* was the first species to enter the country in 1928. The Rand Piscatorial Association facilitated this importation. These fish were imported from England and shipped to Cape Town from where they were propagated at state hatcheries in Stellenbosch and King Williams Town (Harrison 1952).

1.2.3 Cape Floristic Region

The first introduction of *M. salmoides* into Cape waters took place during 1930 and by 1932 good catches were reported by the local anglers (Harrison 1952). This created a demand for the further importation of other species and because the *M. salmoides* was not doing well in the faster flowing rivers, the importation of *M. dolomieu* was investigated to fill this niche. The Cape Piscatorial Society organized the importation and the first batch of 29 *M. dolomieu* arrived in Cape Town on 22 October 1937 (Harrison 1952). The Cape Piscatorial Society also imported 54 *M. punctulatus* in 1939 that were obtained from the state of Ohio and they were earmarked for larger turbid rivers (de Moor & Bruton 1988). *Micropterus punctulatus* were bred in the Jonkershoek hatchery and some were taken to Natal for propagation (Harrison 1952). Marr (2011) reported that *M. salmoides* had been introduced into 26 major catchments in the CFR (constituting 83 % of the CFR area), *M. dolomieu* was introduced into 17 major catchments (80 %) and *M. punctulatus* into nine major catchments (77 %).

1.2.4 Olifants- Doorn River system

The first introduction of bass into the ODR system took place when 36 *M. salmoides* yearlings were stocked from the Jonkershoek hatchery into the Bulshoek Dam in 1933 (Harrison 1952). This was followed by stocking in the Clanwilliam Dam in 1936 and 1937 (Harrison 1952). The first *M. dolomieu* introduced into the ODR system were into the Jan Dissels River in 1943, while the first *M. punctulatus* were introduced above Citrusdal in 1945. (van Rensburg 1966). Today the mainstream Olifants and Doring River is believed to be 100 % invaded (Swartz 2000; Paxton *et al*. 2002).

Micropterus salmoides is the only species of black bass that has been introduced into farm dams in headwater plateaus above natural barriers in the ODR system. According to literature, *M. salmoides* was introduced into four tributaries in the ODR system (Paxton 2008; Marr 2011; Marr *et al.* 2012). The Koue Bokkeveld is extensively developed for irrigation farming and the water is stored in hundreds of off stream dams. Most of these dams in the Koue Bokkeveld are stocked with *M. salmoides* and these dam populations are most likely the source for the black bass invasion in the upper Olifants, Leeu and Riet Rivers (I. Smit pers. comm.).

1.3 Impacts of black bass on native fish abundance in the Cape Floristic Region and Olifants- Doorn River system

Various studies have documented the impact of black bass on native fish species in the CFR (e.g., Weyl & Lewis 2006; Shelton *et al*. 2008; Weyl *et al*. 2010; Ellender *et al*. 2011). All these studies found that black bass predation has a negative influence on native fish species composition and abundance. Similar impacts were seen in the ODR where *Micropterus salmoides* began to impact on native fish in the ODR system as early as 1938 (Harrison 1952). Harrison (1952) reported that the bass were preying on the thousands of Clanwilliam sandfish *Labeo seeberi* (Gilchrist & Thompson, 1911) that were congregating for their upstream spawning migration below the Cascades in the mainstream Olifants River. Barnard (1943) did a revision of the native fish of the South West Cape Region and raised his concern about the impact of alien fish on the native species. Harrison surveyed a large pool at the head of the Olifants River valley known as Keerom Pool in 1938 and he reported that native species of all size were plentiful. When Harrison revisited the pool in 1949, he noted that there was a marked decrease in the numbers of native fish, especially the smaller species (Scott 1982).

In the 1960's a closed season was enforced to protect black bass during spawning from 1 September to 14 December but anglers could still catch Clanwilliam yellowfish *Labeobarb*us *capensis* (A. Smith, 1841). According to Harrison (1952) this showed that black bass was regarded as a superior angling species to the native *L. capensis*. Jubb (1961) reported that none of the smaller fish species were found in the mainstream of the Clanwilliam and

Citrusdal areas during fish surveys in the Olifants River and tributaries during 1960. Van Rensburg (1966) did extensive surveys between Keerom and Klawer in the Olifants Management Area during 1963 and 1964 and reported that black bass was present almost everywhere in the mainstream as well as in the Ratel, Boontjies and Rondegat tributaries. The only fish that van Rensburg (1966) encountered in the Heks River was black bass but he did not specify the species found in these surveys. He also surveyed the lower section of the Doring River near the confluence of the Olifants River where he also recorded black bass and no other species. He also mentioned that he never found native minnows and *L. capensis* in the presence of black bass in the tributaries that he surveyed. During these surveys he did not record any minnows or Cape galaxias *Galaxias zebratus* (Castelnau, 1861) in the mainstream Olifants River.

Gaigher (1973) reported that no juveniles of large native fish or small native species were found where alien species were present. He was also the first person to remark that the native fish will only survive above waterfalls that prevent black bass from accessing these areas. He gave a good description of the black bass barrier in the Ratel River where he noted that above this small waterfall it looked like an aquarium with redfins and small Clanwilliam sawfin *Barbus serra* Peters, 1864. He also noted that there are similar areas that protect native fish from alien invasive fish but did not provide details. Skelton (1974) described a new species of redfin in the Twee River catchment that is protected from black bass by a 7-meter fall. This barrier has been well documented by further studies in the Twee River catchment (Marriott 1998; Impson *et al*. 2007; Marr *et al*. 2009; Tweddle 2009; Marr 2011, Marr *et al*. 2012).

The late seventies to the early eighties was also the era when sentiments towards native fish in the ODR system changed by the removing of restrictions on alien fish and initiating projects aimed at conserving native fish (Gaigher *et al*. 1980; Scott 1982). Gaigher *et al*. (1980) did extensive surveys in the ODR system and regarded *M. dolomieu* as the most destructive predator in the river system. *Labeobarbus capensis* was regarded as the flagship species of the ODR system by the then Department of Nature and Environmental Conservation. With the decline in their numbers, it was decided to construct an artificial breeding station for *L. capensis* on the banks of the Olifants River near Clanwilliam (Scott

1982). From 1982, yearlings were actively stocked into the headwaters of tributaries above black bass barriers and dams. The stocking continued until 1996 when the breeding station was closed due the poor water quality that caused diseases among the fry (Impson *et al*. 2007). Impson *et al*. (2007) reported that artificial breeding of *L. capensis* also had negative consequences that included the stocking of *L. capensis* above the Twee River waterfall where they impacted the native fish.

Bills (1999) did extensive fish surveys in the ODR system in 1998 for his studies on the Clanwilliam rock catfish *Austroglanis gilli* (Barnard, 1943) and spotted rock catfish *Austroglanis barnardi* (Skelton, 1981). He noted that he encountered *M. dolomieu* and *M. punctulatus* all over the system and recorded new distribution records for *M. punctulatus*. He also noted that *A. gilli* was able to co-exist with *M. dolomieu* and *M. punctulatus* in the following ODR system tributaries: Jan Dissels River, Heks River, Matjies River and Boontjies River. He did not encounter any other native fish in the presence of black bass in the Jan Dissels River. In 1999 Impson (1999) did an extensive survey of the upper Doring River between De Mond and Elandsvlei and he reported that black bass was present in all pools but that the large native species were still present. Subsequent surveys by Paxton *et al*. (2002) in 2001 confirmed this and their surveys extended to the confluence of the Olifants River.

A study done by Mthombeni (2009) on the biology of *A. gilli* and *A. barnardi,* two of the ODR system endemic species, indicated that there is co-occurrence with black bass species due to their nocturnal behaviour. Swartz *et al*. (2004) studied the genetics of the native minnows (*Barbus* spp. and *Pseudobarbus* spp.) in the ODR system and he noted that the predation by black bass caused fragmentation in minnow populations as there could be no gene flow between tributaries due to black bass predation. He also suggested that black bass displace minnows through predation rather than competition. He also noted that the biggest impact on the minnows was on the fiery redfin *Pseudobarbus phlegethon* (Barnard, 1938) as they occupy mid-to lower section of tributaries in the ODR system.

Woodford *et al*. (2005) compared the fish composition above and below a natural black bass barrier in the lower Rondegat River identified as the Rooidraai Waterfall. Five native species were present above the barrier with only one native species co-occurring with *M. dolomieu* below the barrier (Woodford *et al.* 2005; Tweddle 2009; Weyl *et al*. 2013; Weyl *et al*. 2014). Although there were also other anthropogenic influences on the biota of the river, they concluded that *M. dolomieu* was responsible for the absence of the other four native species below the barrier. These findings were confirmed in 2012 when the river below the black bass barrier was treated with rotenone to eradicate *M. dolomieu* (Jordaan *et al*. 2012; Weyl *et al*. 2013; Weyl *et al*. 2014). Woodford *et al*. (2005) regarded *M. dolomieu* as the alien fish that caused the most damage to the indigenous fish populations in the ODR system and they recommended that controlling the spread of black bass in the ODR system should be a priority. Black bass has caused either a decline or total disappearance of native fish species in each of the tributaries studied to date. However, a basin wide assessment on the establishment, spread and impact of black bass is currently lacking and constrains the implementation of effective conservation measures.

1.4 Natural black bass barriers

The continued persistence of a large number of, especially the smaller, native fish species in the ODR appears to be due to the existence of barriers that prevent the upstream migration and establishment of black bass and other alien fishes across the complete system. Natural physical fish barriers can be classified as waterfalls, chutes or cascades (or a combination of these) that prevent the upward movement of fish in a stream environment (Powers & Orsborn 1985). Powers and Orsborn (1985) define flowing water as a waterfall when the water falls over a ledge and loses contact with the substrate for a period. A chute is a steep section were the water stays in contact with the substrate while a cascade is a series of falls with breaks and pools that maintains a steep gradient and turbulent water surface (Powers & Osborn 1985).

Apart from the barriers in the ODR system mentioned in the previous section there have been a couple of others recorded as well. Ramollo *et al*. (2012) reported on the status of the fish in the Oorlogskloof River and reported that the barrier that constituted the upper limit of black bass in the river was large boulders below the Oorlogskloof Nature Reserve boundary. Darwall *et al*. (2009) also reported that black bass has penetrated the Jan Dissels

River up to cascades, which they cannot get over because of their poor jumping abilities. The precise location of this cascade was not recorded.

According to Lodge (1993) knowing what constitutes a natural barrier for invasive aquatic species and its location is necessary to assist in the management of invasive species, as well as for the restoration of the native species. Marchetti *et al*. (2004) supports this notion as he indicated that an understanding of the extent of freshwater invasions is important for protecting native species diversity and primarily for developing management strategies, risk analysis, prevention and eradication measures. This study will document the location and nature of all the natural black bass barriers in the tributaries and mainstream (Olifants Gorge) of the ODR system so that this information can assist in the conservation of the native species.

1.5 Artificial barriers as a management tool

There are three options for the management of invasive alien fish in the environment: eradication (eliminating alien fish from geographical area), control (minimize impact of invasive fish) and containment (preventing further spread of species) (Britton *et al*. 2010). Artificial barriers form an integral part of most of these management options and have been used extensively in native fish restoration projects (Fausch *et al*. 2009). Globally artificial barriers have been used to limit the upstream movement of lampreys and fishes (Novinger & Rahel 2003). In New Zealand, artificial barriers were constructed to prevent salmonids from invading headwaters with native threatened fish (Chadderton 2001). In California, isolation barriers have been constructed to protect native threatened salmonids from alien invasive salmonids (Fausch *et al*. 2009). South Africa is one of the few developing countries taking action against invasive alien fish and artificial barriers form a key aspect of these projects. The first reported project to eradicate black bass from a tributary in the CFR was in the Blindekloof River in the Eastern Cape where *M. salmoides* was eradicated from a stretch of this river (Skelton 1993). There was no management action in the form of an artificial barrier to prevent the re-invasion of black bass and in 2010 a survey by Ellender *et al*. (2011) reported that black bass has reinvaded the Blindekloof River. More recently artificial barriers were used in projects to eradicate black bass from two tributaries (Rondegat River and Thee River) in the ODR system (Twedle 2009; Weyl *et al*. 2013; Weyl *et al*. 2014). Jordaan *et al*. (2012) suggested that to halt alien fish invasions, barriers need to be integrated into the holistic management plans created for alien fish eradication. These sentiments were also mentioned by Moyle (1976) and Impson *et al*. (2002) in that conservation efforts should halt range expansion of alien species through eradication and by the construction of in-stream physical barriers to prevent further invasion of tributaries. Studies by Kerby *et al*. (2005) and Chakona and Swartz (2012) highlighted that artificial barriers need to be chosen carefully to ensure that protected river sections encompass optimal habitats for all indigenous species. Kerby *et al*. (2005) also noted that barrier selection should be species specific in order to attain the goals of the specific project. The height of barriers should not restrict the movement of native migratory fish and therefore it is essential that artificial barriers should only be constructed to a height that prevents black bass from the upper reaches of the river and not the native fish. There seems to be paucity of information on the height of artificial barriers that would prevent upstream movement of black bass.

Bagley (1995) did a literature study on selected invasive fish in Arizona, USA but could not find any information on the jumping ability of black bass. In a literature review on the effects of stream barriers on fish movement, Brown *et al*. (2009a) reported that no information was found on the leaping ability of *M. dolomieu*. Gomez & Wilkinson (2008), state that *M. dolomieu* are not aggressive swimmers and a vertical drop of 46 cm can be a barrier to them. Meixler *et al*. (2009), modelled the jumping ability of *M. dolomieu* using its maximum darting speed (3.42 m/s) and average total length (0.38 m). The model calculated that *M. dolomieu* has a maximum jumping ability of 60 cm. This study will guide the height of artificial barriers as part of restoration projects in the CFR.

1.6 Eradication and management options for black bass in the Cape Floristic Region

CapeNature took the lead in South Africa with the first completed eradication projects using a piscicide (rotenone) and mechanical methods in rivers to eradicate invasive alien black bass (Jordaan *et al*. 2012). The Rondegat River was treated with rotenone in 2012 and 2013 to eradicate *M. dolomieu* from a four kilometre invaded stretch of the river below a natural black bass barrier (Jordaan *et al*. 2012, Marr *et al.* 2012, Jordaan & Weyl 2013, Weyl *et al*.

2013). In the Thee River *M. punctulatus* was removed using mechanical methods between 2010 and 2013 (van der Walt 2011; Jordaan *et al*. 2012). In both projects, the use of artificial barriers was a key component of the projects. In the Thee River, temporary gabion barriers were used to isolate *M. punctulatus* in stretches of the river while in the Rondegat River a water abstraction weir formed the lower limit barrier that prevented the reinvasion of black bass. CapeNature is planning to rehabilitate more rivers in the CFR and in 2013 a preliminary analysis was done where 14 rivers has been earmarked for alien fish eradication. Data from this study are vital to finalize and prioritize this list. In addition, the data obtained from this research will be incorporated into the rehabilitation plans for these rivers and for a freshwater fish conservation plan for the ODR system. Artificial barriers will form an integral part of these plans.

Various studies have recommended that action should be taken against black bass in the ODR system. Bills & Impson (2013) recommended that black bass should be eradicated in certain tributaries while Swartz (2000) recommended that some of these tributaries should be restocked with minnows. Marr (2011) recommended the removal of black bass from Tandfontein Dam in the Twee River catchment. In light of the very recent new legislation on alien invasive species management that came into effect on 1 October 2014, properly informed management plans for the control of black bass became even more imperative. The new regulations under the National Environmental Management: Biodiversity Act (Act No. 10 of 2004) (South Africa 2014a; South Africa 2014b) have divided alien invasive species in South Africa into four categories (1a, 1b, 2 and 3) with different management implications for fish in each category. *Micropterus dolomieu*, *M. punctulatus* and *M. floridanus* have been listed under category lb in National Parks, Provincial Reserves, Mountain Catchment Areas and Forestry Reserves declared in terms of the Protected Areas Act. *Micropterus salmoides* is different as it is listed in category 2 in formal protected areas. The regulations also specify that none of the four *Micropterus* spp. in South Africa may be introduced into a discreet catchment in which they do not occur or introduced above an artificial or natural barrier within a discreet catchment. This study will guide the required management programs in the formal conservation areas, as the information on black bass distribution in ODR system conservation areas will be clarified.

1.7 Objectives of this thesis

In order to provide input into the conservation of native fishes and management of black bass populations, this thesis has four main objectives:

1. To determine and map the extent of the black bass invasion in the ODR system.
2. To describe (height, slope, and location) and classify the barriers that limits the upward movement of the black bass in tributaries of the Olifants- Doorn River system.
3. To determine the predatory impact of black bass on native fish abundance within the ODR system by comparing fish abundance above and below black bass barriers.
4. To identify priority tributaries for eradication of black bass in the ODR system.

1.8 Structure of the thesis

This thesis is composed of five chapters of which chapters 3 and 4 have been compiled as stand-alone manuscripts to facilitate publication in peer-reviewed journals. Chapter 5 has been prepared to serve as both a discussion chapter for this thesis and to provide a management recommendations document for CapeNature.

Chapter 2 provides information on the study site and native and alien freshwater fish in the ODR system. This study investigated 41 tributaries in the ODR system that contain freshwater fish and in order for the reader to understand the nature and location of these tributaries comprehensive maps and descriptions of these tributaries are included.

Chapter 3 focuses on the distribution of black bass and the physical natural barriers that limit the upward movement in tributaries of the ODR system. The upper limit of black bass distribution in each tributary has been identified and the physical characteristics of the black bass barriers (height, slope, type) that prevent complete invasion of tributaries are described. The upper limit of native cyprinid species distribution is also documented and discussed.

In Chapter 4, the focus is on the predatory impact of black bass on the native fish in the invaded tributaries of the ODR system. To quantify this impact the results of this basin wide study are evaluated in relation to a similar study done on a tributary level in the Rondegat River.

In Chapter 5, the focus is on the management of black bass in the ODR system. CapeNature has prioritized a number of tributaries in the ODR system for alien fish eradication based on the threatened status of the native fish species. In this chapter, we revisit the CapeNature list of prioritised tributaries by adding more factors to the decision matrix based on information from Chapters 3 and 4. This will enable more informed decisions to be made and these results will be presented as a revised list to CapeNature. The different options for the eradication and/or control of black bass in these priority tributaries are also evaluated and discussed.

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CHAPTER 2

STUDY AREA

2.1 General introduction

This study is confined to the Olifants- Doorn River (ODR) system in the Western Cape, South Africa. The total size of the catchment is approximately 56 446 km^2 (DWAF 2005) and within this system the black bass distribution, distribution barriers and the impact of black bass on native fish will be investigated. The main river is known as the Olifants River while the two largest tributaries are the Doring River and Sout River (Figure 2.1). The mean annual precipitation (MAP) for the ODR catchment varies from 1400 mm in the upper catchment in the Groot Winterhoek Mountains to 100 mm in the northern Knersvlakte (DWAF 2005). This chapter will provide detailed descriptions and maps of the four catchment management areas of the ODR as it has been divided by the Department of Water Affairs (DWAF 2005). These management areas are known as the Olifants River, Knersvlakte, Koue Bokkeveld and Doring areas. Detailed descriptions of the tributaries in each management area are provided in Annexure A. The tributary catchment boundaries were digitized using Arc GIS 10.1 while the altitudes and channel lengths mentioned in the management area and tributary description where extrapolated from 1: 50 000 topographical maps. For the description of the channel morphology standard stream habitat terms as defined by Helm (1986) were used while the stream orders were classified using the method of Strahler (1957). Only the perennial tributaries were classified into stream orders, while the non-perennial tributaries were classified into seasonal or ephemeral.

There are currently ten described native freshwater species in the ODR system and eight of these ten species are endemic to this system (Jordaan *et al.* 2012). Eleven species of alien fish has also been recorded in the ODR system, including three black bass species *Micropterus* spp. A concise description of all the native fish species and the three black bass species follows the management area descriptions.

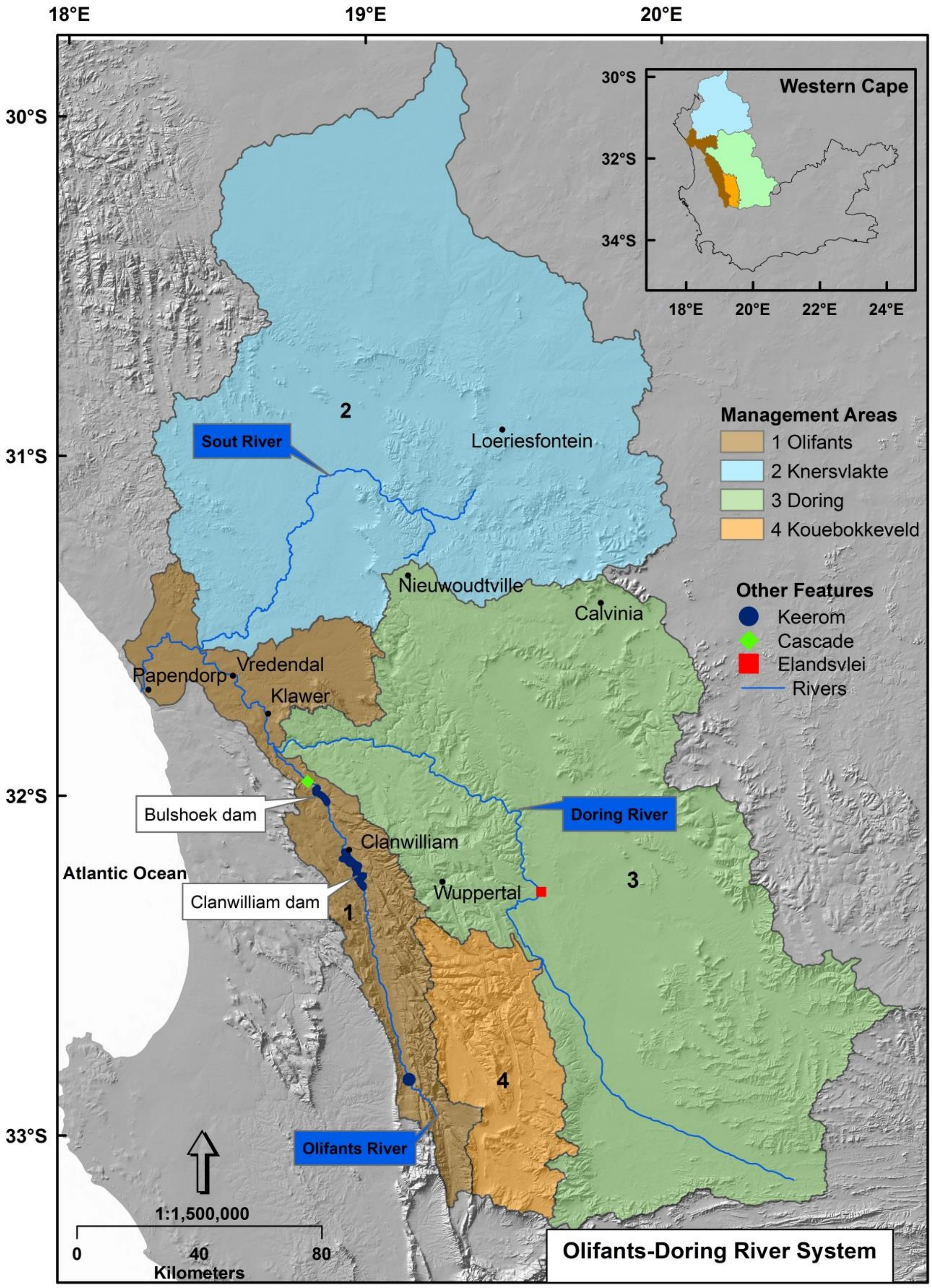

Figure 2.1 A map showing the Olifants- Doorn River catchment, the main rivers within this system and the four management areas it has been divided into by the Department of Water Affairs.

2.2 Study sites

2.2.1 Olifants River Management Area

The Olifants River Management Area has a size of 5257 km^2 (DWAF 2005) and comprises the catchments of the mainstream Olifants River and its tributaries excluding the Sout and the Doring Rivers (Figure 2.2). The Olifants River rises in the Skurwe-, Witzenberg- and the Groot Winterhoek Mountains flanking the Witzenberg Valley at a maximum altitude of 1800 m. The Witzenberg Valley at an altitude of 800 m is an intensively cultivated area with apple and pear orchards dominating the landscape. From the Witzenberg Valley, the Olifants River flows for approximately 280 km in a northern direction before it enters the Atlantic Ocean near Papendorp. The Olifants River Management Area falls within the Western Folded Mountains ecoregion (Kleynhans *et al*. 2005). The main channel of the Olifants River is divided into five geomorphological zones according to the channel morphology and physical habitat. These zones are: headwater plateau (Witzenberg Valley), headwall river (Olifants River Gorge), mountain river (below Olifants Gorge to Keerom), foothill river (Keerom to Klawer) and lowland river (Klawer to estuary) (Rowntree *et al*. 1996). The water quality in the tributaries that rise in the Cederberg and Koue Bokkeveld mountains is influenced by the sandstones and quartzites and tends be clear with a low pH and conductivity (DWAF 2005). Water quality in the main stream up to the foothill river is good according to the River Health Programme (2006) while lower down the quality is impacted by urban effluent, dam releases and agriculture (DWAF 2005). The Olifants Management Area falls within the Fynbos Biome and sandstone fynbos vegetation types (Mucina & Rutherford 2006) dominate vegetation in the catchment.

The geology of the upper catchment is comprised of fine-grained shale and mudstones of the Bokkeveld Group (Witzenberg Valley) and sandstones of the Table Mountain Group (Mucina & Rutherford 2006). The middle reaches are dominated by sandstones and quartzites of the Table Mountain group while the lower Olifants River are dominated by shale of the Malmesbury Group (Mucina & Rutherford 2006). Due to the physiographic diversity of the catchment, there is a high degree of variation in the climatic conditions. The average rainfall for this area is 460 mm (River Health Programme 2006). The highest rainfall is at the source (Groot Winterhoek >1400 mm y^{-1}) in the south and decrease towards the north (Clanwilliam Dam <300 mm y^{-1}) (Dallas 1997). The rainfall is mostly in the winter months (June–August) while the summers are dry and hot. The main land-use is irrigated agriculture (citrus and grapes) but the towns of Citrusdal, Clanwilliam, Klawer, Vredendal, Lutzville also fall within this area (River Health Programme 2006). There are two in-stream impoundments in the mainstream Olifants River. The Clanwilliam Dam at the town of Clanwilliam has a capacity of 122 million m^3 while the Bulshoek Dam (30 km below Clanwilliam dam) has a capacity of 5.7 million m^3 (DWAF2005). The Bulshoek Dam was completed in 1923 while the Clanwilliam Dam was completed in 1933 and raised in the late 1960s (DWAF 2005). The dam wall of the Clanwilliam Dam is going to be raised by a further 13 meters and this will increase the storage capacity to 240 million cubic meters (F. Mouski pers. comm. 2013). A 186 km channel system from the Bulshoek Dam supplies drinking and irrigation water for the lower Olifants River Valley that is mainly dominated by wine grape cultivation and urban areas (DWAF 2005). Water abstraction in the middle section of the Olifants River is severe during the peak summer months (Jan–Feb) with sections of the river drying up (DWAF 2005).

The Olifants Management Area has 18 tributaries with catchment sizes ranging from 23 to 198 km^2 (Figure 2.2 and Table 2.1). Sixteen of these tributaries are perennial and two are seasonal. The perennial tributaries have stream orders between 1 and 3 (Table 2.1). Most of these tributaries are heavily impacted by agricultural development and water abstraction but the Bo-Boschkloof and Diepkloof Rivers are still in a pristine condition. The water quality as categorised by the River Health Programme (2006) are predominantly good in this management area. A detailed description of each tributary is provided in Appendix A. A visual representation of the catchment area and its tributaries is also presented (Figures 2.3 and 2.4).

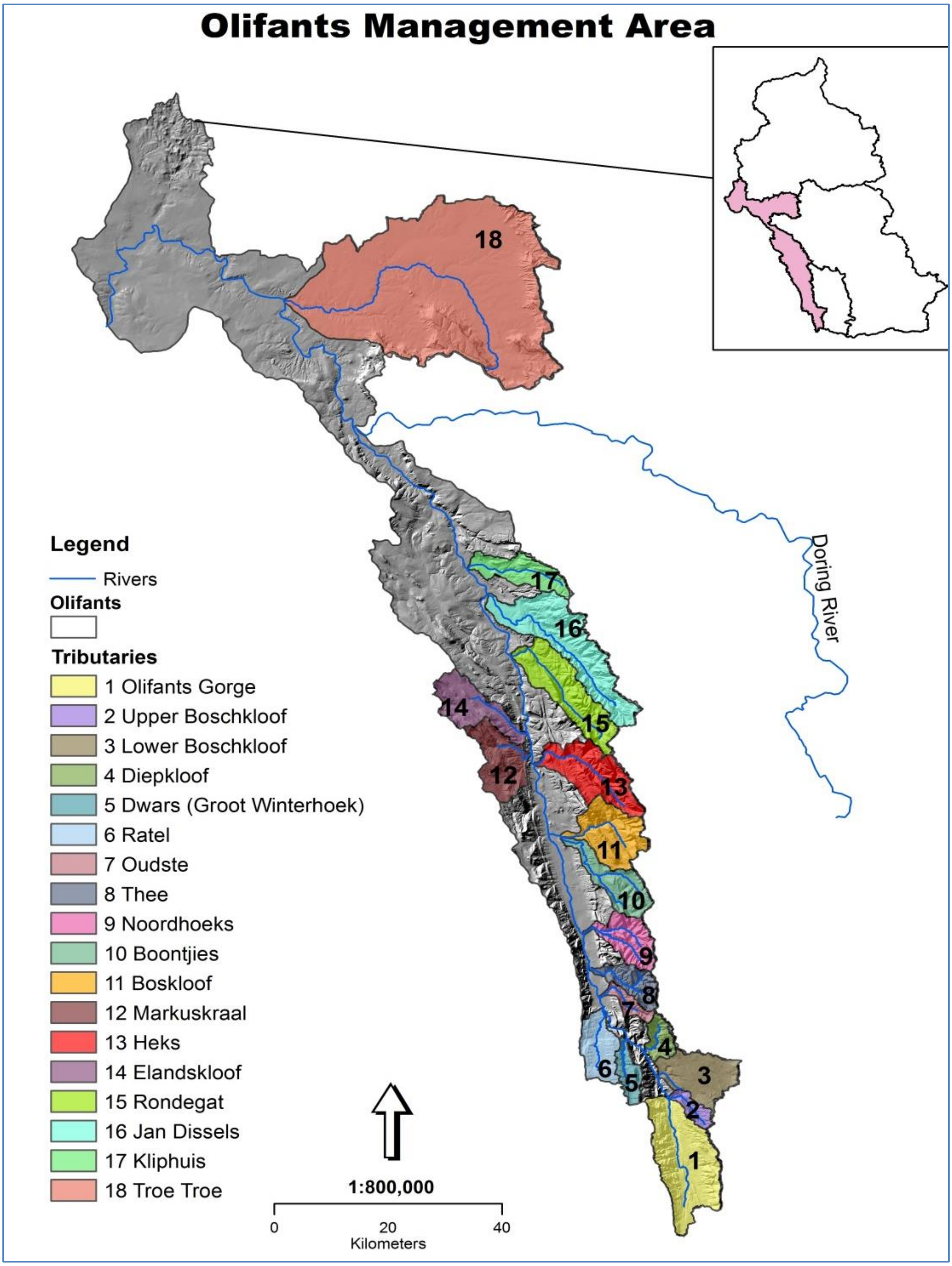

Figure 2.2 A map of the Olifants Management Area with all the tributaries that formed part of this study.

Table 2.1 Catchment size, stream order and flow regime of the 18 tributaries in the Olifants Management area that was surveyed for black bass in this study.

River	Catchment size km²	Stream order	Flow regime
Olifants Gorge	198	3	perennial
Upper Boschkloof River	24	2	perennial
Lower Boshkloof River	100	2	perennial
Diepkloof River	32	2	perennial
Dwars River	34	2	perennial
Ratel River	69	3	perennial
Oudste River	23	1	perennial
Thee River	50	3	perennial
Noordhoeks River	70	3	perennial
Boontjies River	81	3	perennial
Boskloof River	110	2	perennial
Markuskraal River	97	2	perennial
Heks River	128	3	perennial
Elandskloof River	93	2	perennial
Rondegat River	141	2	perennial
Jan Dissels River	206	3	perennial
Kliphuis River	73	NA	seasonal
Troe Troe River	786	NA	seasonal

Figure 2.3 The upper catchment of the Diepkloof River rises in the Koue Bokkeveld Mountains in the background of the photograph (Photo: author).

Figure 2.4 A typical pool in the upper Rondegat River, Olifants- Doorn River system (Photo: author).

2.2.2 Knersvlakte Management Area

The Knersvlakte Management Area has a total catchment size of 23 245 km^2 (Figure 2.5). The main river in the management area is the Sout River that rises in the Bokkeveld, Hantam and the Namakwaland Mountains. The average rainfall for this area is 179 mm (River Health Programme 2006). The geology is mostly composed of tillites and shale of the Ecca and Vanrhynsdorp Groups (Mucina & Rutherford 2006). The Sout River and its tributaries are all ephemeral (DWAF 2005). Land-use consists mainly of livestock farming, mining and conservation areas (Knersvlakte Provincial Nature Reserve). The main towns in the area are Nuwerus, Bitterfontein and Loeriesfontein. Succulent vegetation types dominate the vegetation (Mucina & Rutherford 2006). Much of the catchment is invaded by alien mesquite *Prosopis glandulosa* trees (River Health Programme 2006). The photographs in Figures 2.6 and 2.7 provide an idea of the typical landscape associated with this management area.

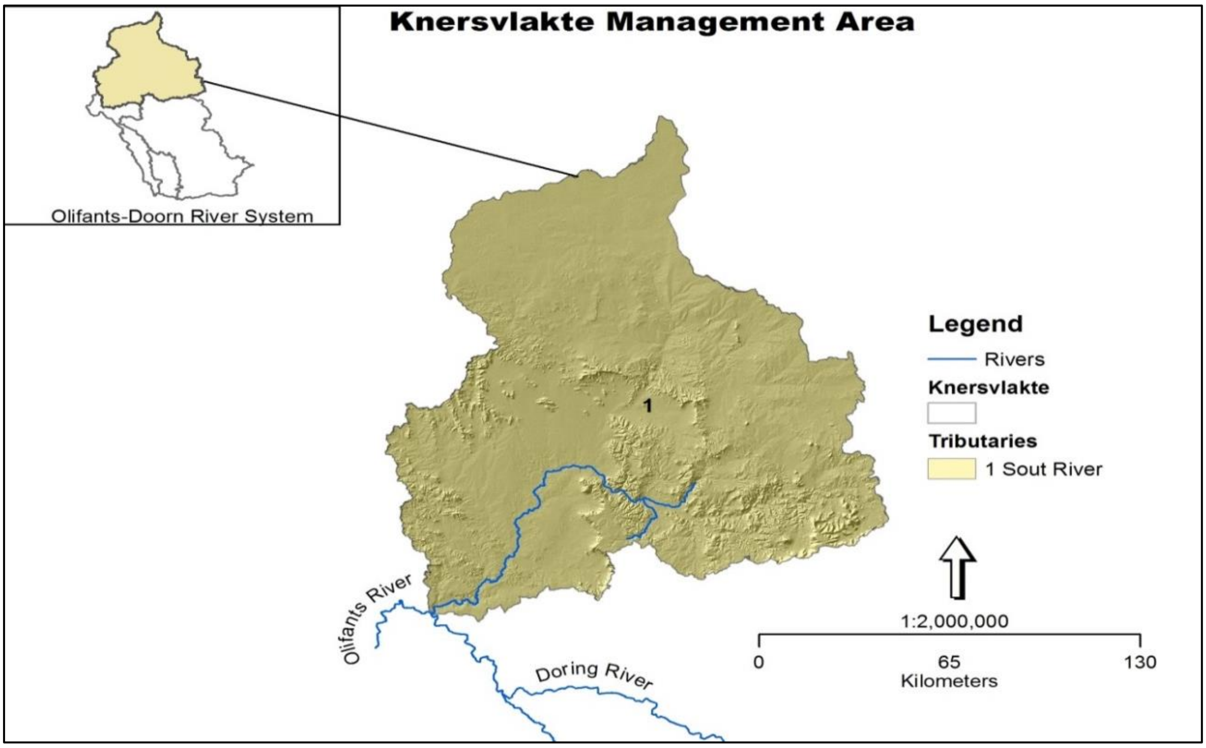

Figure 2.5 The Knersvlakte Management Area with its main tributary, the Sout River.

Figure 2.6 The Sout River that flows through the Knersvlakte Management area (Photo: author).

Figure 2.7 One of the few pools in the Sout River that retains water throughout the year (Photo: author).

2.2.3 Doring River Management Area

The Doring River and its tributaries rise in the Cederberg, Koue Bokkeveld and Roggeveld Mountains and has a catchment size of 18 248km^2 (Figure 2.8) (River Health Programme 2006). The upper Doring River is mostly dry from its source south of the Ceres Karroo to the confluence with the Groot River, which is the first perennial tributary that joins the Doring River. The tributaries with the largest catchment are the Tankwa and upper Doring River that drains the Tankwa Karoo and Ceres Karoo while the most of the other tributaries drains from the Cederberg- and Koue Bokkeveld Mountains (DWAF 2005). The Tankwa River and upper Doring River are also the driest areas in the management area with both rivers being ephemeral (DWAF 2005). The Doring Management Area falls within the Greater Karroo and Western Folded Mountains Ecoregions (Kleynhans *et al*. 2005). The average rainfall for this area is 220 mm (River Health Programme 2006). There is a marked difference between the rainfall in the west (Cederberg) and the arid eastern areas (DWAF 2005). There is also a marked difference between the geology of the Cederberg areas that are dominated by sandstones and quartzite's from the Table Mountain Group to the shale's of the Bokkeveld group in the Ceres- and Tankwa Karroo (Mucina & Rutherford 2006). Succulent Karroo vegetation types dominate vegetation in the Tankwa and upper Doring River while the other tributaries draining from the west and north all have their headwaters in sandstone fynbos vegetation types (Mucina & Rutherford 2006).

The flow in the Doring River has a natural bi-modal flow pattern with the tributaries in the west providing clear water with low nutrients, pH and conductivity water in the winter (River Health Programme 2006). The eastern tributaries provides water with higher nutrients, pH and conductivity during summer rain (River Health Programme 2006). Land-use consists mostly of livestock farming in the drier areas while vegetables and lucern are cultivated along the Doring River and major tributaries. Eco tourism forms a vital part of the economy of the area (DWAF 2005). Conservation areas include the Tankwa Karroo National Park, Cederberg Wilderness Area, Matjies River Provincial Nature Reserve and Oorlogskloof Provincial Nature Reserve. The only major in-stream impoundment in the mainstream is a private five-meter high weir near the confluence of the Tankwa River with the Doring River. The only major towns in the area are Calvinia and Niewoudtville. There are 10 tributaries within the area of which six are seasonal, two perennial and two ephemeral (Table 2.8). The photographs in Figures 2.9 and 2.10 provide an idea on how the catchment area and its tributaries look like. A detailed description of each tributary is provided in Appendix A.

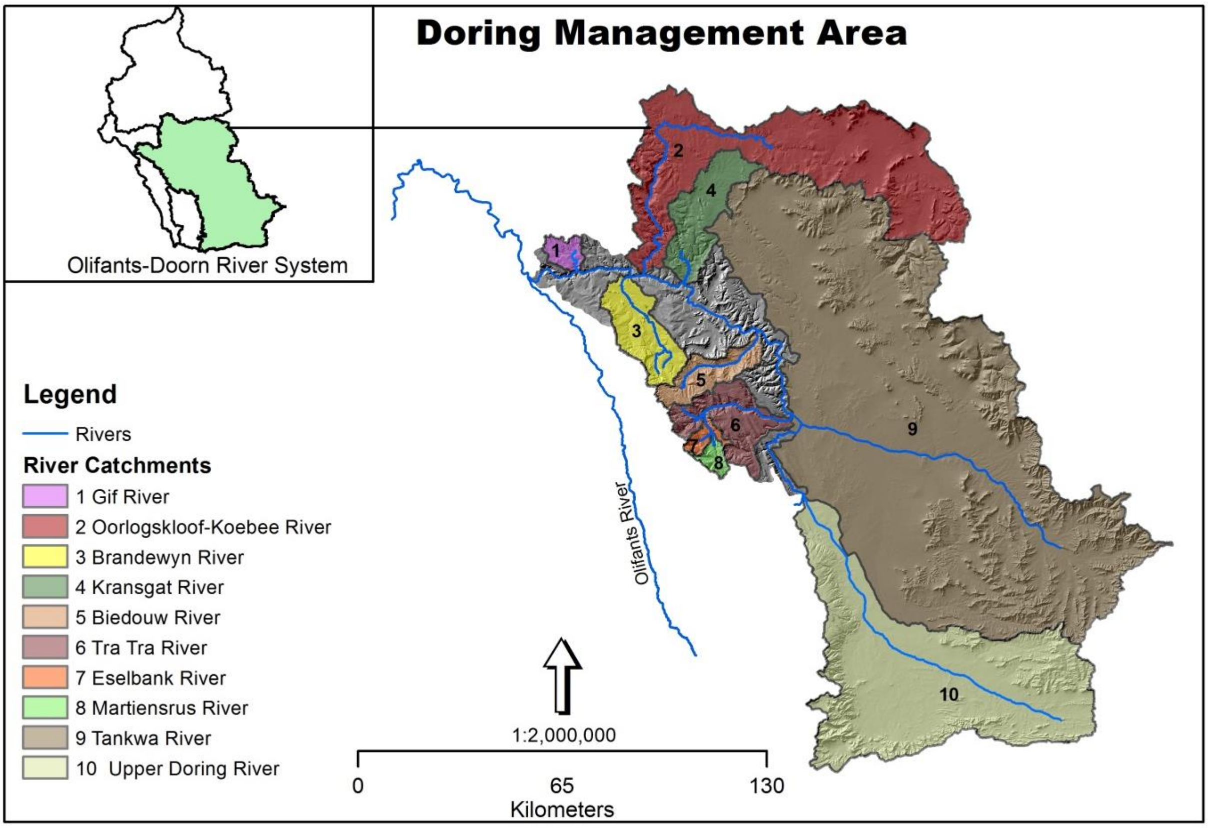

Figure 2.8 The Doring Management Area and its tributaries that form part of this study.

Table 2.2 Catchment size, stream order and flow regime of the 10 tributaries in the Doring Management area that was surveyed for black bass in this study.

River	Catchment size km²	Stream order	Flow regime
Gif River	109	NA	seasonal
Oorlogskloof River	2851	NA	seasonal
Brandewyn River	490	NA	seasonal
Kransgat River	576	NA	seasonal
Biedouw River	329	NA	seasonal
Tra Tra River	522	3	perennial
Eselbank River	81	2	perennial
Martiensrus River	79	NA	seasonal
Tankwa River	14336	NA	ephemeral
Upper Doring River	3808	NA	ephemeral

Figure 2.9 The Eselbank River in the Doring Management area (Photo: author).

Figure 2.10 The mainstream Doring River below the confluence of the Tankwa River (Photo: author).

2.2.4 Koue Bokkeveld Management Area

The Koue Bokkeveld Management Area has a size of 3 072 km^2 and its tributaries are the main contributors of water to the Doring River (Figure 2.11) (River Health Programme 2006). The Groot River and the Riet River are the largest tributaries. Dams dominate the transformed landscape of the Koue Bokkeveld plateau where water is stored for irrigation of fruit trees and vegetables (DWAF 2005). The Koue Bokkeveld falls under the Western Folded Mountains ecoregion (Kleynhans *et al*. 2005) and the mountain geology is dominated by sandstones and quartzite's from the Table Mountain Group while the geology of the Koue Bokkeveld Valley is predominately shale's from the Bokkeveld Group (Mucina & Rutherford 2006). The average rainfall for this area is 413 mm (River Health Programme 2006). The vegetation is dominated by sandstone and shale fynbos vegetation types (Mucina & Rutherford 2006). The Koue Bokkeveld Valley is flanked by the Skurweberg Mountains on the west, the Swartruggens Mountains on the east and Cederberg Mountains to the north. Sneeukop is the highest peak in the management area and in the ODR system at an altitude of 2073 m extensive areas of this management area are under formal conservation with the Cederberg Wilderness Area being the largest contributor. There are 12 tributaries within the area of which nine are perennial and three seasonal (Table 2.3). The photograph in Figure 2.12 provides an idea on how the catchment area and its tributaries look like. A detailed description of each tributary is provided in Appendix A.

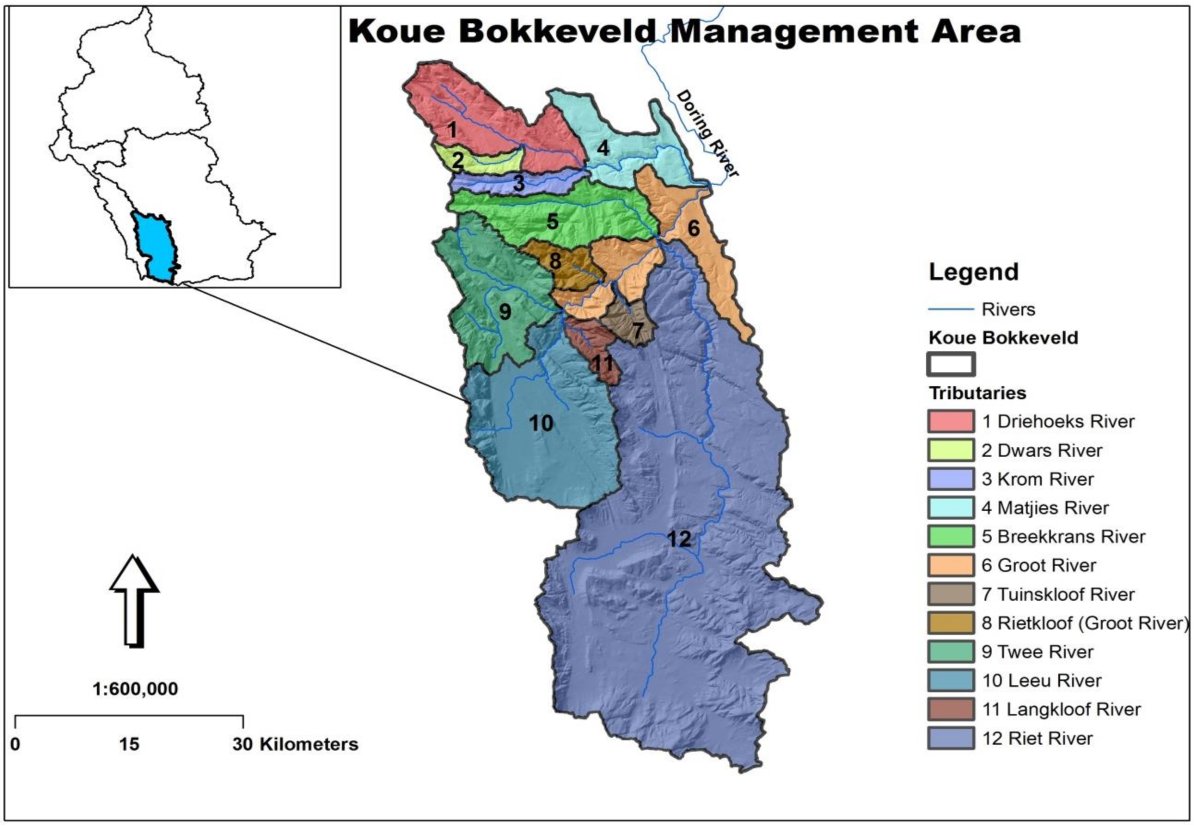

Figure 2.11 The Koue Bokkeveld Management Area and its tributaries that formed part of this study.

Table 2.3 Catchment size, stream order and flow regime of the 12 tributaries in the Koue Bokkeveld Management area that was surveyed for black bass in this study.

River	Catchment size km²	Stream order	Flow regime
Driehoeks River	184	3	perennial
Dwars River	34	2	perennial
Krom River	49	2	perennial
Matjies River	129	3	perennial
Breekkrans River	170	2	perennial
Groot River	202	4	perennial
Tuinskloof River	33	NA	seasonal
Rietkloof River	44	NA	seasonal
Twee River	217	3	perennial
Leeu River	318	3	perennial
Langkloof River	39	1	perennial
Riet River	1555	NA	seasonal

Figure 2.12 The Twee River that drains the northern Koue Bokkeveld (Photo: author).

2.3 Freshwater fish of the Olifants- Doorn River system

The Olifants- Doorn River system is regarded as one of the most important rivers in South Africa in terms of freshwater fish diversity due to its high endemism (Darwall *et al*. 2009). There are currently ten described native species in the ODR (Table 2.4) with eight of these species being endemic and threatened (Darwall *et al*. 2009). The Doring River redfin is not yet formally described but it is regarded as a separate lineage (Swartz 2000) for the purpose of this study. Eleven alien freshwater fishes have also been recorded in the ODR system (Table 2.5). Below follows a description of all 10 described native fish species and the undescribed Doring redfin. Also included are descriptions of the three alien invasive black bass species central to this study.

Table 2.4 Distribution and International Union for Conservation of Nature (IUCN) Red List status of the native freshwater fish of the Olifants-Doorn River system, Western Cape and Northern Cape, South Africa.

Species	Common name	Distribution	IUCN Red List Status
Family Austroglanididae			
Austroglanis banardi	Spotted rock catfish	Endemic	Endangered
Austroglanis gilli	Clanwilliam rock catfish	Endemic	Vulnerable
Family Cyprinidae			
Labeobarbus capensis	Clanwilliam yellowfish	Endemic	Vulnerable
Barbus serra	Clanwilliam sawfin	Endemic	Endangered
Barbus calidus	Clanwilliam redfin	Endemic	Vulnerable
Barbus erubescens	Twee River redfin	Endemic	Critically endangered
Barbus anoplus	Chubbyhead barb	Indigenous	Data deficient
Pseudobarbus phlegethon	Fiery redfin	Endemic	Endangered
Pseudobarbus sp. "phlegethon Doring"	Doring River redfin	Endemic	Critically endangered
Labeo seeberi	Clanwilliam sandfish	Endemic	Endangered
Family Galaxiidae			
Galaxias zebratus	Cape galaxias	Indigenous	Data deficient

Table 2.5 Names and status of alien fish recorded in the Olifants- Doorn River system, Western Cape and Northern Cape, South Africa. Records were obtained from the CapeNature and the South African Institute for Aquatic Biodiversity (SAIAB) freshwater fish databases.

Species	**Common name**	**Status**
Family Anabantidae		
Sandelia capensis	Cape Kurper	Indigenous translocated alien
Family Centrarchidae		
Micropterus dolomieu	Smallmouth bass	Alien
Micropterus salmoides	Largemouth bass	Alien
Micropterus punctulatus	Spotted bass	Alien
Lepomis macrochirus	Bluegill sunfish	Alien
Family Cichlidae		
Tilapia sparmanii	Banded tilapia	Alien
Oreochromis mossambicus	Mozambique tilapia	Alien
Family Cyprinidae		
Cyprinus carpio	Common carp	Alien
Family Salmonidae		
Oncorhynchus mykiss	Rainbow trout	Alien
Salmo trutta	Brown trout	Alien
Family Clariidae		
Clarias gariepinus	Sharptooth catfish	Indigenous translocated alien

2.3.1 Description of the native freshwater fish of the Olifants- Doorn River system

(a) <u>Family: Austroglanidae</u>

(i) Clanwilliam rock catfish *Austroglanis gilli* (Barnard, 1943)

A small catfish with maximum size of 164 mm standard length (SL) that prefers rocks and cobbles in clear perennial tributaries (Skelton 2001) (Figure 2.13). It feeds on insects taken from the bottom and is mostly nocturnal. According to Bills (1999), *A. gilli* favour deeper pools in the lower and upper sections of tributaries and mirror the distribution of the widespread minnow, *Barbus calidus.* It is one of the species that appears to be able to co-exist with black bass in the ODR system (Mthombeni 2009). There is genetic morphological variation recorded from the populations in the Jan Dissels River and the rest of the ODR system (Bills 1999).

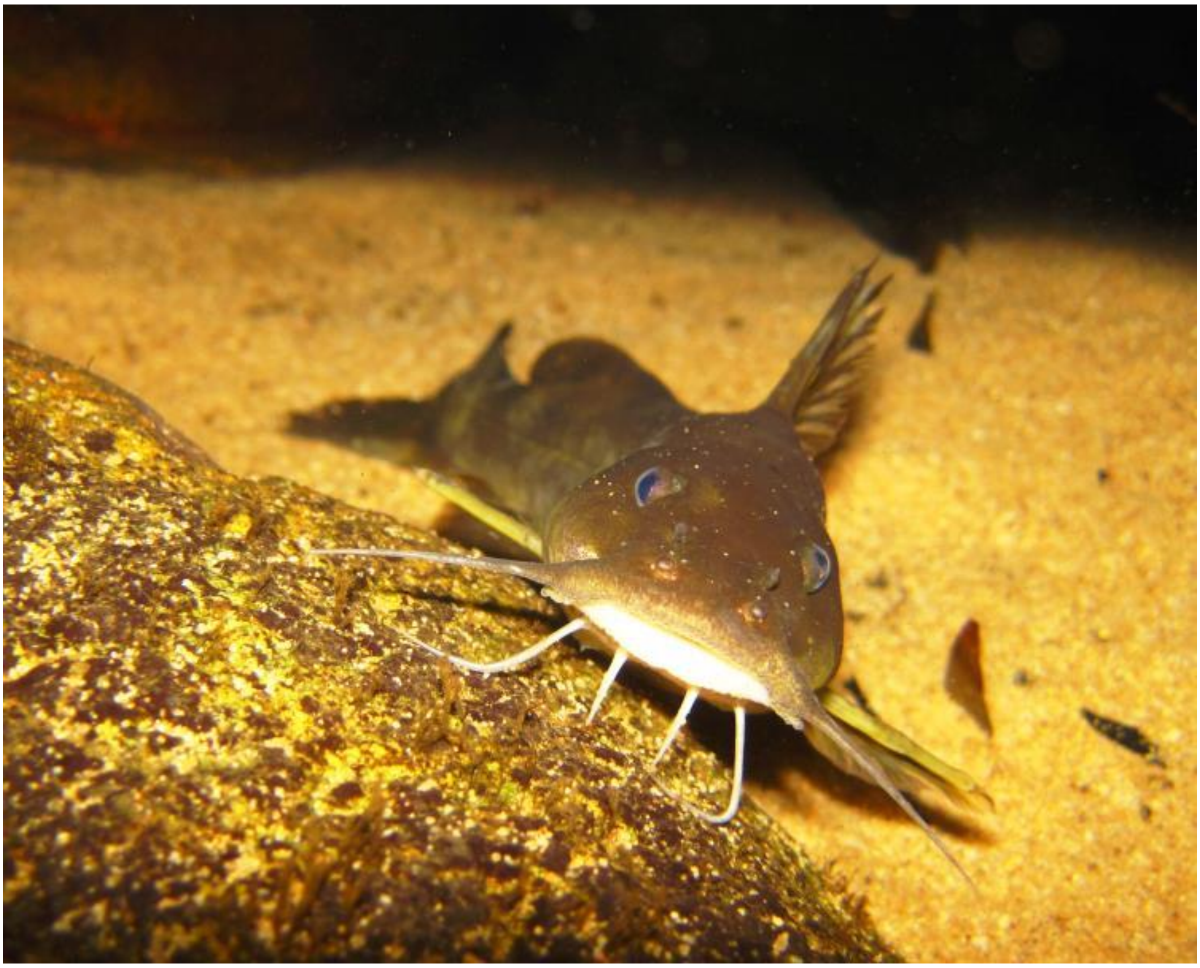

Figure 2.13 An adult Clanwilliam rock catfish from the Thee River, Olifants- Doorn River system (Photo: author).

(ii) Spotted rock catfish *Austroglanis barnardi* (Skelton, 1981)

The spotted rock catfish is small with a maximum size of 128 mm SL that lives in clear streams dominated by cobbles (Skelton 2001) (Figure 2.14). According to a study conducted by Mthombeni (2009), *A. barnardi* mainly feeds on insect larvae. Bills (1999) states that *A. barnardi* is mostly found in the lower cobble sections of tributaries. This species is threatened by black bass *Micropterus* spp., water abstraction, channelling and sedimentation (Bills 1999). The largest population remains in the Noordhoeks River while it has only been recorded in two additional tributaries (Bills 1999; Skelton 2001).

Figure 2.14 Spotted rock catfish in the Noordhoeks River, Olifants- Doorn River system (Photo: C. Garrow).

(b) <u>Family Cyprinidae</u>

In the context of the ODR system, the Cyprinidae can be grouped into two categories, large cyprinids, which attain lengths larger than 30 cm, and small-bodied minnows that seldom exceed 12 cm total length (TL).

Large cyprinids

(i) Clanwilliam sawfin *Barbus serra* (Peters, 1864)

Barbus serra attains a length of 50 cm and is one of the larger endemic species characterized by a serrated dorsal spine (Figure 2.15). The fish shows habitat preference for deep pools and runs in the mainstream and bedrock-dominated tributaries (Skelton 2001; Paxton 2002). They prefer deeper habitats for most of the year while in spring to early summer they prefer shallower habitats during the spawning period (Paxton 2008). It primarily feeds on aquatic insects, other invertebrates, algae and detritus from the bottom (Paxton 2002). Spawning occurs in late spring when *B. serra* deposits adhesive demersal eggs in moderate to high flow velocity riffle areas where they are incubated over two to three days (Paxton 2008). It is widely distributed in the ODR system.

Figure 2.15 Clanwilliam sawfin photographed in the Eselbank River, ODR system (Photo: author).

(ii) Clanwilliam sandfish *Labeo seeberi* (Gilchrist and Thompson, 1911)

Labeo seeberi is one of the large cyprinid species of the ODR system that attains 550 mm FL and is distinguishable by its inferior mouth, single pair of barbels and papillate lips (Figure 2.16) (Skelton 1987). *Labeo seeberi* favours deep runs and deep pools, which is why they thrive in mainstreams and larger tributaries (Skelton 2001). They have specialized lips that enable them to feed on algae, diatoms, microscopic crustaceans, small invertebrates and detritus by grazing on rocks as well as grubbing in soft sediments (van Rensburg 1966; Skelton 2001). *Labeo seeberi* is a migratory fish that achieves high fecundity, delayed maturation and a contracted breeding season implies that the life history of this cyprinid matches with that of periodic strategists (Paxton 2008). Masses of *L. seeberi* migrate upstream during spring and summer for breeding (Skelton 2001) and spawn when flows ease during this season (Paxton 2008).

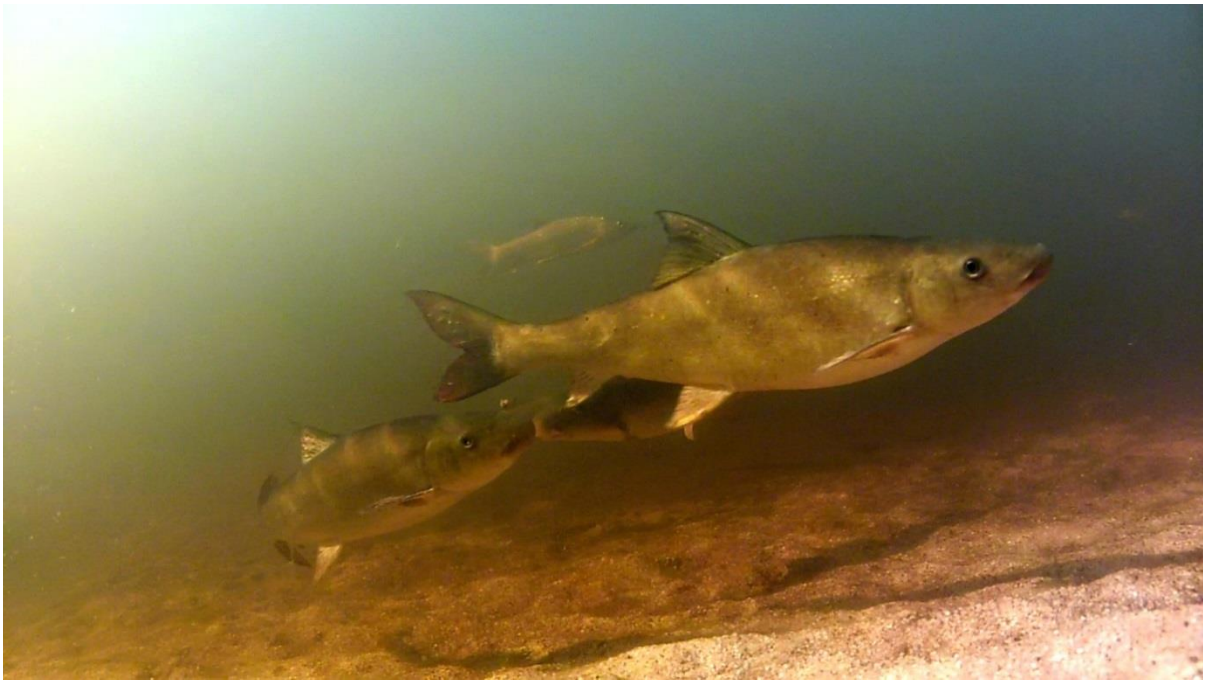

Figure 2.16 Adult Clanwilliam sandfish from the upper Biedouw River in the ODR system (Photo: author).

(iii) Clanwilliam yellowfish *Labeobarbus capensis* (A. Smith, 1841)

Labeobarbus capensis is the largest of the native species in the ODR system with a maximum size of 987 mm TL (Figures 2.17 and 2.18). It is omnivorous feeding on insects, snails crab and small fish (Skelton 2001). This species was once widespread in the mainstream of the Olifants and Doorn River and larger tributaries but their numbers are considered to have declined due to on-stream dams, water abstraction and predation by black bass (Skelton 2001; Paxton 2008). *Labeobarbus capensis* prefers larger pools and rifles.

Figure 2.17 A large Clanwilliam yellowfish from the Olifants Gorge (Photo: author).

Figure 2.18 Sub-adult Clanwilliam yellowfish from the Olifants Gorge (Photo: author).

Minnows

(i) Clanwilliam redfin *Barbus calidus* (Barnard, 1938)

Barbus calidus is a widely distributed minnow, which is recognized by the two barbels on each side of its head (Figure 2.19). It attains a length of 82 mm (SL) (Barnard 1943). *Barbus calidus* predominantly feeds on aquatic insects from the water surface (Skelton 1987). It is mostly found together with other small minnow species such as *Pseudobarbus phlegethon*, and juveniles of large cyprinids such as *B. serra, Labeo seeberi*, *L. capensis* and two species of Austroglanis, *A. gilli and A. barnardi*. The breeding of *B. calidus* takes place during summer when adult males congregate in a breeding school of 30 to 50 individuals on vertical rock substrates facing flowing water and female's later join up to spawn (Skelton, 1987). *Barbus calidus* is distributed in 19 tributaries of the Olifants- Doorn River system.

Figure 2.19 An adult Clanwilliam redfin from in the Thee River, ODR system (Photo: author).

(ii) Chubbyhead barb *Barbus anoplus* (Weber, 1897)

Barbus anoplus is a small minnow that is distinguished from other minnows by its bluntly rounded snout with terminal mouth, numerous radiating striate on the scales and absence of red fins (Figure 2.20) (Barnard 1943). It is a widely distributed species in South Africa occurring from Highveld Limpopo to upland Kwazulu-Natal, as well as the coastal rivers of Eastern and Western Cape (Skelton 2001). It is mostly associated with a habitat that is sheltered or has cover with marginal vegetation with preference of cooler waters ranging from small habitats to large rivers (Skelton 2001). *Barbus anoplus* is an omnivorous fish and predominantly feeds on insects, seeds, algae, diatoms and zooplanktons (Skelton 2001). The breeding season of the *B. anoplus is* during the summer months (Skelton 2001).

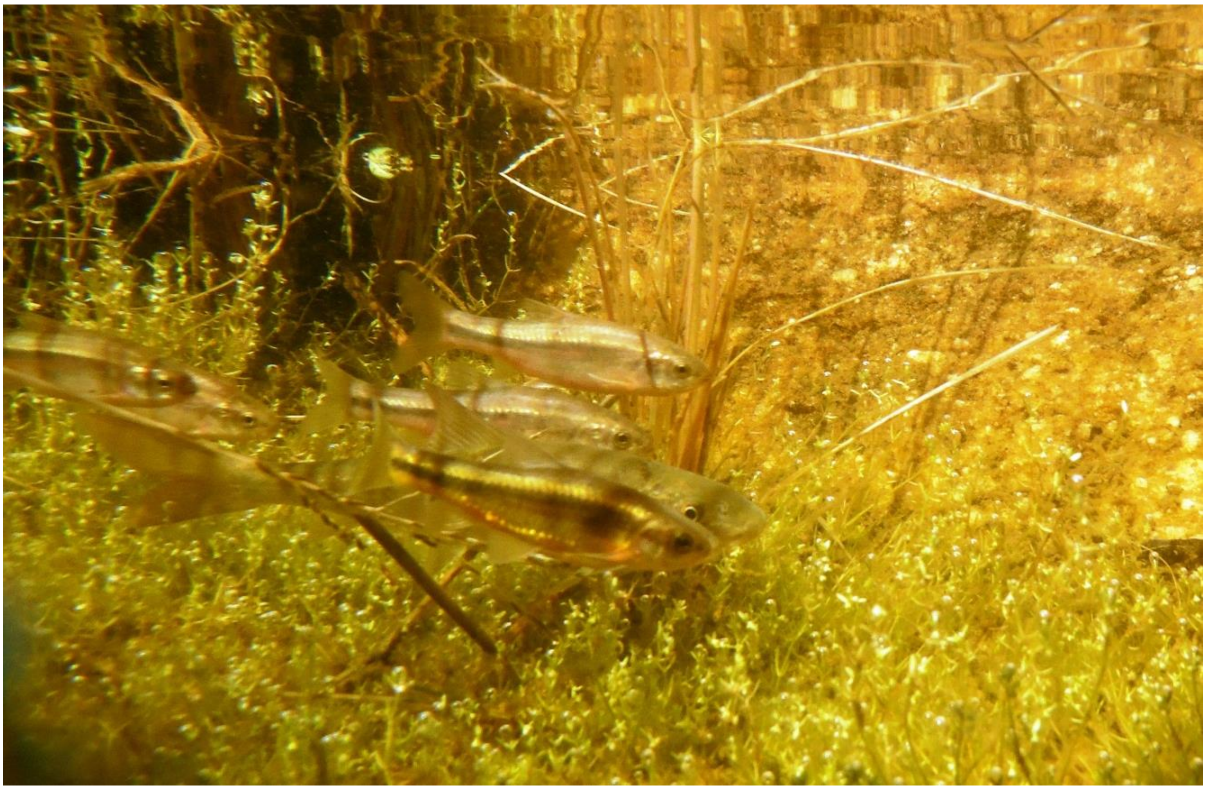

Figure 2.20 A school of chubbyhead barbs in the Kransgat River. The golden coloured specimen in the foreground is a male in breeding colours (Photo: author).

(iii) Twee River redfin *Barbus erubescens* (Skelton, 1974)

Barbus erubescens is a small cyprinid minnow that belongs to the serrated-rayed group of minnows, but is different from other *Barbus* species in having seven branched rays in the anal fin (Figure 2.21) (Skelton 1974). It attains a total length of 95 mm SL. It is described as an opportunistic feeder (Marriott 1998), with aquatic and other insects forming its principle diet on the surface and mid-waters. The preferred habitat features of *B. erubescens* are typically clear and cool water that is slightly peat stained, boulders and sandy substrates at depths of more than 1 m (Skelton 1974; Marriott 1998). It breeds during summer when adult males congregate to form nuptial schools and thereafter attend to females (Skelton 1974; Skelton 1987). Females release eggs in boulders and rock crevices. This minnow is restricted to the Twee River catchment (Skelton 2001).

Figure 2.21 A school of male Twee River redfins in breeding colours from the Twee River, ODR system (Photo: author).

(iv) Fiery redfin *Pseudobarbus phlegethon* (Barnard, 1938)

Pseudobarbus phlegethon is a small minnow that attains a maximum body size of 71 mm SL (Figure 2.22) (Barnard 1943; Skelton 1977). The preferred habitat of *P*. *phlegethon* is rocky or sandy bottomed pools and riffles in clear flowing streams (Skelton 2001). It preys on small bottom-living insects and detritus making it an omnivore (Skelton 2001). Breeding commences during summer and males become territorial (Skelton 1977; Skelton 2001).

Figure 2.22 A pair of fiery redfins photographed in the Oudste River, ODR system (Photo: author).

(v) Doring River redfin *Pseudobarbus sp. "phlegethon Doring"*

Pseudobarbus sp. "phlegethon Doring" is an undescribed species that is known from two tributaries of the Doring River and has been identified to be genetically different from *P. phlegethon* that occurs in the Olifants River tributaries (Swartz 2000) (Figure 2.21). In the Driehoeks River, they are found in sandy-bottomed pools while in the Breekkrans River they are mostly associated with bedrock pools (Swartz *et al*. 2004).

Figure 2.23 A male Doring redfin photographed in the Breekkrans River, Olifants- Doorn River system (Photo: author).

(c) Family Galaxiidae

(i) Cape galaxias *Galaxias zebratus* (Castelnau, 1861)

Galaxias zebratus is a small mountain fish that has been described as a Gondwanan relict (Figure 2.24) (Skelton 1994). *Galaxias zebratus* has been identified as a species complex with distinct and divergent lineages (Skelton & Swartz 2011; Chakona *et al*. 2013). *Galaxias zebratus* is mostly found in small streams or pools with muddy bottoms (Barnard 1943). It favours gentle currents within sheltered banks near the head of pools. It feeds on drifting insects and other material. In the presence of alien invasive fish, its pattern of habitat selection will change to deeper habitats with low flow velocity and in stream vegetation (Shelton *et al*. 2008). *Galaxias zebratus* breeds during spring or summer depending on local conditions and it attains maturity at 40 mm (Skelton 2001).

Figure 2.24 Two adult Cape galaxias from the Thee River, Olifants- Doorn River system (Photo: author).

2.3.2 Description of the black bass Micropterus spp. in the Olifants Doorn River system

Micropterus spp. are predatory fishes native to North America and there are currently eight described species (Near *et al*. 2003). Four *Micropterus* spp. where introduced in South Africa and three are present in the ODR system (Harrison 1952; Harrison 1953).

(a) <u>Family Centrarchidae</u>

(i) Largemouth bass *Micropterus salmoides* (Lacepede, 1802)

Micropterus salmoides is olive green with a series of blotches along its lateral line (Figure 2.25). They differ from the other two species in the ODR system by having a larger mouth, different colouration, and jaw that extends beyond their eye. According to Skelton (2001), they can attain 60 cm TL. *Micropterus salmoides* can occupy a variety of habitats but prefer lakes with submerged aquatic vegetation (Brown *et al*. 2009b). The optimal temperature range for their growth is 24-30°C (Brown *et al*. 2009b). Breeding commences in summer when males construct a bowl shaped nest in shallow water (Brown *et al*. 2009b). Females can lay up to 14 000 eggs depending on their body weight and the male will guard the nest and the developing larvae (Brown *et al*. 2009b). Fry are 3 mm in length when they hatch. Juvenile bass mostly consume insects while adults consume fish, crabs, frogs and small water birds (Brown *et al*. 2009b).

Figure 2.25 *Micropterus salmoides* photographed in the Riet River, Olifants- Doorn River system (Photo: author).

(ii) Smallmouth bass *Micropterus dolomieu* (Lacepede, 1802)

Micropterus dolomieu is dark brown with vertical bands and red eyes (Figure 2.26). Their jaw extends to the middle of their eye. They can attain 55 cm SL (Skelton 2001). They prefer clear streams and can tolerate cooler water than *M. salmoides* (Skelton 2001). Optimal growth rate is similar to *M. salmoides* (Brown *et al*. 2009b). Brown *et al*. (2009a) reports that *M. dolomieu* are visual hunters that require clear water. According to de Moor & Bruton (1988), *M. dolomieu* can survive a temperature range between 4 and 35°C but cannot tolerate polluted or silted rivers. Males construct the nest, guard the eggs and protect the fry (Brown *et al*. 2009b). The diet of *M. dolomieu* is similar to *M. salmoides* although their smaller gape size restrict them to smaller prey (Brown *et al*. 2009b).

Figure 2.26 *Micropterus dolomieu* photographed in the Diepkloof River, Olifants- Doorn River system (Photo: author).

(iii) Spotted bass *Micropterus punctulatus* (Rafinesque, 1819)

Micropterus punctulatus is similar in shape and size to *M. dolomieu* but has different colouration. *Micropterus punctulatus* has dark diamond shaped markings along its sides of its body and a dark patch on the posterior side of its gill cover (Figure 2.27) (de Moor & Bruton 1988). They can attain a length of 60 cm TL (Skelton 2001). According to Skelton (2001) *M. punctulatus* prefers slightly turbid water of slow flowing rivers and dams.

Figure 2.27 Sub-adult *M. punctulatus* photographed in the Thee River, Olifants- Doorn River system (Photo: author).

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CHAPTER 3

BLACK BASS *MICROPTERUS* SPP. DISTRIBUTION IN THE HEADWATERS OF THE OLIFANTS- DOORN RIVER SYSTEM AND A DESCRIPTION OF PHYSICAL BARRIERS PREVENTING FURTHER SPREAD

3.1 Introduction

Three North American black bass species were introduced into the Olifants- Doorn River (ODR) system for recreational angling more than 80 years ago (Harrison 1952; Harrison 1953). The initial spread of black bass in the mainstream Olifants River and Doring River have been well documented (Barnard 1943; Harrison 1952; Jubb 1961; van Rensburg 1966; Gaigher 1973; Gaigher *et al.* 1980) and the river system is now considered fully invaded (Swartz 2005; Impson 2001; Marr 2011). Black bass have also invaded most of the tributaries of the ODR system and comments dating as far back as 40 years suggested that native fish could only survive above barriers that protected them from black bass predation (Gaigher 1973). Recent research has supported this concern where it has been shown that black bass have a devastating effect on native fish populations (Woodford *et al*. 2005; Weyl *et al*. 2013) which highlights the need for detailed information and action to curb the problem.

Harrison (1953) mentioned the first record of natural physical black bass barriers in the Cape Floristic Region (CFR). According to him smallmouth bass *Micropterus dolomieu* Lacepede, 1802 were introduced into the Berg River near Paarl in 1938. This invasion was monitored and by 1947, their distribution stretched 35 km upstream to physical barriers in the headwaters of the Wemmers River (Harrison 1953). Observations on the upper limit of black bass indicate that natural barriers in the form of waterfalls and cascades limited their spread in tributaries. Although some studies (e.g., Gaigher 1973; Skelton 1974; De Moor & Bruton 1988; Woodford *et al*. 2005; Darwall *et al*. 2009; Ramollo *et al*. 2012; Bills & Impson 2013) refer to these barriers few adequately describe the location and nature of these barriers. In the ODR system, only five barriers are mentioned in literature although there could potentially be many more. Gaigher (1973) for example, mentioned a black bass barrier in the Ratel River where he noted that above a small waterfall, it looked like an aquarium with redfins (*Barbus* sp.) and small Clanwilliam sawfin *Barbus serra* Peters, 1864. He also noted that there are similar areas in the ODR system that protect native fish from alien invasive fish but did not provide details. Skelton (1974) noted that the Twee River waterfall (Figure 3.35) protected the Twee River redfin *Barbus erubescens* Skelton, 1974 from the black bass invasion. This barrier was subsequently well documented by further studies in the Twee River catchment (Marriott 1998; Impson *et al*. 2007; Marr *et al*. 2009; Tweddle 2009; Marr 2011; Marr *et al*. 2012). The upper limit of the black bass in the Rondegat River (Figure 3.20) is also well documented as the Rooidraai Waterfall (Woodford *et al.* 2005; Tweddle 2009; Weyl *et al*. 2013; Weyl *et al*. 2014). Ramollo *et al*. (2012) reported on the status of the fish in the Oorlogskloof River and reported that the barrier that constituted the upper limit of black bass in the river was large boulders below the Oorlogskloof Nature Reserve boundary. Darwall *et al*. (2009) also reported that black bass has penetrated the Jan Dissels River up to cascades which they cannot get over because of their poor jumping abilities, but did not provide a precise location of this cascade.

According to Lodge (1993) knowing the location and what constitutes a natural barrier for invasive aquatic species is necessary to assist in management of the invasive species as well as for the restoration of the native species. Marchetti *et al*. (2004) supports this notion as they indicated that an understanding of the extent of freshwater invasions is important for protecting native species diversity and primarily for developing management strategies, risk analysis, prevention and eradication measures. Given the temporal and spatial disparities in information on natural barriers, the current study aims to provide a comprehensive assessment of the distribution of black bass in the ODR system and describe the physical barriers that prevent the upward movement of black bass into tributaries.

This was the first study to capture the distribution of black bass in all the tributaries and mainstream (Olifants Gorge) of the ODR system by locating all the natural black bass barriers in the black bass invaded tributaries. To do this the current study used multiple detection methods to determine: the extent of the black bass invasion in the ODR system; the locations of natural black bass barriers; the physical characteristics of these black bass barriers (height, type) and whether there was a difference in barrier height for the different black bass species. In addition, the upper limit of native cyprinid fish species will also be documented, as this can provide a measure of the remaining habitat available to native cyprinids that is protected from black bass by natural barriers. This information will assist in the conservation of native species because it will allow for the inclusion of barrier characteristics in future assessments of invasion risk.

3.2 Material and methods

3.2.1 Determining the extent and upper limit of the black bass invasion in the Olifants-Doorn River system

Field surveys to determine the distribution of black bass and locate the upper limit of black bass distribution in tributaries of the ODR system were conducted between October 2012 and September 2014. The general method was to use historical black bass location data as a starting point and then survey upstream to the upper limit of the black bass presence. Tributaries with no historical black bass data were surveyed from their confluence with larger tributaries or the mainstream Olifants and Doring River. Perennial tributaries were classified into stream orders as defined by Helm (1986). Tributaries that were non-perennial were classified into ephemeral or seasonal according to the definition of Helm (1986).

Tributaries were surveyed upstream through visual observations that included: 1) above water observations; 2) underwater visual observation through snorkelling and 3) observation through underwater video recording. In shallow areas, black bass could easily be detected from the riverbank due to the clarity of the water in the majority of the tributaries. In pools where no black bass were observed snorkel surveys were conducted. Snorkel surveys were conducted by a single person that entered the pool on the downstream side and then swam upstream in a zig-zag pattern. If bass were detected the snorkeler moved to the next pool upstream and followed the same procedure. Underwater video recordings with GoPro Hero 2 video cameras were used to assist with locating the presence or absence of black bass and to identify different black bass species (Ellender *et al*. 2012) Up to three cameras were used depending on the size of the pool and the cameras were left to record for at least 30 minutes. This method was only used in pools deeper than two meters when the other two methods did not detect black bass. When no black bass were located in pools up to 500 m above a waterfall, cascade or chute the natural feature was recorded as the natural black bass barrier.

3.2.2 Identification of black bass species

The different black bass species were identified through visual observation and if there was doubt, underwater photographs with a Canon D10 underwater camera were taken for identification. Identification was based on differences in morphology (jaw position in relation to the eye) and the colouration of body and eye (Skelton 2001).

3.2.3 Description and classification of natural black bass barriers

The geographical location of the barrier was recorded with a Garmin Juno 3d GPS. A clear colour photograph from below the barrier was taken with a Canon D10 digital camera. Each natural barrier that defines the upper limit of black bass in the tributaries of the ODR was measured using survey equipment which consisted of a Pentax AP-120 dumpy level, expandable tripod, a five meter graduated staff for vertical measurement and a 50 m tape for horizontal measurements. Barriers were categorised based upon their physical appearance into falls, cascades and chutes. Powers & Orsborn (1985) define a waterfall when the water falls over a ledge and loses contact with the substrate for a period. A chute is a steep section were the water stays in contact with the substrate while a cascade is a series of falls with breaks and pools that maintains a steep gradient and turbulent water surface (Powers & Orsborn 1985). For falls, the vertical drop was measured while for chutes and cascades vertical and horizontal measurements were taken to determine the slope gradient. If there was more than one waterfall into a pool, both waterfalls were measured and the lowest waterfall was regarded as the effective drop. For a cascade, the highest vertical drop was regarded as the effective drop that prevented black bass from getting up the barrier.

3.2.4 Extent of native cyprinids above black bass barriers

To determine the areas not invaded by black bass, the upper limit of the native cyprinids was located by snorkelling pools above black bass barriers until no cyprinids were located for three consecutive pools. The pools were snorkelled by a single person entering pools on the downstream side and swimming upstream in a zig-zag pattern. The upper limit of the native cyprinids was recorded with a Garmin Juno 3d GPS if no native fish was observed for three consecutive pools. Invaded and uninvaded areas were digitized using Google Earth (KML) and converted into shape files for Arc GIS 10.1. The extent of the black bass invasion was assessed and illustrated according to the management areas in the ODR system as defined by DWAF (2005) and described in Chapter 2.

3.2.5 Data analysis

The data collected from measuring the black bass barriers were used to: (1) physically describe and categorize the barrier; (2) determine mean, minimum and maximum vertical height of the barriers and the average gradient of chutes; (3) determine if there was a significant difference in barrier height between the different black bass species. To determine the length of river invaded by black bass the invaded river channel was digitized on Google Earth (KML files) and converted into shape files for Arc GIS 10.1. To test if there was a significant difference between barrier height that effects the distribution for *M. dolomieu* and spotted bass, *Micropterus punctulatus* (Rafinesque, 1819) the non-parametric Mann-Witney U-test was used ($p = <0.05$).

3.3 Results

3.3 1 Extent of black bass invasion in the Olifants- Doorn system

Forty-one tributaries in the ODR system were surveyed for the presence of black bass. This study recorded black bass in 22 tributaries and 17 of these tributaries were found to have a natural black bass barrier. Black bass were absent from 19 tributaries and one tributary contained no fish. Black bass were generally absent from ephemeral, seasonal and first order streams and generally present in second to fourth order streams (Table 3.1). Four tributaries in the ODR system contained *M. salmoides* above barriers that restricted *M. dolomieu* and *M. punctulatus.* These rivers were the Driehoeks River, Krom River, Leeu River and the Riet River. All these rivers have headwaters plateaus with suitable habitat for *M. salmoides*. In these rivers, *M. salmoides* either were introduced directly to the stream or came via overflows of farm dams (Paxton 2008; Marr 2012). As a result, they were excluded from further analysis. The extent of black bass invasion in the Olifants, Doring and Koue Bokkeveld management areas of the ODR system is shown in Figures 3.1, 3.2 and 3.3 and summarised in Tables 3.2 and 3.3. The Groot River, Olifants River mainstream and Doring River mainstream was 100 % invaded with black bass, while the percentage length invaded of the other tributaries ranged between 0.46 and 98.46 %. The longest invaded stretch was the 200.9 km Olifants River mainstream followed by the Doring River mainstream at 181.9

km. The tributary with the longest invaded stretch was the Riet River with 75.9 km followed by the Koebee/Oorlogskloof River at 52.4 km. The river with the shortest invasion was the Boskloof River with only 50 m invaded by black bass. The combined data from the entire ODR system that includes the Olifants and Doring mainstreams indicate that only 178.2 km of the available 961 km was black bass free. Black bass has thus invaded 81.5 % of the available stream length that were historically occupied by native cyprinid species (Tables 3.2 and 3.3).

Table 3.1 Presence and absence of black bass in the different tributary categories of the Olifants- Doorn River system, Western Cape, South Africa.

Stream Type	**Present**	**Absent**	**Total**
Ephemeral	0	3	3
Seasonal	3	8	11
First Order	0	2	2
Second Order	7	5	12
Third Order	11	1	12
Fourth Order	1	0	1
Total	22	19	41

Table 3.2 The total extent of the *Micropterus* spp. invasion in the Olifants- Doorn River system, Western Cape and Northern Cape, South Africa.

Area of ODR	**Length invaded by *Micropterus* spp. (km)**	**Stream length with native cyprinids, no *Micropterus* spp. (km)**	**Total stream length *Micropterus* spp. and native cyprinids (km)**	**Stream length invaded *by Micropterus* spp. (%)**
All tributaries combined (n= 41)	400	178	578	69.2
Olifants River mainstream	201	0	201	100
Doring River mainstream	182	0	182	100
Totals	783	178	961	81.5

Table 3.3 Summary of the scope of black bass invasion in tributaries of the Olifants- Doorn River system, Western Cape, South Africa (Y= present).

Management Area	Tributary	Stream order (E= ephemeral; S= seasonal)	Black bass present	*Micropterus dolomieu*	*Micropterus punctulatus*	*Micropterus salmoides*	Natural bass barrier present	Bass species per tributary	Stream length invaded by black bass (km)	Stream length with native cyprinids and no bass (km)	Stream length with bass and or cyprinids (km)	Extent of black bass invasion (%)
Olifants	Olifants Gorge	3	y	y	y		y	2	4.9	5.6	10.5	46.9
	Upper Boschkloof River	2						0	0.0	0.3	0.3	0.0
	Lower Boshkloof River	2						0	0.0	0.0	0.0	0.0
	Diepkloof River	2	y	y			y	1	4.3	2.3	6.6	64.7
	Dwars River	2	y	y			y	1	1.0	1.1	2.0	48.5
	Ratel River	3	y	y	y		y	2	2.2	5.5	7.7	28.2
	Oudste River	1						0	0.0	7.5	7.5	0.0
	Thee River	3	y		y			1	5.1	5.3	10.4	49.3
	Noordhoeks River	3						0	0.0	18.0	18.0	0.0
	Boontjies River	3	y	y	y		y	2	5.8	6.7	12.4	46.5
	Boskloof River	2	y	y	y		y	2	0.1	10.6	10.7	0.5
	Markuskraal River	2						0	0.0	1.2	1.2	0.0
	Heks River	3	y	y			y	1	21.3	1.1	22.3	95.3
	Elandskloof River	2						0	0.0	0.3	0.3	0.0
	Rondegat River	2	y	y	y		y	2	1.3	20.4	21.7	5.9
	Jan Dissels River	3	y	y			y	1	31.6	2.1	33.7	93.8
	Kliphuis River	s						0	0.0	0.2	0.2	0.0
	Troe Troe River	s						0	0.0	1.1	1.1	0.0
Knersvlakte	Sout River	E						0	0.0	0.0	0.0	0.0
Doring	Gif River	s						0	0.0	4.2	4.2	0.0
	Oorlogskloof River	s	y	y	y		y	2	52.4	18.7	71.1	73.8
	Brandewyn River	s						0	0.0	3.1	3.1	0.0
	Kransgat River	s						0	0.0	1.0	1.0	0.0
	Biedouw River	s	y		y		y	1	32.7	0.9	33.6	97.4
	Tra Tra River	3	y	y	y		y	2	34.1	0.5	34.6	98.5
	Eselbank River	2	y	y	y		y	2	8.9	1.9	10.8	82.3
	Martiensrus River	s						0	0.0	0.0	0.0	0.0
	Tankwa River	E						0	0.0	5.3	5.3	0.0
	Upper Doring River	E						0	0.0	0.0	0.0	0.0
Koue Bokkeveld	Driehoek River	3	y			y		1	24.8	0.9	25.7	96.3
	Dwars River	2						0	0.0	0.0	0.0	0.0
	Krom River	2	y			y		1	8.1	0.0	8.1	100.0
	Matjies River	3	y	y	y		y	2	13.4	11.0	24.5	54.9
	Breekkrans River	2	y	y	y		y	2	19.3	4.2	23.5	82.1
	Groot River	4	y	y	y			2	31.7	0.0	31.7	100.0
	Tuinskloof River	s						0	0.0	0.0	0.0	0.0
	Rietkloof River	s						0	0.0	0.1	0.1	0.0
	Twee River	3	y	y	y		y	2	0.9	34.2	35.1	2.5
	Leeu River	3	y	y	y	y	y	3	20.6	0.0	20.6	100.0
	Langkloof River	1						0	0.0	3.0	3.0	0.0
	Riet River	s	y			y		1	75.9	0.0	75.9	100.0
	Total		22	17	15	4	17		400.2	178.2	578.4	

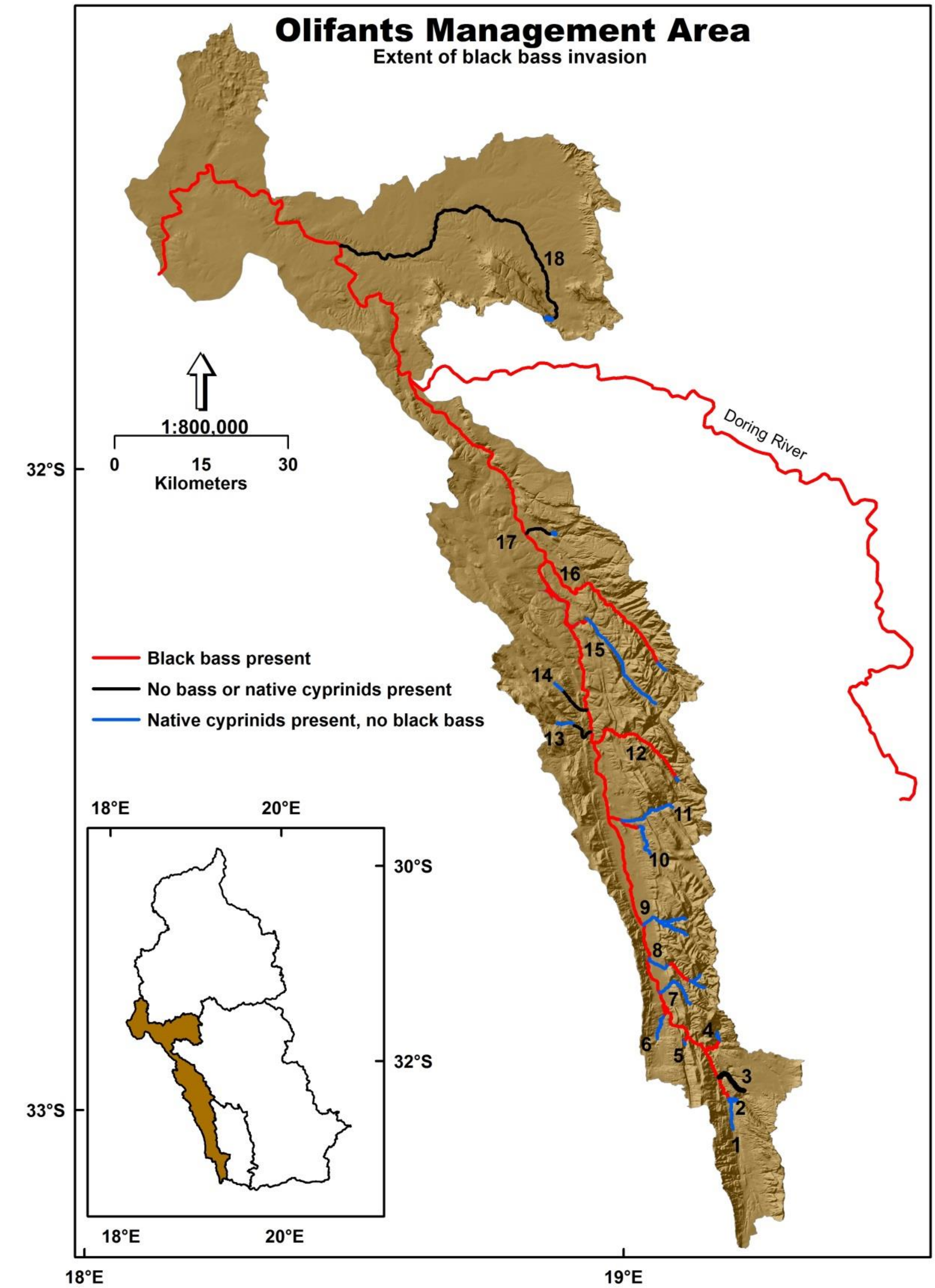

Figure 3.1 The extent of black bass invasion in the Olifants Management Area of the Olifants- Doorn River system. 1= Olifants Gorge, 2= Upper Boschkloof River, 3= Lower Boschkloof River, 4= Diepkloof River, 5= Dwars River 6= Ratel River, 7= Oudste River, 8= Thee River, 9= Noordhoeks River, 10= Boontjies River, 11= Boskloof River, 12= Heks River, 13= Marcuskraal River, 14= Elandskloof River, 15= Rondegat River, 16= Jan Dissels River, 17= Kliphuis River, 18= Troe Troe River.

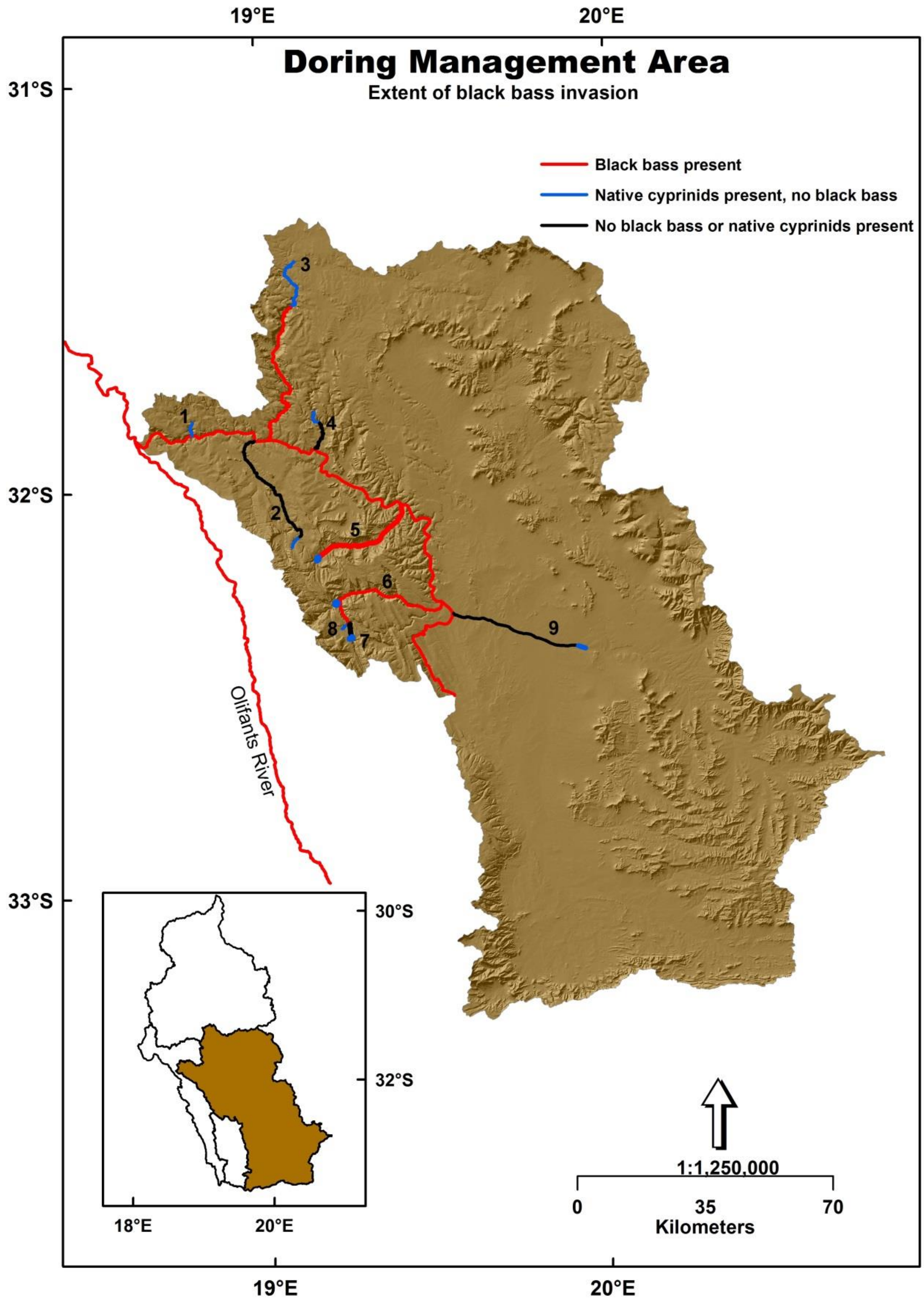

Figure 3.2 The extent of black bass invasion in the Doring Management Area of the ODR system. 1= Gif River, 2= Brandewyn River, 3= Koebee/Oorlogskloof River, 4= Kransgat River, 5= Biedouw River, 6= Tra Tra River, 7= Martiensrus River, 8= Eselbank River, 9= Tankwa River.

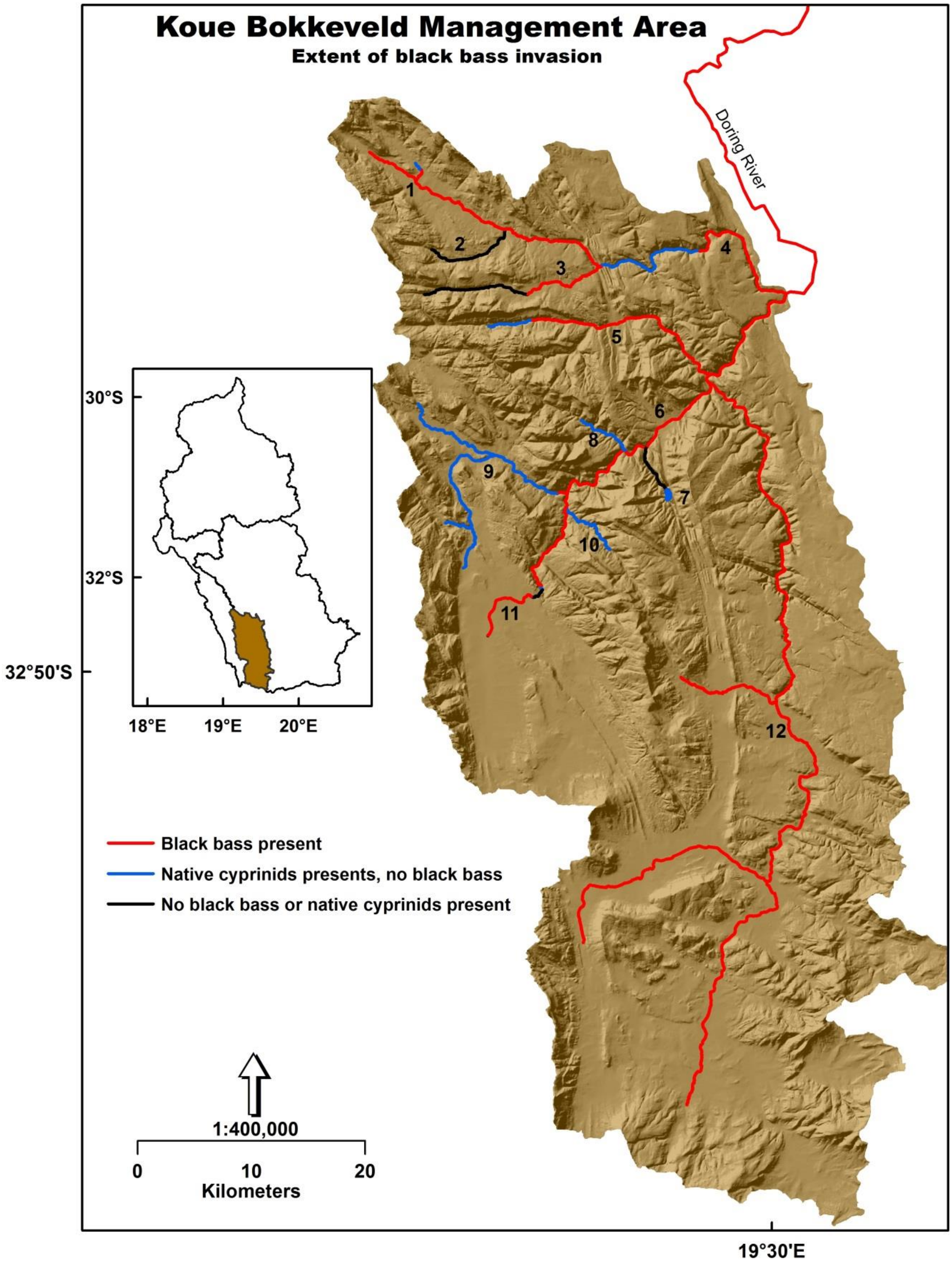

Figure 3.3 The extent of black bass invasion in the Koue Bokkeveld Management Area of the ODR system. 1= Driehoek River, 2= Dwars River, 3= Krom River, 4= Matjies River, 5= Breekkrans River, 6= Groot River, 7= Tuinskloof River, 8= Rietkloof River, 9= Twee River, 10= Langkloof River, 11= Leeu River, 12= Riet River.

3.3.2 Natural black bass barriers

Seventeen natural black bass barriers were identified and the location maps and photographs of the barriers can be found in Figures 3.5 to 3.38. The 17 barriers were classified into 14 waterfalls, two cascades (Figures 3.6 & 3.12) and one chute (Figure 3.14). Table 3.4 has for more details on the location and characteristics of each barrier.

Table 3.4 Summary of the barrier data collected from the 17 *M. dolomieu* and *M. punctulatus* invaded tributaries. Figure reference refers the photograph of each barrier.

	Tributary	Effective drop (m)	Location (lat / long)		Barrier type	Figure ref.
Olifants Management Area						
1	Olifants Gorge	0.78	33^{o} 00' 25.91"	19^{o} 12' 02.11"	cascade	3.6
2	Diepkloof River	1.44	32^{o} 55' 02.00"	19^{o} 11' 01.03"	fall	3.8
3	Dwars River	0.78	32^{o} 54' 44.80"	19^{o} 07' 17.58"	fall	3.10
4	Ratel river	0.83	32^{o} 52' 21.51"	19^{o} 05' 04.10"	cascade	3.12
5	Boontjies River	1.67	32^{o} 34' 44.71"	19^{o} 02' 29.67"	chute	3.14
6	Boskloof River	0.77	32^{o} 34' 04.81"	19^{o} 00' 41.42"	fall	3.16
7	Heks River	0.49	32^{o} 30' 04.08"	19^{o} 06' 45.05"	fall	3.18
8	Rondegat River	1.34	32^{o} 16'39.26"	18^{o} 58' 35.19"	fall	3.20
9	Jan Dissels River	1.17	32^{o} 19' 23.60"	19^{o} 04' 59.83"	fall	3.22
Doring Management Area						
10	Oorlogskloof River	1.59	31^{o} 32' 53.87"	19^{o} 05' 50.55"	fall	3.24
11	Biedouw River	1.55	32^{o} 10' 06.29"	19^{o} 09' 45.50"	fall	3.26
12	Tra Tra River	1.22	32^{o} 16' 58.62"	19^{o} 12' 43.71"	fall	3.28
13	Eselbank River	1.09	32^{o} 20' 06.36"	19^{o} 14' 41.60"	fall	3.30
Koue Bokkeveld Management Area						
14	Matjies River	0.97	32^{o} 30' 27.39"	19^{o} 26' 35.06"	fall	3.32
15	Breekkrans River	0.80	32^{o} 33' 39.15"	19^{o} 17' 16.83"	fall	3.34
16	Twee River	3.50	32^{o} 41' 53.75"	19^{o} 18' 35.56"	fall	3.36
17	Leeu River	0.69	32^{o} 46' 20.26"	19^{o} 17' 32.05"	fall	3.38

The average height of the 17 barriers is 1.21 m while the median is 1.09 m. The lowest effective drop was the 0.49 m waterfall that demarcated the upper limit of *M. dolomieu* in the Heks River (Figure 3.18). The highest effective drop was the 3.50 m waterfall on the Twee River (Figure 3.36). *Micropterus dolomieu* were present below 14 barriers and *M. punctulatus* were present below nine barriers. *Micropterus dolomieu* were the only black bass present below eight barriers while *M. punctulatus* was the only black bass present below three barriers. There was co-occurrence of the two black bass species below six barriers. Figure 3.4 indicates the mean barrier height for the two species. The data indicates that there is no significant difference between the barrier height restricting upstream movement of *M. dolomieu* (mean ± S.D. height 1.25 ± 0.76 m, n= 13) and *M. punctulatus* (1.31 ± 0.90, n= 9) (Mann-Witney U-test; Z= 0.1002, p= 0.92034, U= 56.5).

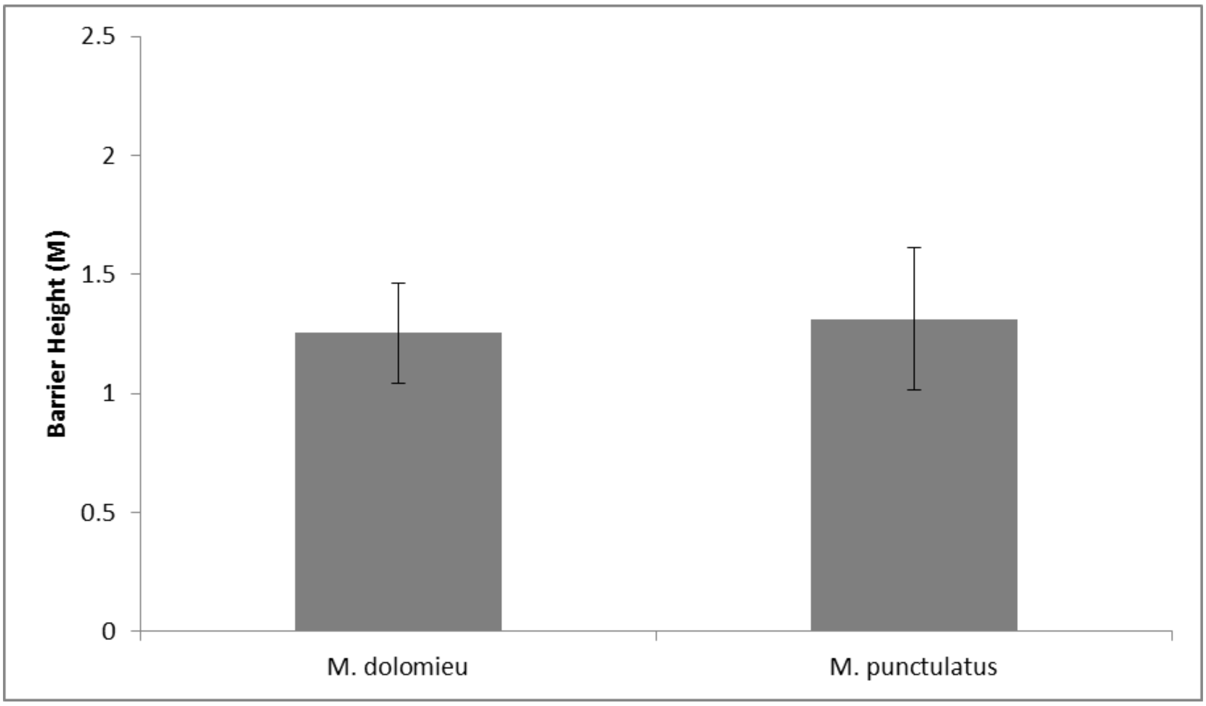

Figure 3.4 Average height of natural barriers restricting the upstream movement of *Micropterus dolomieu* (n= 13) and *Micropterus punctulatus* (n= 9). Error bars are standard deviation.

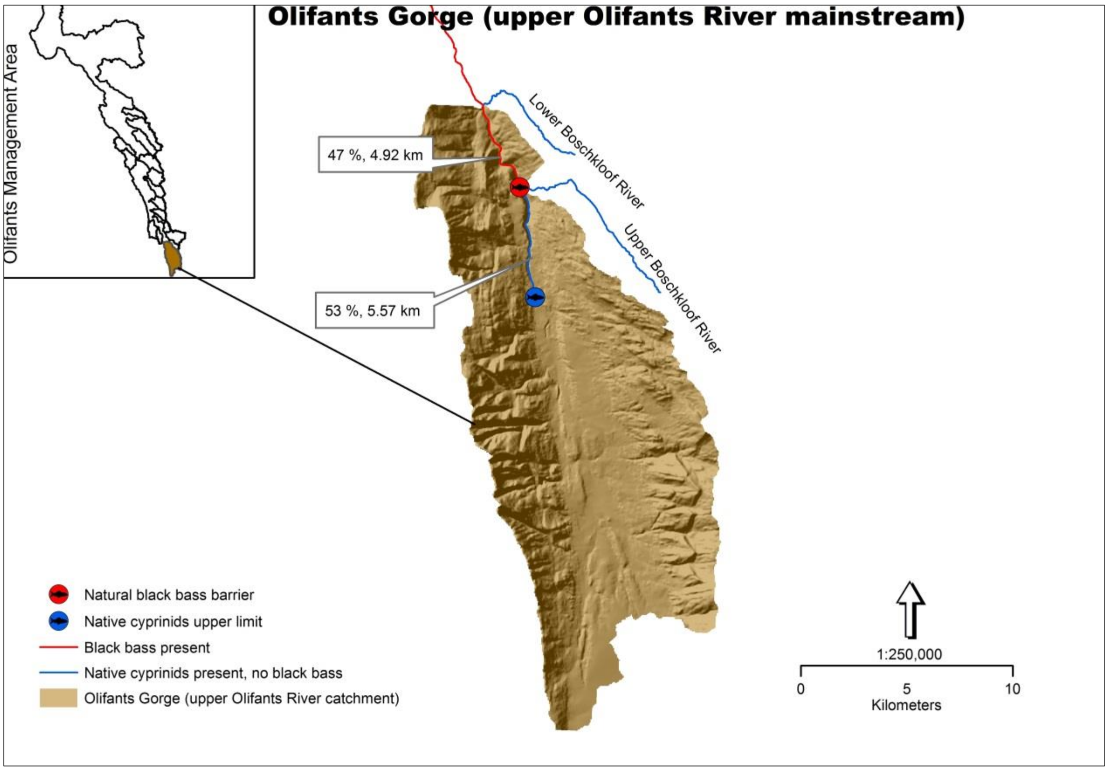

Figure 3.5 Extent of black bass invasion in the Olifants Gorge.

Figure 3.6 Black bass barrier in the Olifants Gorge. The barrier is a cascade with the highest effective drop of 0.78 m at the top of the cascade.

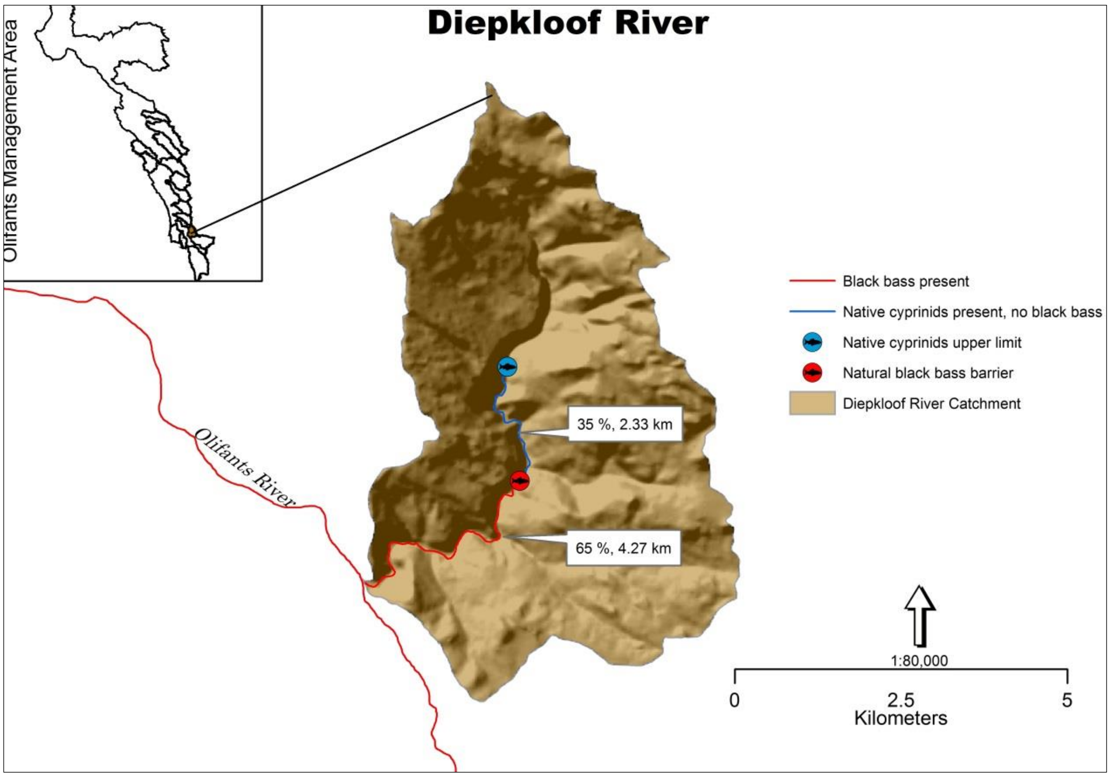

Figure 3.7 Extent of black bass invasion in the Diepkloof River.

Figure 3.8 Black bass barrier in the Diepkloof River. The effective drop of the waterfall is 1.44 m.

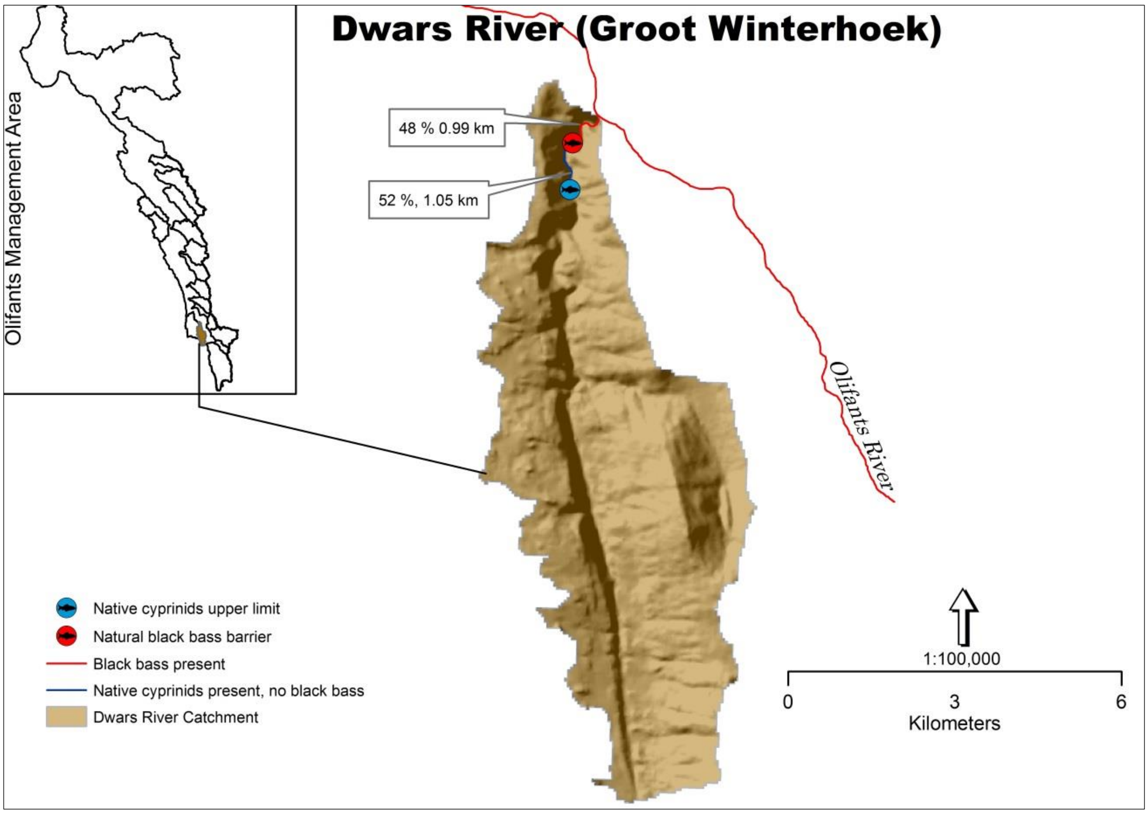

Figure 3.9 Extent of black bass invasion in the Dwars River.

Figure 3.10 Black bass barrier in the Dwars River. The single waterfall has a drop of 0.78 m.

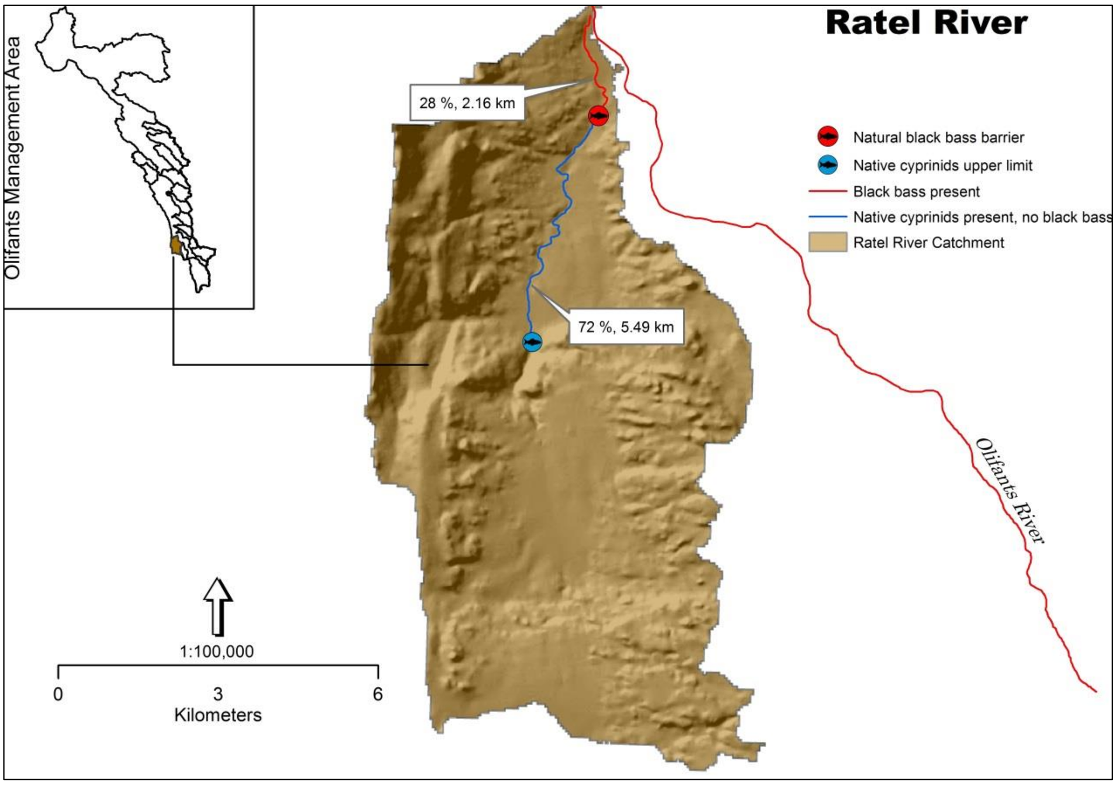

Figure 3.11 Extent of black bass invasion in the Ratel River.

Figure 3.12 Black bass barrier in the Ratel River. The barrier is a cascade with multiple falls. The highest drop is 0.825 m located at the top of the cascade.

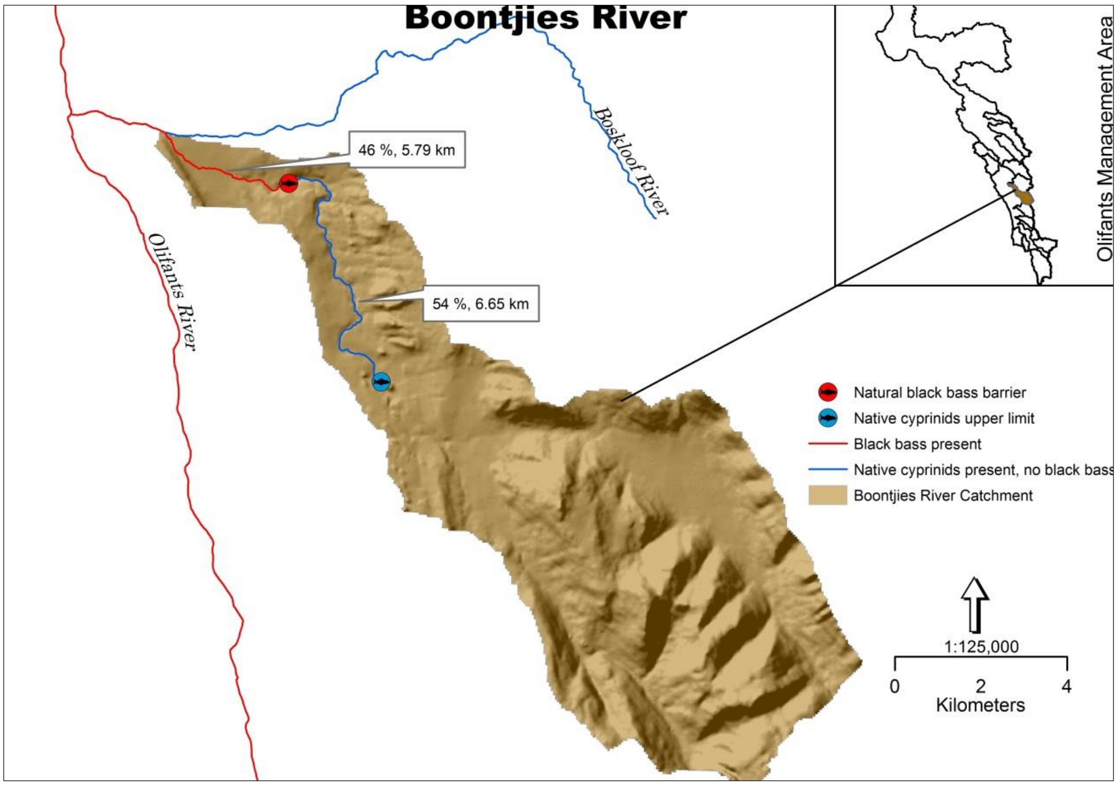

Figure 3.13 Extent of black bass invasion in the Boontjies River.

Figure 3.14 The black bass barrier in the Boontjies River. This barrier is classified as a chute with a gradient of 0.538 ° and a total drop of 1.67 m.

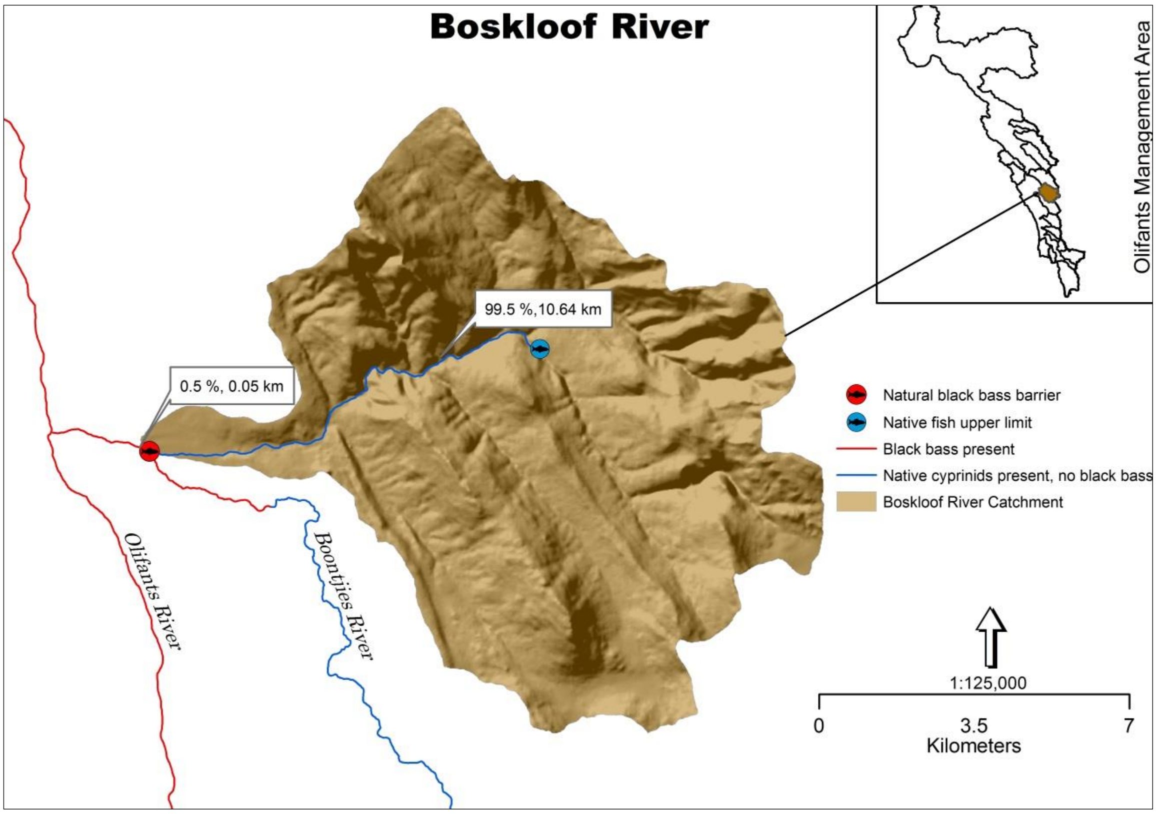

Figure 3.15 Extent of black bass invasion in the Boskloof River.

Figure 3.16 Black bass barrier in the Boskloof River. The barrier is a single fall of 0.77 m.

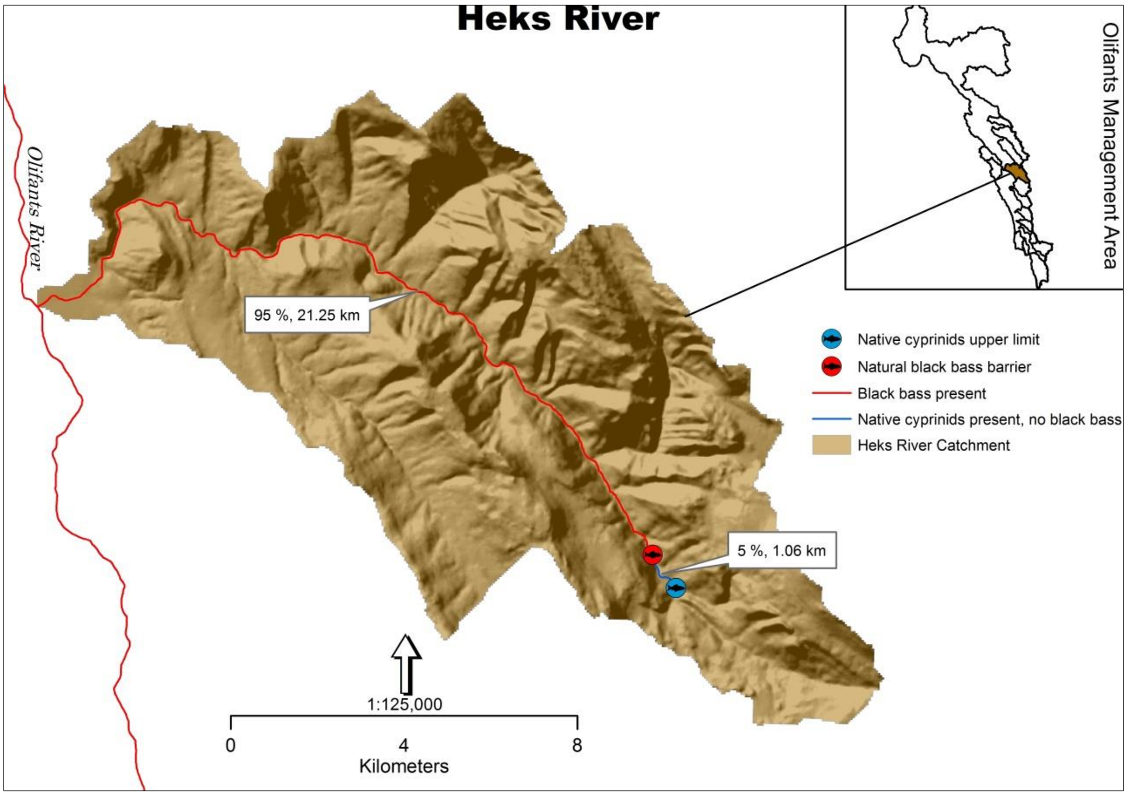

Figure 3.17 Extent of black bass invasion in the Heks River.

Figure 3.18 Black bass barrier in the Heks River. The barrier is comprised of two similar falls and the lowest one at 0.49 m is regarded as the effective drop. This is the lowest recorded barrier.

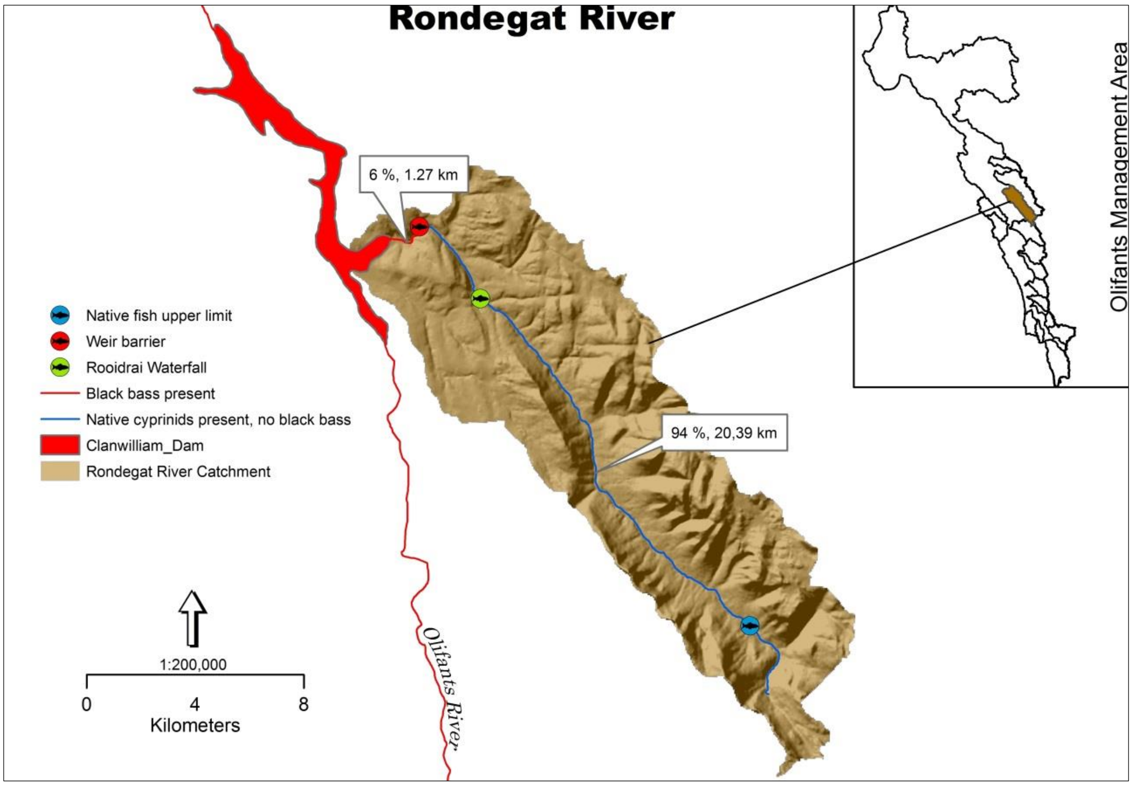

Figure 3.19 Extent of black bass invasion in the Rondegat River.

Figure 3.20 The Rooidraai waterfall (1.34 m) was the black bass barrier in the Rondegat River up until 16 March 2013 when the second rotenone piscicide treatment of this river took place. The current black bass barrier is an artificial weir 4 km below this site. Chapter 5 has more detail on the chemical eradication of black bass from this river.

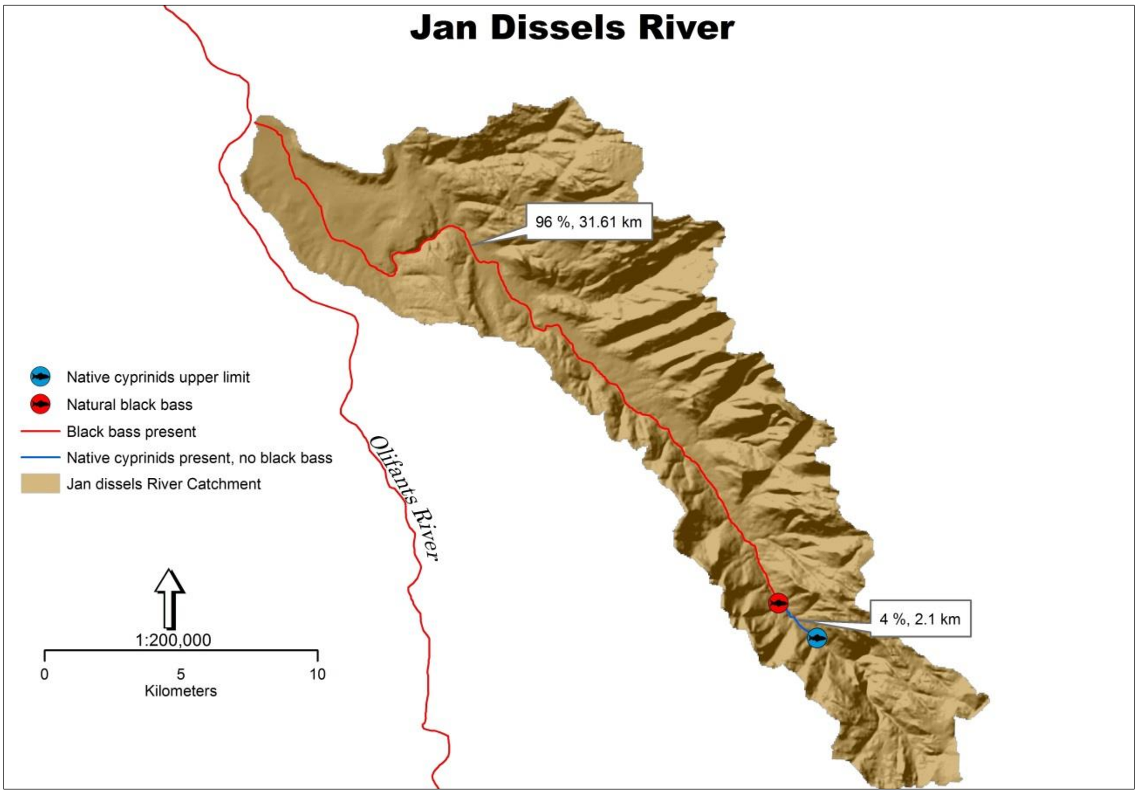

Figure 3.21 Extent of black bass invasion in the Jan Dissels River.

Figure 3.22 Black bass barrier in the Jan Dissels River. The single fall barrier has a drop of 1.17 m and is located in the Cederberg Wilderness Area.

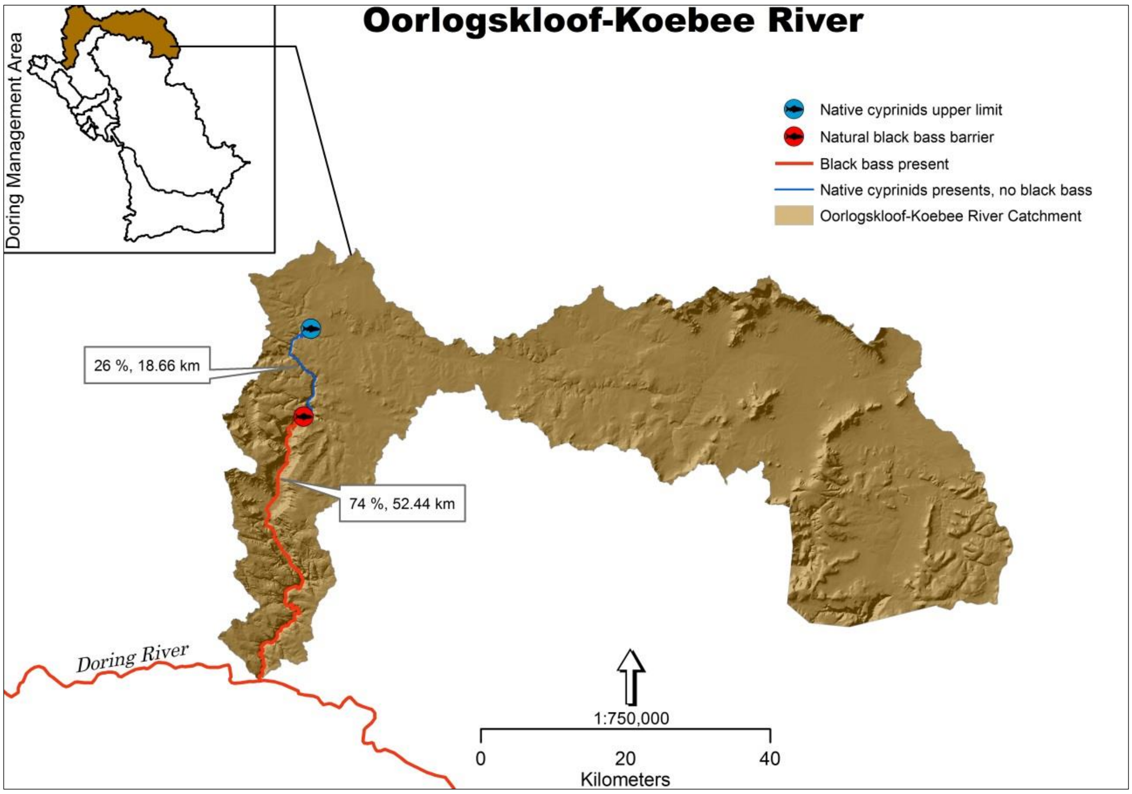

Figure 3.23 Extent of black bass invasion in the Oorlogskloof-Koebee River.

Figure 3.24 Black bass barrier in the Oorlogskloof- Koebee River. The waterfall has a vertical drop of 1.59 m.

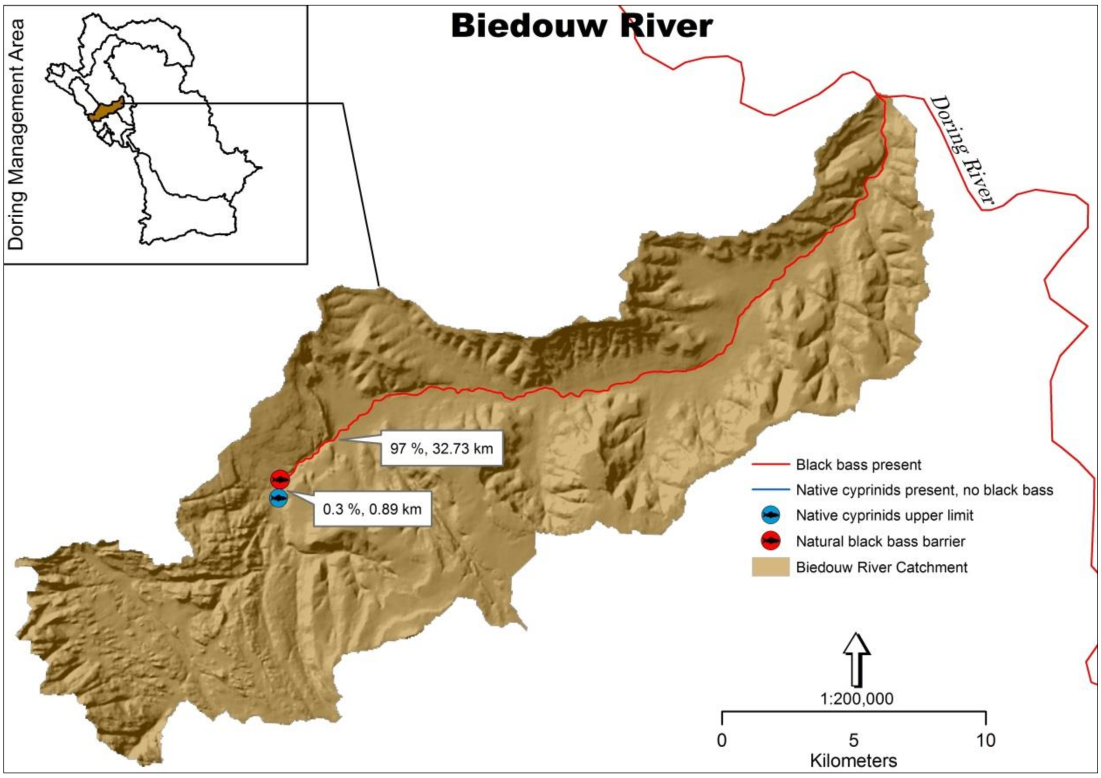

Figure 3.25 Extent of black bass invasion in the Biedouw River.

Figure 3.26 Black bass barrier in the Biedouw River. The waterfall has a vertical drop of 1.55 m.

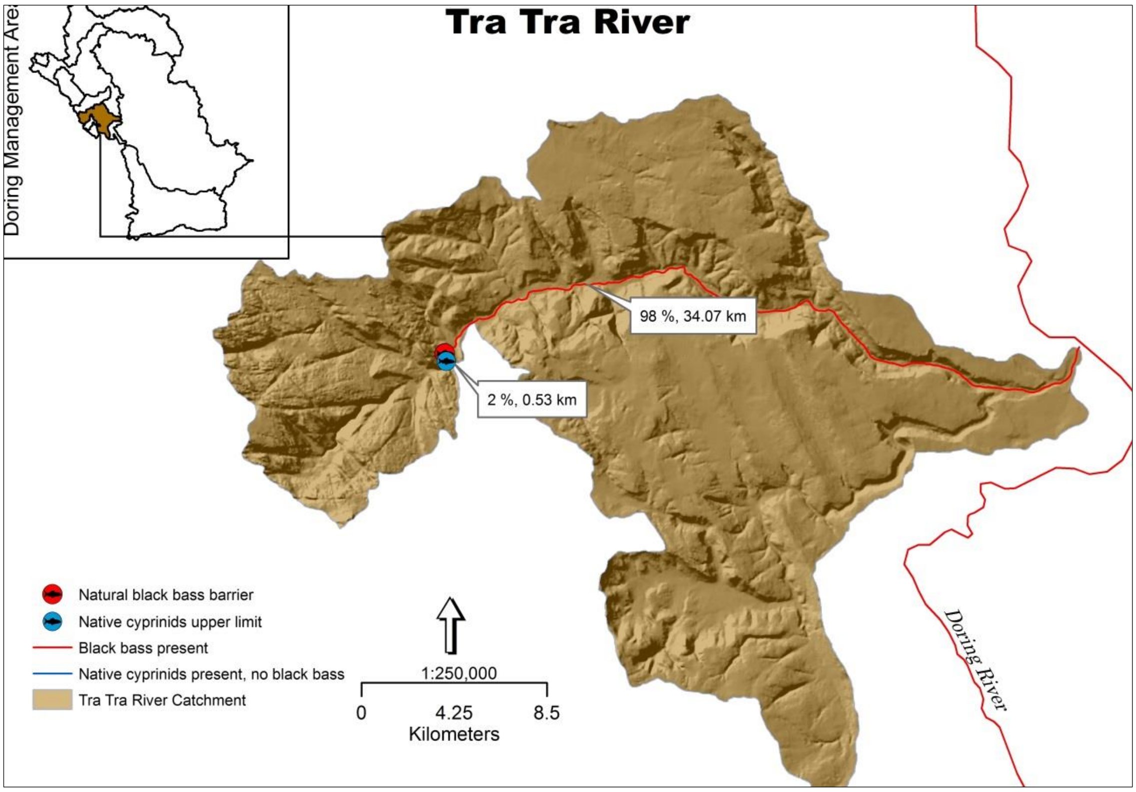

Figure 3.27: Extent of black bass invasion in the Tra Tra River.

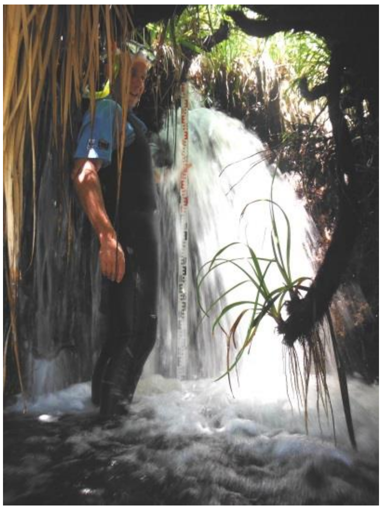

Figure 3.28 Black bass barrier in the Tra Tra River. The barrier is located under dense bed of palmiet *Prionium serratum* and is comprised of two parallel waterfalls with the lowest fall at 1.22 m.

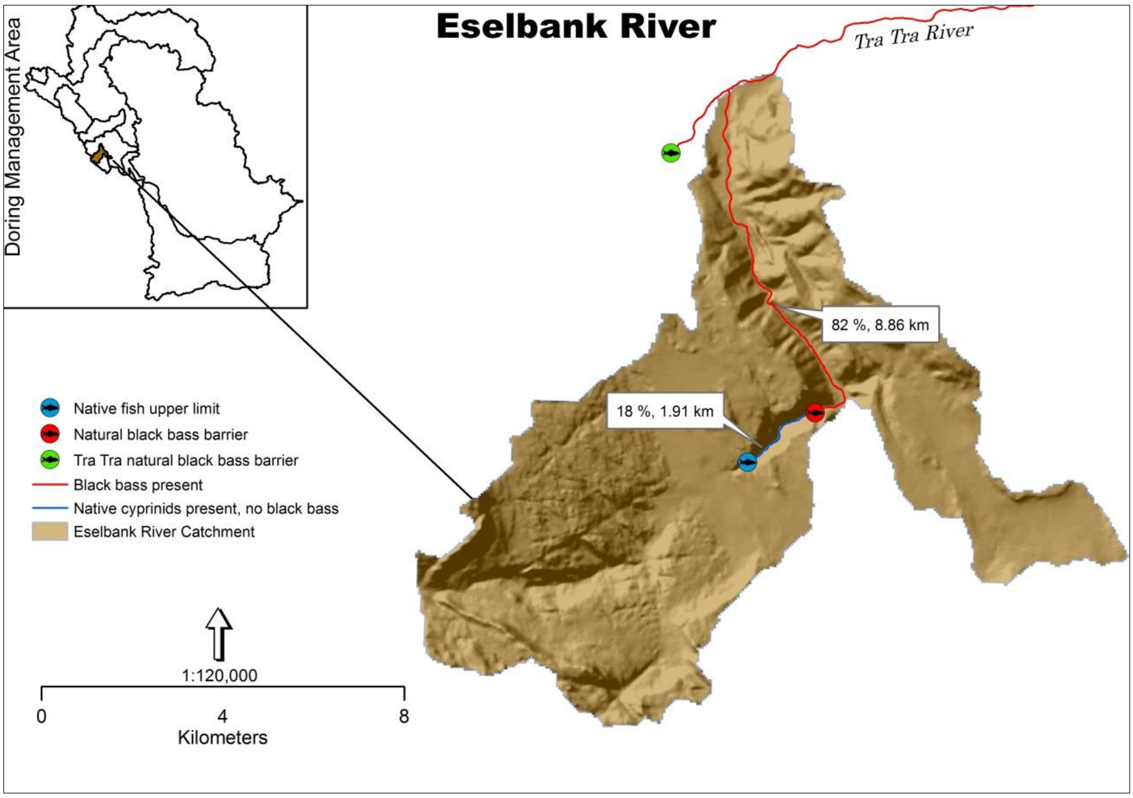

Figure 3.29 Extent of black bass invasion in the Eselbank River.

Figure 3.30 Black bass barrier in the Eselbank River. The barrier is two falls on the sides of a large boulder. The lowest fall is 1.09 m high and is regarded as the effective drop.

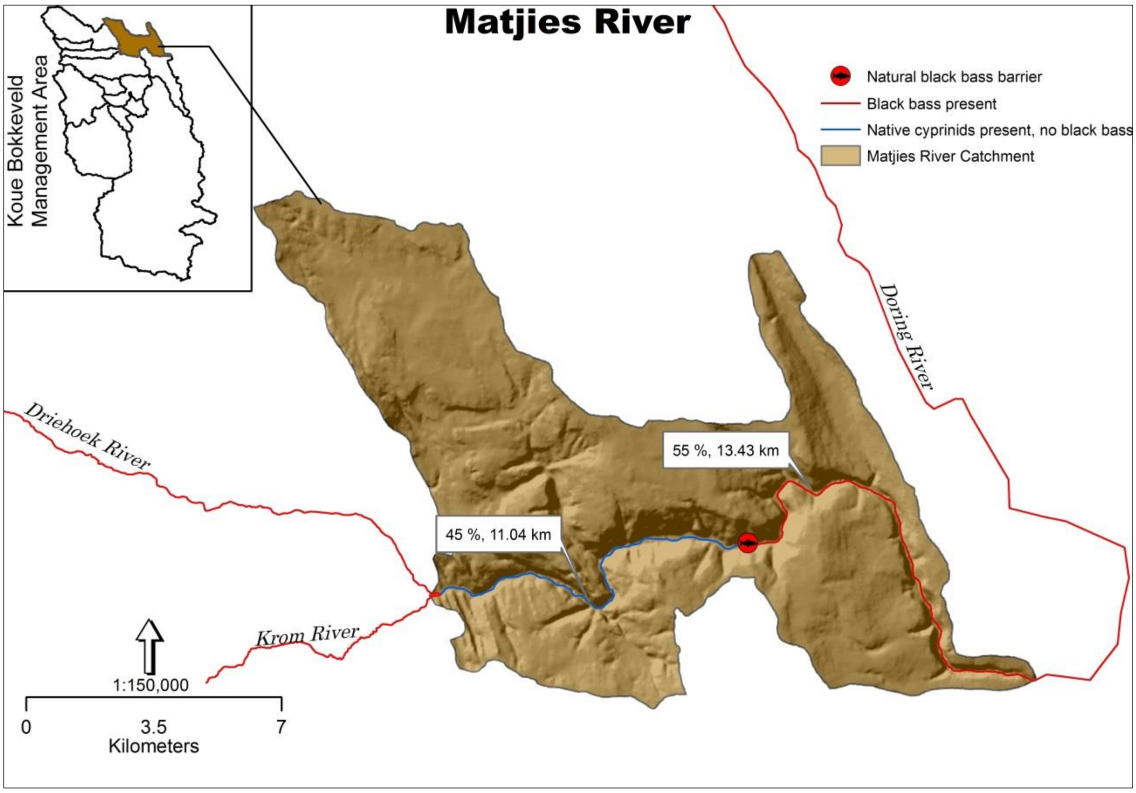

Figure 3.31 Extent of black bass invasion in the Matjies River.

Figure 3.32 Black bass barrier in the Matjies River. The barrier is a single fall with a drop of 0.97 m.

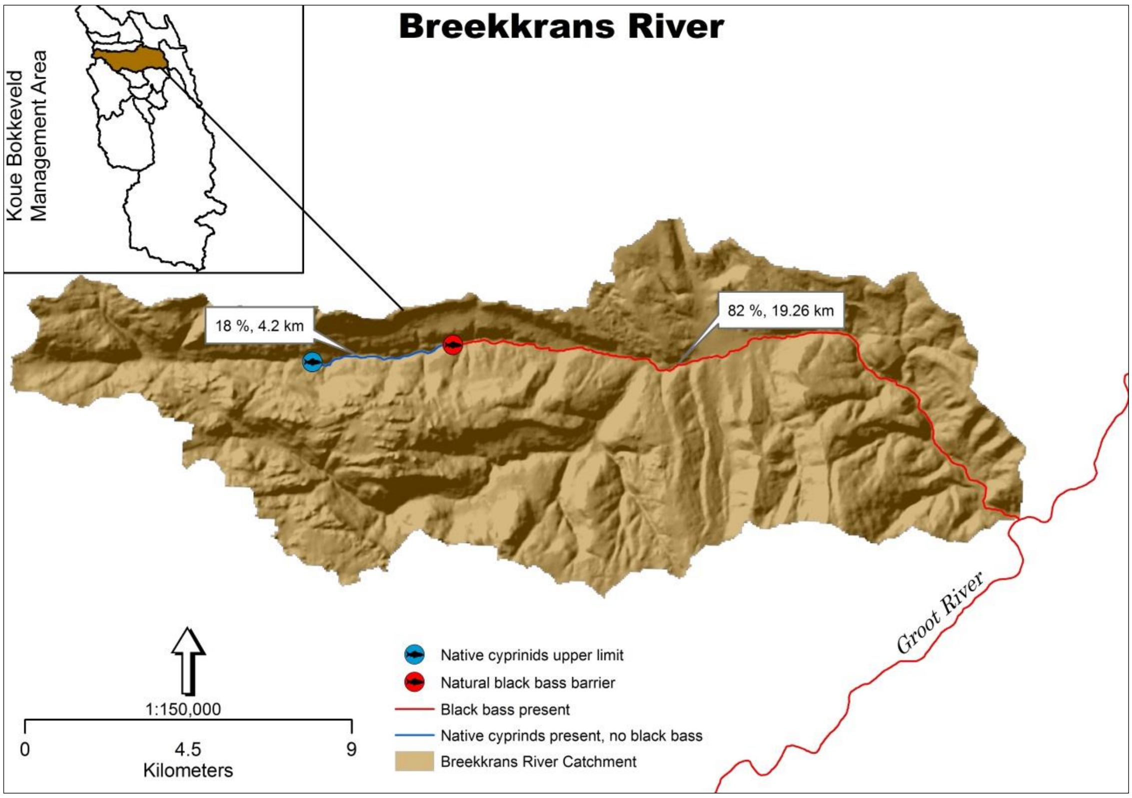

Figure 3.33 The extent of black bass invasion in the Breekkrans River.

Figure 3.34 Black bass barrier in the Breekkrans River. The barrier is two falls on the sides of a large boulder. The lowest drop (effective drop) is 0.80 m.

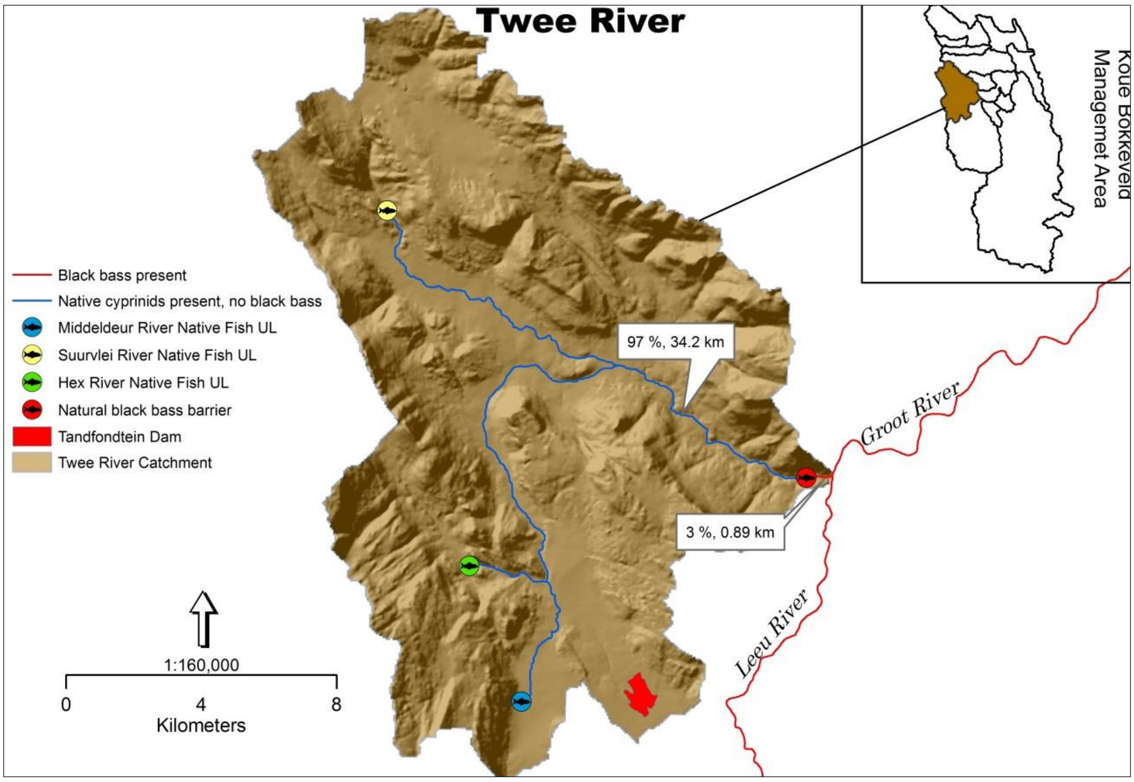

Figure 3.35 Extent of black bass invasion in the Twee River.

Figure 3.36 Black bass barrier in the Twee River. The total height is 7.35 m and the effective drop is the bottom fall that is 3.5 m high.

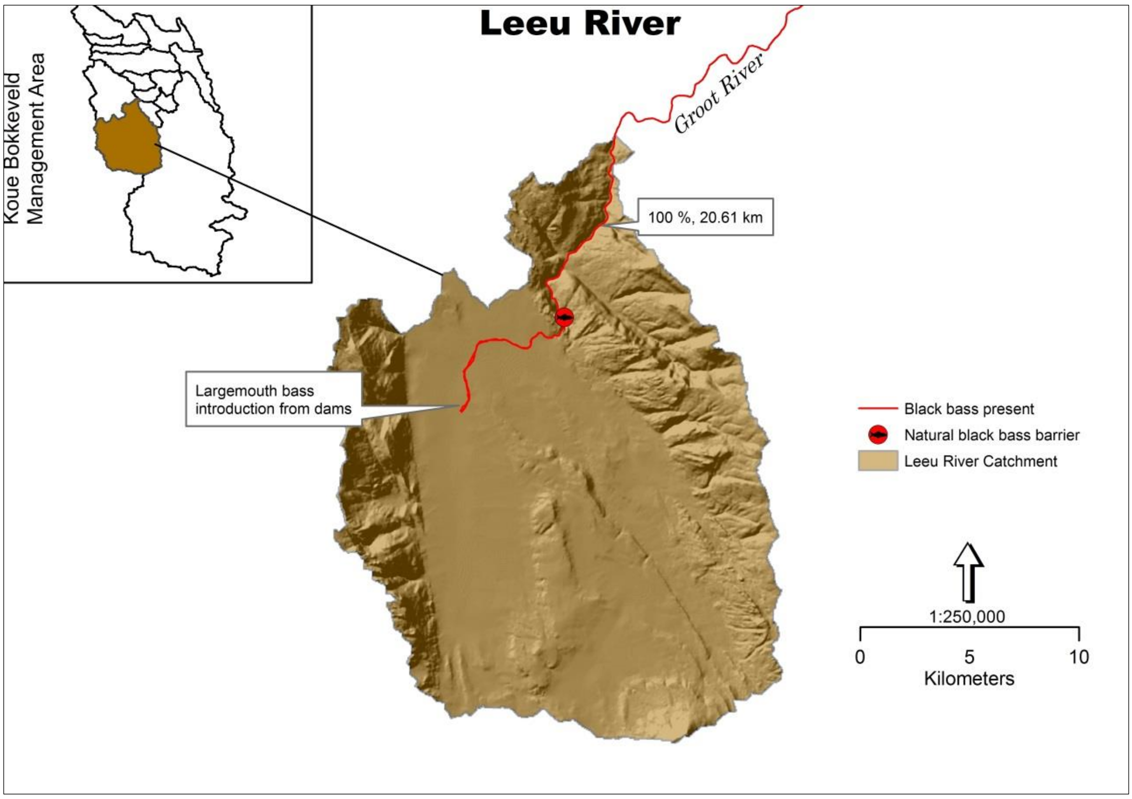

Figure 3.37 Extent of black bass invasion in the Leeu River.

Figure 3.38 Black bass barrier in the Leeu River. The single fall has a height of 0.69 m.

3.3.3 Native cyprinid upper limit

The location of the upper limit of the native cyprinids above the 17 natural bass barriers is presented in Table 3.5. In most cases, the upper limit was a physical barrier in the form of a waterfall. The Clanwilliam redfin *Barbus calidus* Barnard, 1938 was in most instances the species that demarcated the upper limit. The freshwater fish distribution data collected during this study were combined with historical records and summarized as Appendix B.

Table 3.5 Location of native cyprinid upper limit in black bass invaded tributaries of the Olifants- Doorn River system. The Twee River is comprised of three sub-tributaries. Lc= *L. capensis,* Bs= *B. serra,* Bc= *B. calidus,* Ba= *B. anoplus,* Be= *B. erubescens.*

Tributary	**Location of cyprinid upper limit**		**Species at upper limit**
	latitude	**longitude**	
Olifants Gorge	33° 03' 14.93"	19° 12' 26.86"	Lc, Bs
Diepkloof River	32° 54' 06.23"	19° 10' 54.98"	Bc
Dwars River (Groot Winterhoek)	32° 55' 12.04"	19° 07' 15.26"	Bs, Bc
Ratel river	32° 54' 38.59"	19° 04' 13.36"	Bc
Boontjies River	32° 37' 15.6"	19° 03' 48.99"	Bc
Boskloof River	32° 32 54'.98"	19° 06' 20.67"	Bc
Heks River	32° 30' 29.35"	19° 07' 05.23"	Bc
Rondegat River	32° 10' 28.74"	19° 09' 42.59"	Bc
Jan Dissels River	32° 20' 05.93"	19° 05' 53.02"	Bc, Bs
Oorlogskloof/Koebee River	31° 26' 20.9"	19° 06' 37.9"	Ba
Biedouw River	32° 10' 28.74"	19° 09' 42.59"	Bc, Lc, Bs
Tra Tra River	32° 17' 09.89"	19° 12' 46.16"	Bc
Eselbank River	32° 20' 41.06"	19° 13' 44.05"	Bc
Matjies River	32° 26' 04.19"	19° 10' 51.70"	Bs, Bc, Lc
Breekkrans River	32° 33' 52.2"	19° 14' 48.3"	Bc
Twee River			
Twee River (Hex)	32° 43' 13.33"	19° 12' 11.46"	Be
Twee River (Suurvlei)	32° 37' 44.27"	19° 10' 55.40"	Be
Twee River (Middeldeur)	32° 45' 24.06"	19° 13' 07.87"	Be
Leeu River	No natives	No natives	

3.4 Discussion

3.4.1 Extent of the black bass invasion in the Olifants Doorn River system

Black bass has been present in the ODR system for at least 80 years (Harrison 1952) and the results of this study indicate that *M. dolomieu and M. punctulatus* have invaded most of the larger perennial and seasonal tributaries up to natural barriers in the ODR system as predicted by Gaigher (1973). It must also be noted that only *M. dolomieu* and *M.*

punctulatus were recorded immediately below the black bass barriers. This is because high gradient streams with bedrock-dominated morphology, fast flowing turbulent water and sparse aquatic vegetation are not preferred habitat for *M. salmoides* (Brown *et al*. 2009b). Riverine *M. salmoides* prefer wide, slow-moving water with aquatic vegetation (Brown *et al*. 2009b). The channel morphology at black bass barriers is also not conducive for the breeding requirement of *M. salmoides* which need sand or gravel in shallow water to construct their nests (Brown *et al*. 2009b). However, *Micropterus salmoides* were present in the headwater sections of four river plateaus due to human induced introductions and if the data of their presence are included, the results indicate that 81.5 % of native cyprinid range in the ODR system is black bass-invaded. Darwall *et al*. (2009) state that more than 80 % of the ODR system is invaded by alien fish but, if the other alien fish in the ODR system (e.g., trout, bluegill) are incorporated with the data from this study, the figure could be well over 90 %.

It could be argued that the 19 tributaries that have not been invaded by black bass do not fulfil the habitat requirements of black bass or that there are other natural or anthropogenic factors that prevented their invasion. A study by Lawrence (2013) found that low water temperature was a factor limiting the upward movement of *M. dolomieu* in the state of Oregon, USA. This is most likely not the case in the ODR system where summer water temperatures (22 – 27 ^{o}C) (Impson *et al*. 2007) are generally within the preferred range (13–28 ^{o}C) of *M. dolomieu* and *M*. *punctulatus* (de Moor & Bruton 1988; Brown *et al*. 2009a). High turbidity and high sedimentation loads, which negatively influence the hunting and breeding potential of black bass (Sweka & Hartman 2003; Brown *et al*. 2009a), can also be excluded as limiting factors because all of the rivers containing fish in this study had clear water with good visibility.

Low flow may well be a limiting factor for the presence of black bass as ephemeral and seasonal tributaries generally did not contain black bass (Table 3.2). In the Knersvlakte Management Area for example, all tributaries were ephemeral and the only permanent water in the Knersvlakte (Sout River) was saline (tested at 37.1 ppt during this study). This salinity was beyond the 17 ppt tolerance of *M. salmoides* (Brown *et al*. 2009b) and the pools only contained alien Mozambique tilapia *Oreochromis mossambicus* (Peters, 1852) which can tolerate salinities of up to 67 ppt (Uchida *et al*. 2000). In the three seasonal tributaries where black bass were present (Riet River, Biedouw River and Oorlogskloof River), deep pools provide refuge for black bass during the dry season (December-April) when flow ceases. A study by Ellender *et al*. (2011) documented an invasion by black bass under similar conditions in the Blindekloof River, Eastern Cape Province. The two first order streams (Oudste River and Langkloof River) which also had no black bass are relatively small tributaries with minimum flow during the dry season. The Oudste River is also cut off from the Olifants River due to water abstraction in the lower reaches and this prevents access for black bass to the middle and upper reaches.

The absence of black bass from two second and one third order tributary is most likely a result of the absence of connectivity with the main-stem Olifants River. The Noordhoeks River is a third order tributary where, as a result of water abstraction, the lower 1 km is dry during summer. As this was the only factor that appeared to restrict the bass invasion, an alien fish barrier was constructed to protect this river from alien fish species in 2013 (Z. Olivier pers. comm.). The Elandskloof and Marcuskraal Rivers are both small second order tributaries where the lower reaches are channelized. This channelization coupled with water abstraction might be the reason for the absence of black bass. Absence of bass in the second order Dwars River is a consequence of this river flowing into the lower reaches of the Driehoeks River were black bass are absent due to a natural barrier lower down in the system (Matjies River). Both the Upper- and Lower Boschkloof Rivers are second order tributaries that enter the Olifants River mainstream with steep falls and cascades that probably prevent access to black bass.

3.4.2 Micropterus salmoides distribution

Micropterus salmoides seems to be the only species of black bass that has been introduced into farm dams in headwater plateaus above natural barriers in the ODR system. In the Driehoek River catchment a large population of *M. salmoides* exist in the deep pools on the Driehoek plateau but it is absent from the areas dominated by bedrock and fast flowing water (Paxton 2008). A population of *M. salmoides* is also present in the middle to lower Krom River (Figure 3.3) and they were introduced into the catchment for angling purposes (Marr *et al*. 2012). *Micropterus salmoides* are also present in the upper Leeu River and the

Riet River. In both rivers the only logical explanation is that they were introduced above natural barriers on the Koue Bokkeveld plateau. The Koue Bokkeveld is extensively developed for irrigation farming and the water is stored in hundreds of off-stream dams. Most of these dams in the Koue Bokkeveld are stocked with *M. salmoides* and these dam populations are most likely the source for the black bass invasion in the upper Olifants, Leeu and Riet Rivers (I. Smit pers. comm.). *Micropterus salmoides* were also introduced in 2010 into a dam on Tandfontein farm in the Twee River catchment due to ignorance by a local angler (Marr 2011). More tributaries in the ODR system could potentially be invaded by *M. salmoides* due to stocking of dams in developed headwaters such as the Ratel River.

3.4.3 Location of black bass barriers

The locations of natural black bass barriers in the tributaries were in general located high up in the headwaters of tributaries. The presence of native fish above the natural black bass barriers imply that their distribution is not hampered by black bass barriers. There are some exceptions in the case of the Twee River barrier, which has a combined drop of 7.35 m and an effective drop of 3.5 m. This barrier would currently be impassable to any of the native or alien fish species in the ODR system. The composition of the native species confirms this statement as the only fish species that were present above this barrier before the introduction of alien fish were Cape galaxias *Galaxias zebratus* (Castelnau, 1861) and *B. erubescens* (Skelton 1974; Marriott 1998) which have evolved in isolation (Marr *et al*. 2009).

3.4.4 Types of black bass barriers

Fifteen of the seventeen natural black bass barriers in the ODR system are bedrock waterfalls or chutes. The only two barriers that were not formed by boulders or bedrock are the barriers in the Boskloof and Tra Tra Rivers (Figures 3.16 and 3.28). The Tra Tra black bass barrier is two waterfalls formed by a dense bed of palmiet *Prionium serratum* (Drège) and sandstone cobbles. The barrier on the Boskloof River is also a conglomerate of clay and river cobbles amongst a stand of common reeds *Phragmites australis* (Cav.) Trin. ex Steud. At both the Tra Tra and Boskloof Rivers, the black bass barriers showed visual evidence of head cut erosion and these barriers could be vulnerable in the case of a large flooding event. Two of the black bass barriers consisted of a series of small falls that formed a cascade in the Ratel River and Olifants Gorge (Figures 3.12 and 3.6). The highest vertical fall in the Ratel

River cascade (0.8 m) was regarded as the effective drop that prevented the upstream movement of black bass and in the Olifants gorge it was considered the drop of 0.78 m. Only one shoot made up a barrier and that was in the Boontjies River where it had a gradient of 0.538 ° and a total drop of 1.67 m (Figure 3.14). Powers & Orsborn (1985) also classified natural barriers into waterfalls, chutes and cascades. They also listed debris jams as barriers but these were not encountered in the ODR system.

3.4.5 Height of black bass barriers

This study could not find a significant difference in the barrier height for *M. dolomieu* and *M. punctulatus.* This comes as no surprise as these species are morphologically similar in shape and size (Skelton 2001). No literature could be found on the height of natural black bass barriers although there have been discussions on what the height of artificial barriers should be to stop black bass. In the Mooinooi River, South Africa, the Department of Environmental Affairs investigated the construction of an artificial black bass barrier to prevent black bass from impacting on a population of rainbow trout (DWAF 2003). Their study calculated that a 60 cm *M. dolomieu* could jump 1.49 m. This was calculated at a swimming speed of 5.4 m/second. This seems to be an overestimation of the jumping ability of *M. dolomieu* because the majority of the black bass barriers in the ODR system were much lower than 1.49 m. It must also be mentioned that this study never encountered black bass of 60 cm length and the largest black bass was just over 40 cm. The black bass in the headwaters of the ODR are relatively small due to the lack of food in the nutrient poor tributaries (de Moor & Bruton 1988). This was also illustrated during the rotenone treatment of the Rondegat River where no black bass larger than 30 cm were collected during the treatment (Weyl *et al*. 2013). In a report by Gomez & Wilkinson (2008), it is stated that *M. dolomieu* are not aggressive swimmers and a vertical drop of 46 cm can be a barrier to *M. dolomieu.* In a study by Meixler *et al*. (2009), they modelled the jumping ability of *M. dolomieu* using its maximum darting speed (3.42 m/second) and average total length (0.38 m). The model calculated that *M. dolomieu* has a maximum jumping ability of 60 cm. These figures correspond better with the results of this study, as the lowest natural black bass barrier was 0.49 m. This study confirms the statement by Darwall *et al*. (2009) that black bass possess poor jumping abilities.

The ultimate aim of measuring the natural black bass barriers in the ODR was to determine the height artificial black bass barriers should be in future if they are to form part of river rehabilitation projects in the CFR. The suggested height for these artificial barriers is 80 cm as this is slightly higher than the lowest barriers in this study if the anomaly of the Heks River barrier is not incorporated. The black bass barrier in the Heks River of 0.49 cm is 30 cm lower than any of the other 16 black bass barriers in the ODR system. In other tributaries, black bass was also found above natural barriers that exceeded the height of the Heks River barrier and this would suggest that bass could possibly pass the Heks River barrier. The most likely explanation for bass not occurring past this low barrier is the lack of suitable black bass habitat as the area above the bass barrier consists of multiple small cascades and shallow pools. A study in North America found that there was a correlation between black bass densities and the depth of pools with fewer bass in shallower pools (Lawrence 2013).

3.5 Concluding remarks

This study showed that *M. dolomieu* and *M. punctulatus* are adapted to and established in the majority of perennial tributaries in the ODR system. The only factor limiting them from occupying all the habitable streambeds is natural barriers in the form of waterfalls, cascades and chutes. Climate change might pose a risk to a few of these barriers in terms of severe flooding events while human assisted dispersal of black bass above natural barriers might also be a continued threat. The study also showed that black bass have poor jumping abilities and the recommended height of artificial barriers as part of a management program should be between 80 and 100 cm depending on the size of the tributary.

Determining the upper limit of the native cyprinids formed an important component of this chapter as this helped to express the extent of the black bass invasion relative to the habitat available in the ODR system. Having established the location of natural black bass barriers in the system, the system wide impacts of black bass invasions on native fishes could be determined. This is the focus of the next chapter (Chapter 4).

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CHAPTER 4

PREDATORY IMPACT OF INVASIVE ALIEN BLACK BASS *MICROPTERUS* SPP., ON INDIGENOUS FISHES IN THE HEADWATERS OF THE OLIFANTS- DOORN RIVER SYSTEM

4.1 Introduction

Worldwide freshwater fish introductions have resulted in negative impacts on the receiving environment (Gozlan *et al*. 2010). Black bass (a collective term for fishes in the genus *Micropterus*) are freshwater predatory fishes (Brown *et al*. 2009a; Brown *et al*. 2009b) native to North America and has been introduced globally to enhance sport fisheries (Loppnow 2013). Casal (2006) reported that largemouth bass *Micropterus salmoides* (Lacepede, 1802) has been introduced into 72 countries and this species is listed as one of the 100 worst invaders globally (Lowe *et al*. 2000). Smallmouth bass *M. dolomieu* Lacepede, 1802 has been introduced into 24 countries and are regarded as invasive in nine countries (Loppnow 2013). The main documented impacts of black bass are predation on native fishes (Jackson 2002; Ellender & Weyl 2014).

Three species of black bass (*M. dolomieu*, *Micropterus punctulatus* (Rafinesque, 1819) and *M. salmoides*) were introduced into the Olifants- Doorn River (ODR) system in the Cape Floristic Region of South Africa between 1933 and 1945 (Harrison 1952; Harrison 1953). Their establishment was aided by legislative support, such as a 3-month closed angling season enforced in the 1960s during the black bass spawning period (Scott 1982). Protection of black bass continued until the late 1970s and early 1980s when angling restrictions on alien fish were removed and projects aimed at conserving native fish were initiated (Gaigher *et al*. 1980; Scott 1982). By then however, black bass had spread throughout the system (Harrison 1952; Harrison 1953; van Rensburg 1966) and currently, the upper limit of black bass in ODR tributaries is mostly defined by natural barriers in the form of waterfalls and cascades in the upper reaches of these tributaries (De Moor & Bruton 1988; Bills & Impson 2013; Chapter 3).

Impacts of black bass introductions were documented from as early as 1938 when Harrison (1939) reported that *M. salmoides* were preying on the thousands of Clanwilliam sandfish *Labeo seeberi* (Gilchrist & Thompson, 1911) that were congregating for their upstream spawning migration below the Cascades (Figure 2.1) in the mainstream Olifants River. Barnard (1943), during fieldwork associated with his revision of the native fish of the South West Cape Region also raised his concern about the impact of alien fish on the native species. For example, a large pool at the head of the Olifants River valley known as Keerom Pool (Figure 2.1 indicates the location) contained plentiful native species of all sizes when surveyed by Harrison (1939), but a 1949 survey (conducted after the black bass invasion) noted a marked decrease in the numbers of native fish, especially of the smaller species (Scott 1982). Further anecdotal evidence was reported in a 1949 letter by Mr TH Brooks to the Cape Piscatorial Society: "For the past two seasons I have looked in vain for the shoals of yellowfish (*Labeobarbus capensis*) and other indigenous fingerlings - in previous seasons the shallows in both the Olifants and Jan Dissels Rivers were black with these fingerlings. If as I think the bass are destroying the 'yellows', then I regret my part in introducing the bass" (Gaigher 1973, p. 75).

During 1960, Rex Jubb conducted fish surveys in the Olifants River system and mentioned that the smaller species could not be found within the mainstream where it flowed through the Clanwilliam and Citrusdal areas (Jubb 1961). Van Rensburg (1966) did extensive surveys between Keerom and Klawer in the Olifants Management Area (Figure 2.1) between November 1963 and October 1964 and he mentioned that black bass were present almost everywhere in the mainstream and in some tributaries (Ratel River, Boontjies River, Heks River and Rondegat River). In the Heks River, black bass were the only fish that he encountered. Van Rensburg (1966) also mentioned that he never found native minnows or small Clanwilliam yellowfish *Labeobarbus capensis* (Smith 1841) in the presence of black bass in the tributaries. He also did not report any minnows or Cape galaxias *Galaxias zebratus* (Castelnau 1861) in the mainstream Olifants River.

Gaigher (1973) surveyed the ODR system in the early 1970's and reported that no juveniles of large native fish or small native species could be found where alien species were present. He was also the first person to remark that the native fish would only survive above waterfalls that prevent black bass access to the native fish above these barriers. He gave a good description of the black bass barrier in the Ratel River where he noted that: "Above a natural barrier, a small fall of only a metre and a half however, the river is literally an aquarium of "red-fins" and under-yearling sawfins" (Gaigher 1973, p. 76-77). He also noted that there are similar areas that protect native fish from alien invasive fish in the ODR system but did not provide details on the precise locations. Skelton (1974) described a new species of redfin in the Twee River catchment that he mentioned was protected from black bass by a seven meter waterfall.

Gaigher *et al*. (1980) did extensive surveys in the ODR system and regarded *M. dolomieu* as the most destructive predator in the ODR system. Bills (1999) did extensive fish surveys in the ODR system in 1998 while undertaking research on Clanwilliam rock catfish *Austroglanis gilli* (Barnard, 1943) and spotted rock catfish *Austroglanis barnardi* (Skelton, 1981). He noted that he encountered *M. dolomieu* and *M. punctulatus* all over the ODR system but found that *A. gilli* was able to co-exist with *M. dolomieu* and *M. punctulatus* in the Jan Dissels River, Heks River, Matjies River and Boontjies River tributaries (Figures 2.2 and 2.8). However, he did not encounter any other native fish in the presence of black bass in the Jan Dissels River. In 1999 Impson (1999) did an extensive survey of the upper Doring River between De Mond and Elandsvlei (Figure 2.1) and he reported that black bass were present in all pools but that large individuals of the large-bodied native species (*L. capensis, L. seeberi* and *B. serra*) still managed to co-exist with the black bass. Subsequent surveys by Paxton *et al*. (2002) in 2001 confirmed this and his survey extended to the confluence of the Olifants River.

Swartz *et al*. (2004) studied the genetics of the redfin species in the ODR system and he noted that the predation by black bass prevented gene flow between tributaries and thus caused fragmentation in redfin populations. He also suggested that black bass displace redfins through predation rather than competition. He also noted that the biggest impact on the minnows was on the fiery redfin *Pseudobarbus phlegethon* (Barnard, 1938) as they occupy mid-to lower sections of tributaries in the ODR system. The mainstream Olifants and Doring River is 100 % invaded by black bass (Swartz 2000; Paxton *et al*. 2002).

The most data on bass impacts are available for the Rondegat River, which has been studied in detail since 2003 (Weyl *et al*. 2014). Woodford *et al*. (2005) compared the fish species composition above and below a natural black bass barrier in the lower Rondegat River. Five native species were present above the barrier with only one of the larger native species co-occurring with *M. dolomieu* below the barrier. Although there were other anthropogenic influences on the biota of the river, they concluded that *M. dolomieu* was responsible for the absence of the other four native species below the barrier. Woodford *et al*. (2005) regarded *M. dolomieu* as the alien fish that caused the most damage to the indigenous fish populations in the ODR system and they recommended that controlling the spread of black bass in the ODR system should be a priority. Consequently the Rondegat River below the black bass barrier was treated with rotenone to eradicate *M. dolomieu* in 2012 (Jordaan *et al*. 2012; Weyl *et al*. 2013; Weyl *et al*. 2014).

While there is much literature on black bass introductions and impacts in the ODR, there has never been a comprehensive basin-wide assessment of establishment and spread. In addition, prior to the current study the status of the black bass invasion in ODR was neither qualified nor quantified. This constrains the implementation of effective conservation measures. To contribute to the knowledge on black bass invasions in the ODR the current chapter presents research on the fish species composition above and below other natural bass barriers in the ODR system to provide the first system wide study of black bass impacts on native species. To do this, the hypothesis that "native fish abundance is lower in invaded pools immediately below barriers limiting the upstream movement of black bass" was tested.

4.2 Materials and Methods

4.2.1 Data collection procedures

(a) Determining the extent of the black bass invasion

Field surveys to locate black bass invaded tributaries and the upper limit of black bass distribution in rivers of the ODR system were conducted between October 2012 and September 2014. The methods used and locations of invasion barriers are documented in Chapter 3 and a brief summary is provided here (Table 4.1).

Table 4.1 Summary of the extent of the black bass invasion in the Olifants- Doorn River system in the 41 tributaries investigated as part of this study (More information in Chapter 3).

Management Area	Tributary	Stream order (E= ephemeral; S= seasonal)	Black bass present	Micropterus dolomieu	Micropterus punctulatus	Micropterus salmoides	Natural bass barrier present	Bass species per tributary	Stream length invaded by black bass (km)	Stream length with native cyprinids and no bass (km)	Stream length with bass and or cyprinids (km)	Extent of black bass invasion (%)
Olifants	Olifants Gorge	3	y	y	y		y	2	4.9	5.6	10.5	46.9
	Upper Boschkloof River	2						0	0.0	0.3	0.3	0.0
	Lower Boshkloof River	2						0	0.0	0.0	0.0	0.0
	Diepkloof River	2	y	y			y	1	4.3	2.3	6.6	64.7
	Dwars River	2	y	y			y	1	1.0	1.1	2.0	48.5
	Ratel River	3	y	y	y		y	2	2.2	5.5	7.7	28.2
	Oudste River	1						0	0.0	7.5	7.5	0.0
	Thee River	3	y		y			1	5.1	5.3	10.4	49.3
	Noordhoeks River	3						0	0.0	18.0	18.0	0.0
	Boontjies River	3	y	y	y		y	2	5.8	6.7	12.4	46.5
	Boskloof River	2	y	y	y		y	2	0.1	10.6	10.7	0.5
	Markuskraal River	2						0	0.0	1.2	1.2	0.0
	Heks River	3	y	y			y	1	21.3	1.1	22.3	95.3
	Elandskloof River	2						0	0.0	0.3	0.3	0.0
	Rondegat River	2	y	y	y		y	2	1.3	20.4	21.7	5.9
	Jan Dissels River	3	y	y			y	1	31.6	2.1	33.7	93.8
	Kliphuis River	s						0	0.0	0.2	0.2	0.0
	Troe Troe River	s						0	0.0	1.1	1.1	0.0
Knersvlakte	Sout River	E						0	0.0	0.0	0.0	0.0
Doring	Gif River	s						0	0.0	4.2	4.2	0.0
	Oorlogskloof River	s	y	y	y		y	2	52.4	18.7	71.1	73.8
	Brandewyn River	s						0	0.0	3.1	3.1	0.0
	Kransgat River	s						0	0.0	1.0	1.0	0.0
	Biedouw River	s	y		y		y	1	32.7	0.9	33.6	97.4
	Tra Tra River	3	y	y	y		y	2	34.1	0.5	34.6	98.5
	Eselbank River	2	y	y	y		y	2	8.9	1.9	10.8	82.3
	Martiensrus River	s						0	0.0	0.0	0.0	0.0
	Tankwa River	E						0	0.0	5.3	5.3	0.0
	Upper Doring River	E						0	0.0	0.0	0.0	0.0
Koue Bokkeveld	Driehoek River	3	y			y		1	24.8	0.9	25.7	96.3
	Dwars River	2						0	0.0	0.0	0.0	0.0
	Krom River	2	y			y		1	8.1	0.0	8.1	100.0
	Matjies River	3	y	y	y		y	2	13.4	11.0	24.5	54.9
	Breekkrans River	2	y	y	y		y	2	19.3	4.2	23.5	82.1
	Groot River	4	y	y	y			2	31.7	0.0	31.7	100.0
	Tuinskloof River	s						0	0.0	0.0	0.0	0.0
	Rietkloof River	s						0	0.0	0.1	0.1	0.0
	Twee River	3	y	y	y		y	2	0.9	34.2	35.1	2.5
	Leeu River	3	y	y	y	y	y	3	20.6	0.0	20.6	100.0
	Langkloof River	1						0	0.0	3.0	3.0	0.0
	Riet River	s	y			y		1	75.9	0.0	75.9	100.0
	Total		22	17	15	4	17		400.2	178.2	578.4	

The initial survey indicated that *M. dolomieu* or *M. punctulatus,* or both, invaded 17 tributaries in the ODR system and that a natural barrier always defines their upper limit. Sixteen of the 17 bass-invaded tributaries (Table 4.1) were chosen for further study. The only exclusion was the Rondegat River where *M. dolomieu* were eradicated using rotenone as part of the Rondegat rehabilitation project in March 2012 and March 2013 (Weyl *et al*. 2013; Weyl *et al*. 2014). The results of pre-rotenone distributions of native fish and black bass in the Rondegat River were however included in the presence/absence comparative analyses.

(b) *<u>Fish species and abundance above and below bass barriers</u>*

Snorkel surveys were used to determine the species composition and abundance below and above natural black bass barriers in the ODR system.

In each of the 16 tributaries, the first three pools below and first three pools above black bass barriers were surveyed to record fish species composition and abundance. A pool was defined as a portion of the stream with reduced current velocity and is in most cases deeper than the surrounding areas (Helm 1985). Pools are preferred habitat of black bass species in rivers (Edwards *et al*. 1983) and are suitable for sampling using snorkel surveys. The average (± S.D.) dimensions of the pools in the 96 sample sites were 24.2 ± 15.6 m long, 6.6 ± 3.0 m wide and 0.78 ± 0.3 m deep.

Pools sampled were always located within 500 m below and 500 m above the black bass barriers. To record fish abundance and species composition a single snorkeler entered pools on the downstream side and then swam upstream in a zigzag pattern to the top of the pool as a single pass. This minimized the initial disturbance and prevented visibility problems. Only pools were sampled for this study because all the native and bass species occupy pool habitats (Skelton 2001). The observer communicated the data to a land based assistant whom recorded the data on a standard data sheet that was developed for this study (Appendix C). Fish were counted as the snorkeler passed them to reduce double counting of fish.

(c) <u>Estimating fish abundance and length</u>

Estimation of fish length was done through visual observation by the snorkeler. Training exercises were done before the surveys whereby the snorkeler first estimated fish length and then captured the fish to verify results. Only after a satisfactory level of competency was achieved were surveys initiated. Although the estimations are a subjective measure it is considered useful as all the estimations were done by the same person in the same way which thus make comparisons of species composition and size possible between streams, as well as above and below barriers. Fish species were divided into length classes depending on the species. The native minnow species (excluding *B. anoplus*) was classified into one of four total length (TL) size classes: 0-3, 3-6, 6-9, >9 cm. *Barbus anoplus* was classed into three length classes: 0-3, 3-6, 6-9. The larger native cyprinids (*L. capensis*, *B. serra* and *L. seeberi*) were classified into five length classes: 0-5, 5-15, 15-30, 30-45, >45 cm. The native rock catfish species were classified into four length classes: 0-5, 5-10, 10-20, >20 cm. Black bass species were classified into five length classes: 0-10, 10-20, 20-30, 30-40, >40 cm.

4.2.2 Data analysis

Each pool sampled was regarded as a sample site. Therefore, tributary specific fish abundance was assessed in three sample sites below the bass barrier and three sample sites above the bass barrier resulting in 96 sample sites. Species composition was expressed as the percentage that any species contributed to the total number of fish either above or below the bass barrier in each tributary.

To assess for the relationship between native fish and black bass abundance the data were graphed. This preliminary analysis indicated that the dataset was binary and thus further analyses were conducted using a two regions (above and below barrier) x two (presence absence) contingency table (Zar 1999) to determine whether the location of a site below or above a barrier has a significant effect ($p = 0.05$) on whether a native species is present. In this case, the dataset was expressed as 16 tributaries. In addition, length frequency of native fish in invaded and non-invaded zones was also expressed graphically.

4.3 Results

4.3.1 Species composition above and below bass barriers

There was a marked difference in the native species composition above and below the black bass barriers in the 16 tributaries with natural bass barriers (Tables 4.2 and 4.3). Seven native species were recorded above the sixteen black bass barriers while only four native species were recorded below the black bass barriers. Three of the four native species recorded below the black bass barriers were the large cyprinids (adult >25 cm) endemic to the ODR system namely *L. capensis*, *Barbus serra* (Peters 1864) and *L. seeberi*. *Barbus calidus* Barnard, 1938 was the most frequent native species above bass barriers as it was recorded in 10 out of the 16 rivers. *Barbus calidus* were also the only minnow species recorded below a black bass barrier with two specimens recorded in the Breekkrans River. One native species, *L. seeberi* was only recorded in the Oorlogskloof tributary above a barrier.

There was also a marked difference in alien fish species other than black bass below and above black bass barriers with five other alien species recorded above black bass barriers and only two species co-occurring with black bass below barriers. Alien species other than black bass were recorded in six tributaries above barriers but only in three tributaries below black bass barriers. Only two of the three introduced black bass species were recorded in the three pools below black bass barriers. The other black bass, *M. salmoides* have been recorded in four tributaries where they have been introduced above natural barriers (Paxton 2008; Marr 2011; Marr *et al*. 2012). *Micropterus dolomieu* was the most frequent species and was recorded in 13 tributaries while *M. punctulatus* was recorded in nine tributaries with co-occurrence of the two species in six tributaries.

Table 4.2 A summary of the species abundance below black bass barriers from 16 black bass invaded tributaries. Values displayed are the combined numbers of fish sampled in the three sample pools below each black bass barrier.

Tributary	Native species abundance											Bass species				Other alien fish abundance						
	B. calidus	L. capensis	A. gilli	B. serra	B. anoplus	G. zebratus	P. phlegethon	L. seeberi	A. barnardi	B. erubescens	All native species abundance	M. dolomieu	M. punctulatus	M. salmoides	All black bass abundance	S. trutta	O. mykiss	L. macrochirus	S. capensis	O. mossambicus	T. sparmanii	Other aliens abundance
Olifants Gorge		9									9	7			7							0
Diepkloof River											0	8			8							0
Dwars River											0	22	1		23							0
Ratel river		3		5							8	19	3		22							0
Boontjies River											0	9	4		13			4				4
Boskloof River											0	11	12		23						1	1
Heks River											0	5			5							0
Jan Dissels River											0	11			11							0
Oorlogskloof River											0	33			33			1303			210	1513
Biedouw River		5		7				2			14		7		7							0
Tra Tra River											0	6	12		18							0
Eselbank River											0	10			10							0
Matjies River											0	5			5							0
Breekkrans River	2										2		4		4							0
Twee River		20									20	4	6		10							0
Leeu River											0		22		22							0

Table 4.3 A summary of the species abundance above black bass barriers from 16 black bass invaded tributaries. Values displayed are the combined numbers of fish sampled in the three sample pools below each black bass barrier.

Tributary	Native species abundance											Black bass				Other alien fish abundance						
	B. calidus	L. capensis	A. gilli	B. serra	B. anoplus	G. zebratus	P. phlegethon	L. seeberi	A. barnardi	B. erubescens	All native species abundance	M. dolomieu	M. punctulatus	M. salmoides	Black bass species abundance	S. trutta	O. mykiss	L. macrochirus	S. capensis	O. mossambicus	T. sparmanii	Other aliens abundance
Olifants Gorge		266									266				0	1						1
Diepkloof River	192										192				0		2					2
Dwars River	395			120							515				0							0
Ratel river	930	106		153							1189				0							0
Boontjies River											0				0			101				101
Boskloof River							3				3				0						284	284
Heks River	18		1								19				0							0
Jan Dissels River	396	2									398				0							0
Oorlogskloof		153		15	3			4			175				0			15			186	201
Biedouw River	420	68									488				0							0
Tra Tra River	1597	150									1747				0							0
Eselbank River	1056	80		122							1258				0							0
Matjies River	148	82									230				0							0
Breekkrans River	185		1								186				0							0
Twee River		118									118				0			75	1			76
Leeu River											0				0							0

4.3.2 Co-occurrence of native species and black bass

Relationships between abundance of black bass and abundances of individual native species across all snorkelled pools are shown in Figure 4.1. The relationship between black bass and native fish abundance is mainly binomial. *Labeobarbus capensis* was found to co-occur with black bass in only four tributaries (Biedouw River, Ratel River, Twee River and Olifants Gorge) while *B. serra* was found below the black bass barriers in the Ratel and Biedouw River. The Biedouw River was the only site with *L. seeberi* below the black bass barrier. Smaller-bodied minnow species were absent in the presence of bass, the only exception was *Barbus calidus* that were sampled in 10 tributaries above the black bass barriers but only in one tributary below the black bass barrier (Breekkrans River). In that case, the sample comprised only two adult fish.

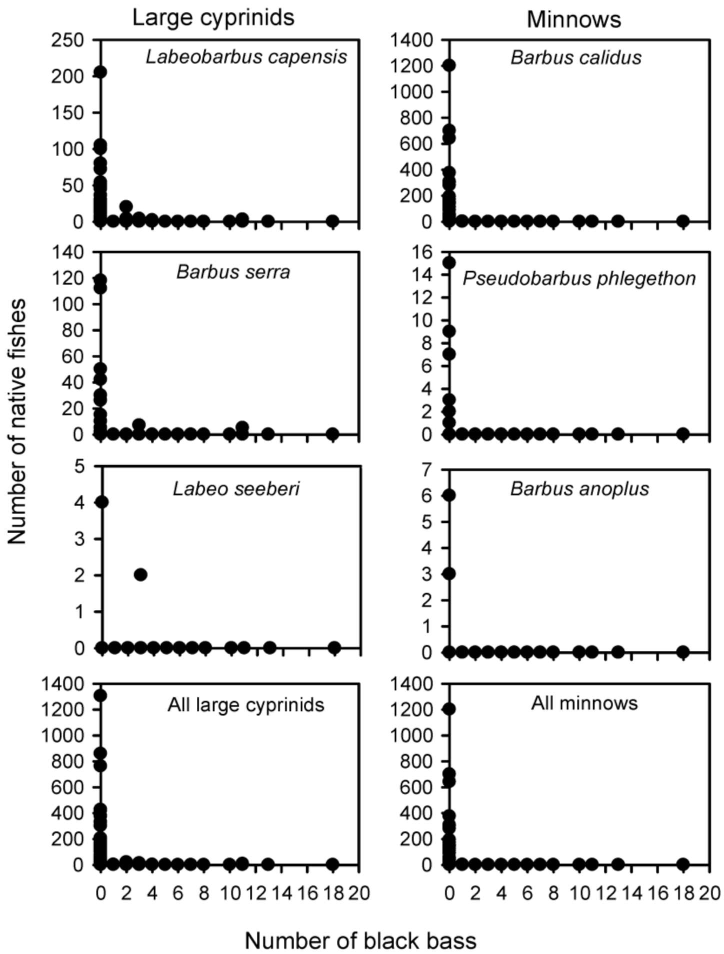

Figure 4.1 Relationships between abundance of black bass and abundances of individual native species across all snorkelled pools. Each data point represents a sample pool. Only eight sample pools out of 96 contained both native species and black bass.

4.3.3 Presence / absence of native species.

The presence and absence of native fishes above and below invasion barriers for 17 rivers (including historical data for the Rondegat River) are presented in Table 4.4 and Figure 4.2. *Austroglanis gilli* was also recorded in the Heks and the Breekkrans River but their data were discarded due to their cryptic and nocturnal behaviour that might lead to bias and incorrect interpretation (Weyl *et al*. 2013). All native species were present in more tributaries above barriers than they were below but this trend was not always statistically significant. Results of the contingency table analysis of the presence/absence of native fishes above and below barriers in 17 rivers are provided in Table 4.4. There was no significant difference in the presence of large cyprinids (*L. capensis, B. serra, L. seeberi*) above and below barriers. The small minnows *B. calidus* ($p < 0.001$) and *P. phlegethon* ($p < 0.05$) were present in a significantly higher proportion of tributaries above barriers than below. *Barbus anoplus* was sampled in one study site above the bass barrier in the Oorlogskloof (one specimen) and one sample site above the black bass barrier in the Eselbank River (one specimen).

Table 4.4 Summary of Chi-square 2 x 2 Contingency Table analysis of the dependence of the presence/absence of native fishes on river reach (below or above invasion barriers) in the Olifants Doorn River system, Western Cape, South Africa. n= 17 tributaries.

Species	**Below (present/absent)**	**Above (present/absent)**	**CHI Square Value**	**Df**	**P**
B. calidus	1/16	11/6	12.80	1	<0.001
L. capensis	5/12	10/7	2.98	1	0.08
B. serra	2/15	4/13	0.81	1	0.37
B. anoplus	0/17	1/16	1.03	1	0.31
P. phlegethon	0/17	4/13	4.53	1	0.03
L. seeberi	1/16	1/16	0.00	1	1.00
All minnows	1/16	12/5	15.06	1	<0.001
All native fishes	6/11	15/2	10.08	1	0.001

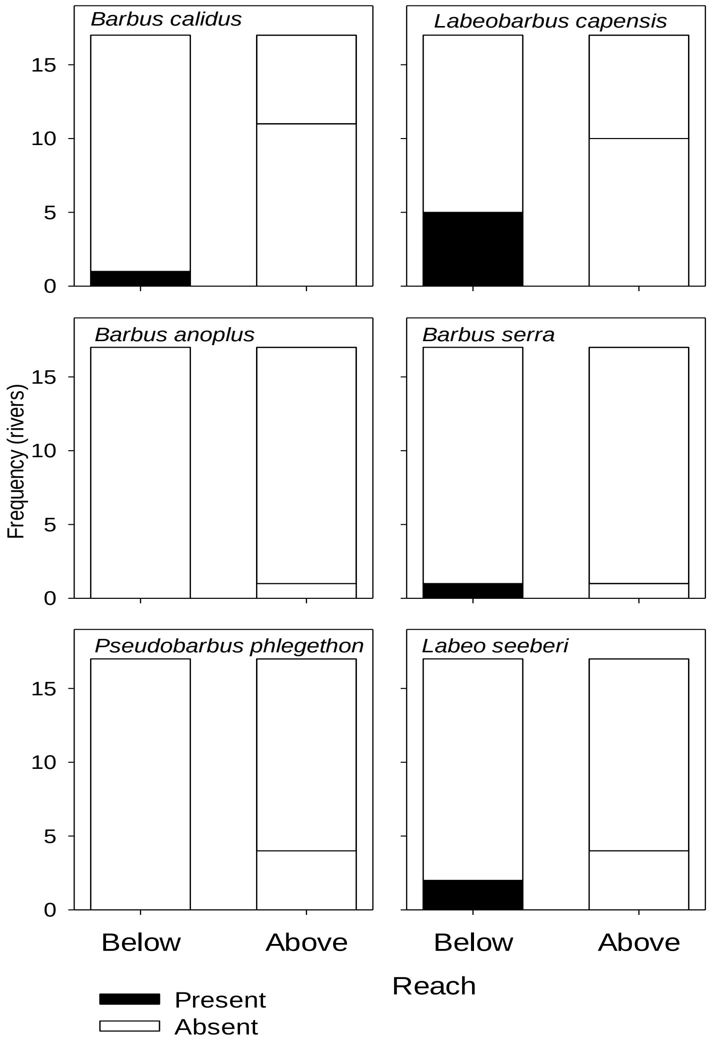

Figure 4.2 Proportions of 17 tributaries at which each of six native fish species were present or absent above and below 17 black bass invasion barriers in the Olifants- Doorn River system, Western Cape and Northern Cape, South Africa.

4.3.4 Length structure of native fish populations

(a) <u>Large native cyprinids</u>

Only larger length classes of the larger native species were present below the bass barriers (Figure 4.3). In total, 756 *L. capensis* and 285 *B. serra* between 0-5 cm in length were sampled above black bass barriers while none were found below the barriers. The three large cyprinids in the ODR system (*L. capensis*, *L. seeberi* and *B. serra*) had no specimens smaller than 20 cm in the sampled sites below black bass barriers.

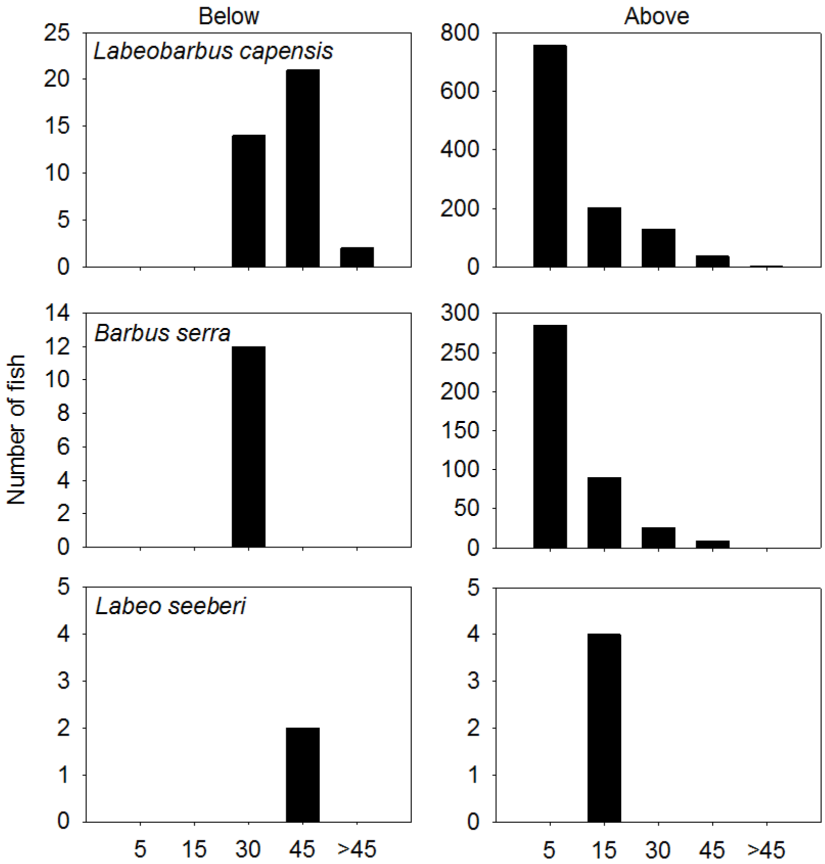

Figure 4.3 Frequency distributions of large native species length classes above and below 16 black bass barriers in the Olifants- Doorn River system, Western Cape and Northern Cape, South Africa. Note that the y-axis scale differ between the above and below barriers graphs for *L. capensis* and *B. serra* due to the large difference in numbers.

(b) <u>*Native minnows*</u>

All the length classes of the native minnows were absent below the black bass barriers (Figure 4.4). The only exception was *B. calidus* with two specimens in the 3-6 cm length class. *Barbus calidus* had large numbers of all the length classes above the black bass barriers. *Pseudobarbus phlegethon* and *B. anoplus* were only encountered above the black bass barriers and their numbers were relatively low compared to *Barbus calidus*.

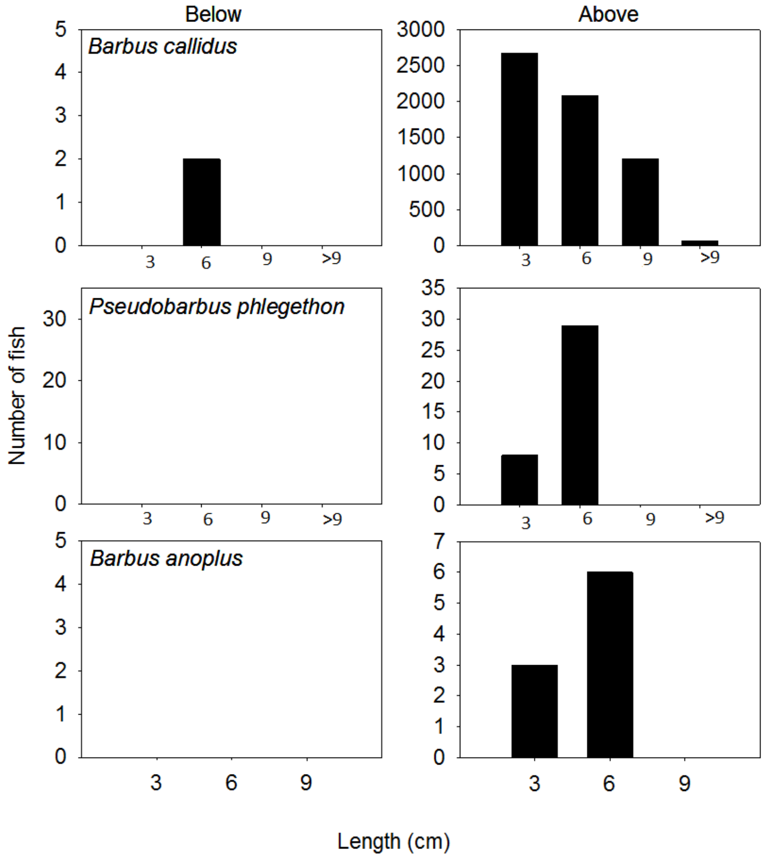

Figure 4.4 Frequency distributions of native minnow species length classes above and below the 16 black bass barriers in the Olifants- Doorn River system, Western Cape and Northern Cape, South Africa.

4.3.5 Length classes of black bass below the black bass barriers

The length classes of *M. dolomieu* and *M. punctulatus* showed similarities as the class most commonly encountered was the 10-20 cm length class (Figure 4.5). The only specimen sampled in the >40 cm length class was *M. dolomieu* in the Olifants Gorge (Figure 3.6).

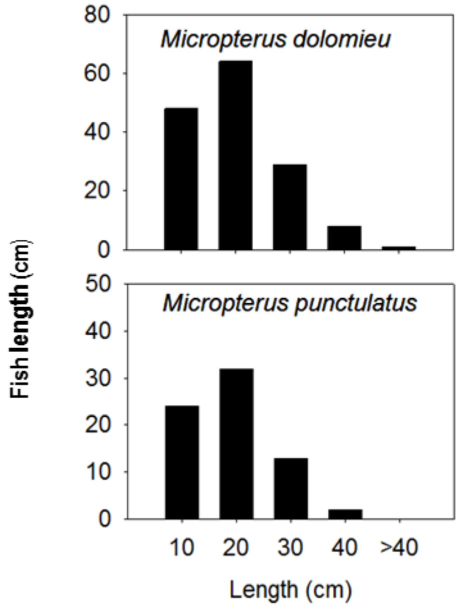

Figure 4.5 Length classes for all the *M. dolomieu* (n= 150) and *M. punctulatus* (n= 71) recorded below the 16 black bass barriers in the Olifants- Doorn River system, Western Cape, South Africa.

4.4 Discussion

4.4.1 Species composition and co-occurrence above and below black bass barriers

Snorkel surveys proofed to be an effective method to sample the headwater tributaries of the ODR system. The majority of tributaries had exceptionally clear water and snorkel surveys are a recognized method to sample fish communities under these conditions (Mullner & Hubert 1998). It has been used extensively in the area (e.g. Woodford *et al*. 2005; Shelton *et al*. 2008; Weyl *et al*. 2013) and is the only practical method that could be used as most of the study sites were located in remote mountain areas. Electrofishing was not feasible due to the low conductivity (Paxton 2008) in the headwater tributaries of the ODR system that render it ineffective (Cooke *et al*. 2012). Electrofishing could also be potentially harmful to threatened species (Mueller 2002; Ellender *et al*. 2012).

The combined and individual results of the species composition data indicate that the smaller minnow species are predated on by the black bass, as they were absent below the black bass barriers in all but one of the 48 sample pools. In that case, the site only contained two individual fish. Above the black bass barriers, the species composition was dominated by native species including the smaller minnow species. These results are consistent with the results from the study done by Woodford *et al.* (2005) on the Rondegat River and with anecdotal observations made by Jubb (1961), van Rensburg (1966) and Gaigher (1973). Ellender *et al.* (2011) found similar results in their study in the Blindekloof River where the native minnows were only present above a black bass barrier. Repeated observations of the fish species composition below and above the black bass barrier at Rooidraai Waterfall on the Rondegat River demonstrated that small minnow species (*B. calidus* and *P. phlegethon*) were absent from the black bass invaded section below the waterfall until *M. dolomieu* were removed from the river (Woodford *et al*. 2005; Weyl *et al*. 2013; Weyl *et al*. 2014). The only native fish present below the black bass barrier were adult *L. capensis* that were too large to be preyed upon by *M*. *dolomieu* (Weyl *et al*. 2013). This was also consistent with the findings of the current study, which demonstrated that *L. capensis* size structure in invaded reaches was dominated by adults (Figure 4.4). The data from the Rondegat River also indicate that the main driver explaining these fish distributions was the presence or absence of black bass (Woodford *et al*. 2005; Weyl *et al*. 2013; Weyl *et al.* 2014). This was supported by the rapid recovery of native fishes following the removal of *M. dolomieu* in the Rondegat River (Weyl *et al*. 2013; Weyl *et al.* 2014).

The only inconsistency with the Rondegat data is the two adult *B. calidus* that were sampled below the black bass barrier during this study in the Breekkrans River. The Breekkrans River had dense riparian vegetation, before a veld fire cleared all the vegetation in February 2013. The river was sampled in November 2013 and it was apparent that the winter rains on the burnt area resulted in the sedimentation of the pools and alteration of the exposed riverbed. The most likely scenario is that two minnows were washed down during winter flooding and thereafter avoided predation from the black bass. Only one individual black bass was found in the same pool with the two minnows. Another indicator of the black bass impact is the difference in minnow numbers above and below black bass barriers. The combined results of all 16 rivers indicate that 4337 *B. calidus* were sampled above the bass barriers but only two below the barriers.

Studies in the ODR system indicate that *P. phlegethon* prefer the middle to lower sections of tributaries (Gore *et al*. 1991; Bills 1999; Swartz 2000) which are generally located below black bass barriers. This would imply that in tributaries where *P. phlegethon* was not sampled above barriers they were probably never present before the black bass invasion. Swartz (2000) noted that black bass could have been responsible for the extinction of *P. phlegethon* in the Jan Dissels River, Heks River, Boontjies River and Ratel River. Only one native minnow, *B. anoplus*, showed no significant difference in terms of presence and absence below and above black bass barriers and this could be attributed to low sample size as it was recorded from only two tributaries. *Barbus anoplus* seems to be the least impacted by black bass as they occurred mostly in the top sections of small tributaries (which were mostly first order streams) where black bass were absent.

Anthropogenic impacts such as water pollution and habitat alteration can potentially alter fish composition, but five of the 22 black bass invaded rivers (Diepkloof River, Dwars River, Heks River, Jan Dissels River and Breekkrans River) in the ODR system have no anthropogenic impacts above the black bass barriers and these rivers show the same pattern as the rest. The presence of other alien species can also not be attributed to the lack of native minnows below black bass barriers as the only other alien species sampled below the black bass barriers were *Tilapia sparrmanii* and *Lepomis macrochirus* (Table 4.2). A study by Gratwicke (2001) in a Zimbabwean stream found that *T. sparrmanii,* a native species in Zimbabwe, was able to co-occur with the native minnow species. This study also found co-occurrence above black bass barriers with native minnows. Also adding to this evidence is the fact that the numbers and diversity of other alien fish above the black bass barriers was more than below. This also suggests that black bass prey on these other alien fish. This implicates that black bass are likely to be the only factor responsible for the significant difference in native species composition above and below the black bass barriers.

The results of this study therefore supported the hypothesis that native fish abundance is lower in invaded pools immediately below barriers limiting the upstream movement of black bass, as was observed in the Rondegat River. These results are in agreement with other studies that found that small bodied fishes are mostly absent in the presence of black bass (Woodford *et al*. 2005; Lowe *et al*. 2008; Weyl *et al*. 2013). Takamura (2007) listed prey size and black bass gape size as factors that determine the performance of black bass as a predator. All the native minnows and the smaller size classes of the large cyprinids in the ODR system can potentially be predated on by black bass due to their small body size. The results from the larger cyprinid size classes suggest that native species longer than 15 cm become immune to black bass predation. The results from this study is in agreement with this statement as the smaller fish and juvenile forms of larger cyprinids were absent below bass barriers while larger cyprinids co-occurred.

Another factor that may affect the predation performance of black bass is the clarity of the water, as black bass are regarded as visual predators (Brown *et al*. 2009a; Brown *et al*. 2009b). All the black bass barriers were located in headwaters with clear water. A third factor affecting black bass performance listed by Takamura (2007) is the refuge for native fish in terms of aquatic vegetation. The headwaters in the ODR are mostly free of weed beds that might provide refuge in other lotic systems. The study by Alexander *et al*. (2014) also demonstrated that black bass predation increases in less complex habitats as these habitats provide less refuge for native fish.

4.4.2 Length classes of black bass

The data from the Rondegat River (Woodford *et al*. 2005; Weyl *et al*. 2013) indicated that the majority of the black bass were in the 0-10 cm length class while the data from this study revealed that most black bass were in the 10-20 cm length class. This could be as a result of the removal of black bass by volunteer anglers before the rotenone treatment in March 2012. The Rondegat River is also a small second order stream while some of the study sites in the 16 tributaries were situated in larger third and fourth order streams containing larger pools that would favour larger black bass.

4.4.3 Genetic isolation of species

This study supports the concerns of Swartz (2000) that predation by black bass leads to isolation of the native minnow species. This isolation leads to total absence of gene flow between tributaries.

4.5 Concluding remarks

This catchment-scale study confirms that black bass has had a negative impact on the native fish in the ODR system since their introduction more than 80 years ago. The available habitat for the threatened native fish would be increased if black bass were eradicated from selected tributaries in the ODR system. Black bass barriers play an important role in protecting native species. The available habitat for threatened native fish can be increased if artificial black bass barriers can be constructed in selective tributaries and black bass eradicated above these barriers.

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CHAPTER 5

THE MANAGEMENT OF INVASIVE ALIEN BLACK BASS, *MICROPTERUS* SPP. IN THE HEADWATERS OF THE OLIFANTS- DOORN RIVER SYSTEM

5.1 Introduction to the control and eradication of alien black bass in the Olifants- Doorn River system

As a result of the almost system-wide invasion (Chapter 3), and widespread impacts on native fishes (Chapter 4), black bass invasions are a major conservation concern. The threatened status of the native fish in the ODR system (Darwall *et al.* 2009) makes management interventions an urgent requirement. The ODR system extends over two provinces, namely the Western Cape Province and the Northern Cape Province. CapeNature is the public institution responsible for biodiversity conservation in the Western Cape Province while the Northern Cape Department of Environment and Nature Conservation (DENC) fulfil the same function in the Northern Cape Province. Part of CapeNature and DENC's responsibilities are the implementation and enforcement of legislation relating to black bass in their respective provinces.

5.1.1 Black bass legislation relevant to the Olifants- Doorn River system

Currently there are two sets of National legislation pertaining to black bass. The National Environmental Management: Biodiversity Act (Act No. 10 of 2004) (hereafter NEM:BA) and the Protected Areas Act (Act No. 57 of 2003). The NEM:BA legislation aims to protect the biodiversity of South Africa. Alien invasive species regulations have been promulgated under the NEM:BA Act and these regulations came into effect on 1 October 2014 (South Africa 2014a; South Africa 2014b). These regulations have divided alien invasive species in South Africa into four categories (1a, 1b, 2 and 3). These four categories specify different management implications towards the alien species. *Micropterus dolomieu*, *Micropterus punctulatus* and *Micropterus floridanus* have been listed under category 1b in National Parks, Provincial Reserves, Mountain Catchment Areas and Forestry Reserves declared in terms of the Protected Areas Act (Act No. 57 of 2003). This means that *Micropterus* spp. in these areas must be controlled by a management plan. They are also listed in category 2 for the introduction into dams, which means that a permit is needed to introduce them into a dam in a catchment where they already occur. They are also listed in category 3 in rivers, lakes and wetlands in which they occur. This means that they are exempted from certain restrictions. The regulations pertaining to *M. salmoides* are different as they are listed in category 2 in formal protected areas. The regulations also specify that none of the four *Micropterus* spp. in South Africa may be introduced into a discreet catchment in which they do not occur or introduced above an artificial or natural barrier within a discreet catchment where they do not already occur. The other provincial legislation relating to black bass is the Nature Conservation Ordinance 19 of 1974 in the Western Cape and the Northern Cape Nature Conservation Act (Act no. 9 of 2009) that is applicable in the Northern Cape Province. Both these sets of provincial legislation prohibit the live transport and/or release of black bass in any water body without a valid permit.

5.1.2 Management of black bass in the Olifants- Doorn River system

Up to 2005, the only management of black bass in the ODR system was to enforce the provincial legislation relating to the transport and stocking of live black bass. In 2001, new opportunities for black bass management arose with international funding for the Cape Action for People and the Environment (CAPE) project. The CAPE projects aim was to conserve and restore the biodiversity of the Cape Floristic Region (CFR) and the adjacent marine environment, while delivering significant benefits to the people of the region. One of the deliverables of the CAPE project was to identify threats to the biodiversity in the CFR (Younge & Fawkes 2003). The CAPE project identified invasive alien fish as a threat to the survival of the native freshwater fish in the CFR and recommended that alien fish should be eradicated from key tributaries in the CFR (Tweddle 2009). The key methods for implementation are chemical (using the piscicide rotenone) and mechanical (capture) methods of removal.

5.1.3 Chemical methods

Four tributaries in the CFR were selected for alien fish eradication and in 2005, Enviro-Fish Africa (Pty) Ltd was contracted to conduct an environmental impact assessment for the four priority CAPE rivers (Marr *et al*. 2012). Two of the four rivers were only invaded by *M. dolomieu* (Rondegat River, ODR and Krom River, Eastern Cape) while the Twee River (ODR) is invaded by Cape kurper *Sandelia capensis* and the Krom River (ODR) by rainbow trout

Oncorhynchus mykiss . It was decided that the Rondegat River, where *M. dolomieu* had invaded the lower 4 km of the river up to a natural waterfall barrier (Rooidraai waterfall), would be the pilot project and the first rotenone treatment took place on 29 February 2012 (Weyl *et al*. 2014). This treatment was planned using inputs from international experts and the American Fisheries Society Rotenone Standard Operating Procedures Manual (Finlayson *et al*. 2010). The Rooidraai waterfall barrier was the site of the first drip station that released rotenone into the river while three other drip stations were evenly spaced lower down in the river. A water abstraction weir lower down was upgraded before the treatment to prevent *M. dolomieu* from re-invading the treatment zone.

Independent monitoring showed that the treatment was successful (Weyl *et al*. 2013; Weyl *et al*. 2014). During the first treatment 470 *M. dolomieu* were removed from the treatment zone while 137 dead native Clanwilliam yellowfish *Labeobarbus capensis* were also collected after the treatment (Weyl *et al*. 2014). A second rotenone treatment (16 March 2013) was conducted as recommended by international best practice (Finlayson *et al*. 2010). No *M. dolomieu* were removed after the second treatment, but approximately 3000 juvenile native fish were killed. This demonstrated that black bass had been eradicated from the treatment area and that there was substantial recruitment of both redfins (*Pseudobarbus phlegethon* and *Barbus calidus*) and *L. capensis* into the area where black bass had been removed (Weyl *et al*. 2013; Weyl *et al*. 2014). Monitoring of invertebrate communities also indicate rapid recovery of aquatic macro-invertebrate fauna after the two rotenone treatments (Woodford *et al*. 2013).

5.1.4 Mechanical methods

Between 2010 and 2013, CapeNature used mechanical methods to control a new invasion of spotted bass *Micropterus punctulatus* in the Thee River, which is one of the tributaries in the ODR system. The Thee River had no natural physical barrier that would prevent black bass from invading the river, but the river resisted invasion for almost 70 years until *M. punctulatus* was observed in 2007 (van der Walt 2011). The resistance to prior invasion was probably due to the lower 1000 meters of the river being dry during the summer months because of water abstraction from a temporary weir. The possibility that humans introduced bass above this point can thus not be excluded. The eradication of *M.*

punctulatus in the Thee River was initiated with the construction of a temporary barrier above the *M. punctulatus* invasion. *Micropterus punctulatus* were removed from the river with a combination of mechanical methods that included spearfishing, gill netting, hand netting and electrofishing. Between 2010 and 2012, 386 *M. punctulatus* were removed. Temporary barriers were also used to make control methods more manageable. In January 2014 *M. punctulatus* were observed above the previously invaded area and a subsequent removal effort located and removed a further 36 *M. punctulatus* from the Thee River. Further surveys in the upcoming years will determine if the eradication of *M. punctulatus* was successful. Literature indicates that globally there have been only a few successful mechanical fish eradication projects in rivers and none have been reported for South Africa (Halfyard 2010). In both the Rondegat and Thee River bass eradication projects artificial and natural barriers formed an integral part of eradication procedure.

The success of the Rondegat and Thee River projects laid the foundation for further action and in May 2013, a workshop was held to identify more tributaries in the CFR that could be earmarked for alien fish eradication. The workshop was attended by 20 representatives of CapeNature, South African Institute for Aquatic Biodiversity (SAIAB), Department of Water Affairs (DWA), freshwater consultants and various formal freshwater fishing institutions. At the workshop, CapeNature presented thirteen potential rivers that could be earmarked for alien fish eradication projects (Table 5.1) and after discussion, a 14th (the Driehoeks River in the Cederberg) was added to the list of rivers. The main criterion for choosing these tributaries was the threatened status of the native species that occur within these tributaries. It was also decided that this was a preliminary list and that the potential of alien fish eradication in other tributaries needs to be investigated further.

Table 5.1 Details of the 14 tributaries prioritised at the workshop of 30 May 2013 for alien fish eradication in the Western Cape Province.

Tributary	Catchment	Key threatened native fish	Key alien fish
Biedouw River	ODR system	*Labeo seeberi*	*Micropterus spp.*
Driehoeks River	ODR system	*Pseudobarbus sp. "phlegethon Doring"*	*M. salmoides*
Breekkrans River	ODR system	*Pseudobarbus sp. "phlegethon Doring"*	*Micropterus spp.*
Jan Dissels River	ODR system	*Barbus serra*	*M. dolomieu*
Heks River	ODR system	*Austroglanis banardi*	*M. dolomieu*
Twee River	ODR system	*Barbus erubescens*	*Sandelia capensis*
Middeldeur River	ODR system	*Barbus erubescens*	*Lepomis macrochirus*
Krom Antonies River	Verlorenvlei	*Pseudobarbus sp*. "burgi Verlorenvlei"	*M. salmoides*
Krom River	Breede River	*Pseudobarbus skeltoni*	*Oncorhynchus mykiss*
Upper Riviersonderend	Breede River	*Pseudobarbus skeltoni*	*Micropterus spp.*
Kars River	Heuningnes River	*Pseudobarbus sp*. "burchelli Heuningnes"	*M. dolomieu*
Poort River	Heuningnes River	*Pseudobarbus sp*. "burchelli Heuningnes"	*M. dolomieu*
Huis River	Breede River	*Pseudobarbus burchelli* Barrydale redfin	*M. dolomieu*
Tradouw River	Breede River	*Pseudobarbus burchelli* Barrydale redfin	*M. dolomieu*

It is envisaged that the current study will assist to make a more informed decision regarding eradication priorities in the ODR system. Seven of the 14 tributaries selected at the workshop on 30 May 2013 are located in the ODR system (Figure 5.1). Five of these rivers have *Micropterus* spp. as the target alien fish that should be eradicated.

The aim of the current chapter was therefore to undertake a prioritisation exercise to determine: (1) in which ODR system tributaries black bass should be eradicated and what order of priority should they be given and (2) if the five bass invaded ODR tributaries in the ODR system selected at the 30 May 2013 workshop are suitable for black bass eradication. In addition, personal experience is used to suggest suitable eradication methods and actions that could be implemented to manage black bass in ODR tributaries.

5.2 Assessment of tributaries suitable for black bass eradication in the Olifants-Doorn River system

The aim of this assessment is to use the data that were gathered during this study to evaluate all the black bass invaded tributaries in the ODR system and compare this prioritisation with the tributaries selected using "expert opinion" during the May 2013 workshop. Eight criterions were considered for the assessment, and which falls within four categories (biological, physical, anthropogenic and logistical feasibility). Table 5.2 lists and elaborates on these eight criteria. The socio economic impact of black bass eradication on the livelihood of stakeholders should also be considered in assessments like this. However, in none of the 22 tributaries evaluated are black bass exploited as an important food source or as an important angling attraction. For these reasons it was not considered in this study.

Table 5.3 is a summary of the assessment where the eight criteria were used to evaluate the 22 black bass invaded tributaries in the ODR system. These eight criteria were then used in a decision making matrix that is illustrated in Figure 5.1.

Table 5.2 List of critical criterion and explanations that were used to evaluate the suitability of tributaries in the Olifants- Doorn River system for black bass eradication.

Category	Explanations
Biological category	
Number of native species	Tributaries that contain only one native species were not further considered for black bass eradication, as it would not be cost effective to rehabilitate the tributary for one native species. Priority tributaries should preferably have a diversity of native species. Although there are 10 native fish species in the ODR system, none of the tributaries has more than six native species.
Length of river invaded by black bass	Rivers with less than 1 500 m invaded by black bass were also not considered, as this would also be not cost effective to construct artificial barriers and eradicate bass from such a short reach of the tributary. A prime example is the Boskloof River of which only 50 meters is invaded. There is no maximum length for eradication projects because projects could be phased into manageable sections.
Physical category	
Suitable site for black bass barrier	As artificial barriers are a key element in the rehabilitation process, all tributaries that do not have a suitable site for a new black bass barrier have been discarded. A suitable site is a narrow section of the river with bedrock below and on the sides of the river channel. The tributaries that did not comply with these criteria had wide channels and no bedrock.
Thick palmiet beds	Palmiet *Prionium serratum* is a native plant that grows in the river channel and in some rivers in the ODR system, it forms thick beds. These thick beds would hamper the spread of piscicide during chemical eradication and would prevent mechanical eradication due to the impenetrable refuge it provides for black bass.
Anthropogenic impacts category	
Pollution from agro chemicals	Agro chemicals have been proven lethal to freshwater fish (Marr 2011) and it is suggested that this threat should first be addressed before tributaries are considered for black bass eradication.
Multiple dams in catchment that contain black bass	Multiple dams that contain black bass in the catchment also disqualify a tributary from black bass eradication. The cost to remove the black bass from these dams would make these projects not viable. If there are few small dams with black bass, it could be cleared with piscicide or by draining the dam.
Logistical category	
Vehicle accessibility to barrier site	A key requirement for black bass eradication would be vehicle access to the site were the artificial barrier should be constructed. Eradication of black bass in the CFR is also limited by funding and tributaries that would require artificial barriers with high cost were discarded.
Barrier cost	CapeNature relies on government funding to execute eradication projects. The funding is limited and projects with too high cost would not be approved.

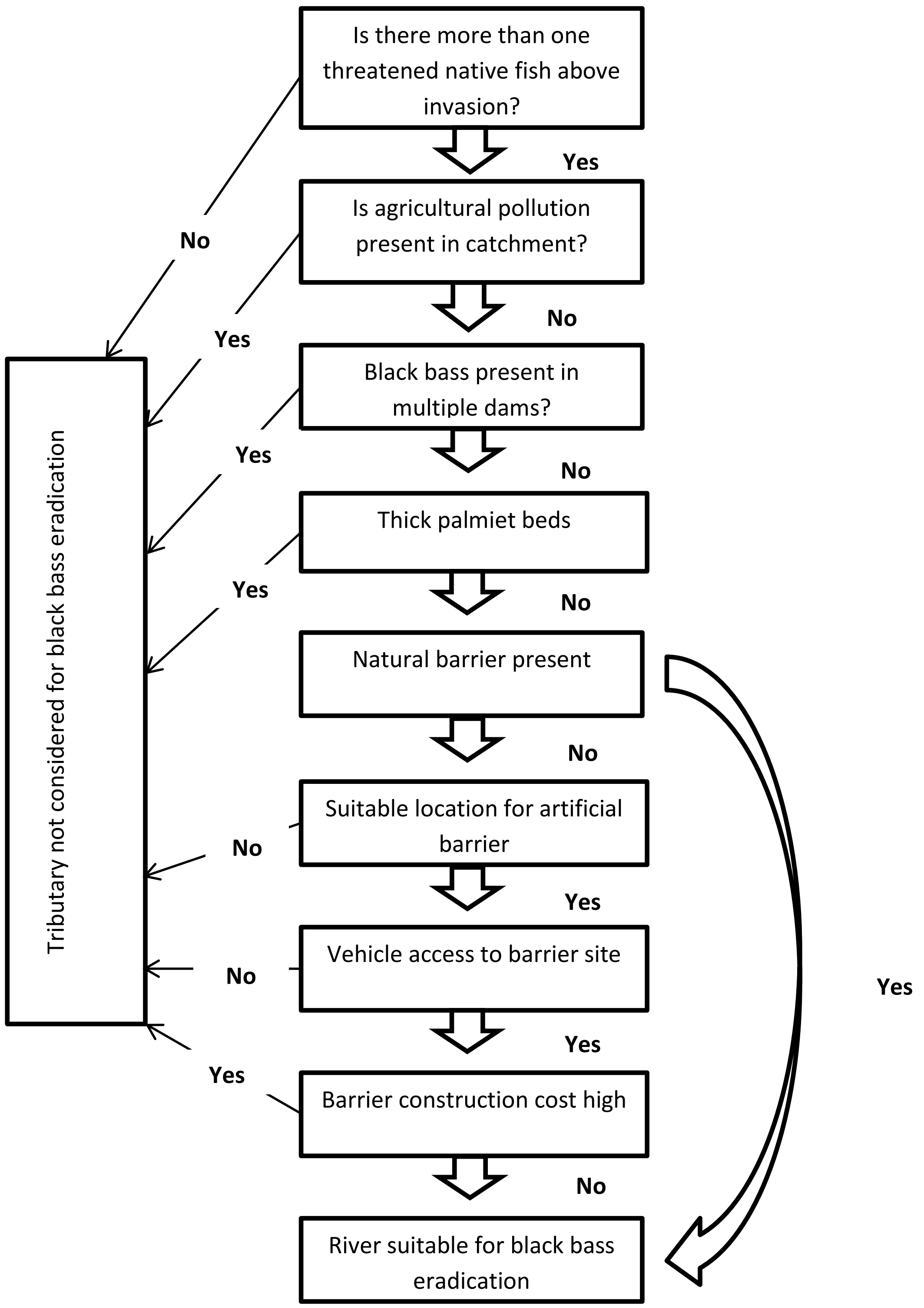

Figure 5.1 Decision support framework for river suitability towards black bass eradication.

Results from the assessment.

The 22 black bass invaded tributaries in the ODR system identified during this study (Chapter 3) and assessment criteria to determine if tributaries are suitable for black bass eradication, are summarized in Table 5.3. If a river did not comply with the requirements of the criterion, it was not considered further for black bass eradication.

Table 5.3 The suitability assessment of the 22 black bass invaded tributaries in the Olifants-Doorn River system in terms of black bass eradication.

Criteria	Olifants Gorge	Diepkloof River	Dwars River	Ratel River	Thee River	Boontjies River	Boskloof River	Heks River	Rondegat River	Jan Dissels River	Oorlogskloof River	Biedouw River	Tra Tra River	Eselbank River	Driehoek River	Krom River	Matjies River	Breekkrans River	Groot River	Twee River	Leeu River	Riet River
Biological																						
Number of native fish species present	2	1	4	4	6	3	5	3	5	5	4	5	6	4	5	1	5	4	1	2	1	1
Length of river invaded by black bass (km)	4.9	4.3	1	2.2	5.1	5.8	0.1	21	1.3	32	52	33	34	8.9	25	8.1	13	19	32	0.9	21	76
Overall category potential to eradicate black bass	yes	no	no	yes	yes	yes	no	yes	no	yes	yes	yes	yes	yes	yes	no	yes	yes	no	no	no	no
Physical																						
Suitable site for new black bass barrier	no	yes	no	no	yes	yes	no	yes	yes	yes	no	yes	yes	yes	yes	yes	no	yes	no	no	yes	no
Thick palmiet beds	no	no	no	yes	no	no	no	no	no	no	no	no	no	no	yes	no	no	no	no	yes	no	no
Overall category potential to eradicate black bass	no	yes	no	no	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	no	yes	no	yes	no	no	yes	no
Anthropogenic impacts																						
Pollution from agro chemicals	yes	no	no	yes	no	yes	yes	no	yes	no	no	No	no	no	yes	no	no	no	yes	yes	yes	yes
Multiple dams with black bass in catchment	yes	no	no	no	no	yes	no	no	no	no	yes	no	no	no	yes	yes	yes	no	yes	no	yes	yes
Overall category potential to eradicate black bass	no	yes	yes	no	yes	no	no	yes	no	yes	no	yes	yes	yes	no	no	no	yes	no	no	no	no
Logistical																						
Vehicle accessibility to barrier site	no	no	no	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes	no	yes	no	no	yes	no
Barrier cost	high	mod	high	high	mod	mod	mod	mod	mod	low	high	mod	mod	mod	mod	mod	mod	mod	high	high	high	high
Overall category potential to eradicate black bass	no	no	no	no	yes	yes	yes	yes	yes	yes	no	yes	no	yes	yes	yes	no	yes	no	no	no	no
Overall potential to eradicate black bass from river	no	no	no	no	yes	no	no	yes	no	yes	no	yes	yes	yes	no	no	no	yes	no	no	no	no

The results from the assessment indicate that only seven of 22 black bass invaded tributaries in the ODR system can realistically be considered suitable for black bass eradication. These tributaries are the Thee River, Heks River, Jan Dissels River, Biedouw River, Tra Tra River, Eselbank River and Breekkrans River (Figure 5.2). Three of these tributaries should be regarded as top priorities for black bass eradication given the criteria and these are the Thee River, Biedouw River and the Breekkrans River. The Biedouw River contains all the large cyprinids in the ODR system and they are currently confined to less than 1 km in the upper reaches and a successful eradication programme can enlarge their range by 25 km. The Breekkrans River contains one of the two known populations of the critically endangered Doring redfin. The Doring redfin population in the Breekkrans River is free of anthropogenic impacts, while the one in the Driehoeks River is impacted by a multitude of human activity. The Thee River is a near pristine river with six native freshwater fish species, of which two species are endangered. Black bass in the Thee River has been removed since 2010 and monitoring should continue until the river could be declared free of black bass. The Jan Dissels River and Heks River should be the next tributaries on the priority list for black bass eradication in the ODR system. Both these rivers have their headwaters in the Cederberg Wilderness Area, where they are protected from anthropogenic impacts. The third priority would be the Tra Tra and Jan Dissels River. Appendix D contains the full prioritising criteria.

Four of the seven black bass invaded tributaries that were identified as suitable for eradication by this study were also listed at the May 2013 workshop. The only river earmarked by the May 2013 workshop for black bass eradication which was found not suitable by this study was the Driehoeks River. Three different criteria found this river not suitable: thick palmiet beds, multiple dams with bass in catchment and agricultural pollution. Although eradication of black bass in the Driehoek River is not a viable option, the control of black bass should be considered. Annual mechanical removal of black bass is proposed to minimize the impact on the native fishes.

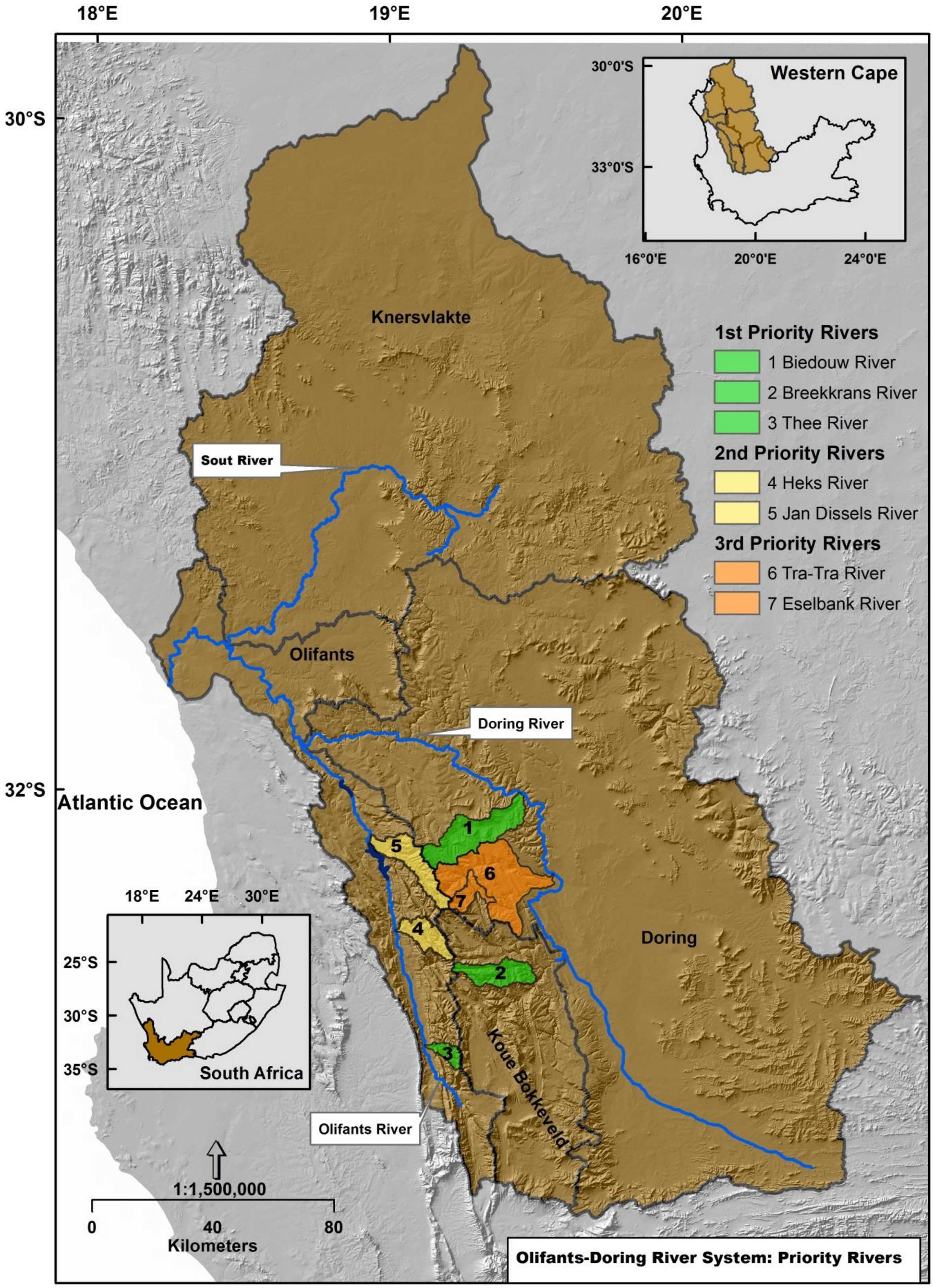

Figure 5.2 Priority river catchments in the Olifants- Doorn River system for the eradication of black bass according to the suitability assessment in Table 5.3.

5.3 Artificial barriers as part of black bass management

The intentional isolation of threatened species with an artificial barrier has been a management practice that has been used on a global scale to protect lampreys and fishes from alien species (Novinger & Rahel 2003). The term used for this practise is isolation management (Fausch *et al*. 2009). In New Zealand, artificial barriers were constructed to prevent salmonids from invading headwaters with native threatened fish (Chadderton 2001). In California, isolation barriers have been constructed to protect threatened salmonids from invasive salmonids (Fauch *et al*. 2009). Kerby *et al*. (2005) also noted that barrier selection should be species specific in order to attain the specific project goals. The proposed method of increasing habitat for the native species in the tributaries of the ODR system involves the construction of artificial barriers in the black bass invaded section of the tributary and then eradicating the black bass above the barrier with chemical or mechanical methods. This is the same strategy used in the Rondegat River project (Weyl *et al.* 2013; Weyl *et al*. 2014). Jordaan *et al*. (2012) suggested that to halt alien fish invasions, barriers need to be integrated into the holistic management plans created for alien fish eradication. The barrier is the first step in the rehabilitation process and eradication of black bass should not be considered before the barrier is completed.

5.3.1 Types of alien fish barriers

Halfyard (2010) summarized the different barrier options suitability in terms of alien fish management. He grouped barriers into two categories namely physical and behavioural barriers (summarised in Table 5.4). According to Novinger & Rahel (2003), artificial barriers can lead to fragmentation of native fish populations but artificial barriers will not increase the fragmentation of native minnow species in the ODR system because they are already fragmented by the black bass (Swartz 2000, Chapter 4). For the rehabilitation projects in the CFR artificial barriers constructed with concrete, gabions or a combination of these is the only practical and financially viable option. Concrete barriers have a longer lifespan but are more costly to build. Carpenter & Terrell (2005) states that gabion structures should only be considered for temporary barriers as they have a limited lifespan. Barriers should also be constructed in ways that do not create a swimming hole that attracts recreational activity (Carpenter & Terrell 2005). There should also be a long-term commitment towards the monitoring of the structural integrity of artificial alien fish barriers.

Table 5.4 Summary of barrier traits and suitability (Halfyard 2010).

Barrier type	100 % containment demonstrated	Maximum reported effectiveness	Suitability for upstream movement	Suitability for downstream movement	Suitability for lentic habitats	Reliability	Level of maintenance required	Relative initial cost
Physical								
Waterfall	Yes	100%	High	Low	Low	High	Low	Low-High
Velocity	Yes	100%	High	Low	Low	High	Low	Mod-High
Screen/nets	Yes	100%	High	High	High	High	High	Mod-High
Behavioural								
Electric	No	99%	High	Mod	High	Mod-High	Low	Mod-High
Bubble barrier	No	98%	Mod	High	High	High	Low	Low
Acoustic	No	95%	High	High	High	High	Low	Low
Light-based	No	95%	High	High	High	High	Low	Low

5.3.2 Artificial barrier height

The height of barriers should not restrict the movement of native migratory fish (Novinger & Rahel 2003) and therefore it is essential that artificial barriers should only be constructed to a height that prevents black bass from entering the upper reaches of the river and not the native fish. This study measured 17 natural black bass barriers in the ODR system and found that a barrier with a vertical drop of 80 - 100 cm would prevent the upstream movement of black bass. The study also found that native fish are present above the natural bass barriers and this indicates that native fish can pass these natural barriers.

5.4 Review of available methods for black bass eradication

Black bass are predatory freshwater fish, native to North America that has been widely introduced to promote recreational fishing opportunities (Loppnow *et al*. 2013). Globally the impact of black bass on aquatic biodiversity is well documented (Findley et al. 2000; Lowe et al. 2000; Elvira & Almodovar 2001; Jackson 2002; Iguchi et al. 2004; Casal 2006; Rahel & Olden 2008; Chapter 4) but there seems to be limited information on the control and eradication of invasive black bass populations (Loppnow *et al*. 2013). Halfyard (2010) reviewed the options for the control (minimize impact of invasive fish), containment (preventing further spread) and eradication (eliminating alien fish from geographical area) of alien fish and the summary of the methods are listed in Table 5.5. These methods were divided into four categories (mechanical, chemical, biological and environmental).

Table 5.5 Summary of control and/or eradication method traits and suitability (Halfyard 2010).

Category	**Method**	**Proven for control**	**Proven 100 % effective for eradication**	**Suitability in lotic environments**	**Suitability in lentic environments**	**Level of effort required**	**Typical number of applications**	**Relative short term cost**	**Risk level**
Mechanical	Electrofishing	Yes	Yes	Mod-High	High	High	Multiple	Mod	Low
Mechanical	Nets, traps and weirs	Yes	Yes	High	High	High	Multiple	Low-Mod	Low
Mechanical	Explosives	No	No	Mod	High	Low	Multiple	Mod	Mod
Mechanical	Angling	Yes	No	High	High	Low-Mod	Multiple	Low	Low
Chemical	Piscicide	Yes	Yes	Mod-High	High	Low	Single	High	Mod
Biological	Species introduction	Yes	Yes	High	High	Low	Multiple	Low	High
Biological	Other biological methods	Yes	No	High	High	Low	Multiple	Low	High
Environmental	Water level manipulation	Yes	Yes	Low[1] Mod[2]	Low[3] High[4]	Low	One[1] Multiple[2]	Low	Low

1= Dewatering, 2= Water flow manipulation, 3= Natural, 4= Impoundments

Loppnow *et al.* (2013) also reviewed control methods for *M. dolomieu* and added one method under the environmental category, which entails the lowering of the oxygen levels in the water. Loppnow *et al.* (2013) concluded that the best way to control invasive black bass would be an integrated pest management approach. A key component of his strategy would be to target black bass nests in combination with adult removals. This strategy is more applicable to lentic environments and is unlikely to succeed in the lotic stream environments of the ODR system.

The success of the Rondegat River chemical black bass eradication project and the Thee River mechanical black bass control project has demonstrated that these methods could be successfully used for future black bass removal efforts in the ODR system. Personal experience in managing the Thee River mechanical black bass eradication project between 2010 and 2013 highlighted seven criteria that are critical in order to be successful with mechanical methods for eradicating of black bass (Table 5.6). These criteria were used to assess the seven tributaries suitable for black bass eradication as identified by this study (Table 5.7).

Table 5.6 List of criteria and explanations for suitability assessment of mechanical black bass eradication in the seven priority tributaries in the Olifants- Doorn River system.

Criteria	**Explanation**
Clear water	All the mechanical methods need clear water to be effective and visibility should be at least two meters.
No pools deeper than two meters	Electrofishing, snorkelling with nets and gill netting becomes ineffective if the water is deeper than two meters.
No thick riparion vegetation	Thick riparian vegetation could prevent access to the river channels for human operators and these areas would remain refuges for alien fish making the eradication effort unsuccessful.
No thick palmiet beds	Thick palmiet would provide refuge for alien fish and none of the mechanical methods would be effective in these areas.
River channel not braided	Braided river channels are found in low gradient areas where the river channel divides to form multiple streams. The multiple streams provide refuge for small alien fish.
Length of project <four kilometers	Experience from the Thee River indicates that up to four kilometres is manageable for a mechanical eradication project.
Assesibilty for mechanical treatment	Mechanical projects usually take more than two years to complete and are labour intensive. The tributary needs to be near roads and accommodation for operators.

Table 5.7 Suitability assessment for mechanical black bass eradication of the seven priority tributaries in the Olifants- Doorn River system that were identified for black bass eradication by this study.

Criteria	Thee River	Heks River	Jan Dissels River	Biedouw River	Tra Tra River	Eselbank River	Breekkrans River
Clear water	yes	yes	yes	yes	yes	yes	yes
No pools deeper than two meter	yes	yes	no	yes	no	yes	yes
No thick riparion vegetation	yes	yes	yes	no	yes	yes	yes
No thick palmiet beds	yes	yes	yes	no	no	yes	yes
River channel not braided	yes	yes	yes	no	yes	yes	no
Length of project <four kilometers	yes	no	no	no	no	no	no
Assesibilty for mechanical treatment	yes	no	no	yes	no	yes	no

According to the assessment, the Thee River is the only bass invaded river in the ODR system that meets all the criteria for mechanical eradication. The Eselbank River could also be a candidate for mechanical eradication but the length of the invaded reach would not be manageable with current CapeNature resources. An alternative would be to construct a temporary gabion structure halfway up the invaded reach and clearing the top section first. Once the bottom section is also cleared, the temporary barrier could be removed. Mechanical eradication should not be considered for the other four tributaries, which leaves chemical eradication as the only viable option for black bass eradication in these tributaries.

5.5 Choice of piscicide: Rotenone vs Antimycin A

Globally two types of piscicide are regularly used in fish restoration projects. Rotenone is a natural plant toxin found in plant roots that was historically used by native people in South America to kill fish for food (Ling 2003). Antimycin A is an antibiotic derived from the soil fungi *Streptomyces* spp. (Moore 2008). Rotenone has been used with repeated success, especially in the USA to eradicate alien fishes from river areas and impoundments for both conservation and recreational fishing purposes (Carpenter & Terrell 2005; Finlayson *et al*. 2010). It has also been successfully used in England (Britton & Brazier 2006), Australia (Lintermans & Raadik 2003) and New Zealand (Pham *et al*. 2013). The piscicide antimycin A has also been used with success in several rivers in the USA (Moore *et al*. 2008). Piscicide use has become controversial because rotenone and antimycin A are also lethal to nontarget species such as aquatic macro-invertebrates, especially at elevated concentrations (Finlayson *et al*. 2010; Vinson *et al*. 2010). To ensure their effective and environmentally responsible use in the USA, manuals have been developed for both antimycin A (Moore *et al.* 2008) and rotenone (Finlayson *et al.* 2010). Moore (2008) notes that the advantage of antimycin A above rotenone is that fish cannot detect antimycin A in the water. Another advantage of antimycin A came from a study by Hamilton *et al*. (2009) which demonstrated that the mortality on the macro-invertebrates in a North American stream was less with antimycin A than rotenone. However, Gilderhus (1972) list one advantages of rotenone above antimycin A. According to his study, fish that show the first symptoms of rotenone can be saved by placing them in freshwater while fish that show the first symptoms of antimycin A cannot be saved. This could be a vital advantage in the ODR system where threatened native fish that occur within the black bass invaded areas earmarked for piscicide treatment can potentially be saved during treatment. These studies indicate that both piscicides have merit for use in the ODR system but further local research is necessary to determine the best option.

5.6 Recommendations

The list of priority rivers in the Western Cape should be amended to include the Tra Tra and Eselbank Rivers as well. The Driehoek River should be taken off the list as this study has found that eradication of black bass is not a viable option. Artificial barriers should be the first priority for any restoration project and the height of the barrier should be a vertical drop between 80 and 100 cm when black bass is the alien species targeted. To ensure long-term success barriers should be constructed with reinforced concrete. As alien fishes are difficult to remove from a system once introduced, awareness creation is thus vital. In the ODR, awareness should focus on preventing the stocking of rivers or impoundments above natural or artificial black bass barriers. To prevent this CapeNature should target the riparian landowners and their workers in these tributaries. A database of landowners contact details should be compiled and these landowners should be targeted with information on an annual basis. CapeNature has already designed appropriate awareness material and this should be distributed to all relevant stakeholders. Future research on black bass in the CFR should determine the extent of the black bass invasion in the other four large catchments in the CFR (Berg River, Breede River, Gouritz River and Gamtoos River).

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APPENDIX A: OLIFANTS- DOORN RIVER TRIBUTARY DESCRIPTIONS

Helm (1986) defines a tributary as a stream feeding, joining or flowing into a larger stream and for the purpose all the tributaries flowing into the Olifants and Doring Rivers were potential study sites. The main criteria for selecting the tributaries for this study are that it should contain water throughout the year. Seasonal and ephemeral tributaries should at least have pools with standing water that could potentially harbour fish. The tributary catchment boundaries were digitized using Arc GIS 10.1 while the altitudes and channel lengths mentioned in the management area and tributary description where extrapolated from 1: 50 000 and 1: 250 000 topographical maps. For the description of the channel morphology stream habitat terms as defined by Helm (1986) were used while the stream orders were classified using the method of Strahler (1957). Description of tributary biota (eg. alien vegetation) that is not referenced in text is from personal observations by the author.

1. Olifants Management Area

A map indicating the location of the respective tributaries can be found in Chapter 2, Figure 2.2.

1.1 Olifants River Gorge

The Olifants River Gorge is defined as the mainstream Olifants River below the Witzenberg Valley up to the confluence with the Lower Boschkloof River at an altitude of 371 m. The catchment includes the Witzenberg Valley and the mountains surrounding the Witzenberg Valley with the highest elevation of 1870 m. This third order stream has a catchment size of 198 km^2. Below the Witzenberg Valley the river enters a narrow bedrock-dominated channel. The geology is dominated by sandstone and quartzite of the Table Mountain Group while the geology of the Witzenberg Valley is shale's of the Bokkeveld Group (Mucina & Rutherford 2006). The channel morphology is dominated by bedrock falls, cascades and pool riffles in the lower gorge. There is no agriculture in the gorge section of river and almost the entire section is declared as a Protected Environment (Jordaan 2012). Natural vegetation is dominated by Winterhoek Sandstone Fynbos (Mucina & Rutherford 2006) while invasive alien black wattle *Acacia mearnsii* occurs in low densities in the riparian zone. Water quality is good (River Health Programme 2006).

1.2 Upper Boschkloof River

This small second order tributary has a catchment size of 24.5 km^2 and rises in the Skurweberg Mountains at a maximum altitude of 1700 m, from where it flows in a western direction before it enters the Olifants Rivers gorge at an altitude of 440 meters. The upper section has steep gradient, while the middle section has a moderate gradient dominated with pools and riffles. The lower section has a steep gradient with multiple waterfalls and cascades. There is no development or dams in the entire catchment. The natural vegetation in the catchment is classified as Winterhoek Sandstone Fynbos with intersections of Northern Inland Shale Band Vegetation (Mucina & Rutherford 2006).

1.3 Lower Boschkloof River

The Lower Boschkloof River is a second order stream and has a catchment size of 100.3 km^2. It rises at a maximum altitude of 1600 m in the Skurwe- and Koue Bokkeveld Mountains. It flows through the Koue Bokkeveld Valley before the river drops down a steep gradient to the Olifants mainstream at an altitude of 370 m. The lower reaches consist of falls, deep plunge pools and shoots. The upper catchment of this tributary is highly modified by agriculture, mainly apples and vegetables (DWAF 2005). There are also numerous in-stream and off-stream dams in the catchment while the river is modified into a narrow channel in the cultivated areas. Natural vegetation in the Koue Bokkeveld plateau consisted mostly of Koue Bokkeveld Alluvium Fynbos and Koue Bokkeveld Shale Fynbos (Mucina & Rutherford 2006), which is mostly transformed for agriculture (Marr 2011). The remaining natural vegetation consists of Winterhoek Sandstone Fynbos (Mucina & Rutherford 2006).

1.4 Diepkloof River

The Diepkloof River is a second order mountain stream with a catchment size of 32.6 km^2 which rises in the Koue Bokkeveld Mountains at a maximum altitude of 1736 m. It flows in a southern direction and enters the Olifants mainstream at altitude of 297 m. There is no development in the entire catchment and the area is managed as a private conservation area although it has no formal status. The channel morphology consists of bedrock-dominated falls, plunge pools and cascades in the upper reaches while the lower reaches are dominated by pools and riffles. The natural vegetation in the catchment is classified as Winterhoek Sandstone Fynbos with intersections of Northern Inland Shale Band Vegetation (Mucina & Rutherford 2006). Scattered pines *Pinus* spp. in the surrounding mountains is the only alien vegetation in the catchment.

1.5 Dwars River

The Dwars River is a second order stream with a catchment size of 34.7 km^2 that rises in the Groot Winterhoek Mountains at a maximum altitude of 1668 m. It flows in a northern direction and enters the Olifants mainstream at altitude 270 m. The upper section is declared as a Wilderness Area with management roads being the only development. The lower reaches have no development and the area is managed as a private conservation area although it has no formal status. The channel morphology consist of bedrock-dominated falls, plunge pools and cascades in the upper reaches while the lower reaches are dominated by pools and riffles. The natural vegetation in the catchment is classified as Winterhoek Sandstone Fynbos with intersections of Northern Inland Shale Band Vegetation (Mucina & Rutherford 2006). A few scattered invasive *A. mearnsii* trees occur just above the confluence with the Olifants River.

1.6 Ratel River

The Ratel River is a third order tributary of the Olifants River that rises in the Groot Winterhoek Mountains at a maximum altitude of 1150 m and has a catchment size of 69.9 km^2. It flows in a northern direction and enters the Olifants River mainstream at altitude of 235 m as a third order stream. The upper reaches are located on a plateau that is heavily cultivated for various crops that include berries and ornamental flowers. The lower catchment has tourism development and the area is managed as a private conservation area although it has no formal status. The natural vegetation in the catchment is classified as Winterhoek Sandstone Fynbos with intersections of Northern Inland Shale Band Vegetation (Mucina & Rutherford 2006). Alien vegetation is mostly restricted to the developed upper plateau and consists mainly of *A. mearnsii* and *Pinus* spp. The channel morphology consist of narrow bedrock-dominated runs, falls and cascades in the upper section while the lower section is dominated by bedrock pools and runs. Before the confluence with the Olifants River the river becomes braided with extensive palmiet *Prionium serratum* islands.

1.7 Oudste River

The Oudste River is a small first order tributary of the Olifants River with a catchment size of 23.9 km^2 that rises in the Koue Bokkeveld Mountains at a maximum altitude of 1702 m. It flows in a north-western direction and enters the Olifants mainstream at an altitude of 270 m. There are no developments in the catchment while land-use consists of grazing and flower picking. When the river enters the Olifants River Valley the river dries up in the summer months due a water abstraction point that directs the water into farm dams. The channel morphology consist of bedrock-dominated falls, plunge pools and cascades in the upper reaches while the lower reaches are dominated by pools and riffles. The natural vegetation in the catchment is classified as Olifants Sandstone Fynbos (Mucina & Rutherford 2006). The catchment is mostly free of alien vegetation although scattered bramble *Rubus* sp. is present in the riparian zone.

1.8 Thee River

The Thee River is a third order tributary of the Olifants River with a catchment size of 50.4 km^2. It rises in the Koue Bokkeveld Mountains at a maximum altitude of 1781 m. The Thee River flows in a north-western direction and enters the Olifants River at an altitude of 209 m. Two holiday cottages are the only developments before the river enters the Olifants River Valley. A water abstraction point one kilometre above the confluence with the Olifants River supplies the local farms and is responsible for zero water flow below this point during the summer months. The lower catchment is also developed into citrus orchards. Land-use in the upper catchment consists of grazing and flower picking. The channel morphology consist of bedrock-dominated falls, plunge pools and cascades in the upper reaches while the lower reaches are dominated by long shallow pools and riffles. The natural vegetation in the catchment is classified as Olifants Sandstone Fynbos (Mucina & Rutherford 2006). The catchment is mostly free of alien vegetation although scattered *Rubus* sp. and prickly pear *Opuntia* sp. occurs in the riparian zone.

1.9 Noordhoeks River

The Noordhoeks River is a third order tributary of the Olifants River with a catchment size of 70.5 km^2 that rises in the Koue Bokkeveld Mountains at a maximum altitude of 1708 m. The upper reaches of the river consist of two similar sized tributaries known as the Voorste and Agterste Rivers. The general flow of the river is in a western direction and it enters the Olifants River at an altitude of 194 m. There are no developments in the mountain reaches. Water abstraction is responsible for zero flow in the bottom kilometre during the summer months. An alien fish barrier was constructed in 2013 at the point where the river enters the Olifants River Valley. The lower catchment is also developed into citrus orchards. Land-use in the upper catchment consists of grazing and flower picking. The channel morphology consists of bedrock-dominated falls, plunge pools and cascades in the upper section while the lower section is dominated by long shallow pools and riffles. The natural vegetation in the catchment is classified as Olifants Sandstone Fynbos while the transformed vegetation in the Olifants River valley consisted of Leipoldtville Sand Fynbos (Mucina & Rutherford 2006). The catchment is mostly free of alien vegetation although scattered *Rubus* sp. does occur in the riparian zone.

1.10 Boontjies River

The Boontjies River is a third order tributary of the Olifants River with a catchment size of 329.6 km^2 that rises in the Koue Bokkeveld Mountains at a maximum altitude of 1801 m. It flows in a north-western direction and enters the Olifants River at an altitude of 153 m. The upper catchment is extensively cultivated for citrus and subsistence farming while extensive parts of the lower catchment have also been converted into citrus orchards. The channel morphology varies between bedrock-dominated runs, falls, plunge pools and cascades in the upper section while the lower section is dominated by long shallow pools and riffles. The natural vegetation in the catchment is classified as Olifants Sandstone Fynbos (Mucina & Rutherford, 2006). The lower reaches are heavily invaded by black wattle *A. mearnsii* and Port Jackson willow *Acacia saligna.*

1.11 Boskloof River

The Boskloof River is a second order sub-tributary of the Boontjies River with a catchment size of 110.4 km^2 that rises in the Cederberg Mountains at an altitude of 1746 m. It flows in a north-western direction and merges with the Boontjies River at an altitude of 165 m. The upper catchment in the Cederberg Wilderness area is pristine. Below the Wilderness Area the river enters the Olifants River Valley where the agriculture is dominated by citrus farming. The channel morphology consist of bedrock-dominated falls, plunge pools and cascades in the upper reaches while the lower section is dominated by long shallow pools, riffles and cascades. The natural vegetation in the upper catchment is classified as Olifants Sandstone Fynbos while, patches of Citrusdal Vygieveld is present in the valley (Mucina & Rutherford 2006). The lower reaches are moderately infested with *A. mearnsii* and *A. saligna.*

1.12 Heks River

The Heks River is a third order tributary of the Olifants River with a catchment size of 128.5 km^2 that rises in the Cederberg Mountains at an altitude of 2026 m (Sneeuberg). It flows in a north-western direction and merges with the Olifants River at an altitude of 144 m. The upper catchment is in the Cederberg Wilderness Area with footpaths as the only development. Below the wilderness area the river enters the Olifants River Valley where the land-use is dominated by citrus farming. The channel morphology consist of bedrock-dominated falls, plunge pools and cascades in the upper reaches while the lower reaches is dominated by long shallow pools and riffles. The natural vegetation in the upper catchment is classified as Olifants Sandstone Fynbos while patches of Citrusdal Vygieveld are present in the valley (Mucina & Rutherford 2006). The lower reaches are moderately infested with *A. mearnsii* and *A. saligna.*

1.13 Markuskraal River

The Marcuskraal River is a second order tributary of the Olifants River with a catchment size of 97.4 km^2 that rises in the Olifants River Mountains at a maximum altitude of 1202 m. It is one of only two perennial tributaries that enter the Olifants River from the western side at an altitude of 138 m. The river is heavily impacted through anthropogenic influences that include in-stream dams, channelization and water abstraction. A sub-tributary known as Grootkloof is the only reach of the river that is more or less free from these major impacts although there is also cultivated land and water abstraction in its upper catchment. Agriculture is dominated by citrus farming. The channel morphology consists of small cobble mountain streams with shallow pools. The natural vegetation in the upper catchment is classified as Olifants Sandstone Fynbos and Cederberg Sandstone Fynbos (Mucina & Rutherford 2006). The lower catchment is moderately infested with *A. saligna*.

1.14 Elandskloof River

The Elandskloof River is a second order tributary of the Olifants River with a catchment size of 93.8 km^2 that rises in the Olifants River Mountains at a maximum altitude of 1096 m. It flows in a western direction and enters the Olifants River at an altitude of 128 m. The river is impacted through anthropogenic influences that include in-stream dams, channelization and water abstraction. Farming practises along the river are dominated by vegetable and Rooibos tea cultivation. The channel morphology consists of small mountain streams with shallow pools. A series of in-stream dams have totally transformed the middle reaches of the river while the lower reach has been channelized. The dominant natural vegetation in the catchment is Graafwater Sandstone Fynbos (Mucina & Rutherford 2006). The lower reach is moderately infested with *A. saligna.*

1.15 Rondegat River

The Rondegat River is a second order tributary of the Olifants River with a catchment size of 141.6 km^2 that rises in the Cederberg Mountains at a maximum altitude of 1618 m. It flows in a north-western direction and enters the Olifants River (Clanwilliam Dam) at an altitude of 111 m. The upper catchment is located the Cederberg Wilderness Area that includes the Algeria conservation complex and associated tourism infrastructure. Below the formal conservation area the river flows through agricultural areas dominated by tourism ventures, citrus and livestock farming. The channel morphology consist of bedrock-dominated falls, plunge pools and cascades in the upper reaches while the lower reaches are dominated by long shallow pools and riffles. The natural vegetation in the upper catchment is classified as Olifants Sandstone Fynbos and Cederberg Sandstone Fynbos (Mucina & Rutherford 2006). The upper and lower reaches of the river have been cleared from alien trees while sections of the middle reaches are heavily infested with gum trees *Eucalyptu*s spp., *A. mearnsii* and *A. saligna.* Other impacts on the aquatic environment include overgrazing of the riparian zone by cattle. In 2012 and 2013 black bass was eradicated from a 4 km stretch of the lower

Rondegat River with rotenone (Weyl *et al.* 2014). A modified water abstraction weir prevents the re-invasion of black bass (Weyl *et al.* 2014).

1.16 Jan Dissels River

The Jan Dissels River is a third order tributary of the Olifants River with a catchment size of 206 km^2 that rises in the Cederberg Mountains at an altitude of 1930 m (Sneeukop). The well-known Crystal Pool is located in the upper reaches of this river. It flows in a north-western direction and enters the Olifants River at the town of Clanwilliam at an altitude of 75 m. The upper catchment is located in the Cederberg Wilderness Area. Below the formal conservation areas the river flows through transformed areas that include citrus orchards and livestock pastures. The channel morphology consist of bedrock-dominated falls, plunge pools and cascades in the upper section while the lower section is dominated by long shallow pools and riffles. The natural vegetation in the upper catchment is classified as Cederberg Sandstone Fynbos with Olifants Sandstone Fynbos in the middle reaches (Mucina & Rutherford 2006). The lower catchment contain Citrusdal Vygieveld and Leipoldtville Sand Fynbos (Mucina & Rutherford 2006). The upper reaches of the river are infested with blackwood *Acacia melanoxylon* while the middle and lower reaches are infested by red sesbania *Sesbania punicea, A. mearnsii* and *A. saligna.*

1.17 Kliphuis River

The Kliphuis River is a seasonal tributary of the Olifants River with a catchment size of 73.5 km^2 that rises in the Pakhuis Mountains at a maximum altitude of 1077 m. It flows in a north-western direction and enters the Olifants River at an altitude of 72 m. The upper reaches are located in the Cederberg Wilderness Area. The river then drops down a steep gradient to the Olifants River where an in-stream dam and water abstraction prevent any water from reaching the main stream during the summer months. The lower reaches are also channelized. The channel morphology consists of bedrock-dominated falls, plunge pools and cascades in the upper section while the lower section is channelized. The natural vegetation in the upper catchment is classified as Cederberg Sandstone Fynbos and Olifants Sandstone Fynbos with Citrusdal Vygieveld in the lower reaches (Mucina & Rutherford 2006). The catchment is mostly free of alien vegetation.

1.18 Troe Troe River

The Troe Troe River is a seasonal tributary that rises in the Matzikamma Mountains south of Vanrhynsdorp and joins the Olifants River near the town of Klawer. The Troe Troe River has a catchment size of 786 km^2. From the Matzikamma Mountain the river drops down two spectacular waterfalls into the valley below. The geology of the upper catchment is dominated by sandstone formations while lower down the geology is dominated by shale (Mucina & Rutherford 2006). The upper catchment is dominated by Sandstone Fynbos while the mid to lower catchment is characterised by succulent Karoo vegetation types (Mucina & Rutherford 2006).

2. Knersvlakte Management Area

A map indicating the location of the respective tributaries can be found in Chapter 2 Figure 2.5.

2.1 Sout River

The Sout River and its sub- tributaries (Kromme, Hantams and Goerap) are all ephemeral and saline due to the low rainfall and saline soil. Natural vegetation of the catchment is dominated by Hantam Karoo in the east and Knersvlakte Vygieveld in the west (Mucina & Rutherford 2006). Alien invasive mesquite *Prosopis glandulosa* trees have invaded much of the riparian zones.

3. Doring Management Area

A map indicating the location of the respective tributaries can be found in Chapter 2 Figure 2.8.

3.1 Gif River

The Gif River is a seasonal tributary of the Doring River with a catchment size of 109.7 km^2 that rises in the Gifberg Mountain at a maximum altitude of 794 m. It flows in a southern direction and enters the Doring River at an altitude of 62 m. The main land-use in the catchment is livestock farming, dry land rooibos cultivation, citrus farming and eco-tourism. The channel morphology consists of small mountain streams with step pools and cascades. The lower reaches are dominated by long shallow cobble pools and riffles. The natural vegetation in the upper reaches of the tributary is Bokkeveld Sandstone Fynbos while lower down towards the Doring River the vegetation is Doringrivier Quartzite (Mucina & Rutherford 2006). The lower catchment is moderately infested with *A. saligna*.

3.2 Oorlogskloof/Koebee River

The Oorlogskloof/Koebee River is a seasonal tributary of the Doring River with a catchment size of 2852 km^2 that rises in the Hantam Mountains near the town of Calvinia at a maximum altitude of 1672 m. This seasonal tributary flows in a north-western direction to the town of Niewoudtville from where it flows in a southern direction until the confluence with the Doring River at an altitude of 116 m. The upper catchment is located the Hantam Area where sheep farming dominate the landscape. Farms are often overgrazed and much of the catchment is invaded by *P. glandulosa* (Ramollo *et al.* 2012). Below Niewoudtville the river enters the Oorlogskloof Gorge which is also a declared Provincial Nature Reserve. The gorge has steep cliffs and is almost inaccessible and this has prevented the anthropogenic impacts that are common in the upper catchment. Below the Oorlogskloof Nature reserve the riparian zone are infested with blue gums *Eucalyptus camaldulensis*. The channel morphology consist of bedrock-dominated falls, plunge pools and cascades in the upper reaches while the lower reach is dominated by long shallow pools and riffles. The natural vegetation in the upper catchment is classified as Bokkeveld Sandstone Fynbos and Vanryhnsdorp Shale Renosterveld (Mucina & Rutherford 2006).

3.3 Brandewyn River

The Brandewyn River is a seasonal tributary of the Doring River with a catchment size of 490 km^2 that rises in the northern Cederberg Mountains at an altitude of 1432 m. A sub-tributary known as the Boontjies River forms part of this system. From its source in the Cederberg Mountains its flows in a northern direction through the Agter Pakhuis Valley where the flow becomes seasonal due to water abstraction until it joins the Doring River at an altitude of 107 m. The mostly pristine upper catchment is located in the Cederberg Wilderness Area and Bushmanskloof Private Game Reserve. Farming in the middle and lower catchment is dominated by livestock production, as well as lucern, citrus and rooibos tea cultivation. The channel morphology consist of bedrock-dominated falls, plunge pools and cascades in the upper reaches while the lower reaches are dominated by long shallow pools and riffles. The natural vegetation in the upper catchment is classified as Cederberg

Sandstone Fynbos while Doringrivier Quartzite Karoo is present in the valley (Mucina & Rutherford 2006). The lower catchment is moderately infested with *A. mearnsii* and *A. saligna.*

3.4 Kransgat River

The Kransgat River is a seasonal tributary of the Doring River with a catchment size of 576 km^2. The headwaters are located in the Hantam Mountains at a maximum altitude of 1075 m. It enters the Doring River at an altitude of 150 m. Land-use is dominated by livestock and rooibos farming. The channel morphology consists of small mountain streams with step pools and cascades. The lower reaches are dominated by long shallow cobble pools and riffles. The natural vegetation in the upper catchment are classified as Bokkeveld Sandstone Fynbos and Vanryhnsdorp Shale Renosterveld while lower towards the Doring River it becomes Doringrivier Quartzite (Mucina & Rutherford 2006).

3.5 Biedouw River

The Biedouw River is a seasonal tributary of the Doring River with a catchment size of 329 km^2 that rises in the Cederberg Mountains at a maximum altitude of 1744 meters. The headwaters of the river are known as the Heuningvlei River and flows through a small settlement known as Heuningvlei. Below Heuningvlei the river enters a narrow gorge that is dominated by sandstone boulders and steep edges. Below the gorge the river enters the Biedouw Valley and flows for another 30 km before it enters the Doring River at Uitspanskraal at an altitude of 196 m. Water abstraction takes place in the gorge and this supplies water for the irrigation of lucern on farms below the gorge. Other land-uses include eco-tourism and livestock farming. The channel morphology in the gorge consist of bedrock-dominated falls, plunge pools and cascades while the Biedouw Valley section are dominated by shallow pools and rifles. The natural vegetation in the upper catchment is classified as Cederberg Sandstone Fynbos (Mucina & Rutherford 2006). The gorge area contains Agter-Sederberg Scrubland with Tanqua Karoo in the Biedouw Valley (Mucina & Rutherford 2006). The lower gorge area is heavily infested with *A. mearnsii* and poplar trees *Populus sp*. while the Biedouw Valley is moderately infested with *P. glandulosa*.

3.6 Tra Tra River

The Tra River is a third order tributary of the Doring River with a catchment size of 522 km^2 that rises in the Cederberg Mountains at a maximum altitude of 1626 m. The headwater is dominated by cascades and falls with plunge pools. At the town of Wuppertal the river enters a wide valley and the channel morphology changes to shallow pools and riffles. The Tra Tra River joins the Doring River at Elandsvlei at an altitude of 263 m. Various communal settlements are located along the river with rooibos, vegetable and livestock farming being the main farming activities. Natural vegetation in the upper catchment is Cederberg Sandstone Fynbos while the lower catchment is dominated by Agter Sederberg Scrubland (Mucina & Rutherford 2006). The lower reaches are moderately infested with oleander *Nerium oleander* (River Health Programme 2006).

3.7 Eselbank River

The Eselbank River is a second order tributary of the Tra Tra River with a catchment size of 81 km^2. The river rises in the Cederberg Mountains at an altitude of 1930 m (Sneeukop). It flows in an eastern direction to the Eselbank plateau before it drops down a spectacular waterfall into a gorge for about 2.2 km after which it enters the Martiensrus Valley. The Eselbank River joins the Tra Tra River below the town of Wuppertal at an altitude of 475 m. The channel morphology in the gorge is dominated by boulder cascades, deep pools and runs. Below the gorge the river is characterized by cobble riffles and shallow pools. Land-use is dominated by subsistence vegetable farming and livestock. Natural vegetation in the upper catchment is mainly Cederberg Sandstone Fynbos with Agter- Sederberg Shrubland in the Martiensrus Valley (Mucina & Rutherford 2006). The Martiensrus Valley is heavily infested with *S. punicea*.

3.8 Martiensrus River

The Martiensrus River is a seasonal tributary that rises in the Cederberg Mountains at an altitude of 1969 m (Tafelberg) and has a catchment of 80 km^2. From the Cederberg Mountains it flows down the Martiensrus Valley until it joins the Eselbank River at an attitude of 593 m. The river stops flowing in the dry summer months while only a few pools with water remain. The channel morphology in the Martiensrus Valley is characterized by cobble riffles and shallow pools. Land-use is dominated by subsistence vegetable farming and livestock. Natural vegetation in the upper catchment is mainly Cederberg Sandstone Fynbos with Agter- Sederberg Shrubland in the Martiensrus Valley (Mucina & Rutherford 2006). The Martiensrus Valley is heavily infested with *S. punicea*.

3.9 Tankwa River

The Tankwa River is the Doring River tributary with the largest catchment (14 335 km^2). The river is ephemeral and rises in the Roggeveld Mountains at a maximum altitude of 1650 m. The catchment is also the driest in the Doring Management Area and the river only flows after major rain events that occur mainly in the summer months (DWAF 2005). The Oudebaaskraal Dam is a massive in stream dam in the river and this is the largest privately built dam in South Africa. It was recently incorporated into the Tankwa Karroo National Park that lies within the Tankwa River catchment. The main agricultural activity is seasonal livestock farming and game farming. Below the Oudebaaskraal Dam some lucern farming also takes place. The channel morphology is dominated by sandy pools and cobble riffles. Natural vegetation consists of Koedoes Berge-Moordenaars Karoo in the upper catchment with Tanqua Karoo and Tanqua Wash Riviere in the lower catchment (Mucina & Rutherford 2006). *P. glandulosa* is an invasive tree in the Tankwa River riparian zone. When the river is flowing it is full of sediment due to the shale geology of the catchment (DWAF 2005).

3.10 Upper Doring River

The Doring River above the confluence with the Groot River is known as the upper Doring River. The Upper Doring River has a catchment of 3808 km^2 and the headwaters are located in the Swartruggens Mountains. The Upper Doring is ephemeral with flows that only occur after major rainfall events. Land-use consists of eco-tourism and livestock farming. The natural vegetation in the mountain catchment comprise of Swartruggens Quartzite Fynbos and Matjiesfontein Quartzite Fynbos while in the valley lower down the vegetation is Ceres Karoo Tanqua Wash Riviere and Tanqua Karoo (Mucina & Rutherford 2006).

4. Koue Bokkeveld Management Area

A map indicating the location of the respective tributaries can be found in Chapter 2 Figure 2.11.

4.1 Driehoek River

The Driehoek River is a third order tributary and forms the headwaters of the Matjies River with a catchment of 184 km^2. It rises in the Cederberg Wilderness Area at a maximum altitude of 1969 m and flows in an eastern direction until the confluence with the Krom River at an altitude of 725 m. The channel morphology is characterised by a relatively wide channel on the flat Driehoek plateau with alternating pools, rifles and runs. The larger pools are deep with sand and silt on the bottom. Below the Driehoek plateau the river enters a narrow gorge area with sandstone dominated cascades, falls and riffles. Before the confluence with the Krom River the gradient is low with extensive reed beds. The upper catchment of the Driehoek River contains Cederberg Sandstone Fynbos and Northern Inland Shale Band Vegetation (Mucina & Rutherford 2006). Thick riparian vegetation in the lower section is dominated by wild almond *Brabejum stellatifolium.* The river is mostly clear of alien vegetation with exception of non-invasive oak trees *Quercus* spp.

4.2 Dwars River

The Dwars River is a second order tributary of Driehoeks River and rises at a maximum altitude of 2027 m (Sneeuberg). It has a catchment of 33 km^2 and is regarded as a second order stream at its confluence with the Driehoeks River at altitude of 839 m. The headwaters have a steep gradient with alternating falls, cascades and runs before it reaches a plateau area at the Dwars River farm where the river is channelized before it drops again to the Driehoeks River. The upper catchment is located in the Cederberg Wilderness area while the middle reaches are in the Dwars River Contract Nature Reserve. Other land-uses along its banks consists of grape and fruit farming. There are no dams in the catchment although water is abstracted from the river for irrigation and human consumption. Natural vegetation is dominated by Cederberg Sandstone Fynbos and Northern Inland Shale Band Vegetation (Mucina & Rutherford 2006). There is no alien vegetation present.

4.3 Krom River

The Krom River rises in the Cederberg mountains at an maximum altitude of 1723 m and has a catchment size of 49.6 km^2. The Krom River stretches all the way to the Driehoeks River which it joins at an altitude of 725 m from where it becomes known as the Matjies River.. A large pool, known as Disa Pool is a prominent landmark in the upper river and below this pool the river flows through a narrow valley dominated by bedrock steps, pools and chutes. Lower down, the valley opens with the river becoming braided with a low gradient and sandy bottomed pools and runs. The lower reaches are located in the Matjies River Provincial Nature Reserve while most of the upper reaches are located in the Krom River Contract Nature Reserve. The natural vegetation in the upper catchment is Cederberg Sandstone Fynbos and linear strips of Northern Inland Shale Band Vegetation (Mucina & Rutherford 2006). Alien vegetation is restricted to the area surrounding the Krom River farmstead and comprise of *Populus* spp. and *Quercus* spp.

4.4 Matjies River

The Matjies River starts at the confluence of the Krom and Driehoeks Rivers at an altitude of 725 m and has a catchment size of 395 $km^{2.}$ It joins the Groot River as a third order stream at an altitude of 413 m. Channel morphology is dominated by bedrock steps, falls, chutes and cascades in the upper section while lower down the river is more a pool-riffle system with sandy bottomed pools in the lower gradient areas. Land-use consists of conservation areas in the form of the Matjies River Provincial Nature Reserve and other private nature reserves. Natural vegetation consists of Swartruggens Quartzite Fynbos and Swartruggens Quartzite Karoo (Mucina & Rutherford 2006). Invasive alien *Nerium oleander* occurs throughout the length of the river.

4.5 Breekkrans River

The Breekkrans River has a catchment size of 170 km^2 and rises in the Cederberg Mountains at a maximum altitude of 1746 m. The Breekkrans River enters the Groot River at an altitude of 446 m as a second order stream. The upper high gradient reaches are dominated by bedrock falls and cascades while lower down the river has alluvial braided channels dominated by shallow pools and rifles. The land-use consists of private conservation areas in the upper catchment while water is abstracted for citrus farming in the middle reaches. The lower catchment is not utilised due to the remoteness. The natural vegetation of the upper catchment is dominated by Cederberg Sandstone Fynbos while Agter- Sederberg Shrubland is the dominant vegetation type in the mid and lower sections (Mucina & Rutherford 2006). The middle and lower reaches are also heavily invaded by *Nerium oleander*.

4.6 Groot River

The Groot River is the main perennial tributary of the Doring River and is fed by its sub tributaries (Leeu, Langkloof, Twee, Breekkrans, Matjies River, Tuinskloof River, and Rietkloof River) which give a total catchment of 3035 km^2. The Groot River joins the upper Doring River at De Mond as a fourth order river at an altitude of 390 m. The main channel of the Groot River is dominated by riffles and pools. Water is abstracted at the Mount Cedar farm for citrus and olives cultivation. Natural vegetation in the lower catchment is Agter-Sederberg Shrubland, Swartruggens Quartzite Karoo, and Swartruggens Quartzite (Mucina & Rutherford 2006).

4.7 Tuinskloof (Groot River)

Tuinskloof River is a small first order tributary of the Groot River with a catchment size of 33.5 km^2. It rises in the Skurweberg Mountains at maximum altitude of 1809 and joins the Groot River at an altitude of 500 m. The channel morphology is bedrock-dominated with waterfalls, plunge pools and cascades in the upper reaches. The natural vegetation is Cederberg Sandstone Fynbos in the upper reaches with Agter-Sederberg Shrubland lower down (Mucina & Rutherford 2006). There are no anthropogenic impacts in the catchment and the land-use is eco-tourism.

4.8 Rietkloof River (Groot River)

Rietkloof River is a small seasonal tributary of the Groot River that rises in the Cederberg mountains at an altitude of 1629 m and joins the Groot River at an altitude of 515 m. There is no agricultural development in the catchment and the due to the remoteness the whole catchment is pristine. The channel morphology consists of overgrown sandy runs with bedrock falls and cascades in the upper reaches. Natural vegetation consists of Cederberg Sandstone Fynbos (Mucina & Rutherford 2006).

4.9 Twee River (Groot River)

The Twee River comprises three tributaries namely the Suurvlei, Middeldeur and Hex Rivers and has a total catchment size of 216 km^2. The Suurvlei River rises in the southern Cederberg Mountains and flows down a steep gradient into an intensively cultivated valley. The Middeldeur River rises in the Koue Bokkeveld Mountains from where it flows as a steep gradient mountain stream down into the Koue Bokkeveld valley. The Hex River rises in the Koue Bokkeveld Mountains and joins the Middeldeur above the De Straat Waterfall. The Twee River joins the Leeu River at an altitude of 575 m and from this point the river is regarded as the Groot River. The channel morphology in the upper reaches is bedrock-dominated and includes fast flowing, rocky riffles and cascades while, shallow pools with sandy and rocky substrates occur lower down. There are also large pools, up to 10 m in depth, narrow channels and four substantial waterfalls.

Due to the fertile soils of the valleys the catchment is heavily impacted by crop production that is dominated by deciduous fruit and vegetables (DWAF 2005). The upper Suurvlei River is also impacted by pine plantations while water abstraction is prevalent throughout the catchment (DWAF 2005). Water is stored in many dams in the valleys and headwaters. Natural vegetation in the higher elevation mountains consists mostly of Cederberg Sandstone Fynbos with linear strips of Northern Inland Shale Band while the vegetation on the valley floor is made up of Koue Bokkeveld Alluvium Fynbos and Koue Bokkeveld Shale Fynbos (Mucina & Rutherford 2006). Riparian vegetation is dominated by *Brabejum stellatifolium* and *Prionium serratum*.

4.10 Leeu River

The Leeu River is a third order river that rises in the Koue Bokkeveld- and Skurweberg Mountains at a maximum altitude of 2070 m and enters the Koue Bokkeveld Valley as a number of small mountain streams. It has a catchment size of 380 km^2. In the Koue Bokkeveld Valley the Leeu River forms an extensive wetland system before it drops down a steep gorge to its confluence with the Groot River. Most of the Koue Bokkeveld Valley has been transformed for deciduous fruit and vegetable production and large scale water abstraction with storage dams occurs in the area. The channel morphology consists of bedrock channels in the high gradient areas and alluvial channels in the Koue Bokkeveld Valley. Natural vegetation in the Koue Bokkeveld Mountains consists mainly of Koue Bokkeveld Sandstone Fynbos while the valley has Koue Bokkeveld Shale Fynbos and Koue Bokkeveld Alluvium Fynbos (Mucina & Rutherford 2006). The lower reach of the river has been invaded by *A. mearnsii* and *Eucalyptus* spp.

4.11 Langkloof (Leeu River)

The Langkloof is a small first order mountain stream tributary of the Leeu River that rises at an altitude of 1809 m in the Skurweberg Mountains. Channel morphology is bedrock dominated with cascades, falls and chutes. It has a catchment of 39 km^2 and the catchment is almost pristine with no water abstraction or agricultural development. The natural vegetation consists of Cederberg Sandstone Fynbos (Mucina & Rutherford 2006). The only alien vegetation is *A. mearnsii* near the confluence with the Leeu River (River Health Programme 2006).

4.12 Riet River

The Riet River rises in the Waboomsberg, Skurweberge and Swartruggens Mountains at a maximum altitude of 2070 m. It flows through the southern Koue Bokkeveld where the river is heavily impacted by anthropogenic influences that include water abstraction for deciduous fruit and vegetables, in-stream dams and alien vegetation. The river exits the Koue Bokkeveld area and enters a bedrock-dominated area in the Swartruggens Mountains. There is great variation in the channel morphology from its source to confluence ranging from bedrock cascades to pools and riffle lower down. The river flows through this remote area until its confluence with the Groot River as a third order stream at an altitude of 450 m. Due to the length of the river there is a diversity of vegetation types throughout its length which include Winterhoek Sandstone Fynbos (upper catchment), Koue Bokkeveld Shale Fynbos, Ceres Shale Renosterveld (middle catchment), Matjiesfontein Shale Renosterveld and Swartruggens Quartzite Fynbos (lower catchment) (Mucina & Rutherford 2006).

APPENDIX B: Freshwater fish distributions in the tributaries of the Olifants- Doorn River system, South Africa (y= present).

		Native species												Bass species				Other Alien fish						
Management Area	**Tributary**	**B. calidus**	**Labeobarbus capensis**	**Austroglanis gilli**	**B. serra**	**Barbus anoplus**	**Galaxias zebratus**	**Pseudobarbus phlegethon**	**Labeo seeberi**	**P. plegethon "Doring"**	**Austroglanis barnardi**	**B. erubescens**	**Number of native species per tributaries**	**Micropterus dolomieu**	**Micropterus punctulatus**	**Micropterus salmoides**	**Bass species per tributry**	**Salmo trutta**	**Oncorhynchus mykiss**	**Lepomis macrochirus**	**Sandelia capensis**	**Oreochromis mossambicus**	**Tilapia sparmanii**	**Total alien species**
Olifants	Olifants Gorge		y		y								2	y	y		2	y		y				4
	Upper Boschkloof River				y								1				0							0
	Lower Boshkloof River						y						1				0							0
	Diepkloof River	y											1	y			1		y					2
	Dwars River	y	y	y	y								4	y			1							1
	Ratel river	y	y	y	y								4	y	y		2							2
	Oudste River	y		y			y	y					4				0							0
	Thee River	y	y	y			y	y			y		6		y		1						y	2
	Noordhoeks River	y	y	y			y	y			y		6				0						y	1
	Boontjies River	y	y	y									3	y	y		2						y	3
	Boskloof River (Boontjies River)	y	y	y			y	y					5	y	y		2						y	3
	Grootkloof (Markuskraal)					y							1				0						y	1
	Heks River	y		y							y		3	y			1							1
	Elandskloof River					y							1				0							0
	Rondegat River	y	y	y			y	y					5	y	y		2						y	3
	Jan Dissels River	y	y	y	y		y						5	y			1							1
	Kliphuis River					y							1				0							0
	Troe Troe River					y							1				0							0
Knersvlakte	Sout River												0				0					y		1
Doring	Gif River				y				y				2				0						y	1
	Oorlogskloof/Koebee River		y		y	y			y				4	y	y		2			y			y	4
	Brandewyn River	y	y										2				0						y	1
	Kransgat River					y			y				2				0						y	0
	Biedouw River	y	y	y	y				y				5		y		1			y				0
	Tra Tra River	y	y	y	y		y		y				6	y	y		2			y			y	4
	Eselbank River (Tra Tra River)	y	y	y	y								4	y	y		2							2
	Martiensrus River(Eselbank)					y							1				0							0
	Tankwa River					y							1				0							0
Koue Bokkeveld	Driehoek River (Matjies River)	y	y		y		y			y			5			y	1							1
	Dwars River (Driehoeks River)						y						1				0							0
	Krom River (Matjies River)			y									1			y	1		y	y				3
	Matjies River (Groot River)	y	y	y	y				y				5	y	y		2		y					3
	Breekkrans River (Groot River)	y		y		y				y			4	y	y		2							2
	Groot River		y										1	y	y		2							2
	Tuinskloof (Groot River)					y							1				0							0
	Rietkloof (Groot River)					y							1				0							0
	Twee River (Groot River)		y				y					y	2	y	y		2		y	y	y			5
	Leeu River (Groot River)		y										1	y	y	y	3			y				4
	Langkloof (Leeu River)	y			y	y							3				0							0
	Riet River (Groot River)					y							1			y	1			y			y	3
	Total tributaries per species	19	19	16	13	13	11	5	6	2	3	1		17	15	4		1	4	8	1	1	12	

APPENDIX C: Field example of datasheet for snorkel surveys below and above black bass barriers in the Olifants- Doorn River system, South Africa.

	Pools below barrier			Pools above barrier				
Diepkloof 21012014	**1 below**	**2 below**	**3 below**	**1 above**	**2 above**	**3 above**	**Bass barrier**	**Native fish upper limit**
Pool location south	32 55 01.425	32 55 01.708	32 55 01.369	32 55 00.961	32 55 00.855	32 54 57.882	32 55 02.00	32 54 06.23
Pool location east	19 10 58.259	19 10 57.618	19 11 00.884	19 11 01.609	19 11 02.673	19 11 04.390	19 11 01.03	19 10 54.98
Pool sizes L,W,D	20,8,0.7	18,5,0.5	7,8,0.8	10,10,0.4	15,5,0.3	40,4,0.4		B. callidus
Native fish								
L. capensis >5								
L. capensis 5-15								
L. capensis 15-30								
L. capensis 30-45								
L. capensis <45								
Total L. capensis								
B. serra >5								
B. serra 5-15								
B. serra 15-30								
B. serra 30-45								
B. serra <45								
Total B. serra								
L. seeberi >5								
L. seeberi 5-15								
L. seeberi 15-30								
L. seeberi 30-45								
L. seeberi 45<								
Total L. seeberi								
B. callidus >3				150		295		
B. callidus 3-6				30	15	80		
B. callidus 6-9				12	5			
B. callidus 9<								
Total B. callidus				192	20	375		587
P. phlegethon >3								
P. phlegethon 3-6								
P. phlegethon 6-9								
P. phlegethon <9								
Total P.phlegethon								
P. phlegethon doring >3								
P. phlegethon doring 3-6								
P. phlegethon doring 6-9								
P. phlegethon doring <9								
Total P. phlegethon doring								
A. gilli >10								
A. gilli 10-20								
A. gilli <20								
Alien fish								
M. dolomieu >10								
M. dolomieu 10-20	3	2	2					
M. dolomieu 20-30			1					
M. dolomieu 30-40								
M. dolomieu <40								
Total M. dolomieu	3	2	3					8
M. punctulatus >10								
M. punctulatus 10-20								
M. punctulatus 20-30								
M. punctulatus 30-40								
M. punctulatus <40								
Total M. punctulatus								
M. salmoides >10								
M. salmoides 10-20								
M. salmoides 20-30								
M. salmoides 30-40								
M. salmoides <40								
Total M. salmoides								
O. mykiss >5								
O. mykiss 5-15						2		
O. mykiss 15-30								
O. mykiss 30-45								
O. mykiss <45								
Total O.mykiss						2		2

APPENDIX D: Full criteria for prioritising tributaries (Olifants- Doorn River system, South Africa) for black bass eradication

Criteria	Olifants Gorge	Diepkloof River	Dwars River	Ratel River	Thee River	Boontjies River	Boskloof River	Heks River	Rondegat River	Jan Dissels River	Oorlogskloof River	Biedouw River	Tra Tra River	Eselbank River	Driehoek River	Krom River	Matjies River	Breekkrans River	Groot River	Twee River	Leeu River	Riet River
Biological																						
Number of native fish species present	2	1	4	4	6	3	5	3	5	5	4	5	6	4	5	1	5	4	1	2	1	1
Number of critically endangered fish present	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0
Number of endangered fish present	1	0	1	1	2	0	1	1	1	1	2	2	2	1	1	0	2	1	0	0	0	0
Length of river with native species (km)	5.6	2.3	1.1	5.5	5.3	6.7	11	1	20	2.1	19	0.9	0.5	1.9	0.9	0	11	4.2	0	34	0	0
Length of river invaded by black bass (km)	4.9	4.3	1	2.2	5.1	5.8	0.1	21	1.3	32	52	33	34	8.9	25	8.1	13	19	32	0.9	21	76
Alien vegetation present in riparian zone	yes	no	no	yes	no	yes	yes	yes	yes	yes	yes	yes	yes	no	no	yes	yes	no	yes	yes	yes	yes
Overall category potential to eradicate black bass	yes	no	no	yes	yes	yes	no	yes	no	yes	yes	yes	yes	yes	yes	no	yes	yes	no	no	no	no
Physical																						
Natural downstream black bass barriers present	no	no	no	no	no	no	no	no	no	no	no	no	no	no	yes	no	no	no	no	no	no	yes
Artificial downstream black bass barriers present	no	no	no	no	no	no	no	no	no	yes	no	no	no	no	no	no	no	no	no	no	no	no
Suitable site for new black bass barrier	no	yes	no	no	yes	yes	no	yes	yes	yes	no	yes	yes	yes	yes	yes	no	yes	no	no	yes	no
Complexity of River:																						
Deep pools (< 3 m)	yes	no	no	yes	no	no	no	yes	no	no	yes	yes	yes	no	yes	yes	yes	no	yes	yes	yes	yes
Submerged aquatic vegetation	no	no	no	no	no	no	no	no	no	no	no	no	no	no	yes	no	no	no	no	no	no	no
Thick palmiet beds	no	no	no	yes	no	no	no	no	no	no	no	no	no	no	yes	no	no	no	no	yes	no	no
Braided river channel	no	no	no	yes	no	no	no	no	no	yes	no	no	no	no	yes	no	no	yes	yes	no	no	no
Overall category potential to eradicate black bass	no	yes	no	no	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	no	yes	no	yes	no	no	yes	no
Anthropogenic impacts																						
Livestock in riparian zone	no	no	no	yes	yes	yes	yes	no	yes	yes	yes	yes	yes	yes	no	no	no	no	no	no	no	yes
Pollution from agro chemicals	yes	no	no	yes	no	yes	yes	no	yes	no	no	No	no	no	yes	no	no	no	yes	yes	yes	yes
Water abstraction	yes	no	no	yes	no	yes	yes	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	yes
Multiple dams with black bass in catchment	yes	no	no	no	no	yes	no	no	no	no	yes	no	no	no	yes	yes	yes	no	yes	no	yes	yes
Overall category potential to eradicate black bass	no	yes	yes	no	yes	no	no	yes	no	yes	no	yes	yes	yes	no	no	no	yes	no	no	no	no
Land use																						
Length of tributary in state conservation area (km)	0	0	0	0	0	0	4.4	1	3.4	2.1	10	0	0	0	0	0	9.4	0	0	0.3	0	0
Length of tributary in private conservation area (km)	5.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.7	0	0	3.2	0	0
National Freshwater Ecosystem Priority Area	yes	yes	yes	yes	yes	no	yes	yes	yes	no	yes	yes	no	yes	yes	yes	yes	yes	yes	yes	no	no
Overall category potential to eradicate black bass	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes	yes	yes	yes	yes
Social																						
Potential angler conflict	no	no	no	no	no	no	no	no	no	yes	no	no	no	no	no	no	no	no	no	no	no	yes
Landowner cooperation	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no
Potential stewardship sites	yes	yes	yes	yes	yes	no	no	yes	yes	no	no	yes	no	no	yes	yes	yes	yes	no	yes	yes	no
Potential for job creation	no	no	no	yes	yes	yes	yes	no	yes	yes	no	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	no
Overall category potential to eradicate black bass	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes	yes	yes	yes	yes
Logistical																						
Vehicle accessibility to barrier site	no	no	no	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes	no	yes	no	no	yes	no
General accessibility for eradication	mod	low	low	high	high	mod	high	low	high	mod	low	mod	low	mod	mod	mod	low	mod	low	mod	low	low
Barrier cost	high	mod	high	high	mod	mod	mod	mod	mod	low	high	mod	mod	mod	mod	mod	mod	mod	high	high	high	high
Overall category potential to eradicate black bass	no	no	no	no	yes	yes	yes	yes	yes	yes	no	yes	no	yes	yes	yes	no	yes	no	no	no	no
Overall potential to eradicate black bass from river	no	no	no	no	yes	no	no	yes	no	yes	no	yes	yes	yes	no	no	no	yes	no	no	no	no