An Assessment of the Effects of Habitat Degradation and Exotic Fish Species Invasions on the Distribution of Three Endemic Cyprinids Barbus capensis, Barbus serra and Labeo seeberi...

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ODRFS
olifants-doring rivers fish survey

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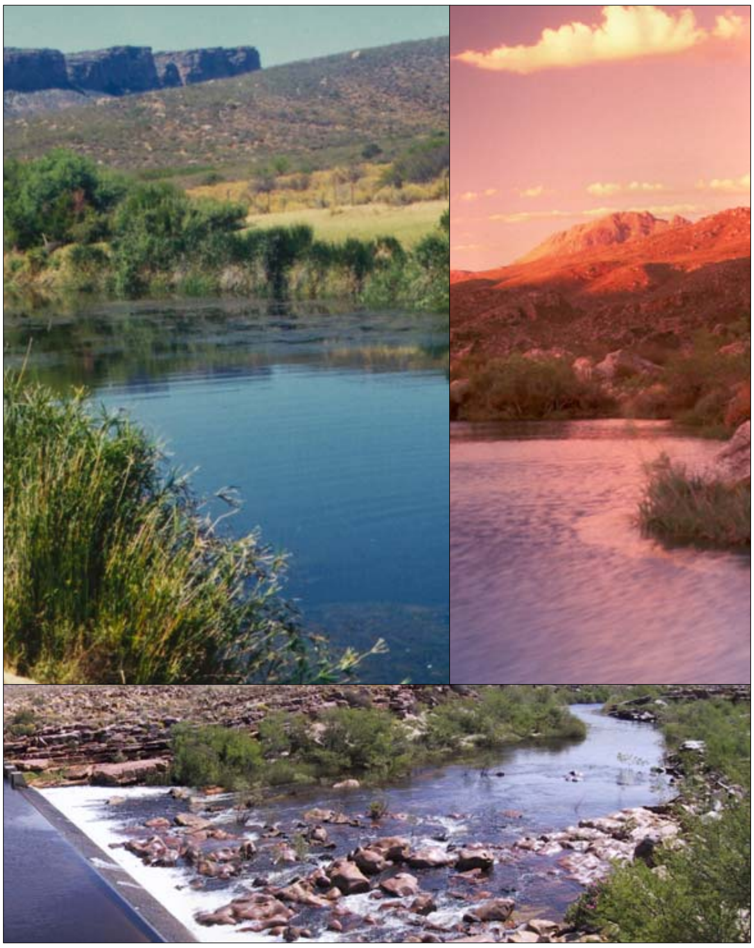

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FINAL REPORT

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OLIFANTS-DORING RIVERS FISH SURVEY

AN ASSESSMENT OF THE EFFECTS OF HABITAT DEGRADATION AND EXOTIC FISH SPECIES INVASIONS ON THE DISTRIBUTION OF THREE ENDEMIC CYPRINIDS: *BARBUS CAPENSIS, BARBUS SERRA* AND *LABEO SEEBERI* IN THE OLIFANTS AND DORING RIVERS, WESTERN CAPE

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DEPARTMENT OF WATER AFFAIRS AND FORESTRY

AND DEPARTMENT OF AGRICULTURE

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EXECUTIVE SUMMARY

This study reports the results of two surveys undertaken by Southern Waters during February and October 2001 of the distributions of three indigenous cyprinids in the Olifants and Doring River Basin, South Western Cape: the Clanwilliam yellowfish *Barbus capensis*, the sawfin *Barbus serra* and the Clanwilliam sandfish *Labeo seeberi*, as well as two North American fish species which have been introduced into the catchment: smallmouth bass *Micropterus dolomieu* and bluegill sunfish *Lepomis macrochirus*. The objectives of the study were to provide updated information on the distribution of these species in the mainstem of the two rivers, to review existing distribution records, to provide a literature review of research in the catchment and comment on proposed water developments. A total of 16 sites in the catchment were sampled using a variety of gear and techniques including: gill-nets, seine-nets, electrofishing, dive-transects and hand-nets during the summer (February) and spring (October) of 2001. Apart from two *B. capensis* caught in the Olifants River, all the indigenous fish sampled in these surveys were found in the Doring River and its tributaries. *L. seeberi* was most frequently caught in gill-nets (385), followed by *B. capensis* (51) and *B. serra* (40). *Lepomis macrochirus* (1635), caught primarily by seine-net, was the most abundant introduced species. *Micropterus dolomieu* (150) were found to be widespread in the catchment, occurring at 13 of the sites visited. Only two of the sites were free of exotic species: the Oorlogskloof River and the Biedouw River. Juvenile and sub-adult *B. serra* and *L. seeberi* (*c*. 50 - 300 mm TL) were caught on the Oorlogskloof River during the summer and spring survey, and age 0+ *L. seeberi* were found in the mainstem of the Doring River and in the Biedouw River during the spring survey. No *B. capensis* juveniles were found during either of the surveys.

In addition to the results of the above survey, this paper presents an analysis of historical species distribution records for *B. capensis, B. serra, L. seeberi, M. dolomieu* and *L. macrochirus* in the Olifants and Doring rivers system. Distribution records spanning the period 1882 - 1998 were compiled from several sources and presented on a GIS database. Analysis of the distribution of these species suggested that *B. capensis* is concentrated in eastern tributaries of the Olifants River, *B. serra* in the Doring River tributaries and *L. seeberi*, in the mainstem of the Doring River as well as in the Koebee and Oorlogskloof rivers. Based on historical accounts and species distribution records, evidence is presented that the number indigenous fish has declined and the populations become fragmented since the introduction of exotic species and the intensification of agricultural activity and water resource developments in the catchment over this same period. Several hypotheses are proposed regarding habitat use, migration patterns and breeding strategies. The impacts of a proposed dam to be built on the Olifants River as well as conservation and management guidelines based on existing data are presented and suggestions for future study are made. These are summarised below.

Likely impacts of the proposed dam development at Melkboom on *B. capensis*, *B. serra* and *L. seeberi* populations:

- ***Inundation of the cobble-bed riffles*** Riffles which are used as spawning sites by the species which occur downstream of Ou Drif (*B. capensis*, *B. serra* and *L. seeberi*) would be drowned by the backup waters of the dam, thereby contributing to the overall decline in critical spawning habitat available in the catchment, and further reducing recruitment levels of indigenous fish.

- ***Obstructing migration*** Movement by fish populations between the Olifants River and Doring River would be obstructed (the impact which this would have on the present status of indigenous fish would depend on whether the lower reaches of the Olifants River below the Bulshoek Weir continue to support significant numbers of these fish - the 2001 surveys suggest that this may not be the case).

- ***Facilitating invasion*** It is expected that total numbers of invasive species (*M. dolomieiu*, *M. salmoides* and *L. macrochirus*) will increase, and their range will extend into areas from where they are presently excluded by unfavourable habitat conditions. It is expected that the dam would function as a supply source for exotic species from where active colonisation of the upstream reaches of the Doring River would take place. This will increase predation pressure on the indigenous species breeding in the mainstem of the Doring River.

- ***Downstream flow transformation*** Flows downstream of the dam will be attenuated resulting to overall loss in the quantity and quality of instream maintainance and spawning habitat (again, this depends on the extent to which the downstream reaches are utilised by indigenous fish populations).

Research needs and areas targeted for future study include the following:

- ***Key conservation areas*** The identification of key conservation areas, based on species distribution records, is considered a priority. A number of sites are proposed, but more information will be needed before a more detailed assessment can be made:

- ***Environmental flows*** Environmental flow studies that take into account the spawning requirements of the indigenous species i.e., silt-free riffles, minimum riffle depths and velocities and cues for spawning, as well as summer pool persistence and the likely effects on fish survival of a prolonged or more extreme dry season precipitated by water abstraction, are needed .

- ***Fragmentation*** Tagging studies to determine fish movement within the system are required to determine the extent to which indigenous fish populations utilise the catchment and the degree to which these populations have become fragmented.

- ***Habitat degradation*** Increasing the proportion of lentic habitat (due to water abstraction) in the catchment promotes the persistence of exotic species and provides refugia which enable them to recolonise areas from which they would otherwise have been excluded. Increased lentic conditions also result in a loss of habitat and spawning sites for the indigenous species. The effect of current and future habitat degradation on the indigenous fish populations in the system can be assessed with more confidence if their conservation status and likely response is better understood. The effects of pesticides, fertilizers and mineralisation on these fish will require focussed attention in future studies.

- ***Synergistic effects*** The effects of each ecosystem impact cannot be assessed in isolation. The synergistic effects of flow modification, habitat degradation, instream obstacles to migration and invasion by exotic species need to be considered.

- ***Life history and population dynamics*** An understanding of the impacts of the various factors listed above cannot be predicted without a knowledge of the life histories and population dynamics of the species in question. Such studies would provide data on: the geographical location of sub-populations, the relationship between tributary and mainstem populations, the paths and distances of migrations, habitat selection, mortality rates and quantitative estimates of abundance. Age determination of fish species is especially important for investigating mortality rates since this data is not available. These studies would also identify factors that are driving the persistence or disappearance of individual populations and the impact of a dam at the confluence of the Olifants and Doring rivers.

To address the deficiencies in knowledge outlined in this report a tagging programme spread over a number of seasons is suggested. The low recapture rate in the present study suggests that large numbers of fish will need to be tagged if an adequate dataset is to be acquired:

- ***Capture and tagging*** It is recommended that the use of gill-nets for sampling fish in the system be replaced by less damaging methods such as fyke or trammel nets. The use of more effective and less damaging tagging methods therefore needs to be investigated.

- ***Gear selectivity*** Until experiments to examine gear selectivity for the species in the system are undertaken and a standardisation method developed, no quantitative comparison of relative densities will be possible.

- ***Future surveys*** No long term systematic surveys have been conducted in the catchment and as a consequence, comparisons between historical periods is complicated by inconsistent sampling effort. Historical distribution patterns are difficult to analyse meaningfully since gear and effort are not reported. Coordination of the research and monitoring in the system will promote a more cohesive effort and a better data set. The outline of a baseline study has been included.

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1. BACKGROUND TO THE STUDY

1.1 Terms of reference

Southern Waters was contracted by the Department of Water Affairs and Forestry, to address recognised deficiencies in the level of knowledge on the distribution, migratory patterns and conservation biology of the large species of indigenous fish in the Olifants-Doring River. This information is required before the Reserve for the Olifants-Doring River can be determined.

Southern Waters was originally contracted to undertake a single survey of the fish in the river system, and the first of the two surveys reported on here was conducted under the auspices of Department of Water Affairs and Forestry. The second survey was made possible using funds from a second, related project, commissioned by the Department of Agriculture, which also included in its Terms of Reference comment on the distribution of indigenous fish in the system.

1.2 Objectives of the study

The primary objective of the present study was to report on the past and present distribution patterns of the three large endemic cyprinids in the Olifants and Doring rivers (listed below) and to contribute information which would generate hypotheses to guide future research into their conservation biology and the impact of dams on catchment-wide utilisation patterns. The distribution of two most abundant of the exotic fish species were considered as well (listed below). Because the larger indigenous cyprinids are believed to utilise the mainstem reaches of the Olifants and Doring rivers extensively for breeding and migration, they are believed to be most at risk from habitat degradation and data on their present distribution ranges and ecological requirements is therefore most urgently required.

Scientific name	**Scientific name**	**Red data status**
Indigenous		
Clanwilliam yellowfish	*Barbus capensis*	Vulnerable endemic species
Clanwilliam sandfish	*Labeo seeberi*	Critically endangered endemic species
Sawfin	*Barbus serra*	Endangered endemic species
Exotic		
Smallmouth bass	*Micropterus dolmieu*	-
Bluegill sunfish	*Lepomis macrochirus*	-

The study aims to achieve these objectives by:

- comparing the past and present distribution records of the alien and indigenous fish species by consolidating the historical distribution records of the above species with the distribution records obtained from two recent surveys which took place in October and February 2001 and presenting these on a GIS database;

- providing a review of the literature available on the ecological requirements of the indigenous fish in the catchment and relating these to the effects of invasion by exotic fish species, flow modification and habitat degradation.

1.3 Dates of the study

Two field surveys were undertaken, one in mid-summer between 4 - 17 February and a second in spring between 13 - 27 October 2001.

2. INTRODUCTION

The Olifants Doring River system in the South Western Cape has been highlighted as a ‘hotspot’ of freshwater fish diversity in South Africa (Skelton *et al*. 1995; Impson 1999) and therefore a catchment of national biogeographic importance. Southern Africa has 24 freshwater fish species listed in the IUCN’s Red List (Skelton 1993) and a large proportion of these are endemic to the Cape ichthoyfaunal region. The indigenous freshwater fish assemblages associated with this region can be characterised as depauperate; with most systems supporting fewer than six species (Skelton 1994). The Olifants Doring River system, with 10 indigenous species, is therefore a noteworthy exception. Endemism in this system is unusually high, with eight species, including six barbine cyprinids and two austroglanidid rock catfishes, endemic to the system itself. The remaining two species (a cyprinid and galaxiid) have wider distribution ranges. This translates to between four and seven endemic species per Quarter Degree Square (QDS), in contrast to the remainder of South Africa where no areas with more than three endemic species per QDS have been identified (Skelton *et al*. 1995).

Their national significance notwithstanding, a substantial decline in the number of indigenous fish in these rivers has been reported by ecologists, sports-fishermen and local farmers in the last fifty or so years. The intensification of agricultural activity in the Olifants River catchment which has precipitated alterations to flow and geomorphological degradation, as well as invasion by exotic fish species, has been implicated in the depletion of these populations (Scott 1982). The Clanwilliam and Bulshoek dams on the Olifants River present impassable obstacles to the migration of fish, and have substantially increased the proportion of lentic conditions in the river, and altered the flow regime of the downstream reaches. They have also provided a haven from which introduced species can invade the rivers in the catchment. Several exotic species including largemouth bass *Micropterus salmoides* and smallmouth bass *Micropterus dolomieu* were introduced into the catchment for sport fishing in the 1930s and 40s. The bluegill sunfish *Lepomis macrochirus* was later introduced as fodder for the angling species. These fish, in particular the bluegill sunfish, occur in high densities throughout the catchment and are believed to prey on the juveniles of native species (Scott 1982). The spread of these fish, assisted by the dams in the Olifants River, is probably most accountable for the decline of native fish populations (Jubb 1961; van Rensburg 1966; Scott 1982; Impson 1997; Gore *et al*. 1991; Lockhart and Impson 1997).

Five of the indigenous species in the catchment are currently listed by the IUCN as threatened, giving the Olifants and Doring rivers the highest concentration of threatened endemic freshwater fishes south of the Zambezi River (Hamman *et al*. 1991). Of these, the three largest cyprinids are most in danger from habitat degradation in the lower and middle reaches: the Clanwilliam yellowfish *Barbus capensis* (Smith

1841), the sawfin *Barbus serra* (Peters 1864) and the Clanwilliam sandfish *Labeo seeberi* (Gilchrist and Thompson 1911).

Conservation measures aimed at the protection of wild populations are most effective where investment is directed and informed by accurate data regarding the biology, life history and ecological requirements of species. A desktop study (Brown and Day 1997) on the feasibility of several dam proposals on the Olifants and Doring Rivers highlighted the absence of comprehensive studies on the fish populations in these rivers and their likely responses to changes in water quantity and quality. The aim of this study, was therefore to contribute towards a greater understanding of the conservation status of the *B. capensis*, *B. serra* and *L. seeberi*. This was done by collating existing information contained in historical accounts, distribution records and scientific studies, and augmenting this with data collected during two surveys conducted primarily on the mainstem of the Doring River during February and October of 2001. This information was then used to develop testable hypotheses to guide future studies and inform conservation and management decisions.

2.1 Historical overview

Concern about the status of the indigenous freshwater fish species in the Western Cape, following the introduction of exotic fish species, was first expressed by Barnard (1943), who conducted a survey of the Olifants River in 1937 and 1938 for his comprehensive work, '*Revision of the Indigenous Freshwater Fishes of the S.W. Cape Region*'. At that time, *M. salmoides* was well established in the lower Olifants River below the Bulshoek Weir following their introduction to the system 1933. Attempts to introduce *M. salmoides* to the river above the Clanwilliam Dam had only just begun and invasion of the upper Olifants River by bass was therefore not yet complete. In 1938, Harrison, who accompanied Barnard on his fieldwork, reported large shoals of *B. capensis* and *B. serra* in the vicinity of Keerom in the upper reaches of the Olifants River above Citrusdal, as well as numerous juveniles of *L. seeberi* and smaller indigenous minnow species (Harrison 1963) .

In 1943, 50 yearling *M. dolomieu* were introduced to the Jan Dissels River below the Clanwilliam Dam and in 1945, a further 1000 fingerlings were introduced to the upper Olifants River at Keerom (Roth 1952). Four years later (1949) observations by Hoehn (1949) and Harrison (1963), at the same site, reveal that *M. dolomieu* had become well established. Although shoals of *B. capensis* were still in evidence, there were numerous bass in close attendance and a noticeable reduction in the numbers of smaller indigenous fish. By 1960, none of the smaller barbine species could be found between Clanwilliam and Citrusdal and *M. dolomieu* were present in large numbers (Jubb 1961). Anglers also expressed their concerns about the disappearance of numerous shoals of what were considered to be ‘a hundred or more' *B. capensis* making their way upstream during the annual spawning runs (Brooks 1950).

The effects of the Bulshoek (constructed in 1919) and Clanwilliam dams (constructed in 1932) as barriers to migration did not go unnoticed and in September of 1938 'thousands' (Harrison 1976: 123) of *B. capensis*, *B. serra* and *L. seeberi* were seen massed below dam walls during the annual spring spawning run – evidence that their continued migration was being thwarted by the barrage.

Harrison (1963: 28) noted that, between Citrusdal and Clanwilliam, the 'rocky defiles' and 'large pools' used for spawning by *B. capensis* and which has previously been found to be rich in indigenous fish species (Barnard 1938), had been blanketed by white sand (Harrison: comments in Jubb 1961). Harrison (1963) attributed the siltation to soil erosion as a result of farming activity in the upper catchment. The effects of water abstraction were noted as early as 1949 when Hoehn (1949) reported that much of water from the Thee and Noordhoeks tributaries had been drawn off for irrigation before reaching the mainstem of the Olifants River.

Apart from the studies already mentioned, several other ecological investigations have been undertaken on the rivers. The first survey of what became a regular sampling programme of the fish in the Olifants River, was conducted by van Rensburg (1966) who visited sites between Keerom and the Bulshoek Dam monthly between 1963 and 1964. He collected a total of 123 *B. capensis* and 410 *B. serra* during this period, suggesting that both species were still relatively abundant. Van Rensburg (1966) found that the gonad mass of *B. capensis* began increasing between August and September, reaching a peak between October and December, before declining in January, and identified the early summer as prime spawning time for these species. He also conducted dietary analyses and determined the age-length relationships for these fish (see Section 6.3). Additional surveys in January 1972, January 1973, September 1979, March 1980, January 1981 and March 1982 by Cape Nature Conservation (CNC) documented the decline of indigenous fish populations over that period (Scott 1982). On the basis of observations made during these surveys, van Rensburg (1966) and Gaigher *et al*. (1980) concluded that competition from exotic fish species was the primary reason for the decline of the indigenous species.

Studies undertaken in the early and mid-1990's recorded *B. capensis* in the mainstem of the Olifants River, both upstream and downstream of Clanwilliam Dam (King and Tharme 1994), although their numbers were reduced from previous studies. Gore *et. al*. (1991) investigated the applicability of Physical HABitat SIMulation model (PHABSIM) (Bovee and Milhous 1978) to describe the availability of hydraulic habitat for several indigenous and exotic fish species in the Olifants River including *B. capensis*, *B. serra* and *M. dolomieu*. The objective of the study was to determine whether, in the absence of exotic fish species, there would be sufficient hydraulic habitat available for indigenous species to recolonise the mainstem of the river. The findings suggested that there was sufficient habitat available and confirmed the views of van Rensburg (1966) and Gaigher *et al*. (1980) i.e., that exotic species were the primary factor responsible for the decline in numbers of indigenous fish in the Olifants River.

However, it should be noted that the study by Gore *et al*. (1991) did not include all life history stages in the assessment of habitat suitability - one of the problems with deriving habitat suitability functions is that they require extensive data sets of the species concerned if all life history stages are to be taken into consideration. In particular, the effects on recruitment levels in the mainstem of loss of cobble-bed riffles due to siltation, or the absence of flows which could act as cues for spawning, were not evaluated. The conclusion that exotic species invasion is primarily responsible for the observed declines therefore needs to be evaluated in this context.

To partly address the need for data on spawning requirements, Cambray *et al*. (1997) and King *et al*. (1998), investigated the importance of dry season pulses for triggering the spawning of *B. capensis* downstream of the Clanwilliam Dam. They arranged for artificial pulses of high flow to be released from the Clanwilliam Dam during the late spring of 1993 and 1994 and monitored the response of fish in the downstream river. Spawning areas were confined to riffle habitat characterised by large boulders and cobble with low embeddedness. King *et al*. (1998) hypothesised that the fish are brought into spawning condition by increasing temperatures possibly associated with increases in the photoperiod and that a minimum temperature of 19 °C, coupled to summer freshes, would be required to trigger spawning.

3. LITERATURE REVIEW

Flow modification and changes to water quality, as well as invasion by introduced species, are recognised as being among the primary factors responsible for the fact that over the last few decades more than 20 percent of the world's freshwater fish species have become extinct, or are threatened or endangered (Revenga *et al*. 2000). The demands for water resources to meet the consumptive and non-consumptive needs of society are soon likely to limit economic development (Linden 2000), suggesting that the present decline in biodiversity is likely to continue. The rate of species extinction in freshwater ecosystems has been estimated to be five times higher than in terrestrial ecosystems (Revenga *et al*. 2000). There is consequently a greater need to conserve those few remaining systems with high levels of endemism and species richness.

The composition and structure of fish assemblages in rivers are regulated by both biotic and abiotic factors. Two hypotheses which address the relative effects of these two factors: the 'stochastic' and the 'deterministic' hypotheses, have been proposed (Grossman *et al*. 1982). The stochastic hypothesis proposes that physico-chemical factors are the primary regulators of relative species abundances through their varying responses to environmental variability. The deterministic hypothesis proposes that competition and predation regulate assemblage structure. It is likely that fish assemblages respond to both these processes (Schlosser 1985) and these are discussed separately below - the latter in relation to invasion by exotic fish species in the Olifants and Doring Rivers.

3.1 The effects of flow modification on riverine fish

Fishes, and other aquatic organisms, living in rivers are behaviourally and physiologically adapted to flowing water and the natural spatial and temporal variability of the flow regime (Gorman and Karr 1978; Schlosser 1982; Stalnaker *et al*. 1986; Bisson *et. al*. 1988). Often a range of hydrological and hydraulic conditions is needed for the successful completion of different stages of the life cycle (Mann 1988; Jackson 1989; Richter 1997). Modifications to flow or physical habitat destruction can therefore disrupt critical life stages and compromise the ability of fish to survive, grow and reproduce. Dams modify the downstream flow regimes by reducing the absolute volume of water in a river and by changing the frequency and intensity of floods. These changes result in loss of habitat, reduced variability and unseasonal flows (Dynesius and Nilsson 1994; Sammut and Erskine 1995). Reducing the absolute volume of water in a river translates to a reduced wetted perimeter - a measure of the total amount of habitat available to fish - and can also reduce water quality by increasing the concentrations of dissolved salts and nutrients rendering it unsuitable for indigenous fishes (Newcombe 1981; Bain *et al*. 1988; Gippel and Stewardson 1998).

Rivers in semi-arid regions usually exhibit strong natural seasonality and the fish in these rivers are adapted to a reduced volume of water during the dry months. Fish are naturally exposed to increased competition and predation during these periods, and may suffer thermal and oxygen stress (Bernado and Alves 1999; Elliot 2000). As flows recommence following the dry season, connectivity between reaches increases, enabling the expansion and redistribution of fish through the system. Flows early in the wet season are therefore important for fish passage and recolonisation and for triggering spawning migrations. The magnitude, timing and frequency of these floods are critical, especially in temperate environments where spawning coincides with the onset of optimal conditions for the survival of eggs and larvae (Schlosser 1982; Bye 1984). If spawning takes place during the dry season, eggs and larvae may be present in the substratum or water column. Flow regulation may result in an extended or more extreme dry season. In the Western Cape where, rivers are used as conduits for irrigation releases, reversal of the flow regime during this period is also possible (i.e. higher flows in the dry season than in the wet season). Unseasonal high flows may displace eggs and larvae thereby reduce survivorship in fish populations (Allan 1995). Table 1 outlines the important components of flood pulses in dry land river ecosystems (Walker *et al*. (1995).

Table 1. Fish responses to the various components of flood pulses (adapted from Walker *et al*. 1995).

Flood pulse component	**Fish response**
Stage amplitude	• large floods promote breeding and recruitment in river and floodplain species, fishery yields have been correlated with flood magnitude; • small floods may provide 'bridging' recruitment, enabling populations to respond to drought conditions and very large floods.
Timing	• floods may not promote recruitment if timing is decoupled from seasonal cycles.
Duration	• successional response determined by length of time water remains on a floodplain.
Rates of change	• steep rising limb may displace species adapted for slow-flow; • steep falling limb may limit recruitment and growth of floodplain dependent species.
Degree of drawdown	• may affect recruitment; • fragmentation of channel reaches.
Frequency	• significance varies with generation time of species.

The quality and availability of pool and riffle habitats, which includes suitable substratum and hydraulic conditions (depth and velocity), are also important for the survival of eggs and larvae during the spawning period. Many species spawn in gravel areas at the tails of pools or in riffles where there is an ample supply of oxygenated water (Fukushima 2001). The reduced frequency and intensity of flushing flows or floods, can reduce mean depths and velocities resulting in sedimentation of riffle areas, reduced intragravelar flow and reduced delivery of oxygen to eggs and larvae (Bok and Immelman 1989; Crisp 1989). Such changes can also affect the availability of invertebrate prey items (Crisp 1989), thereby reducing the food supply for the young fish.

3.2 The effects of invasion by exotic fish species on native fish communities

Competition and predation play an important role in structuring fish communities (Grossman 1982). This is especially true of systems that are subject to invasion by exotic species, particularly where native communities are not adapted for predation pressure. The effects on native species of invasion by introduced species have been well documented (Vitousek 1990; Meffe 1991; Lodge 1993; de Moor 1996; Moyle and Light 1996; Williamson and Fitter 1996; Townsend 1996; Vermeij 1996; Gido and Brown 1999 and Lintermans 2000). One of the most cited examples is the extinction of 200 haplochromine species from Lake Victoria following the introduction of the Nile Perch, an event which is believed to have been the largest vertebrate extinction of the 20th century (Goldschmidt *et al*. 1993). Worldwide, numerous introductions of species of introduced fish have occurred, whether intentionally, for sport and recreational fisheries, or unintentionally through fish farm or aquaria escapees. Different ecosystems and native species exhibit variable susceptibility to invasions, just as some species invade foreign environments more successfully than others. Low rates of recolonisation and dispersal make inland water ecosystems especially susceptible to invasion. Townsend (1996) has highlighted several ways in which local communities may respond to invasion:

(1) no effect;
(2) direct effects such as changes in abundance of local communities and changes in the distribution of native fish as a result of local extinctions;
(3) indirect effects where trophic relationships between species are altered (Goldschmidt *et al*. 1993) and
(4) biological extinctions (extinctions are rare however, invaders more commonly restrict the ecological range of native species, Vermeij 1996).

The success or failure of an invasion is frequently mediated by human modification of ecosystems. Habitat destruction compounds the effects of predation by reducing the availability of refugia, by silting up of cobbles for instance, which are used as refugia by the juveniles and adults of smaller indigenous species (Bills 1999). Dams and reduced flows provide spatial and temporal refuges for introduced species, which are frequently poorly adapted for strong or variable flow conditions (Meffe and Minckley 1985). Increasing the availability of such refugia ensures the persistence of these populations during periods of unfavourable flow conditions and provides a ready source of recruitment from which re-invasions can take place once flow conditions more suited to the invader resume. For example, Meffe (1991), found that the invasion of *L. macrochirus* of streams in South Carolina USA was mediated by the degree of stream regulation. In low-gradient stream with no impoundment and current velocities between 0.07 and 0.25 ms^{-1}, *L. macrochirus* numbers were found to have declined three years after having been introduced. However, in an adjacent tributary in the same drainage system, which had been impounded, colonisation was successful .

3.3 Invasion by exotic fish species and habitat degradation in South Africa

In South African freshwater ecosystems, flow modification, habitat destruction and invasion by introduced species is as much of a problem as elsewhere in the world. During the first half of the 20th century a paradigm prevailed amongst the scientific and angling community, which promoted the introduction of exotic sportfishes such as carp, tench, trout and bass. However, guided by the growth of ecology as a science, the work of taxonomists in revealing the diversity of South Africa's freshwater fishes, and the emergence of the conservation ethic, this paradigm was gradually replaced with an appreciation of the impact of introductions on native fish populations (Coke 1988, Skelton 2000). Unfortunately, by that time exotic species had become well established in South African drainage systems and many indigenous fish species had disappeared from the mainstem of rivers, many finding refuge in tributaries not yet colonised by exotic species.

De Moor (1996), has identified a more recent 'second phase' of invasion in South Africa, where introduced species have become established in systems where they had been previously excluded. De Moor suggests that this may be a result of a breakdown in 'environmental resistance' due to increased disturbance resulting from habitat destruction, flow modification, or an increase in lentic environments following impoundment. De Moor cites several case histories in support of this, including an increase in the range of bass and carp in Kwazulu-Natal between 1964 and 1988 following the construction of several impoundments in this area. Also cited is the invasion of bass into the Gamtoos system following the construction of the Paul Sauer Dam, and in 1980 the first record of bass below the Vaal Barrage where they are now abundant.

In some cases, however, habitat degradation has favoured the persistence of indigenous populations in the face of invasion by exotic species. In Verlorenvlei *Barbus* cf. *bergi* and *Galaxias zebratus* populations are able to coexist with bass *Micopterus* spp., and in parts of Lesotho, *Psuedobarubus quathlambae* coexist with trout *Oncorhynchus mykiss*. In both cases, it appears that predation by exotic species is reduced because of elevated turbidity levels resulting from anthropogenic disturbances (R. Bills, South African Institute for Aquatic Biodiversity, *pers. comm.*).

4. STUDY AREA

4.1 Location

The combined catchments of the Olifants and Doring rivers is centered at around 32ºS and 19ºE (Figure 4.1.1, Appendix A), approximately 250 km north of Cape Town and drains a large catchment of about 46 000 km^2 (Morant 1984).

4.2 The Olifants River

The perennial waters of the Olifants River rise on the Agter-Witzenberg plateau before entering a narrow gorge between the Skurweberg and Kouebokkeveld mountains. A large proportion of the runoff of the Olifants River is derived from a series of tributaries including, amongst others, the Ratels, Boontjies, Rondegat and Jan Dissels Rivers, which emerge from the Cedarberg mountains flanking the eastern banks of the upper Olifants River Valley for approximately 170 km from its source. A considerably smaller component of the runoff is contributed by tributaries rising in the Olifantsrivierberge to the west.

The resistant quartzitic sandstones of the Table Mountain Group (TMG) from which these mountains are derived ensure that the waters of the headwater and foothill reaches are clear and oligotrophic, and of low conductivity (Dallas 1997). Near the foot of the Olifants River Valley upstream of Klawer, the fault-scarp topography typical of the Cape Fold Belt is replaced by low-lying van Rhynsdorp Group deposits. This transition, together with its juncture with the Doring River, is accompanied by a steep increase in conductivity (Dallas 1997).

Discharge in the Olifants River is driven by frontal rains and therefore seasonal, with winter flows occurring over the period June, July and August and summer flows during November to April. Intermediate flows occur in September and October (spring) and May (autumn) (Dallas 1997). Mean annual precipitation (MAP) at the headwaters and southern tributaries of the Olifants River is >1400 $mm.yr^{-1}$ (DWAF 1994). The natural mean annual runoff (nMAR) at the estuary is *c*. 1000 $Mm^3.yr^{-1}$. Present day flows at the estuary of the Olifants River are 70% (*c*. 740 $Mm^3.yr^{-1}$) of the naturalised flow (Basson *et al*. 1998) as a result of water abstraction and impoundments in the catchment (mostly for citrus orchards and vineyards). The Clanwilliam Dam releases water on demand to the Bulshoek Weir from where it is diverted into an extensive system of irrigation canals downstream. Farm dams supply 35% of the water required for agriculture, the Clanwilliam and Bulshoek dams supply a further 44%, and run-of-river abstractions account for the remaining 21% (Basson *et al*. 1998). The relative naturalised flow contributions to the lower Olifants River from the Doring and upper Olifants Rivers are roughly equal (*c*. 510 and 513 $Mm^3.yr^{-1}$ respectively). However, under present day conditions, only 54 % of the upper Olifants River nMAR (*c*. 280 $Mm^3.yr^{-1}$) bypasses the Doring River confluence. The comparatively undeveloped Doring River contributes 78% (*c*. 400 $Mm^3.yr^{-1}$) of its nMAR to the Olifants River at this point (Basson *et al*. 1998).

4.3 The Doring River

The Doring River has its source on the slopes of the Hex River Mountains, the Skurweberg and the Kouebokkeveld Mountains and, in contrast to the Olifants River is a seasonal river. The Doring River catchment straddles the boundary between a winter and a non-seasonal rainfall region: mean annual precipitation (MAP) varies from *c.* 500 $mm.y^{-1}$ near the headwaters to <300 $mm.y^{-1}$ in the northern and eastern regions of the catchment (DWAF 1994). The tertiary catchments in the southern headwater tributaries of the Bontberg and Klein Roggeveld mountains in south of the catchment contribute more than half of the total natural flow (Brown and Day 1997). Although seasonal variation in the Doring River is primarily frontally driven in the southern basin, flows in the mainstem may be augmented in summer by thunderstorm activity over the Karoo. Winter baseflows are high, but drop off sharply in spring, with river flow ceasing for several months each year. During such times the river may resume flow for brief periods, but these flows are highly erratic.

The Groot River, which flows off the eastern flanks of the Cedarberg mountains, is the major tributary of the Doring River and contributes approximately 50% of the runoff at the confluence with the Olifants River. The upper Doring River drains a vast area of the Karoo. From its confluence with the Groot River, the Doring River describes a gradual arc west through the dolerite-intruded mesa-and-butte topography characteristic of the Bokkeveld and Ecca Groups and Dwyka Formation sedimentary sequences of the more arid south-western Karoo, before joining the Olifants River near Klawer about 300 km from its source. Other significant (western) tributaries are: the Tra-tra, Biedouw and Brandewyn Rivers. Flow from these systems is augmented by the Tankwa and Bos/Wolf Rivers, which drain the Karoo, and the Koebee and Oorlogskloof Rivers, which drain parts of the northernmost reaches of the catchment from Calvinia.

The varied geological nature of the Doring River catchment gives rise to the dual nature of the water chemistry. The water quality in the tributaries that rise on the eastern flanks of the Cedarberg is influenced by the quartzitic sandstones of the Table Mountain and Witteberg Groups, and tends to be clear with a low conductivity. During periods of high flow from the Karoo tributaries, turbid, saline waters draining the highly erodable shales and mudstones of the Dwyka Formation and Ecca Group enter the Doring River. Waters flowing from these formations exhibits elevated levels of nutrients, conductivity and pH.

The upper portions of some of the Cedarberg tributaries, in particular those in the Kouebokkeveld, are subjected to extensive impoundment and abstraction. Abstraction also takes place from the other

Cedarberg tributaries, and the Tankwa, the Bos and the Koebee Rivers (Brown and Day 1997). There are gauging weirs at Melkboom and at Aspoort. Large farm dams are found on the mainstem of the Doring River (on the Brakfontein farm) and two on the Beukesfontein River, a tributary of the Doring River.

4.4 Site descriptions

The sites selected for sampling during the survey conducted between 4 -17 February 2001 and between 13 - 27 October 2001, were distributed throughout the Olifants and Doring rivers upstream and downstream of the confluence of the two rivers. The location of each of the study sites is shown in Figure 4.1.1 (Appendix A). Photographs of the sites appear in Appendix B: Plates 1 - 16. Since a major objective of the survey was to accumulate data on the relatively under-sampled mainstem of the Doring River, only three sites were visited on the Olifants River (Keerom, upstream of Clanwilliam Dam and downstream of Bulshoek Dam). Apart from these and the two on the Oorlogskloof and Koebee Rivers, all other sites were located on mainstem of either the Doring, or the Groot Rivers. All sites were easily accessible by vehicle. The Doring River was not flowing at the time of the first (February) survey – and all but one site on the mainstem of the Groot, Doring and Koebee Rivers constituted standing pools. The exception was Site 4 at Aspoort, where the Doring River had resumed flow the night before following a flash flood induced by thunderstorm activity. Physical and chemical data are presented in Figure 4.4.1 (Appendix A) and reported in Tables 1 and 2 (Appendix C).

4.4.1 Site 1: Olifants River Keerom (Plate 1; Appendix B)

Site 1 on the farm Keerom was southernmost site sampled on the Olifants River, downstream of where the river emerges from the Olifants River Gorge. The river here is located in a wide valley bounded by the foothills of the Cedarberg to the east and the Olifantsrivierberge to the west. The riparian belt is lined with indigenous vegetation comprising trees and shrubs characteristic of the Fynbos biome, interspersed with stands of Black wattle (*Accacia mearnsii*). The upstream reach of the study site consists of a pool with sand and silt deposited on what appeared to be bedrock. The channel is wide (*c.* 40 m) and deep (8_{d} 1.8 m; d_{max}. 2.5 m) at this point, but narrows and braids in two cobble-bed riffles around a small island downstream of the pool. The water is clear (1.3 NTU) and, in keeping with rivers rising in Fynbos, the pH (8_{pH} 6.91 - 7.3) and conductivity (22 μS/cm) are low. Water is abstracted from the pool, although farming activity in the immediate vicinity of the riparian belt is minimal.

4.4.2 Site 2: Olifants River at Clanwilliam Dam (upstream reach) (Plate 2; Appendix B)

Site 2 is located upstream of the wet season back fill of the Clanwilliam Dam. The right bank of the river is confined by the foothills of the Cedarberg, the river valley being wider on the left bank of the river. Upstream of the study site, the river braids between dense beds of Palmiet (*Prionium serratum*) over a series of bedrock-steps before flowing into a pool. The single channel (*c*. 30 m wide) is bounded alternately by broad sandbanks and stands of Palmiet. The bed of the river is comprised of medium to course sand with mid-channel bars and low sand waves. In February, river flow was reduced to two narrow channels (*c*. 0.2 m wide) in the bedrock which flowed into a sand-bed pool (δ_d 1.7 m; d_{max}. 2.39 m). The river beyond this point had ceased flowing, having become a series of isolated pools downstream of the study site. During the October survey the river was flowing and the bedrock area was a rapid, and the pool was a deep, fast-flowing run (δ_d 2.14 m d_{max} 4.3 m). Extensive farming activity takes place throughout catchments and water abstraction is likely to be the primary factor responsible for the observed seasonal nature of the river at the site. Conductivity was also higher during the dry summer months (86 μS/cm Oct 2001 - 386μS/cm Feb 2001) possibly as a result of irrigation return flows.

4.4.3 Site 3: Olifants River at Cascade Pools (downstream reach) (Plate 3; Appendix B)

Site 3 was the final site chosen for sampling on the Olifants River. It is located downstream of the rapids known as Cascade Pools, below the Bulshoek dam. The river valley here is moderately confined between steep hills. Stands of Palmiet stabilise both right and left banks. The river is very deep in places (d_{max} 7.4 m) and bed is comprised of embedded cobbles in sand and silt. No velocity was measurable or perceptible either during the summer (February) or spring months (October) and there was no discernable change in depth between the two surveys. Farming activities along this particular reach are not intensive, but orchards lining the river bank are much in evidence further downstream. A series of elevated canals follow the course of the river, diverting water from the Bulshoek Dam and channelling it to farms downstream.

4.4.4 Site 4: Doring River at Aspoort (Plate 4; Appendix B)

The site at Aspoort was located downstream of the confluence of the Doring and Groot Rivers. Immediately upstream of the site, the river braids in several narrow channels through dense stands of acacia *Acacia karoo* and invasive Oleander (*Nerium oleander*). A DWAF gauging weir (E2H002) backs the river up in a pool as it emerges from the acacia. Below the weir, the river flows over a bedrock rapid before entering a deep sand bedded gorge. The braided river upstream of the weir consists of a series of cobble-bed riffles, whereas downstream, a layer of sand and silt overly bedrock and talus. During February 2001 the river was a series of isolated pools (δ_d 2.2 m, d_{max} 3.10), but recommenced flowing for several days following a severe thunderstorm. The conductivity was relatively low in comparison to many of the other sites on the Doring River (90.3 μS/cm).

4.4.5 Site 5: The Doring River at Brakfontein (Plate 5; Appendix B)

Site 5, downstream of Aspoort was visited during February 2001. The Doring River on the farm Brakfontein has been impounded by the landowner and the water backs up into the gorge from which it emerges at this point. Grasses, sedges, reeds (*Phragmites australis*) and acacia (*A. karoo*) line both banks. At no point is the dam much deeper than 1 m (δ_d 1.15 m, d_{max} 1.49), and the height differential between the bed of the dam and the bed of the river downstream of the dam testifies to substantial sedimentation upstream of the dam wall. The conductivity of the Doring River here (140 μS/cm) is higher than recorded at Aspoort.

4.4.6 Site 6: Doring River at Bos-Doring confluence (Plate 6; Appendix B)

Site 6 is located at the confluence of the Doring River and Bos Rivers. The Bos River is an intermittently flowing river that drains part of the Tankwa Karoo and flows into the eastern side of the Doring River. Dense lateral and mid-channel stands of *N. oleander* are more evident here than at any other site visited during the survey. The river braids between stands of *N. oleander* and *A. karoo* as it emerges from an upstream pool into a short riffle that has been modified into a cobble causeway. The river veers west as it passes through a confined river valley amid the mesa-and-butte topography of the Karoo. Conductivity ranges between a mean of 127.4 μS/cm upstream and 143.9 μS/cm downstream of the confluence with the Bos River. The pH is higher (δ_{pH} 8.05) here than at any of the sites upstream of this point on the Doring River, possibly as a result of the increased influence of the Karoo Rivers. The bed of the pool is comprised of a thick layer of very fine anoxic silts and clays deposited by the Bos River from the Ecca Group shales and mudstones of the Karoo.

4.4.7 Site 7: Doring River at Biedouw-Doring confluence (Plate 7; Appendix B)

Site 7 is located at the confluence of the Doring and the Biedouw River, which flows off the north-western flanks of the Cedarberg mountains. The right bank of the river at the site is lined by dense stands of overhanging acacia (*A. karoo*) and on the left bank, by a broad, lateral sand-spit on the inside bend of a meander. When the river is flowing (October 2001) it negotiates a narrow, shallow (δ_d 1.27 m) sandbed channel on the right bank. In the dry summer months (February 2001) it consists of a series of shallow isolated pools (δ_d 0.3 m). The site is similar to the Bos-Doring confluence with respect to its topography. There was no evidence of agricultural activity in the immediate vicinity of the study site.

4.4.8 Site 8: Doring River at Doringbos (Plate 8; Appendix B)

The site on the farm Doringbos was located near the point where the Clanwilliam-Calvinia road crosses the Doring River. The river valley broadens here as the mesas and buttes are more widely interspersed by extensive low-lying plateaus. During spring (October 2001), the river at this point was flowing too strongly to sample at the bridge and a point, further upstream was chosen. The river splits into two channels upstream of a small island. A short riffle in the left channel is followed by a long shallow run (δ_d 1.03 m, δ_v 0.17 m.s^{-1}). Agriculture, primarily sheep farming is extensive in this area, but vegetables and grapes are also grown alongside the river.

4.4.9 Site 9: Doring River at Oudrif (Plate 9; Appendix B)

Site 9 at Oudrif has been developed as a low-impact ecotoursim destination and several dwellings have been built on the slopes above the southern bank of the river. The area sampled in February was downstream of the camp and comprised a series of isolated pools of very high conductivity (δ_{cond} 1425.1, 1919.2 and 1072.8 μS/cm in the upper, middle and lower pools respectively). The highest pH levels for the catchment (δ_{pH} 8.8) were also recorded here during summer. In October 2001, a more accessible site upstream of the February site was chosen where a rapid flows into a deep pool bounded on its right bank by a rocky outcrop. The river exits the pool downstream via a short riffle. The bedrock and talus pool, *c.* 25 m wide and δ_d 1.03 m deep (d_{max} 3.6 m) is covered by shallow layer of silt and sand. In October, conductivity levels in the river had dropped (relative to February) to δ_{cond} 252 μS/cm.

4.4.10 Site 10: Doring River at Melkboom (Plate 10; Appendix B)

Site 10 is the most downstream site on the Doring River and is located at the site of the DWAF gauging weir (E2H003) at Melkboom. Grasses and reedbeds (*P. australis*) line the left and right banks. The river bed is comprised of sand and silt above the weir, while below the weir the river bed and channel margins alternate between bedrock and sand beaches. The river was not flowing in February, but in spring (October) the bedrock area below the weir was a series of runs and riffles. Elevated conductivity levels (δ_{cond} 1000.4 μS/cm) were evident at this site during the February survey, but were lower than those recorded at Oudrif.

4.4.11 Site 11: Tributary: Groot River De Mond (Plate 11; Appendix B)

Site 11 is situated on the Groot River just upstream of De Mond campsite. The campsite is located on the banks of the river shortly after it emerges from a confined rocky gorge and before it is deflected northwards via a low weir towards its confluence with the Doring River. Upstream of the weir the river forms a large pool, in places *c*. 50-60 m wide (δ_d 3.04 m, d_{max} 4.82 m) extending for some distance up the gorge. The tributaries of the Groot River rise on the eastern flanks of the Cedarberg mountains on resistant sandstones and conductivity and pH levels are consequently low (δ_{pH} 7.64) in comparison to the remainder of the Doring River sites. In February, flow was almost imperceptible before it recommenced flow following a thunderstorm. The only flow perceptible during the October survey, was at the weir, below which the river flowed in a series of braided runs and riffles between banks lined with Succulent Karoo shrubs.

4.4.12 Site 12: Tributary: Tra-tra River at Cobus-se-Gat (Plate 12; Appendix B)

Site 12 is located at Cobus se Gat near the farm Elandsvlei on the lower reaches of the Tra-tra River. Cobus-se-Gat is a small recreational where the river enters and exits a shallow pool *c.* 200 m long via two small riffles, the lower of which has been artificially raised with sand bags. Embedded cobbles line the bed of the pool. Mean pool depths vary between $\bar{x}_{d}$ 0.6 m in summer and $\bar{x}_{d}$ 1.5 m in spring.

4.4.13 Site 13: Tributary: Oorlogskloof at Brakwater (Plate 13; Appendix B)

Site 14 is situated on the Oorlogskloof River at Brakwater in the Oorlogskloof Nature Reserve south of Nieuwoudtville. The vegetation of this region consists of a mixture of plants from the Succulent Karoo and Fynbos Biomes . The river here flows through a deep, vegetated gorge with *Rhus lancea* and *P. australis* occurring along the riparian zone. The river at this point is *c*. 12 m wide and the study site comprises a pool ($\bar{x}_{d}$ 1.03 m) bounded by an upstream and downstream riffle. Relatively high conductivity levels ($\bar{x}_{cond}$ 477.5 μS/cm) characterise the water quality here. The bed comprised course sand and gravel with *P. australis* and overhanging trees lining the banks.

4.4.14 Site 14: Tributary: Koebee River at Klein Koebee River confluence (Plate 13; Appendix B)

Site 13 is located on the Koebee River at the Klein Koebee River confluence. The Koebee River flows through a deep, moderately confined valley. The river channel is *c*. 30 m wide and consists of a series of long, deep pools ($\bar{x}_{d}$ 2.03 m) and riffles typical of foothill rivers. No recent farming activity was evident at the site itself, but livestock farming occurs further downstream. The pH and conductivity values measured at this site were high. During the October survey the suspended sediment load was exceptionally high, with mean turbidity levels measured at 81.7 NTU. It is not clear whether the elevated turbidity levels are natural or due to agricultural activity in the catchment, although Abrahams and Pretorius (2000) suggest that these high turbidity levels may be a consequence of the natural erodability of the Karoo soils, overgrazing and disturbance to the riparian zone in the region of the upper Oorlogskloof River, a tributary of the Koebee.

4.4.15 Site 15: Tributary: Biedouw River at Uitspanskraal (Plate 15; Appendix B)

The site on the Biedouw River was not a scheduled study site, but is described here because of the discovery of its importance as a spawning site for *L. seeberi*. The Biedouw River flows from the northern flanks of the Cedarberg into the Doring River downstream of site 7. During the summer months the riverbed is dry, but flow recommences in the winter. The river was flowing when it was visited in spring (October). The site is located on the farm Uitspanskraal where the road crosses the river. The river is *c*. 9.5 m wide at this point and at the time of sampling comprising a sequence of fast-flowing riffles and runs ($\bar{x}_{v}$ 0.22 m.s^{-1}; v_{max} 0.8m.s^{-1}).

4.4.16 Site 16: Olifants River at Klawer (Plate 16; Appendix B)

Site 16 was added to the survey for the October 2001 visit. The site is located on the Olifants River below the confluence with Doring River near the town of Klawer. The river is wide (*c*. 50 m) and deep (δ_{d} 6.27 m, d_{max} 9.3 m) at this point and meanders through intensively cultivated vineyards. Turbidity (δ_{turb} 6.16 μS/cm) and conductivity levels (δ_{cond} 349.25 μS/cm) were elevated here.

5. METHODS

5.1 Sampling methods

Different sampling methods were selected for sampling different species and different size classes of the same species. Thus a range of sampling methods were employed to ensure that sampling was representative of a site. These methods are described below. The survey focussed on *B. capensis*, *B. serra*, *L. seeberi* and the two most frequently caught alien species: *M. dolomieu* and *L. macrochirus*. Although other alien species were caught (including largemouth bass *Micropterus salmoides*, Mozambique tilapia *Oreochromis mossambicus* and banded tilapia *Tilapia sparmannii*), they were not as abundant as *M. dolomieu* and *L. macrochirus* and were not included in the data analysis. This should not, however, diminish the importance of their impact in terms of predation and/or predation on indigenous species.

Dive transect: when visibility permitted, three divers were deployed in the channel, one in the center and one along each bank. The abundance and size ranges of all fish that could be identified were recorded over a 100 m longitudinal transect and expressed as fish/m.

Gill-netting: four gill-nets with mesh sizes of 54 mm, 70 mm, 90 mm and 145 mm were used to sample pools. Each net was 30 m long and 2 m wide and fitted with weighted foot ropes. A set consisted of all four nets placed at predetermined points in the river. CPUE was calculated as no. of fish/m^2/ hr. When the nets were cleared, all live indigenous fish were identified, measured live (mm TL), tagged and released. Indigenous fish species which died in the nets and a sub-sample of all exotic species were kept for biological analysis.

Seine-netting: In February an anchovy seine-net (mesh size 12 mm; length 30 m; depth 2 m) fitted with a weighted foot rope and a 2 m deep bag at its midpoint, was used to sample shallow sandy areas. In October, an anchovy seine-net 20 m in length was used. Between two and three seines were conducted per site, depending on the availability of suitable sandy beaches. Data were expressed as the density of fish/m^2 calculated using the surface area of the section of river seined ($½\pi r^2$).

Electroshocking: an electroshocker was used in shallow cobbled habitats where it was not practical to use a seine-net. CPUE was expressed as number of fish caught per hour electrofished (fish/hr).

Angling: angling using a lure (spinner) was recorded as number of fish caught per hour (fish/hr). An average of 30 minutes was spent angling at each site.

Spearfishing: where visibility permitted, bass and tilapia were caught using a speargun. CPUE was reported as fish/hr.

5.2 Tagging

All indigenous fish > 300 mm TL were tagged using a numbered external anchor tag (Nielsen and Johnson 1992) inserted into the muscle below the dorsal fin by means of a tagging gun.

5.3 Biological analysis

Biological analyses were carried out on all indigenous fish which died in the net. The total length (TL), fork length (FL), standard length (SL) and weight (g) of each fish was recorded. Length-frequency distributions were derived for the three most frequently caught species: *B. capensis*, *B. serra*, *L. seeberi*. The sex, gonad stage (1 – 7) (Griffiths 1997), and gonad mass (g) were also recorded The stomachs of alien and indigenous fish were dissected and fixed in 8% formalin for analysis. Fin-clips were taken from the indigenous species and preserved in 80% ethanol for later genetic analysis.

5.4 Analysis of historical distribution patterns

Geographical Information Systems (GIS) are becoming an important tool in conservation planning and environmental management. They are especially valuable for examining the changing geographic distribution patterns of species in space and time at any scale, having contributed significantly to the value of natural history collections and the study of ecosystem change (Skelton *et al*. 2000). Terrestrial and aquatic species distribution records usually comprise point data that can then be rasterised at a predetermined resolution for studying broad-scale species distribution patterns (Skelton *et al*. 1995; Freitag *et al*. 1998). However, the use of GIS to examine the distribution of aquatic species living in rivers at the catchment scale is complicated by the longitudinal nature of the ecosystem and it is particularly difficult to interpret broad-scale distribution patterns on the basis of point data. Several means of presentation of the historical data were therefore attempted, including the classification of the catchments into quaternary catchments and presenting each species in terms of its frequency of occurrence within in each quaternary catchment. Although broad patterns of distribution could be discerned using this technique, detail was lost. A technique (described below) using an intermediate resolution was therefore decided upon using the density function available in the GIS software package.

Historical distribution analysis: The aim of the historical distribution analysis was to examine, using the existing data, how catchment-wide distribution patterns of alien and indigenous species might have changed in recent years and, where possible, to examine possible broad-scale habitat preferences.

The distribution records of the *B. capensis*, *B. serra* and *L. seeberi* were compiled from six sources:

(1) Cape Nature Conservation (CNC);
(2) the Albany Museum;
(3) the JLB Smith Institute;
(4) FISHBASE (2001);
(5) results of a survey undertaken by Bills (1999) and
(6) data obtained during February and October 2001 surveys.

One of the difficulties of representing these data in a manner that would allow an assessment of changes in distribution is that the effort employed in compiling the different sets of data was inconsistent. There has been no systematic sampling that allows for a time series comparison of changes in distribution. Certain reaches, particularly those that are easily accessible have received the most attention, while other reaches have only been sampled one or two occasions. Furthermore, prior to 1974, there are only 12 distribution records in the data represented here, thus there are very few records of the distribution of species in the catchment prior to the invasion by *Micropterus spp* and *L. macrochirus*.

In order to overcome differences in sampling methods, a relative abundance index (RAI) was used. For each sampling event (i.e. species sampled on the same day at the same location), the species caught were ranked in order of increasing abundance. The species were then given a score between 5 (most abundant) and 1 (least abundant). These data were entered into the GIS and represented geographically as a continuous densities of the RAI. Although this is an artificial representation of distribution, since rivers are discontinuous across the land surface, the technique does give a graphical impression of broad-scale distribution patterns that is hard to convey using point or grid data. Density was calculated as the number of RAI's of each species per square-unit area surrounding a sample point. The RAI's for a particular species found within a predetermined search radius were summed and divided by the surface area. 'Density' in this text therefore refers the density of the RAI's and should, at best, be considered only a proxy for the actual densities. Densities of RAI's are expressed in km^2. The search radius was set at 6.5 km^2, which was found to be wide enough to be assessed without overlap of adjacent systems. Where overlap does occur, densities should be read in conjunction with the associated sampling events (solid circles) near their centre.

In order to examine changes in species distribution, the records for *B. capensis*, *B. serra*, *L. seeberi*, *M. dolomieu* and *L. macrochirus* were divided into a pre-1985 period and present day using a combination of the two most comprehensive recent surveys, namely:

(1) the 1998 survey by Bills (1999), which included many of the tributary systems;
(2) the present surveys which covered sites on the mainstem of the Groot, Doring and Olifants Rivers.

Regional classification: In order to clarify catchment-wide distribution patterns identified on the basis of patterns interpreted from the previous analysis of densities, six broad geographic regions were identified:

1-3 These regions, on the mainstem of the Olifants River, were broadly based on the water quality zones of King and Tharme (1994) for the Olifants River and geomorphological zonation:

- upstream of the Clanwilliam Dam (Olifants Upper: OU);
- downstream of the Clanwilliam Dam (Olifants Lower: OL) ;
- the tributaries of the Olifants River (Olifants Tributaries: OT);

4 the combined mainstems of the Groot and Doring Rivers (Doring-Groot: DG);

5 the tributaries flowing from the eastern flanks of Cedarberg mountains into the Doring and Groot Rivers (Doring Tributaries: DT);

6 the Oorlogskloof and Koebee Rivers (Oorlogskloof-Koebee OK).

Sampling events were overlaid on these regions and classified according to the region in which they occurred. The number of times a particular species was recorded in each region was summed and averaged by the total number of sampling events in that region. The regional means for each species (δ_R= no. of fish/sampling event) are presented as a box-whisker plot. All distribution data were analysed using the GIS software ARCVIEW ©, based on the land covers ENPAT produced by the Department of Environmental Affairs and Tourism (DEAT).

5.5 Analysis of the 2001 survey distribution patterns

Additional, more detailed analyses of the data from the February and October 2001 surveys were also undertaken. The variety of sampling techniques used, and the different selectivity of the gear for different species and size classes made comparison of species abundances and CPUE between sites difficult to represent. Where fish were selected by only one or two sampling techniques, comparison between sites was more straightforward. This was true for the indigenous species which were rarely caught whilst angling or observed but frequently caught in gill and seine-nets. However, *Micropterus* spp. were sampled using a variety of gear, including: electrofishing, angling, seine-nets, and gill-nets and dive transects in comparison to the indigenous species. A scoring system, similar to that described above, was therefore used for the representation of these data. Sampling techniques were standardised by reclassifying the range of CPUE values obtained for each sampling technique into equal interval categories and assigning each category a value between 5 (highest) and 1 (lowest). By ignoring the bias introduced by the size selectivity of the gear, summing the scores obtained for each sampling technique at each site enabled a semi-quantitative comparison to be made between sites. The results were then represented on pie charts subdivided into sampling techniques with the total size of the pie representing the sum of all the scores.

6. RESULTS

6.1 Historical and present-day distribution

The comparison between historical and present day distribution patterns is represented in Figures 6.1.1 - 6.1.5 (a) and (b) (Appendix A). Figure 6.1.6 (Appendix A) represents the mean number of fish of each species per sampling event recorded from each of the geographic regions (OU, OL, OT, DY, DT and OK).

Barbus capensis

Of the three indigenous species examined, *B. capensis* is most regularly distributed through the catchment. Highest densities suggested by the abundances indices mark its occurrence on the upper reaches of the Olifants River and the tributaries flowing off the western flanks of the Cedarberg, particularly the Rondegat, Boskloof and Noordhoeks Rivers. The general patterns of distribution of this species do not appear to have changed substantially between 1985 and 1998. *Barbus capensis* does not appear to be common on the mainstem of the Olifants River between the confluence with the Ratels River and Clanwilliam Dam, although a population is known to persist between the Clanwilliam and Bulshoek Dams (Cambray 1997). It has only been recorded once on the Olifants River below the confluence with the Doring River during the earlier (pre-1985) period - the only time apart from the October 2001 survey that this section of the river has been sampled. On the Doring River it can be found on the mainstem of the Doring and Groot Rivers, as well as the tributaries, particularly the lower reaches of the Driehoeks River to its confluence with the Matjies River.

From Figure 6.1.6 (Appendix A), it is evident that the largest number of *B. capensis* per sampling event (OT: 8_R = 1.06±1.09), has been recorded from the tributaries flowing into the Olifants River off the western flanks of the Cedarberg mountains. A total of 72 fish were recorded in these tributaries over the course of 68 sampling events (Table 1, Appendix C). Numbers of *B. capensis* per sampling event was also high in the mainstem on the upper Olifants River (OU: 8_R = 0.90±0.55).

Barbus serra

Densities appear to be higher in the tributaries of the Doring River during both periods (pre-1985 and post-1997) particularly the Driehoeks River from its confluence with the Matjies River. Despite fairly intensive sampling along on the mainstem and tributaries of the Olifants River, few *B. serra* have been reported from here - the only *B. serra* recorded during the later (post-1997) period, were located in the upper reaches, of the Olifants River above its confluence with the Ratels River. The largest number of *B.*

serra recorded per sampling-event was in the Doring River tributaries (DT: 60; n = 58; 8_R = 1.03±1.23) including the Oorlogskloof-Koebee system (OK: 7; n = 11; 8_R = 0.64±0.67).

Labeo seeberi

L. seeberi appear to have the most restricted distribution of all three indigenous species - having been recorded from the lower reaches of the Olifants River, the mainstem of the Doring River and several of its tributaries: the Koebee, Biedouw and Brandkraals Rivers. While *L. seeberi* were recorded on three separate sampling occasions on the lower Olifants River below the Clanwilliam dam prior to 1985, no *L. seeberi* were recorded here during the 1998 and 2001 surveys.

Historically, *L. seeberi* was least often sampled of all three indigenous species (41). No distribution records exist for *L. seeberi* in the upper Olifants River (OU) and the Olifants Tributaries (OT). Numbers per sampling event were highest in the Oorlogskloof and Koebee rivers (OK: 8_R = 0.909±0.831), in the mainstem of the Doring-Groot (DG: 8_R = 0.50±0.65) and the lower Olifants River (OL: 8_R = 0.35±0.75).

Micropterus dolomieu

M. dolomieu appear to be fairly regularly distributed throughout the catchment regions, although mean number collected per sampling event appear to be slightly higher in the Doring River mainstem and tributaries. By 1985, *M. dolomieu* appear to be well established in the Olifants and Doring Rivers, occurring in both tributaries and mainstem of both rivers. Although there are no available data to confirm their occurrence in the upper reaches of the Olifants River prior to 1985, anecdotal accounts confirm that they were there. There are more records from the Olifants tributaries during the post-1997 period, although the higher densities may reflect a greater interest in the distribution of invasives, and therefore a higher recording rate than the earlier period, rather than increased distribution.

Lepomis machrochirus

Densities of *L. macrochirus* suggest a recent expansion of its distribution along the mainstem of the Olifants River above the Clanwilliam Dam, as well as its presence in the upper reaches of the Olifants River near the confluence with the Ratels River. Very low numbers of *L. macrochirus* were recorded in the historic data (37). No *L. macrochirus* have been reported from the Olifants Tributaries (OT: 0; n = 68), while most *L. macrochirus* have been reported from the mainstems of the Doring and Groot Rivers (DG: 8_R = 0.45±0.69) and the Oorlogskloof-Koebee system (OK: 8_R = 0.55±0.69).

6.2 Detailed analysis of 2001 surveys

Barbus capensis:

A total of 37 *B. capensis* were caught during the February survey and less than half that amount (14) during the October survey, comprising 9.3% and 17.7% of all indigenous fish caught in gill-nets over the two periods, respectively. The results of the sampling survey are presented in Figures 6.2.1 - 6.2.5 (Appendix A) and reported in Tables 1 - 4 (Appendix D).

February: *B. capensis* was caught at six sites during the February survey. The only specimen caught on the Olifants River during this survey was at Cascade Pools at site 3 below the Bulshoek Dam. The highest CPUE values and index of CPUE for *B. capensis* were obtained at the Bos-Doring confluence, where 15 *B. capensis* were caught in gill-nets in the upstream pool near the confluence with the Bos River. A total of six *B. capensis* caught during the February survey were kept for biological examination. Of these two were stage II males, three were females, stages I or II and one was a single large female caught in the Koebee River where gonad development was found to be advanced (stage IV).

October: Two *B. capensis* were caught in gill nets on the Olifants River during the October survey - one at Keerom and another below the Cascade Pools. The highest CPUE for *B. capensis* caught in gill-nets was obtained at the Bos-Doring confluence where the nets had been set in the upstream pool close to the confluence with the Bos River. At Aspoort, a single *B. capensis* was angled and another observed during a dive transect amongst the braided channels upstream of the gauging weir. The summed CPUE index for this site was therefore the highest for the October survey (4). Four *B. capensis* were caught in gill-nets in a run at Doringbos above the road bridge. A single *B. capensis* from these four was kept for biological examination during the October survey and was found to be ripe and running (stage V).

Several sightings of *B. capensis* were not recorded in the dataset since they were reported to the author by anglers: a large specimen was caught upstream of the gorge at De Mond, a single individual was sighted below the braided riffles and runs downstream of the De Mond campsite and another was observed crossing a shallow riffle upstream of the gauging weir at Aspoort. Several *B. capensis* were also reported to have been angled at Aspoort several days prior to the survey.

Barbus serra

A total of 254 *B. serra* were counted and measured during the February survey, 22 of these were tagged and released and four kept for biological examination. In October, 13 *B. serra* >300 mm were caught and one of these was kept for biological examination.

February: *B. serra* were gillnetted at four sites on the Doring River in February: Aspoort (1), De Mond (6), Doringbos (2), and Ou Drif (13). Four were caught in the Koebee River. Two seines of the Oorlogskloof River yielded 227 sub-adults and juveniles (<300 mm TL). Highest CPUE index for *B. serra* larger than 150 mm TL were recorded from Ou Drif. The four *B. serra* examined biologically in February comprised two males and two females from Ou Drif on the Doring River. Gonad development in these individuals ranged from II to IV.

October: 13 *B. serra* were caught from two sites, 10 of these (350 - 450 mm TL) came from Ou Drif in a run below the riffle at the head of the pool. Considerably fewer *B. serra* were caught at Brakwater during October than in February: three (200 - 300 mm TL) were gill-netted, and another 15 (50 -100 mm TL) seined from the pool at Brakwater. A single *B serra* male collected from Ou Drif during October was examined and found to be a ripe and running (stage V).

Labeo seeberi

A total of the 357 *L. seeberi* were caught during February and 52 were caught in October, making them the most frequently caught of the targeted indigenous species during both surveys. Of the 357 caught in February, 271 were tagged and released and 40 kept for biological examination. During October, 44 *L. seeberi* were tagged and released and 8 kept for biological examination.

February: *L. seeberi* were found at 6 of the 14 sites visited: Aspoort (11), De Mond (41), on the Doring River above and below the confluence with the Bos River (130), at Ou Drif (10), and Koebee River (86). Large numbers of *L. seeberi* were also seined (24; 150 - 300 mm TL) and gill-netted (55; 200 - 350 mm TL) at Brakwater on the Oorlogskloof River. Highest CPUE values (0.2708) were obtained from the Bos-Doring Rivers confluence and from the Koebee River (0.1791) during February. Of the 40 *L. seeberi* kept for biological examination, 17 were male and 23 were female. Six of the females had gonad stages of I or II, seven were stage III, and nine were III-V. Fifteen males were judged to be stage II, one stage III and one stage I.

October: The largest number (and the CPUE 0.042) of *L. seeberi* were caught on the Koebee River during October. This was also the site where two recaptures were made. The tag came loose easily from the skin and was lost from the first fish while it was being removed from the net. The second recapture of a specimen of *L. seeberi* was one that had been caught at the same site in February (Tag no. 3595). The wound was still swollen and the tag appeared to be in the process of being ejected from the skin. The six *L. seeberi* kept for biological examination during the October survey from De Mond, the Bos-Doring confluence and the Koebee River were all spent females (stage VII). Two individuals of 298 and 287 mm TL from the Oorlogskloof River were found to be ripe and running (stage VI) and spent (stage VII) females respectively.

On the Biedouw River, 26 young-of-the-year *L. seeberi* between 10 and 20 mm TL were electrofished from the slackwaters of riffles and runs, approximately 800 m from the confluence with the Doring River. Young-of-the-year *L. seeberi* (10 - 20 mm TL) were also collected from backwaters of the Doring River downstream of where the Bos River enters the Doring. The larvae and juveniles were collected from amongst the cobbles of shallow backwaters, which were drying following the winter floods. No juveniles could be found in the main channel, although numerous young bass (*Micropterus* spp. 20 - 30 mm TL) were observed below the riffles during a dive-transect.

Micropterus dolomieu

A total of 112 *M. dolomieu* were recorded in February. *Micropterus dolomieu* were much more readily observed during dive transects than the indigenous species. During October, a total of 38 *M. dolomieu* were recorded.

February: *M. dolomieu* occurred at all sites visited during the February survey, apart from Site 13 at Brakwater on the Oorlogskloof River. The highest indices of CPUE for *M. dolomieu* were obtained for the sites Keerom (Site 1), Ou Drif (Site 9) and Doringbos (Site 8).

October: The only sites where *M. dolomieu* was not found were Site 13 (Oorlogskloof River at Brakwater), Site 7 on the Doring River at the Biedouw River confluence and at Site 15 in the Biedouw River. The sites for which highest indices for CPUE were obtained were: Cascade Pools (Site 3) on the Olifants River below the Bulshoek Dam, Aspoort on the Doring River (Site 4) and Cobus se Gat on the Tra-tra River. Young bass (*Micropterus* spp.) were frequently observed amongst the rocks below riffles during dive-transects.

Lepomis macrochirus

L. macrochirus were the most abundant of the introduced species caught during the February and October surveys. In February, 1116 were counted and measured at 10 sites and an additional ±8000 were estimated to have been caught in two seines of the Doring River in a standing pool above the confluence with Biedouw River. *Lepomis macrochirus* were most frequently caught in a seine-net or by hand-netting. They were observed during dive transects in densities of 5-10 fish.m^{-3} in the marginal vegetation of standing pools, and occasionally in densities estimated to be in the order of 20-30 fish.m^{-3} during February.

February: Sites where *L. macrochirus* were not recorded were two sites on the Olifants River (Keerom, Site 1 and Cascade Pools, Site 2) and in the Oorlogskloof River at Brakwater (Site 13).

October: Although fewer *L. macrochirus* (507) were sampled from fewer sites (5) during the October survey, mean CPUE values were slightly higher in October (0.33) than they were in February (0.25). *Lepomis macrochirus* were also observed at Keerom (Site 1) during the October survey, but not in February.

Total lengths of *L. macrochirus* for both surveys ranged between approximately 15 to 350 mm, but the largest proportion of both surveys (85%) were small (30 and 80 mm TL).

Other species

Other species not discussed here in detail, but which were caught during the February and October surveys included:

- largemough bass *Micropterus salmoides* at Cascade Pools (Site 3);
- Mozambique tilapia *Oreochromis mossambicus* at Klawer (Site 16) and Cascade Pools (Site 3);
- banded tilapia *Tilapia sparmanii* near Klawer (Site 16), Melkboom (Site 10) and the Biedouw-Doring confluence (Site 7);
- chubbyhead barb *Barbus anoplus* at Brakwater on the Oorlogskloof River (Site 13).

6.3 Length-frequency distributions

Length-frequency distributions for the three indigenous fish caught during February and October 2001 are presented in Figure 6.3.1. (a), (b) and (c) (Appendix A). In all three cases there is an absence of a mid-size range class. No *B. capensis* under 450 mm TL were caught, only six *B. serra* between 200 – 380 mm TL and only four *L. seeberi* between 350 – 440 mm TL were caught over the course of both surveys Although age-length relationships for the *B. serra* and *B. capensis* were investigated by van Rensburg (1966), these are not predictive and only report average lengths for fish under 10 years old. No estimate of the ages of the larger fish has therefore been attempted in this study.

Barbus capensis

B. capensis lengths ranged between 450 and 830 mm TL for fish caught during both surveys, with the peak in the February distribution falling between 500 and 550 mm TL. No *B. capensis* of less then 450 mm TL were caught, although individuals smaller than this size are known to occur in the Oorlogskloof River above the upper limit of known invasion by *Micropterus* spp. and *L. macrochirus* (W. Pretorius, Northern Cape Conservation, *pers. comm.*). *Barbus capensis* of less than 450 mm TL have also been observed in the Rondegat River (*pers. obs*.).

Barbus serra

Three modal classes could be discerned from the length frequency histograms derived for *B. serra* from data recorded during the February survey: *c*. (1) 50 – 100, (2) 100 – 200 and (3) 400 to *c*. 500 mm TL. The two smaller modal classes (50 - 100 and 100 - 200 mm TL) represent fish caught at Brakwater (Site 13) in the Oorlogskloof River in February - a site free of exotic species. Individuals of *B. serra* that co-occurred with introduced fish species in the mainstem of the Groot and Doring rivers all measured over 400 mm TL. Far fewer *B. serra* were caught in the Oorlogskloof River in October, possibly because a shorter seine-net was used. Length-frequencies derived from the October survey may therefore be less representative of the population structure. There is evidence for the absence of fish in the 100 - 200 mm TL length-class. *Barbus serra* caught in the mainstem of the Doring River at Ou-Drif (Site 9) during October were smaller on average (400 - 460 mm TL) than the those caught during February.

Van Rensburg (1966) estimated first year growth of *B. serra* at *c*. 90 mm TL, and second year growth at *c*. 55 mm TL (i.e a total length at two years of *c*.145 mm TL). The modal ranges of the February survey exhibit peaks between 60 and 80 mm TL and between 120 and 140 mm TL. It appears, therefore, that the first peak represent one-year-old recruits (i.e., a cohort from the 1999/2000 breeding season), while the second peak represents two-year-old fish (i.e., a cohort from the 1998/1999 breeding season).

Labeo seeberi

The length-frequency distribution for *L. seeberi* over the two surveys fell into four modal-classes: *c*. 10 - 30, 140 – 200, 230 – 330 and 450 - 600 mm TL. The smallest modal-class (10 - 30 mm TL) represents 0+ recruits collected from the Bos-Doring confluence and the Biedouw River during October 2001. These fish are likely to be young-of-the-year from spawning events which would have taken place at these sites during September. Reports from the farmer on the Biedouw River (M. Hough, Uitspanskraal Farm, *pers. comm.*) confirm that massed movements of *L. seeberi* had taken place up the Biedouw River two weeks prior to the October survey. Although *L. seeberi* juveniles at the Bos-Doring confluence were found in the same reach where juvenile *Micropterus* spp. occurred, some habitat separation was evident - *L. seeberi* were found in the drying backwaters left by the winter floods, whereas *Micropterus* spp. occurred in the main channel. The 140 - 200 and 230 - 330 mm TL modal ranges represent the lengths of fish caught in the Oorlogskloof River above the upper limit of invasion. The largest *L. seeberi* (450 - 600 mm TL) were caught in the mainstems of the Doring, Groot and Koebee Rivers.

7. DISCUSSION

Patterns of migration, habitat and food availability, land-use and invasion by introduced fish species all affect the distribution of *B. capensis*, *B. serra* and *L. seeberi* in the Olifants and Doring Rivers Basin. Land-use impacts, primarily agricultural development, have altered both the quality (through run-off of nutrients, pesticides and mineralisation) and quantity (through abstraction and impoundments) of water in the Olifants River. Although no direct evidence is presented in the literature that *Micropterus* spp. and *L. macrochirus* feed on the juveniles of the indigenous populations, it is likely that these species have had a major impact on the recruitment success of the three indigenous species. The relative contributions of biological invasions versus habitat modification to the observed changes in abundance and distribution of the indigenous fish, can only be hypothesized on the basis of existing data. Answering these questions, however, will be crucial in deciding on how best to conserve these species and what measures need to be taken to ensure sustainable populations.

7.1 Distribution

Distribution of indigenous species

Very few historical records exist of any of the three indigenous species in the mainstem of the Olifants River above the Clanwilliam Dam to the reaches immediately downstream of Keerom. Although numerous *B. capensis* were seen in 1992 (J. King, University of Cape Town, *pers. comm*.) upstream of Keerom in the Olifants River Gorge, and farmers report that they still occur here in large numbers (Mr. Olivier, Keerom Farm, *pers. comm*.). Distribution records, however, suggest that the Olifants River tributaries, flowing from the Cedarberg mountains, remain an important refuge for *B. capensis*. It appears, therefore, that *B. capensis* may originally have occurred throughout the mainstem and tributaries of the Olifants River above the Clanwilliam Dam, and that invasion by exotic fish species and low water levels during the summer due to water abstraction, has restricted their distribution to the Cedarberg tributaries only. The reach between the Clanwilliam Dam and Citrusdal has been heavily impacted by agricultural activity, and reductions in flow during summer result in a major loss of habitat for fish passage and in elevated concentrations of dissolved solids including pesticides and nutrients (Dallas 1997; present study). The heavy siltation first reported by Harrison (1963), has also reduced *B. capensis* spawning habitat and contributed to recruitment failure in the mainstem. Recent historical records of *B. capensis* and *B. serra* in the mainstem of the upper Olifants River indicate that they are present above the confluence with the Ratels River which is well upstream of the areas of most intensive agricultural development. There are no distribution records for *L. seeberi* in the upper Olifants River throughout the historical period, although Harrison (1963) reports their occurrence here during the early half of the 20th Century

The Olifants River downstream of the Clanwilliam Dam is heavily regulated. Water is released on demand to the Bulshoek Dam from where it is diverted via a system of irrigation canals to farms lower down in the catchment. During both the February and October 2001 surveys there was no discernible velocity at the site below Bulshoek Dam (Cascade Pools, Site 3). All three indigenous species: *B. capensis*, *B. serra* and *L. seeberi*, have been recorded here over the historical period, but *B. capensis* is the only species to have been caught since 1997. *B. capensis* has also been recently recorded, and observed spawning, in the river between the two dams (Cambray *et al*. 1998).

On the lower Olifants River, sampling effort has been limited to the reaches upstream of the confluence with the Doring River and there are only two known sampling events below the confluence. The first sampling event, and the only occasion when an indigenous species was recorded below the Doring River confluence, was in 1917 when a single individual of *B. capensis* was caught. The second sampling event was during the present study (October 2001) when only *O. mossambicus* was caught. Agricultural activity is intensive along the banks of the river here and deterioration of water quality in the form of nutrient enrichment and pesticides is likely to present the most serious threat to the persistence of indigenous fish populations along these reaches. Surveys have revealed that, where citrus production is most intensive, yellowfish are not abundant (Impson 1997). However, it is unclear whether any significant numbers of these fish occurred naturally in these lower reaches.

No *L. seeberi* were caught in the Olifants River, despite a total effort of 19 gill-net-hours on the Olifants River for the combined February and October surveys. The data from the 2001 surveys, however, suggest that a relatively large population of *L. seeberi* persists in the mainstem of the Doring River and that spawning occurs in the mainstem (at the Bos-Doring confluence) and tributaries (on the Biedouw and Oorlogskloof Rivers). *Labeo seeberi* comprised only 14 % of the total number of indigenous species on record between the years 1882 - 1998, but comprised 84 % and 66 % of the total gill-net catch in February and October 2001, respectively. The reasons for this are difficult to isolate. It may be that a greater interest in *B. capensis* (which is considered a fine angling species) resulted in *L. seeberi* being under-reported in the past, or it may reflect the fact that sampling effort was concentrated in the tributaries and upper reaches of the Olifants River which, the present distribution analyses suggest, support greater numbers of this species.

The geographical distributions of *L. seeberi* and *B. serra* - the former in the Doring, Groot and Oorlogskloof Rivers and the latter in the tributaries of the Doring River flowing off the Cedarberg mountains - are more restricted than that of *B. capensis*. It is suggested, setting aside invasion, that this may be linked to food and habitat availability. Many *Labeo* species have been found to avoid smaller tributaries and favour slow-flowing water over sand or mud, hence the common name ‘sandfish’ or ‘mudfish’ (Skelton 1998). The mouth of this species is ventral and adapted for grubbing in the sediments.

In his analysis of the stomach contents of *L. seeberi*, van Rensburg (1966) found that 70 % consisted of unidentified organic material and the remainder of algae, diatoms, dinoflagellates and copepods. The fact that *L. seeberi* was frequently found in highly turbid waters on the Doring River during February and October where light penetration is likely to limit primary productivity, suggests that this species may depend more on detritus for its nutrition than on benthic algae. Organic matter and detritus are more likely to settle out of suspension in the middle and lower reaches of rivers and many of the reaches where *L. seeberi* have been recorded are characterised by deep pools with slow moving water and accumulations of sediment and detritus on the bed.

Like *L. seeberi*, *B. serra* seems to occur in greater concentrations in the Doring than in the Olifants River, but unlike *L. seeberi*, evidence from past and present surveys suggests that it is concentrated in the tributaries. *Barbus serra* formed a relatively small proportion of the gill-net catch (6 % and 25 % respectively) during the February and October 2001 surveys which were limited to the mainstems of the rivers . A survey by Impson (1999) noted a similar pattern. Only one *B. serra* was recorded from the mainstem of the Doring River in the vicinity of De Mond, compared with 33 *L. seeberi* and 19 *B. capensis*. Impson suggested that this may either be due to a greater susceptibility to predation, or that *B. serra* favours tributaries like the Ratels and upper Matjies Rivers. Van Rensburg (1966) analysed the stomach contents of 48 *B. serra* and found that they contained predominantly animal material, a large proportion of which consisted of chironimid larvae, although copepods, ostracods and dinoflagellates were also found. A much smaller proportion (10 %) consisted of filamentous algae and diatoms. The lower accumulation of organic detritus and the greater availability of invertebrates in the upper reaches of rivers (Brussock and Brown 1991), may therefore be a major factor influencing the distribution of this fish.

Although research has previously focussed on the Olifants river and the present study suggests that the Doring River is important as a refuge for indigenous populations, there appears to have been a significant and corresponding reduction in the Doring River populations which has been noted by anglers and riparian landowners (K. Hough, Elandsvlei Farm; M. Brett, angler, *pers. comm.*). Since the Doring River mainstem is relatively undisturbed this supports the view of van Rensburg (1966), Gaigher *et al*. (1980) and Gore *et al*. (1991) that invasion by exotic species is a primary cause of decline in indigenous populations.

An alternative explanation for the decline in both the Olifants and Doring Rivers is that the impacts, such as habitat degradation, water quality deterioration and the construction of in-channel barriers, in the Olifants River have affected fish numbers throughout the system. One possibility is that, in accordance with the River Continuum Concept (RCC Vannote *et al*. 1980) which predicts that productivity is likely to be higher in the lower reaches of rivers, the reaches below the confluence of the Doring River near

Klawer would have provided rich feeding grounds to support large numbers of indigenous fish. If this was indeed the case, then the present populations may represent a remnant of a much wider meta-population which would have undergone far more extensive spawning migrations. This scenario cannot be tested and no indication of the extent of the original populations in the lower river can be gained from the single sampling event in 1917. However, regardless of the definitive reasons for the difference between the two systems, the higher numbers of fish in the Doring River would underline the importance of protecting both habitat and water quality in order to conserve the remaining mainstem populations. This is especially true for *L. seeberi*, which may select for mainstem habitats.

Distribution of exotic species

Historical distribution records show the expansion of *L. macrochirus* on the mainstem of the Olifants River, but indicate that they failed to colonise the tributaries. Large numbers of *L. macrochirus* were recorded in pools in the mainstem of the Doring and Groot Rivers during this study. Densities surveyed at these sites were much higher (20 –30 fish/m^{-3}) than at the sites visited on the Olifants River, which may be attributable to the temporal refuge provided by the fragmentation of the Doring River during summer into a series of isolated pools, allowing populations to increase before the onset of the winter floods. Although *L. macrochirus* does not seem to have successfully invaded the upper reaches of the Tra-tra and Biedouw Rivers, *M. dolomieu* have been recorded here on several occasions. Both species appear to have expanded their distribution since 1985. *Micropterus dolomieu* has been successful in colonising a few of the Olifants River tributaries (notably the Heks and Boskloof River), whereas the sensitivity of *L. macrochirus* to high flow velocities (Meffe 1991) appears to have limited its distribution to the mainstem. Large numbers of *M. dolomieu* juveniles were seen at the foot of riffles during dive transects. *Lepomis macrochirus* is also found in riffle areas, but may not persist in these habitats for long.

Exclusion of indigenous by exotic fish species

Evidence that there may be a degree of exclusion of *B. capensis* by *M. dolomieu* is provided by the detailed comparison of their distribution ranges on the Rondegat and Jan Dissels Rivers, on and just below the Clanwilliam Dam. The historical distribution of *M. dolomieu* as indicated by the RAI's for the period 1882 - 1998 on the Jan Dissels and Rondegat Rivers (Figure 7.1.1; Appendix A), when superimposed on the distribution of *B. capensis* for the same period, indicates that *Micropterus dolomieu* is found throughout the Jan Dissels River, but its distribution on the Rondegat River is limited to the lower reaches by a waterfall which is impassable to this species (D. Impson, Cape Nature Conservation, *pers. comm.*). *Barbus capensis* no longer occurs in any significant numbers in the Jan Dissels River but is found throughout the Rondegat River to its headwaters. Further studies will be required to determine whether the separation of these species is due to the exclusion of *B. capensis* by *M. dolomieu*, or to differences in habitat availability.

Historical records of fish distributions (CNC unpublished data, Abrahams and Pretorius 2000) show that neither *M. dolomieu* nor *L. macrochirus* were found in the Oorlogskloof River at Brakwater between 1982 and 1987 (Abrahams and Pretorius 2000). Exotic species have not been reported here since 1988 when high flows were believed to have flushed these fish from the system. A natural barrier in the form of a waterfall or rapid (probably at Kameel se Gat, Abrahams and Pretorius 2000) has since prevented re-invasion from the Koebee River and a small indigenous barbine cyprinid, *Barbus anoplus* has reappeared in the system. Impson (1995) suggested that indigenous *B capensis*, *B. serra* and *L. seeberi* juveniles in the Oorlogskloof river may have escaped predation because of elevated turbidity levels in this system. Higher turbidity levels and therefore lower levels of predation in the mainstem of the Doring River may also explain why populations of the indigenous species persist here in greater numbers than in the Olifants River. Whatever the relative affects of predation in the two systems may be, it appears that the co-existence of juveniles of the indigenous species with invasive species does not occur, or may only be possible for limited periods before the more aggressive and faster growing exotic species eliminate indigenous fry through competition and/or predation, particularly over the critical summer period in the Doring River.

The presence of age 0+ fish at the Bos-Doring confluence, suggests that spawning by *L. seeberi* may take place in the mainstem of the Doring River. Alternatively, the age 0+ fish found in the mainstem were washed out of the Bos River which was just upstream of the site where these fish were found. In order for these juveniles to successfully recruit to adult populations, they would need to survive the summer conditions in the Doring River with competition and predation in overcrowded pools reaching critical levels towards the end of summer. The presence of numerous age 0+ *Micropterus* spp. in the same reach as the *L. seeberi* juveniles (which are likely to be slower-growing than the invasive species), suggests that this may be the most critical period in the life history of the indigenous young. In order to determine the fate of these juveniles further monitoring of indigenous and alien species would be required over the summer period.

7.2 Population structures, spawning and migration

Migration

The movements of freshwater fish on a seasonal basis for spawning, feeding, or to escape adverse environmental conditions are an essential component of the life cycle of many species. The most common pattern of movement involves a downstream migration into the more productive lower reaches for feeding and an upstream migration into the oxygenated, silt-free headwater reaches for spawning (Wootton 1990). Harlen (1970) has described three forms of migratory movement in fish:

(1) local and seasonal movements within the same geographical area;

(2) more extensive dispersals where only the breeding area is well defined;

(3) true migrations which entail movement between widely separated and well defined areas by a large proportion of the population.

Spawning migration by cyprinids is not well researched, but examples are given in Mills (1991). Massed movement of fish accompanied by spawning activity in the Olifants River has been reported for *B. capensis, B. serra* and *L. seeberi* (Harrison 1976) and for *B. capensis* by Cambray *et al*. (1997) and King *et al*. (1998). However, the extent of these movements and the proportion of the population which undergo them remains unclear. The observed spawning 'migrations' may be more of the nature of spawning 'runs' into upstream riffles in the mainstem or nearby tributary systems. The degree to which the indigenous fish populations utilise the full extent of the Olifants and Doring Rivers Basin is one of the major issues which need to be addressed before the full impact of water resource development options on these species can be assessed. If spawning migrations are undertaken by resident populations over short distances into neighbouring tributaries and upstream riffles, then the fragmentation effects of weirs and dams *per se* may not be as critical to mainstem recruitment as is believed. If however, populations are dependant for feeding and spawning on extensive movements through the system, between widely separated and geomorphologically distinct habitat types, then fragmentation may indeed be having a major impact on recruitment. If the indigenous fish populations depended on both the Olifants and Doring rivers for their feeding and spawning requirements, the fragmentation of the Olifants River may be affecting the carrying capacity of the system as a whole. Simultaneous declines in population numbers of the three large fish species in both the Olifants and Doring Rivers provide evidence to support this. As more dams are being considered for the system, connectivity could be further drastically reduced.

Re-dispersal into the system after the dry season may be another flow-related factor important to the survival of populations isolated in standing pools when volumes of water are reduced over the course of the summer through evaporation. Summer pool depths and the length of time between the cessation and recommencement of flows may be critical factor in this respect. Bernado and Alves (1999) report that during summer, Mediterranean rivers are subject to extended periods of zero or no flow. During these times, fish are likely to be subjected to extended periods of ecological (i.e. predation and competition) and physiological stress (i.e. increasing temperatures and declining water quality). Following the onset of winter floods, however, recolonisation of the system from downstream to upstream and from fourth order streams to first order streams is possible. Evidence from this study suggests that similar processes may take place in the Doring River. High densities of indigenous fish species were sampled in the Doring River during February 2001, when populations were forced into ever-decreasing volumes of water in the drying pools. The lower densities of fish in pools during October testify to the dispersal of fish through the system at some point after the onset of wet season flows. Populations in the mainstem of the Doring River therefore undergo a seasonal cycle of contraction and expansion: contraction in the summer as populations are forced into ever-shrinking pools, and expansion in early winter as the river starts flowing and fish disperse through the system.

In addition to decreasing pool volumes, other factors, such as the growth of *Potamogeton* spp. may also play a role in limiting the carrying capacity of summer pools. *Potamogeton* was found to occur in the shallower regions of the pool at Site 14 on the Koebee River. No *Potamogeton* was found where depths exceeded one meter. Indigenous fish were only recorded in depths greater than 0.5 m whereas exotic species (*Micropterus* spp. and *L. macrochirus*) were recorded at all depths, including amongst the *Potamogeton*. Evaporation from these pools was high – as evidenced by shrinkage marks on side of pool. This suggests that if flow manipulations increase the duration of the dry season, then survival of isolated indigenous fish populations will be compromised.

Age/size related habitat segregation

This study, and general observations within the catchment provide evidence for age and/or size-related habitat segregation at the scale of geomorphological zones (Rowntree and Wadeson 1999), particularly amongst *B. capensis* and *B. serra*. Large *B. serra* (400 - 500 mm TL) were found in the mainstem of the Doring River (particularly at Ou Drif where highest abundances and CPUE were obtained during both the February and October surveys), whereas *B. serra* caught in the Oorlogskloof River (a tributary of the Doring River) were all no larger than 300 mm TL. Populations of *B. serra* found in the upper reaches of the Sand (Doring River system) and Ratels River (Olifants River system), are of a similar size (*pers. obs*.). A similar pattern is evident in *L. seeberi*: individuals caught in the Oorlogskloof River were between 150 - 350 mm whereas those caught in the mainstem were between 450 - 600 mm TL. Although not sampled during the present study, *B. capensis* individuals in the 200 - 300 mm TL size-class also occur in the Rondegat River, a tributary of the Olifants River (*pers. obs*). Three hypotheses are proposed which may explain the natural spawning behaviour of these species in natural, unmodified conditions:

(1) adults migrate from the mainstem or lower reaches of the tributaries to the headwaters in order to spawn during spring. The offspring remain in the headwaters until shortly after they reach maturity (possibly 250 - 300 mm TL), then migrate back into the mainstem and foothill reaches to feed and grow;

(2) tributary populations may be, to a limited degree, self-sustaining, but are occasionally supplemented by migrations of large adults from the mainstem;

(3) there is very limited or no migration by large adult fish into the tributary systems and limited downstream dispersal of juveniles and sub-adults. Populations in the tributaries are therefore sustained by stunted or growth-limited adults.

Stunted growth may be caused by competition or low productivity and is believed to be a plastic phenotypic response to environmental variability, rather than genetic change (Roff 1992). For example, typical lengths of adult Eurasian perch (*Perca fluviatilis*) range between 150 - 300 mm and some reach 400 - 450 mm. However, in small lakes, dwarf forms have been found which do not exceed 160 mm (Koli 1990 and Tesch 1955 cited in Ylikarjula 2000). In tributaries of both the Olifants and Doring rivers therefore, overcrowding in small pools, or low productivity in oligotrophic headwater systems may cause growth limitation in *B. capensis, B. serra*, and *L. seeberi* (as originally proposed by D. Impson, Cape Nature Conservation and R. Bills, South African Institute for Aquatic Biodiversity, *pers. comm*.). It should be noted that growth limitation has also sometimes been associated with reduced age at maturity (Ylikarjula 2000).

There is some evidence in support of (2) or (3) above, i.e. that tributary populations may be partially or completely self-sustaining. The biological examination of two *L. seeberi* one *B. serra* from the Oorlogskloof River during the October 2001 survey indicated that all three individuals of between 200 - 300 mm TL were ripe and running. Similarly, ripe and running *B. serra* males of between 100 - 150 mm TL have been found in the Ratels River (R. Bills, South African Institute for Aquatic Biodiversity, *pers. comm*.). It is not known whether mainstem populations mature at a larger size, and that a reduced age/length at maturity has resulted from growth limitation. In support of (1) or (3) above that tributary populations are supplemented occasionally or completely by adult migration into the headwaters, Abrahams and Pretorius (2000) have recorded large *B. capensis* in the upper reaches of the Oorlogskloof River during spring, suggesting that they have moved into these upper reaches to spawn. The absence of juveniles from here during their 1999 survey and the present survey, however, suggests that despite some upstream migration, recruitment is not taking place. This may be attributable to the elevated turbidity levels in the Oorlogskloof River (Abrahams and Pretorius 2000), since *B. capensis* require cobble-bed riffles free of silt to spawn (Cambray 1997). Also Hutchings (University of Cape Town, *pers. comm*.) observed individuals of *B. capensis* in the Ratels River approximately 300 mm TL during February 2002 which did not appear to be present during a previous visit in April 2001.

These considerations have important implications for conservation actions. If tributary populations are isolated from the mainstem and make no contribution to mainstem recruitment, then mainstem populations would remain in jeopardy if conservation efforts were directed solely at tributaries. Conservation of tributary systems alone would also be short-sited if mainstem adult populations do make a significant contribution towards recruitment in the tributaries, as the adults will continue to suffer higher mortality from physico-chemical habitat changes in the lower reaches. If tributaries do serve as nursery grounds for the mainstem populations, then the impacts of invasive species would be minimal since the length frequency distributions suggest that these fish would be large enough to escape predation once they moved back into the lower reaches. A combination of genetic and tagging studies would be needed to address these questions and may provide key insights into what has enabled these species to persist in the Olifants and Doring rivers catchment and which may also provide clues to aid their future conservation.

Breeding

It is proposed that *L. seeberi* are unable to persist for long periods in the tributaries since the upper reaches of rivers may not meet their feeding requirements (see Section 7.1). Also, flow in the Biedouw River, where age 0+ *L. seeberi* were found in October, ceases as early as November (K. Hough, Uitspanskraal Farm, *pers. com.*) and any juveniles trapped in the drying pools here would certainly die. If the young of this species enter the mainstem at an earlier age than the other two species, this would make them more vulnerable to predation, and explain their dissappearance from the upper Olifants River where lower turbidity levels enable more efficient predation by exotic species[*]. The occurrence of *L. seeberi* in the upper Olifants River during the early half of the 20th Century confirms that these reaches provide adequate habitat for this species. However, it has since disappeared from both the mainstem and tributaries here. The fact that *B. capensis* and *B. serra* have persisted in the tributaries and to a limited extent, in the mainstem of the Olifants River could be explained by their ability to survive in the tributaries which are free of exotic species until they are at least 300 mm TL, whereafter they may move into the mainstem at which size they may be less vulnerable to predation.

Absence of mid size-classes

One of the features of the population structure of the indigenous species examined in this study was the absence of a mid size-class of all three species in the mainstem of both rivers. Several explanations might account for this: (1) gear selectivity, (2) the failure of the 2001 surveys to target appropriate sites or habitats, or (3) poor recruitment following a period of unfavourable environmental conditions. Although the gear in the present study appeared to target a wide range of size-classes where these occurred, gear selectivity is the most likely explanation for an absence of mid size-classes. High habitat-specificity amongst this size-class seems unlikely, considering the wide range of habitats sampled. However, if these size-classes are indeed absent from current populations, it may suggest several years of recruitment failure in the mainstem or tributaries resulting from a period of unfavourable environmental conditions.

NOTE: The fish of the Olifants and Doring Rivers have historically been exploited for centuries hunter-gatherer communities (Parkington 1977) and their use by local inhabitants is continuing. Reports by farmers from both the Olifants and Doring Rivers testify to harvesting of indigenous fish by clubbing during their annual spawning runs when they were easily accessible (M. Hough, Uitspanskraal Farm, *pers. comm.*).

[*]The Oorlogskloof River may be an exception. While the reasons for this are not clear, a different water quality profile, as a result of rising in the Karoo, may provide part of the explanation.

7.3 Conclusion and recommendations

The effects of invasion and ecosystem change are most evident in the mainstem of the Olifants River where populations of indigenous fish have been entirely eliminated or restricted to the tributaries - a scenario which may extend to the whole catchment if ecosystem modification is allowed to proceed unchecked. It is unlikely that mass spawning migrations of *B. capensis*, *B. serra* and *L. seeberi* in the Olifants River of the kind reported during the first half of the 20th Century will be witnessed again. Given the limited data available, it is unclear whether the indigenous and exotic fish communities have reached equilibrium, however, it would appear that further disturbances to the system - intensified water abstraction or major water resource developments on the mainstem - will precipitate further degradation, certainly with negative consequences for the indigenous fish populations. One possible consequence would be the complete extinction of mainstem populations (this study suggests that this has already happened along some sections of the Olifants River). The following comments relate to the proposed construction of the Melkboom Dam on the Doring River near its confluence with the Olifants River and its possible implications for the fish populations in the two rivers.

- ***Inundation of the cobble-bed riffles*** Riffles which are used as spawning sites by the species which occur downstream of Ou Drif (Site 9: *B. capensis*, *B. serra* and *L. seeberi*) would be drowned by the backup waters of the dam, contributing to the overall decline in critical spawning habitat available in the catchment, and further reducing recruitment levels of indigenous fish.

- ***Obstructing migration*** Movement by fish populations between the Olifants River and Doring River would be obstructed. This would reduce access to spawning and/or feeding sites in either of the two rivers for populations utilising both rivers (the impact which this would have on the present status of indigenous fish depends on whether the lower reaches of the Olifants River below the Bulshoek Weir continue to support significant numbers of fish - the 2001 surveys suggest that this may not be the case).

- ***Facilitating invasion*** It is expected that total numbers of invasive species (*M. dolomieiu*, *M. salmoides* and *L. macrochirus*) will increase significantly, and their range will extend into areas from where they are presently excluded by unfavourable habitat conditions. The dam would function as a supply source for exotic species from where active colonisation of the upstream reaches of the Doring River would take place. This will increase predation pressure on the indigenous species breeding in the mainstem of the Doring River.

- ***Downstream flow transformation*** Flows downstream of the dam will be attenuated resulting in the overall loss in quantity and quality of instream maintainance and spawning habitat (depends on the extent to which the downstream reaches are utilised by indigenous fish populations).

During the Febuary and September 2001 surveys, large *B. serra* (which were absent or caught in very low numbers at other sites) were numerous at Ou Drif (Site 9. on the Doring River) on both occasions. The possibility therefore exists that certain reach-scale properties are associated with greater abundances of this species and without more a complete knowledge of the system it is possible to predict whether important sanctuaries for certain species may be eliminated by the building of the dam. Many of the impacts may therefore be largely hidden or unforseeable because of a lacke of information.

Answering the questions which have been posed in this assessment will require long term data sets (presented here in their nascent stages) based on a detailed and systematic study programme (see Section 7.5) which would enable a better understanding of the ecological principles necessary to implement more effective management and conservation measures, as well as provide accurate and informed input to decisions relating to water development options. Some of the key issues have been listed below. Measures which need to be taken to ensure the sustainability of the indigenous fish populations in the Olifants and Doring Rivers have been comprehensively listed by Impson (1989), Impson (1999) and Bills (1999), and these have not been reiterated here (for recommendations on the conservation and sustainable utilisation of freshwater fishes of the Cape in general see Impson *et al*. 1999):

- ***Key conservation areas*** The persistence of indigenous fish in the system may be in part due to the existence of certain spatial and temporal refugia in the tributaries and mainstems. Instream obstacles, or physical or water quality conditions may limit successful invasion by introduced species, but allow for the downstream dispersal of indigenous recruits. If downstream dispersal of indigenous fish which are large enough to escape predation does occur, then limiting the expansion of exotic species into areas which provide breeding refugia to indigenous species may be the most effective means of future control and conservation. The identification of key conservation areas for the indigenous species should therefore be considered a priority. Criteria for site selection should include:

    - reach, habitat and species representivity;
    - extent of invasion and habitat modification;
    - potential for rehabilitation;
    - presence of areas which are important for completion of important life history stages such as spawning and development.

The Rondegat River has already been identified as an important conservation area for *B. capensis* due the presence of a natural barrier in the form of a waterfall that has prevented invasion. Based on historical and present day distribution records, this study has highlighted other areas that may be of importance including:

Tributaries:

- the Driehoeks River above its confluence with the Matjies River (*B. serra*);
- the Oorlogskloof River (spawning grounds *B. serra* and *L. seeberi*);
- the Biedouw River (spawning grounds for *L. seeberi*)

Mainstem:

- the Olifants River Gorge (for reasons not yet understood, this area on the mainstem of the Olifants River, appears to provide refuge for greater abundances *B. capensis*);
- Ou-Drif (adult B. serra);
- De Mond (adult *B. serra*, *L.seeberi*);
- Bos-Doring confluence (adults *B. capensis*, *L. seeberi*).

Many other sites could be considered once more information becomes available. The co-operation of riparian landowners, local communities and angling groups will be especially important in this regard.

- ***Environmental flows*** Dam construction and water abstraction modify flow regimes by reducing runoff, altering seasonal flow patterns and variability, and changing the magnitude, timing and frequency of floods. Environmental flow studies that take into account the spawning requirements of the indigenous species i.e., silt-free riffles, minimum riffle depths and velocities and cues for spawning, as well as summer pool persistence and the likely effects on fish survival of a prolonged or more extreme dry season precipitated by water abstraction, are needed .

- ***Fragmentation*** Dams and weirs fragment the longitudinal continuity of river systems and are barriers to migration, preventing access to upstream spawning sites or downstream feeding sites. Tagging studies to determine fish movement within the system are therefore required to determine the extent to which indigenous fish populations utilise the catchment. Although the Doring River provides some refuge for indigenous fish species, it carries high silt loads and therefore may not provide ideal spawning sites for species such as the Clanwilliam yellowfish which requires silt-free cobble-bed riffles to spawn (Cambray *et al*. 1997). The fragmentation of the Olifants River, therefore, may be affecting the carrying capacity of the system as a whole. Simultaneous declines in fish populations of both the Olifants and Doring Rivers provides some support to this argument.

Whether a dam on the Doring River near its confluence with the Olifants River will further impact fish populations will depend on what proportion of the current populations continue to use both systems;

- ***Habitat degradation*** The effects of increasing the lentic conditions (i.e. the proliferation of dams and weirs) on fish populations need to be addressed. Increasing the proportion of lentic habitat in the catchment promotes the persistence of exotic species, such as *L. macrochirus*, and provides refugia which enable them to colonise areas from which they would otherwise have been excluded. Increased lentic conditions also result in a loss of habitat and spawning sites for indigenous species. Other ways in which fish habitat is changing in the catchment include siltation of riffle areas due to reduced flows and/or increased levels of erosion. The effect of current and future habitat degradation on the indigenous fish populations in the system can be assessed with more confidence if their conservation status and likely response is better understood.

  The effects of habitat degradation in terms of water quality deterioration on the indigenous fish populations has not received attention in the past. The effects which pesticides and fertilizers have on these fish will require focussed attention in future studies.

- ***Synergistic effects*** The effects of each ecosystem impact cannot be assessed in isolation. The synergistic effects of flow modification, habitat degradation, instream obstacles to migration and invasion by exotic species need to be considered. Based on existing data, it is reasonable to assume that the decline in numbers of indigenous species is due to recruitment failure in the mainstems as a result of predation and/or competition by exotic species and adult and/or juvenile mortality due to physical and chemical habitat degradation. More data will be needed to determine the relative contributions of each impact.

- ***Life history and population dynamics*** An understanding of the impacts of the various factors listed above cannot be predicted without a knowledge of the life histories and population dynamics of the species in question. Such studies would provide data on: the geographical location of sub-populations, the relationship between tributary and mainstem populations, the paths and distances of migrations, habitat selection, mortality rates and quantitative estimates of abundance. Age determination of fish species is especially important for investigating mortality rates since this data is not available. These studies would also identify factors that are driving the persistence or disappearance of individual populations and the impact of a dam at the confluence of the Olifants and Doring rivers.

7.4 Notes on sampling methods

To address the deficiencies in knowledge outlined in this report a tagging programme spread over a number of seasons is suggested. The low recapture rate in the present study suggests that large numbers of fish will need to be tagged if an adequate data set is to be acquired.

- ***Capture and tagging*** The threatened status of these fish introduces into their study considerations regarding the methods used for their capture. Where possible, every effort was made in this study to supplement the 2001 surveys with existing data. Long-term monitoring of the indigenous species is a pre-requisite for effective management and conservation, however, it is strongly recommended that the use of gill-nets for sampling fish in the system be replaced by less damaging methods. Gill-nets were found to be very effective for sampling a range of size-classes for the indigenous species and although a large proportion of the fish survived capture, the long term effects of trauma and physical damage to the fish while in the nets is unknown. Experimentation with fyke or trammel nets (Nielsen and Johnson 1983) is therefore recommended should long-term monitoring be initiated. The anchor tags used in this study left swollen lesions on the skin of the fish and apart from compromising survival of the fish, appeared to be in the process of being ejected from the skin. The use of more effective and less damaging tagging methods therefore needs to be investigated.

- ***Gear selectivity*** The importance of using a variety of sampling methods and gear types is highlighted by the selectivity of the different sampling methods, both in terms of the species they target and their size ranges. However, the variety of sampling techniques used makes comparison between sites, species and times difficult. Until experiments to examine gear selectivity for the species in the system are undertaken and a standardisation method developed, no quantitative comparison of relative densities will be possible.

7.5 Future studies

No detailed long-term or systematic surveys have been conducted in the Olifants River catchment and as a consequence, comparisons between historical periods is complicated by inconsistent sampling effort. The studies which have been conducted (e.g. by Cape Nature Conservation and the present study), comprise sporadic catches in different areas and at different times and do not provide the level of detail or biological information required. The primary objective of a detailed baseline study would be to acquire empirical information on fish migration and catchment-wide habitat utilisation by various life history stages of the indigenous fish. The factors which limit the viability of fish populations, and therefore require the most urgent scientific attention relate to certain 'anchor' points in the life history of fish such as spawning and feeding cycles. Life history strategies have evolved in response to variable biotic and abiotic conditions and are the key to understanding how environmental factors (and anthropogenic disturbances) affect the abundance and distribution of organisms. These strategies include different patterns of migration, growth, age at first reproduction, life span and fecundity. Other factors, including age-specific habitat descriptions and ontogenetic changes in diet composition are critical to understanding the ecological requirements of fish species. In order for scientists to provide managers with clear, unequivocal advice regarding the impacts of water resource developments on fish populations, a detailed knowledge of life history strategies is therefore essential. This information depends on developing accurate age-length relationships which is, as yet, unavailable for any of the three species of interest. The information is required for providing input into Population Viability Analyses (PVA, Shaffer 1990), which predict the extinction probability of threatened organisms based on specific management options, or rule-based models that can predict changes in fish populations resulting from future development scenarios such as dam building. Basic monitoring surveys will not provide the information needed for developing management and conservation guidelines if baseline information on the fish species is not available. Table 5 therefore, lists the rough outline of a detailed baseline study that would provide this information, as well as an estimate of the frequency, duration and number of sites required for such a programme. It should be emphasised that 3-5 years is the minimum duration for a baseline study such as this one, since the fish are long-lived and subject to climatic and hydrological regimes which vary over decadal time periods.

Table 5 List of data requirements including estimates of the sampling frequency, duration and number of sites for a detailed baseline study of indigenous fish populations in the Olifants River.

Information requirements	Data type	Field component	Frequency	Duration	No. of sites	Laboratory
Age-length relationships	otolith* and/or scale samples, length	monitoring survey	biannually	3 – 5 years	8 –10	3 months
Age-specific fecundity*	gonadosomatic relationships, gonad histology	monitoring survey	biannually	3 – 5 years	8 –10	3 months
Age at first reproduction*	gonad histology	monitoring survey	biannually	3 – 5 years	8 - 10	3 months
Adult mortality	length frequencies	monitoring survey	bi-annually	3 – 5 years	8 - 10	-
Diet*	stomach content analysis	monitoring survey	biannually	3 – 5 years	20-30	3 months
Habitat use	physical habitat description	monitoring survey	quarterly	3 – 5 years	20 – 30	-
Migration : Tag-release	grid-referenced localities	monitoring survey	quarterly	3 – 5 years	20 – 30	-
Radio-telemetry	grid-referenced localities	monitoring survey	bi-annually	1 – 2 years	20 – 30	-
Physiological tolerance	water quality tolerances	laboratory and/or field experiments				6 mon - 1year
Egg mortality	counts	laboratory and/or field experiments				3 - 6 months
Larval mortality	length					

* Consideration should be given to the threatened status of these species before collecting biological data.

The studies listed in Table 5 could be run concurrently. Data for determining age-length relationships, age-specific fecundity, adult mortality and migration patterns could be collected on a biannual basis ranging over a period of 3 – 5 years depending on the specific research needs and the representivity of species and age-classes on each sampling occasion. Extended (2-3 month) sampling periods during the autumn and spring of each year would be needed for data collection. Physical habitat information should also be collected during this period. Laboratory work would take place between fieldtrips. For detailed data on all three species, an increase in the sampling effort listed above will be necessary. However, since the sampling techniques appear to be non-selective for the large indigenous cyprinid species, it may be possible to collect some of the data for all three species simultaneously. Once basic life history information has been collected, annual monitoring of populations will be sufficient for determining long-term trends in population dynamics.

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APPENDIX A
Figures

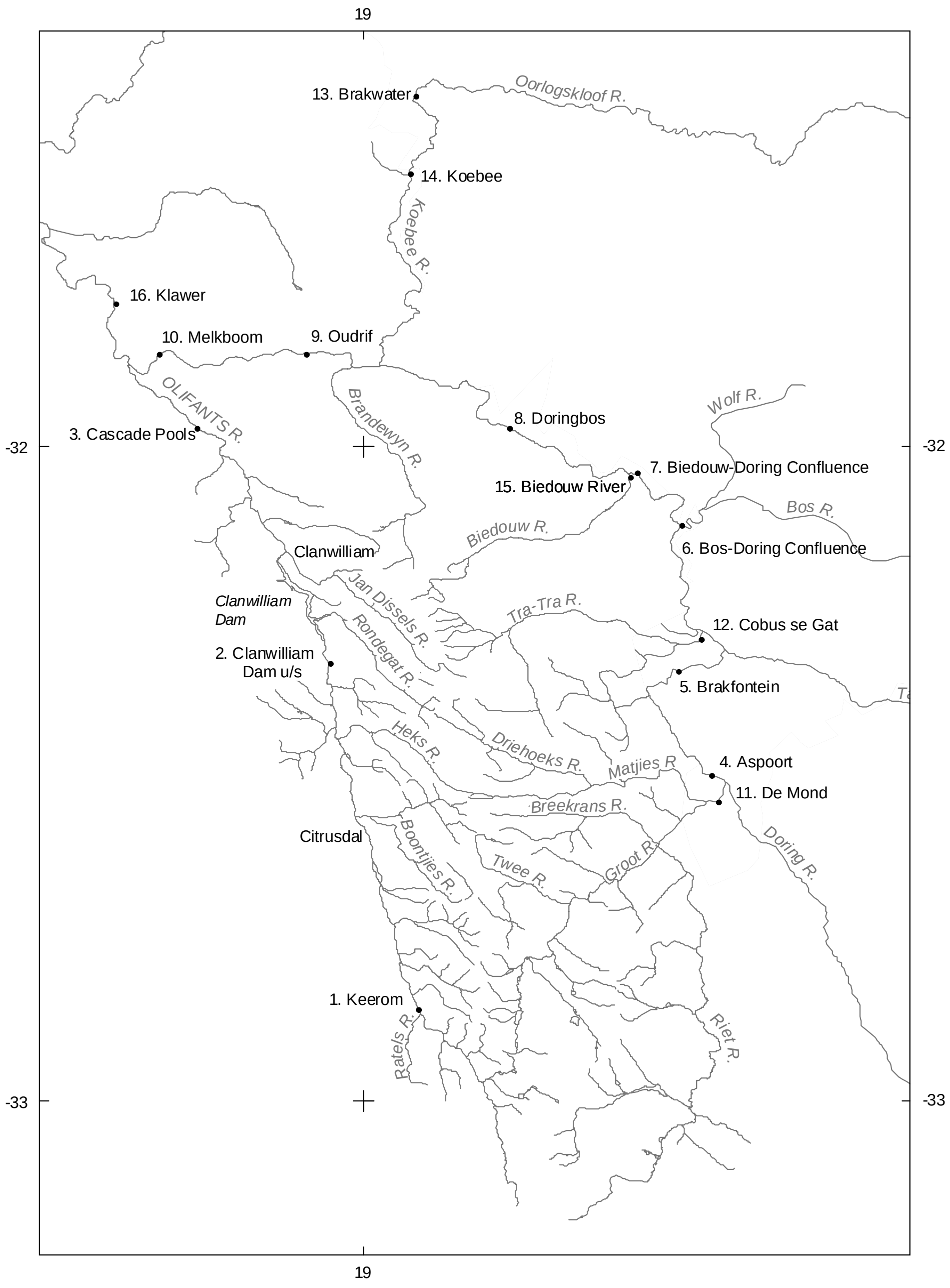


Figure 4.1.1 Map of the Olifants and Doring River Basin, solid circles represent study sites.

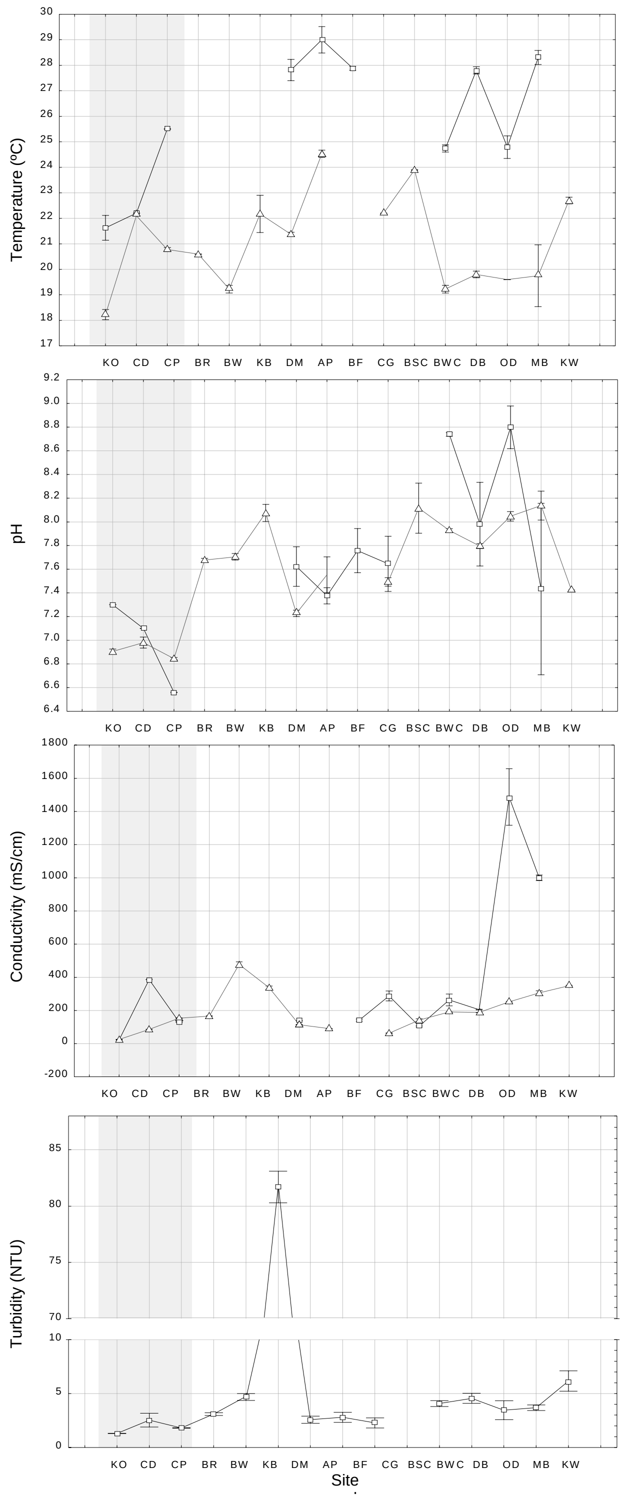
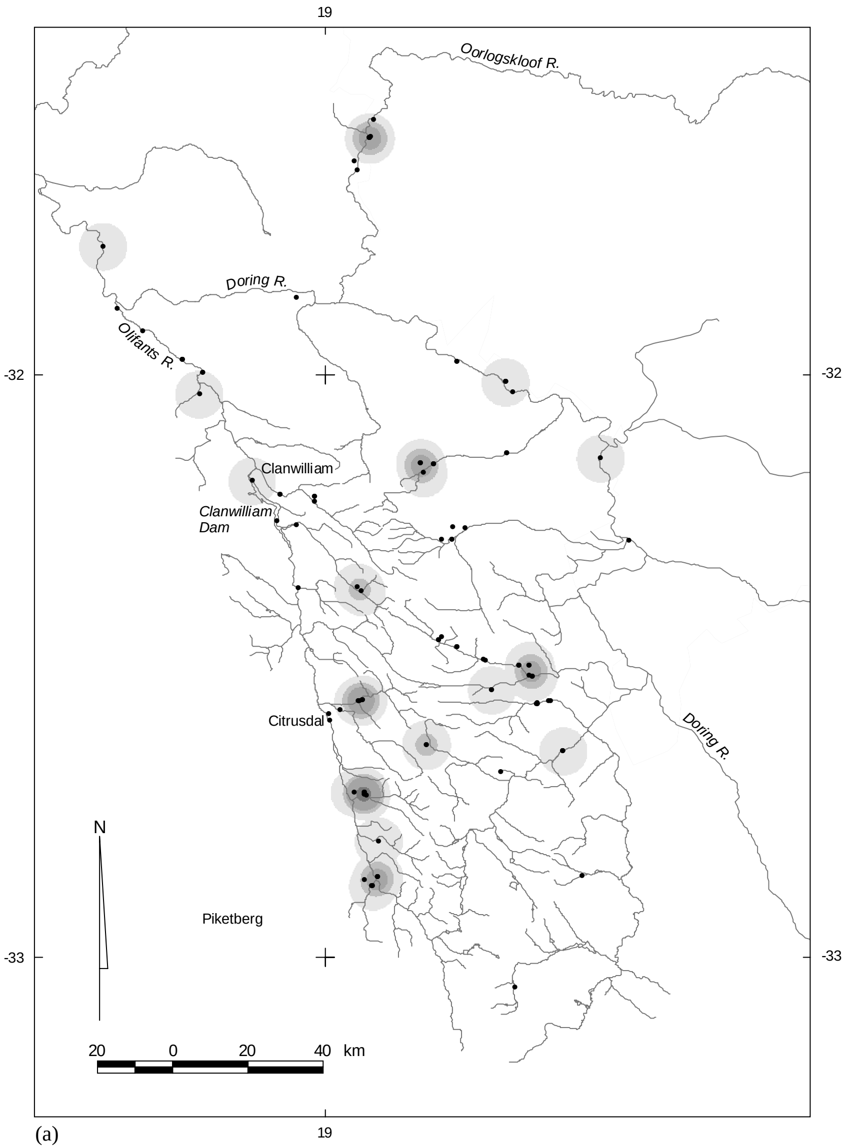


Figure 4.4.1 Mean temperature (°C), pH, conductivity (µS/m) and turbidity (NTU) values obtained for sites visited during △ February and □ October 2001. Shaded bars are sites on the Olifants River. Sites listed: Keerom (KO), upstream Clanwilliam Dam (CD), downstream Cascade Pools (CP), Biedouw River (BR), Brakwater (BW), Koebee (KB), De Mond (DM), Aspoort (AP), Brakfontein (BF), Cobus se Gat (CG), Bos-Doring Confluence (BSC), Biedouw-Doring Confluence (BWC), Doringbos (DB), Ou Drif (OD), Melkboom (MB), Klawer (KW). Boxes represent the mean and bars the maximum and minimum values.



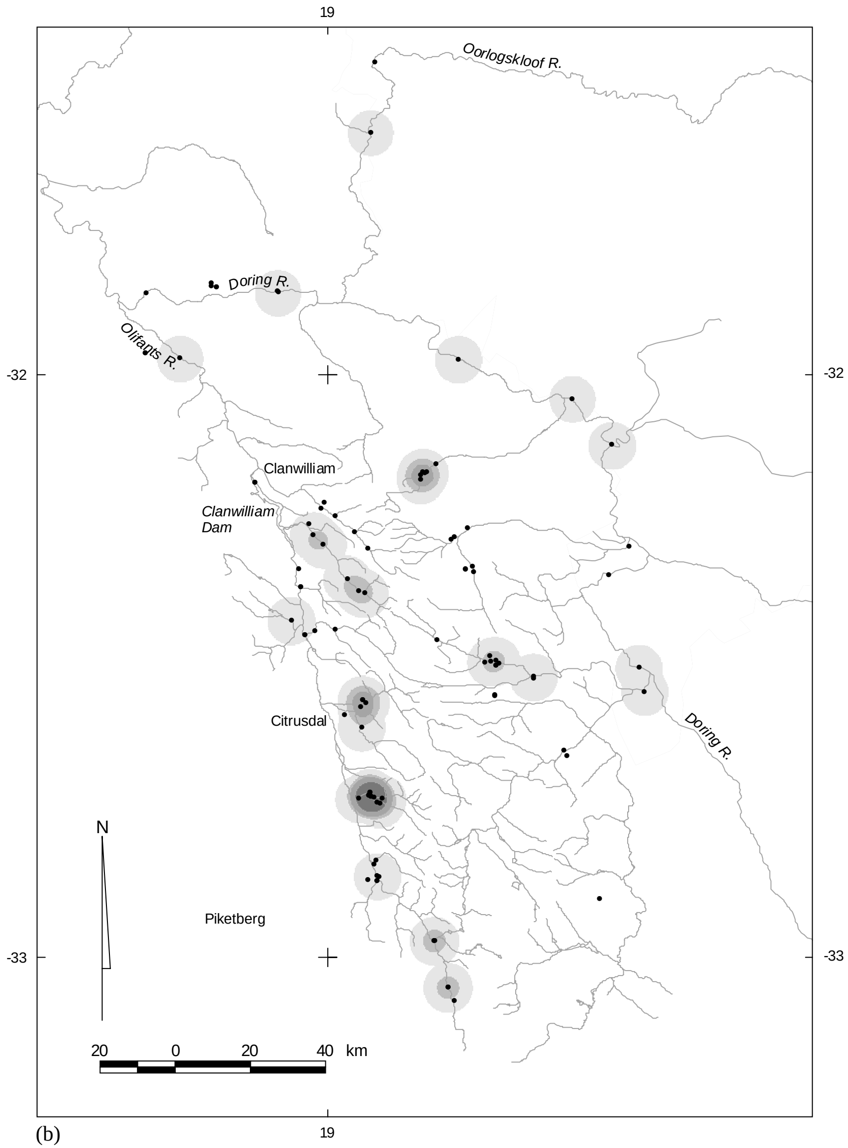


Figure 6.1.1. Map of the Olifants and Doring Rivers showing the occurrence of *Barbus capensis* recorded between the years (a) 1882-1985 and (b) 1998-2001. Shaded areas represent continuous densities derived from abundance indices and expressed as RAI/km^2. Solid circles represent sampling events.

0 - 0.01 0.01 - 0.50 0.50 - 1.00 1.00 - 2.50 2.50 - 6.00 RAI/km^2

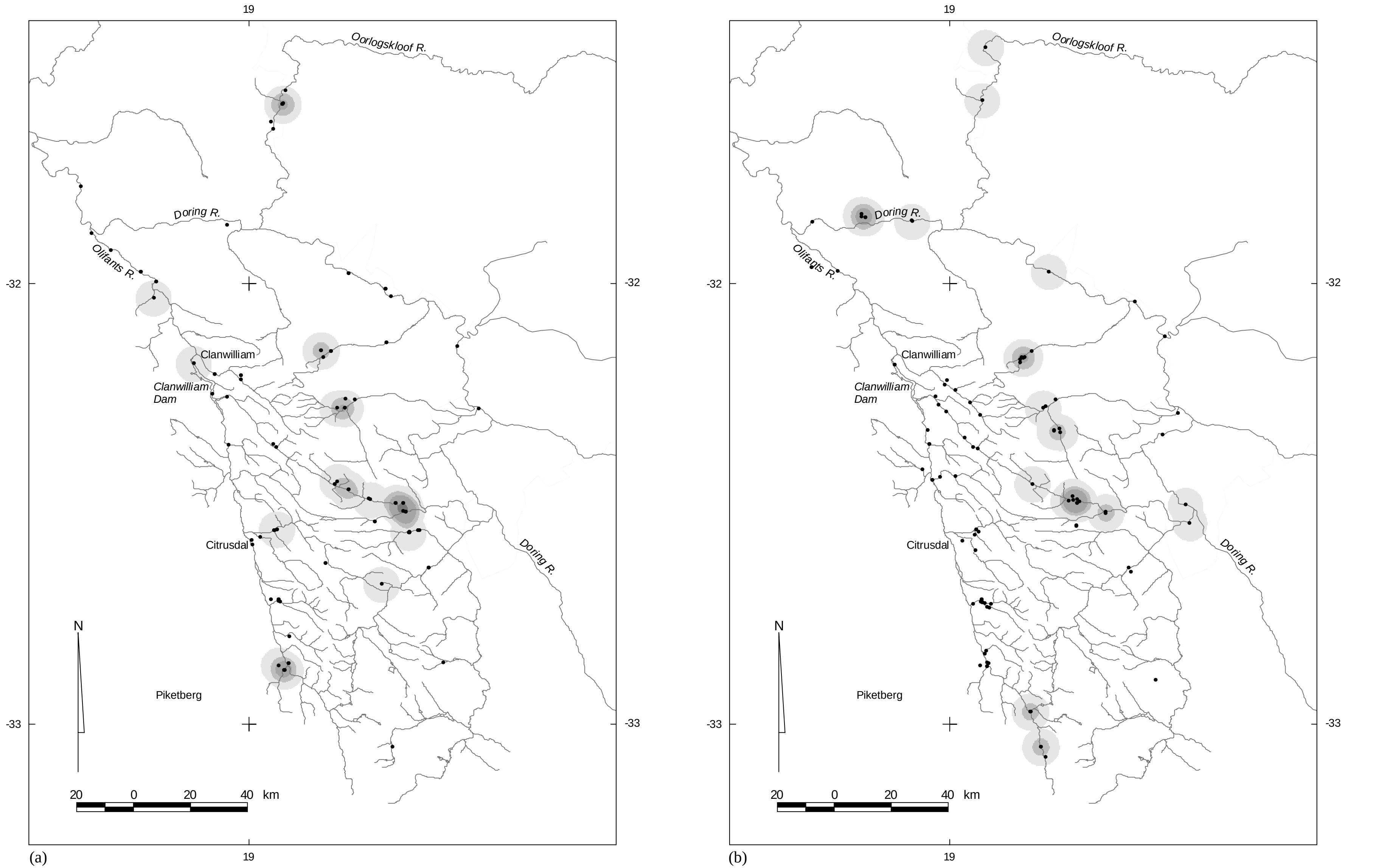


Figure 6.1.2. Map of the Olifants and Doring Rivers showing the occurrence of *Barbus serra* recorded between the years (a) 1882-1985 and (b) 1998-2001. Shaded areas represent continuous densities derived from abundance indices and expressed as RAI/km^2. Solid circles represent sampling events.

0 - 0.01 | 0.01 - 0.50 | 0.50 - 1.00 | 1.00 - 2.50 | 2.50 - 6.00 RAI/km^2

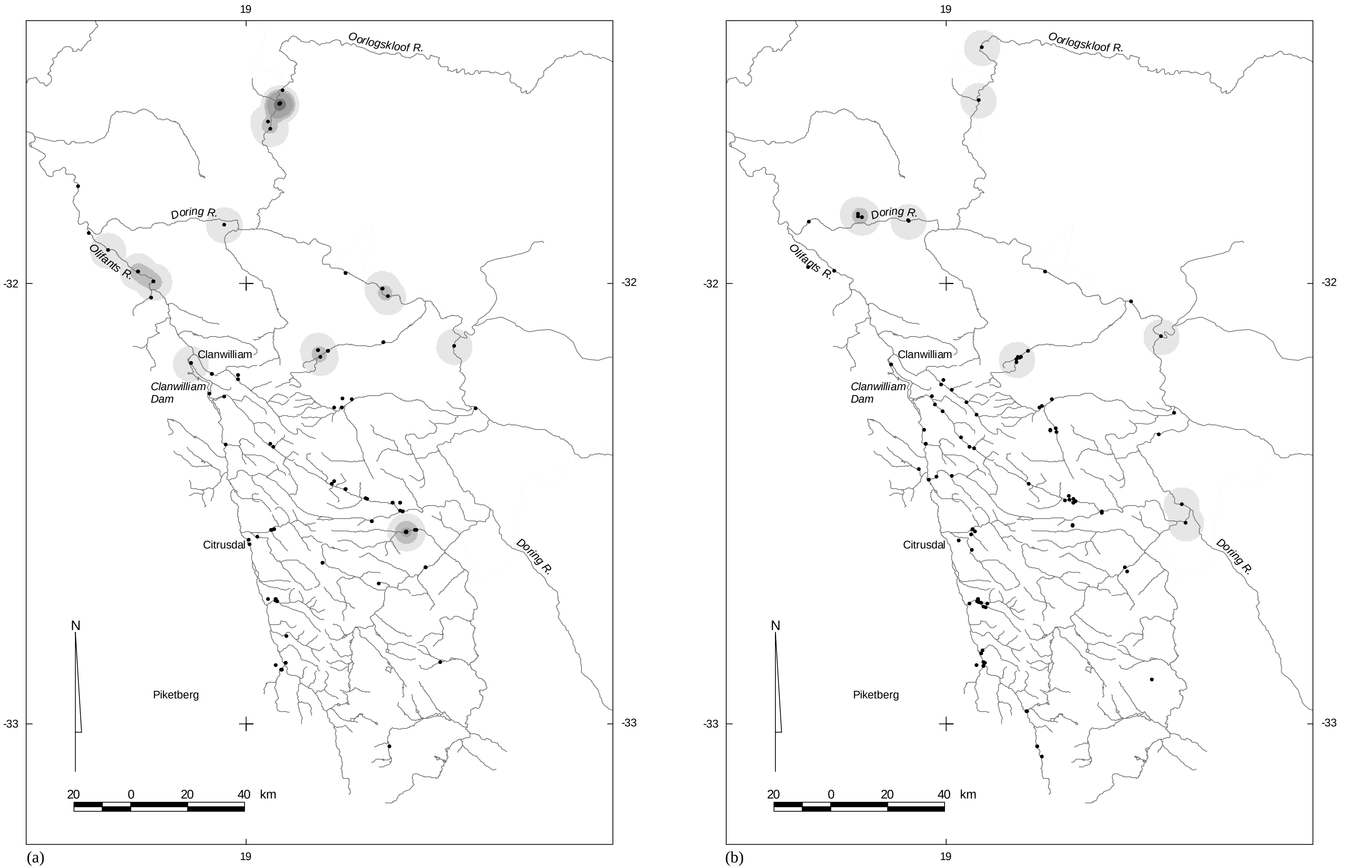


Figure 6.1.3. Map of the Olifants and Doring Rivers showing the occurrence of *Labeo seeberi* recorded between the years (a) 1882-1985 and (b) 1998-2001. Shaded areas represent continuous densities derived from abundance indices and expressed as RAI/km^2. Solid circles represent sampling events.

0 - 0.01 | 0.01 - 0.50 | 0.50 - 1.00 | 1.00 - 2.50 | 2.50 - 6.00 RAI/km^2

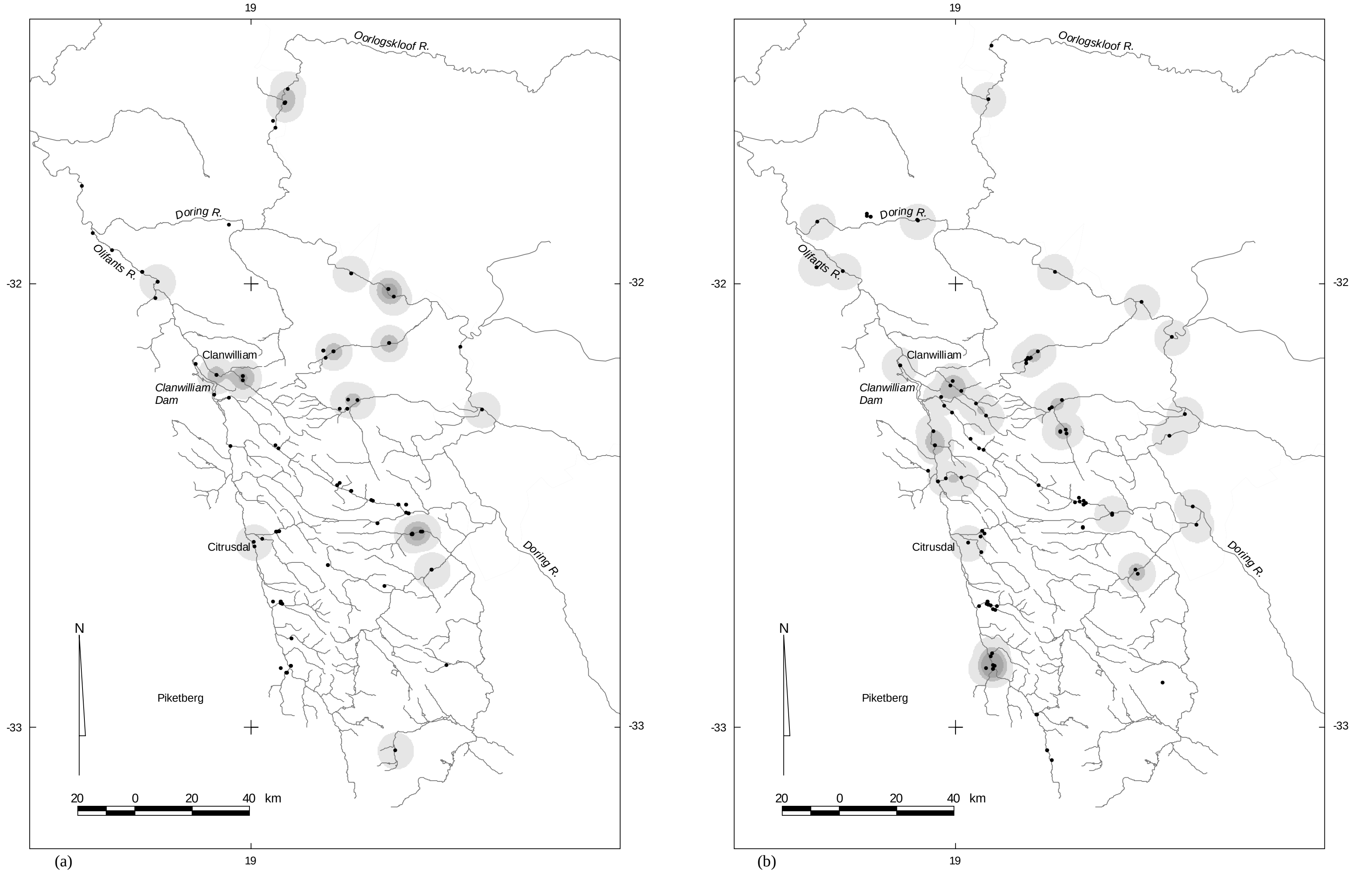


Figure 6.1.4 Map of the Olifants and Doring Rivers showing the occurrence of *Micropterus dolomieu* recorded between the years (a) 1882-1985 and (b) 1998-2001. Shaded areas represent continuous densities derived from abundance indices and expressed as RAI/km^2. Solid circles represent sampling events.

0 - 0.01 | 0.01 - 0.50 | 0.50 - 1.00 | 1.00 - 2.50 | 2.50 - 6.00 RAI/km^2

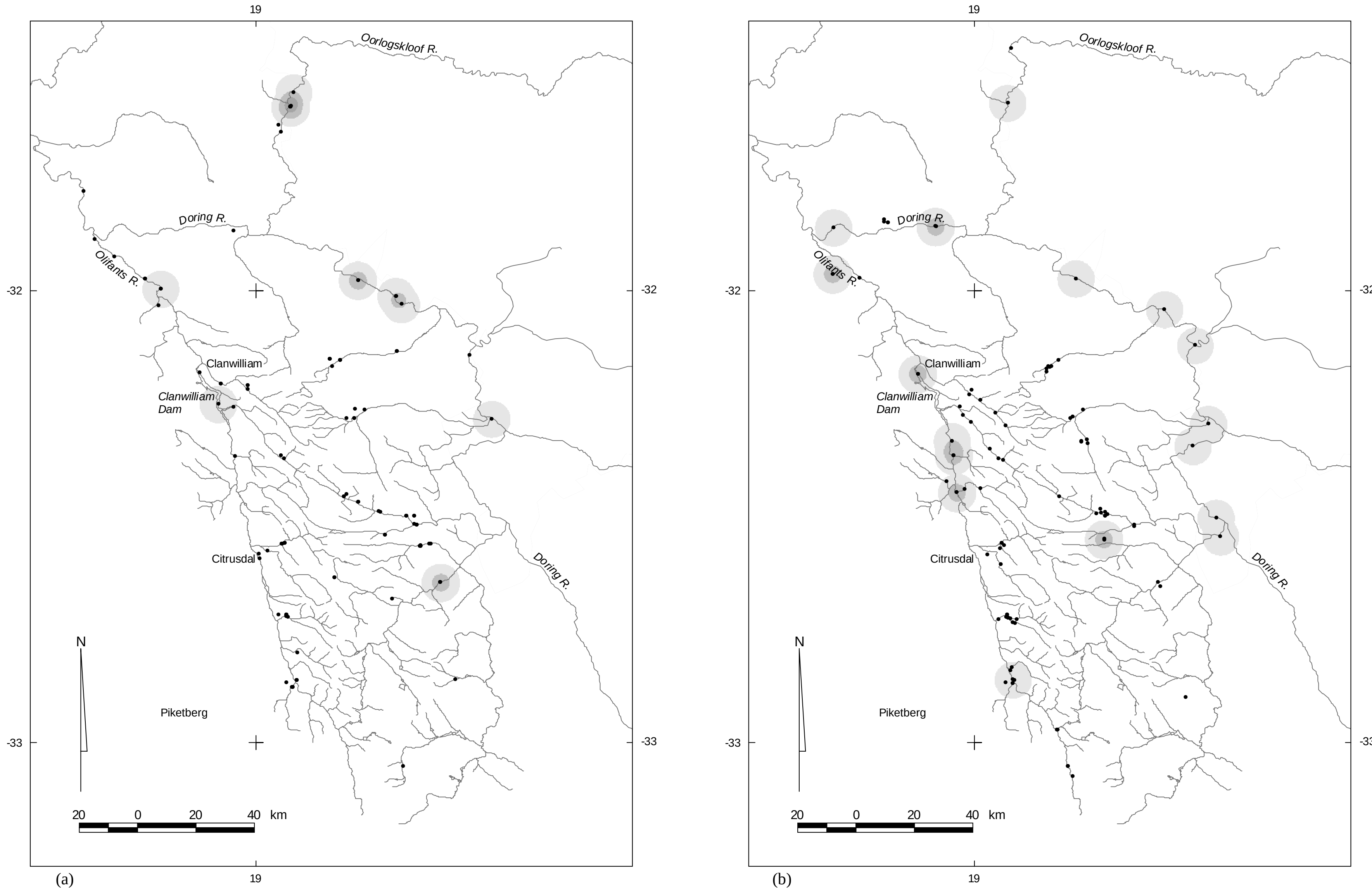


Figure 6.1.5. Map of the Olifants and Doring Rivers showing the occurrence of *Lepomis macrochirus* recorded between the years (a) 1882-1985 and (b) 1998-2001. Shaded areas represent continuous densities derived from abundance indices and expressed as RAI/km^2. Solid circles represent sampling events.

0 - 0.01 | 0.01 - 0.50 | 0.50 - 1.00 | 1.00 - 2.50 | 2.50 - 6.00 RAI/km^2

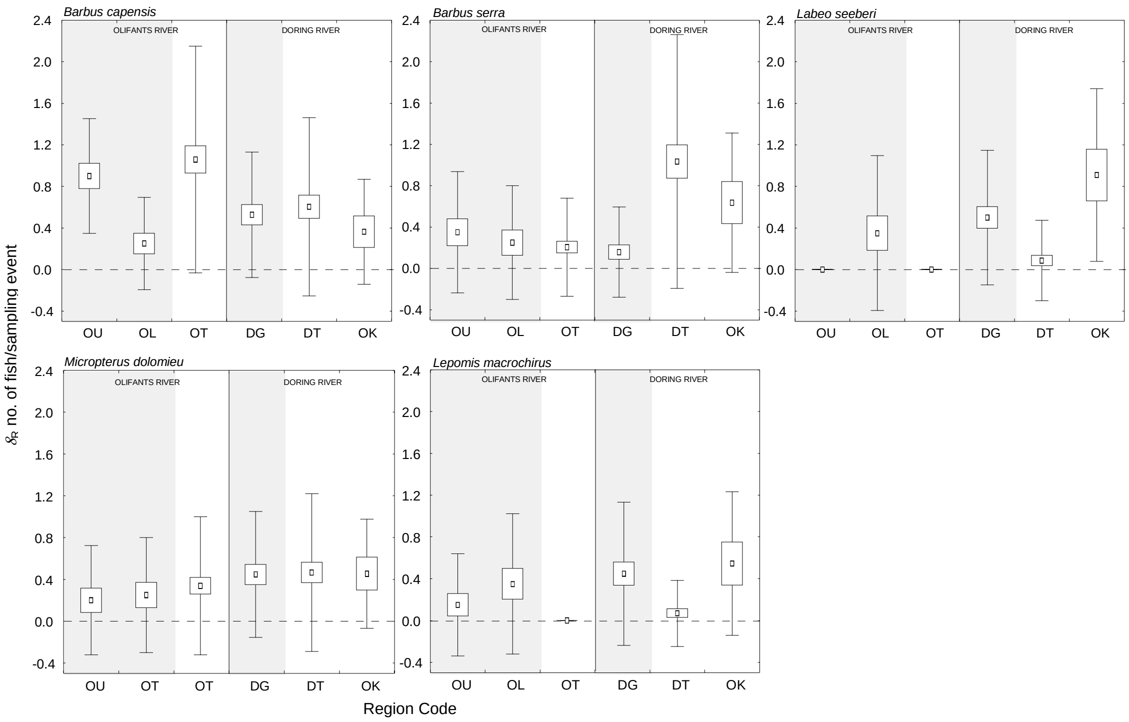
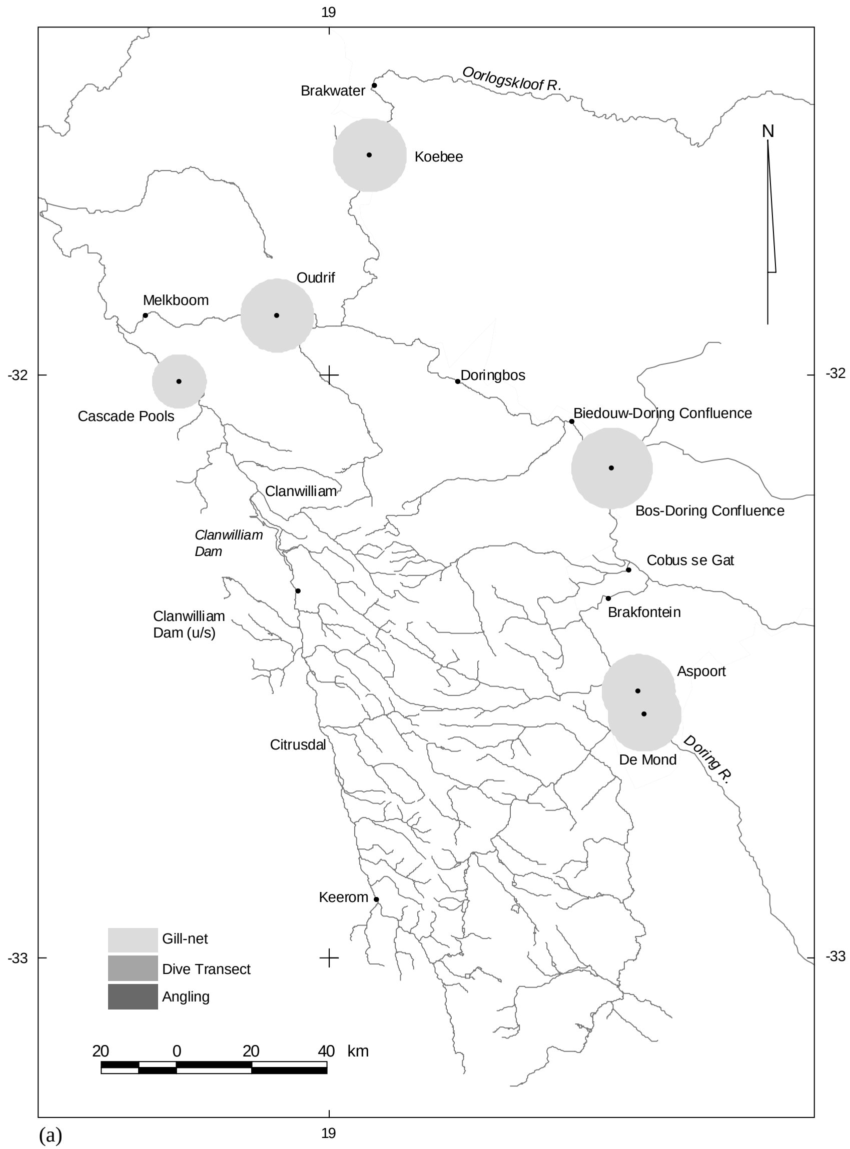


Figure 6.1.6. Distribution of *B. capensis*, *B. serra*, *L. seeberi*, *M. dolomieu* and *L. macrochirus* in six geographic regions over the period (1882 - 1998): the mainstem of the Olifants River (1) upstream (Olifants Upper: OU) and (2) downstream (Olifants Lower: OL) of the Clanwilliam Dam, (3) the tributaries of the Olifants River (Olifants Tributaries: OT), (4) the combined mainstems of the Groot and Doring Rivers (Doring-Groot: DG), (5), the tributaries flowing from the eastern flanks of Cedarberg mountains into the Doring and Groot Rivers (Doring Tributaries: DT) and (6) the Oorlogskloof and Koebee Rivers (Oorlogskloof-Koebee OK). The regional means for each species (δ_R= no. of fish/region = small rectangles, SE = large rectangles, SD = bars).



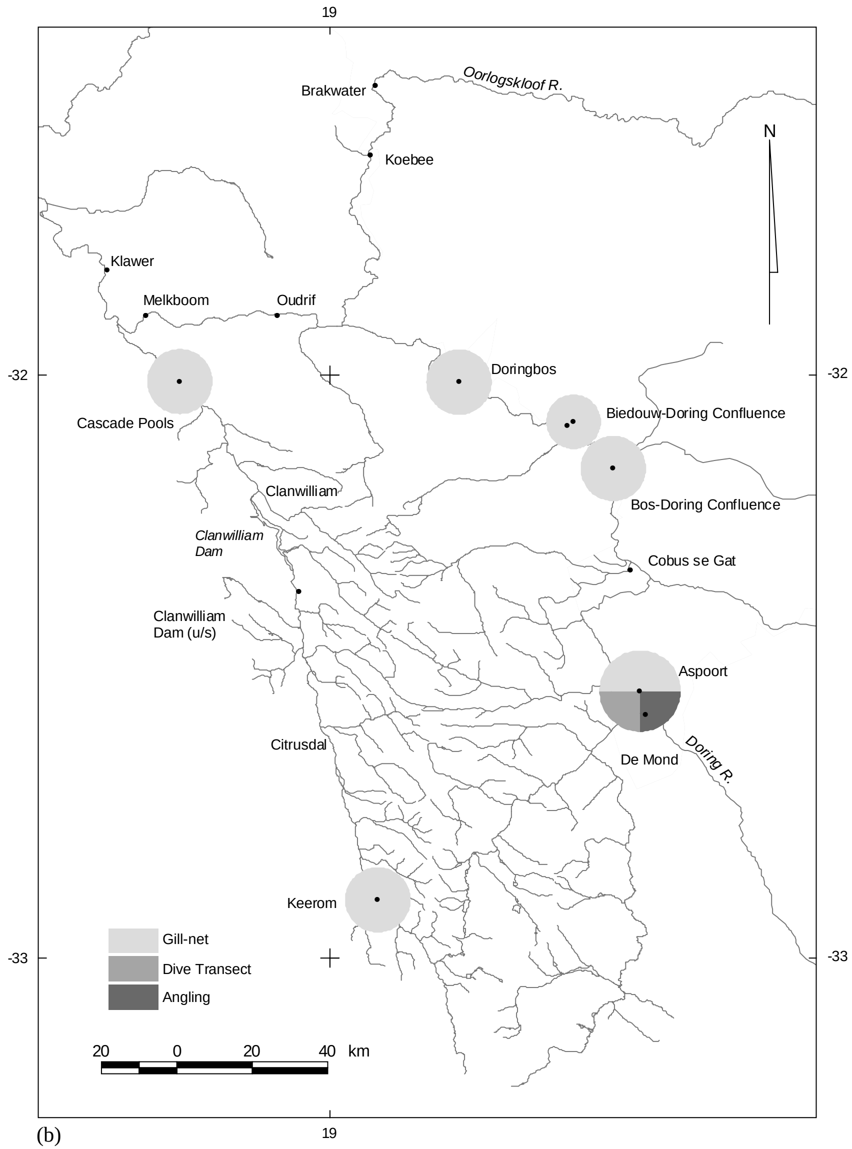
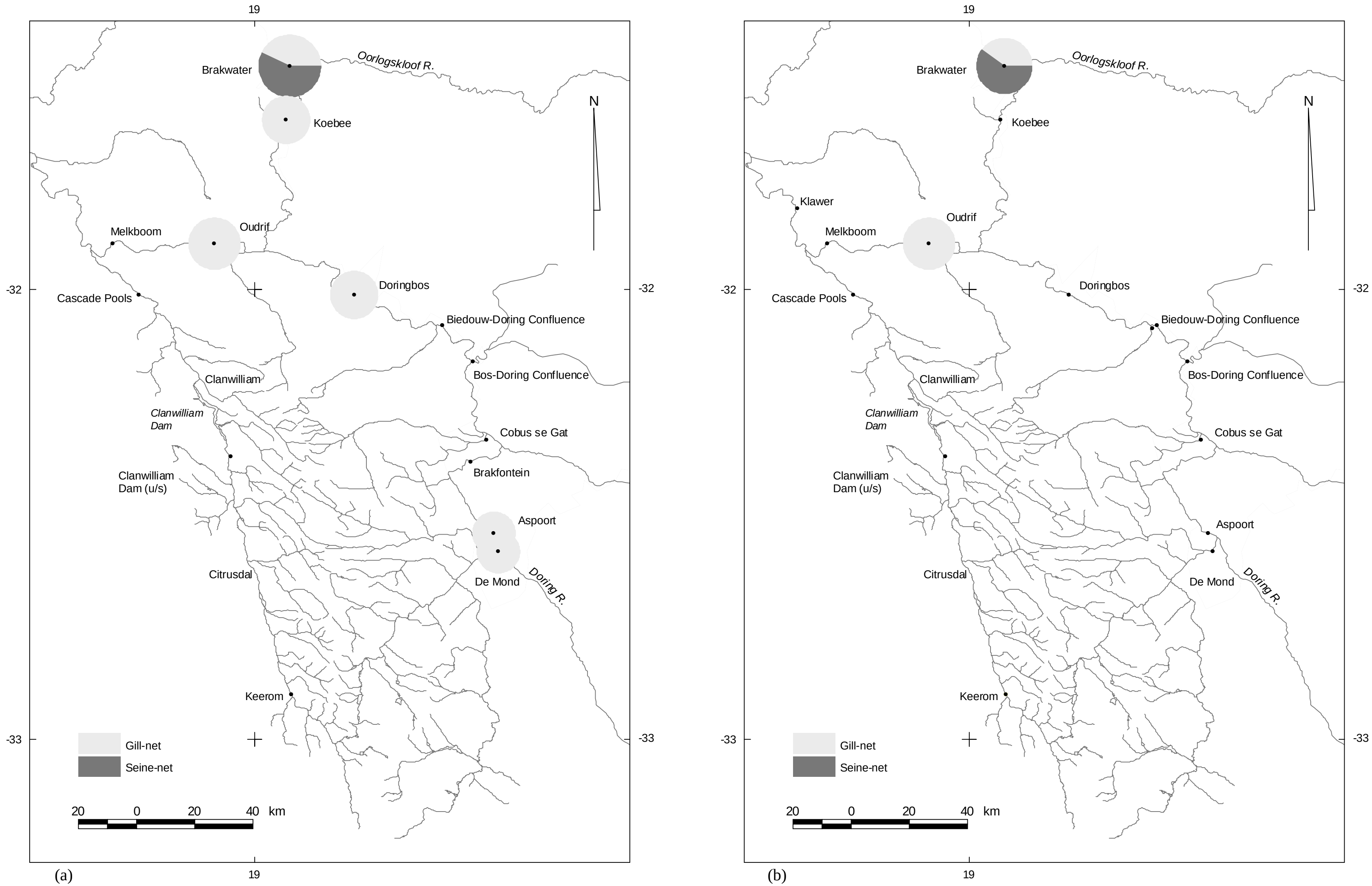


Figure 6.2.1. Map of the Olifants and Doring Rivers showing the distribution of *Barbus capensis* sampled during (a) February and (b) October 2001. The size of the pie-chart represents the summed CPUE indices. Shaded regions of the pie chart represent CPUE indices for each sampling technique.

0 - 0.01 0.01 - 0.50 0.50 - 1.00 1.00 - 2.50 2.50 - 6.00 fish/km^2



(a) (b)

Figure 6.2.2. Map of the Olifants and Doring Rivers showing the distribution of *Barbus serra* sampled during (a) February and (b) October 2001. The size of the pie-chart represents the summed CPUE indices. Shaded regions of the pie chart represent CPUE indices for each sampling technique.

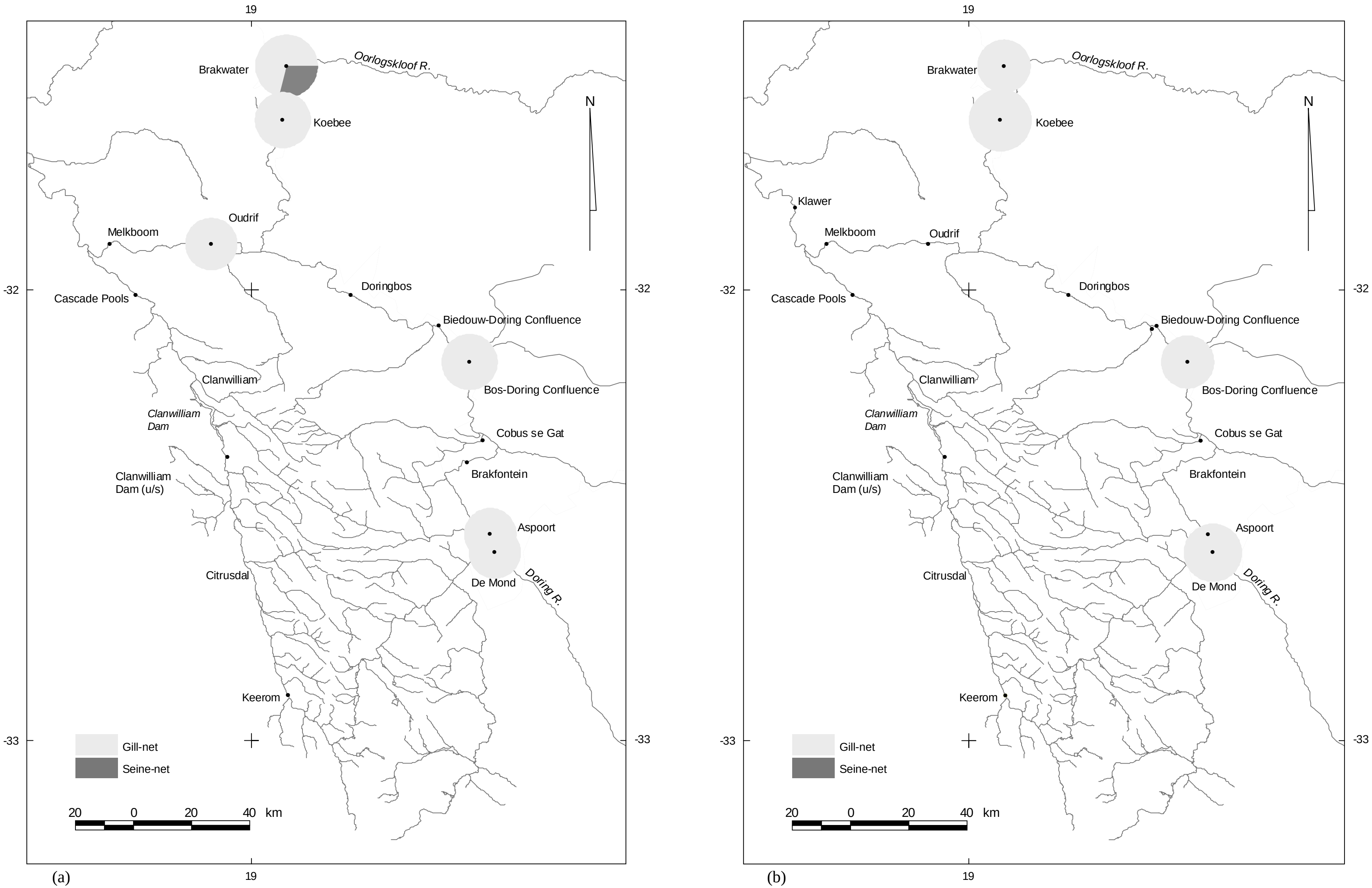
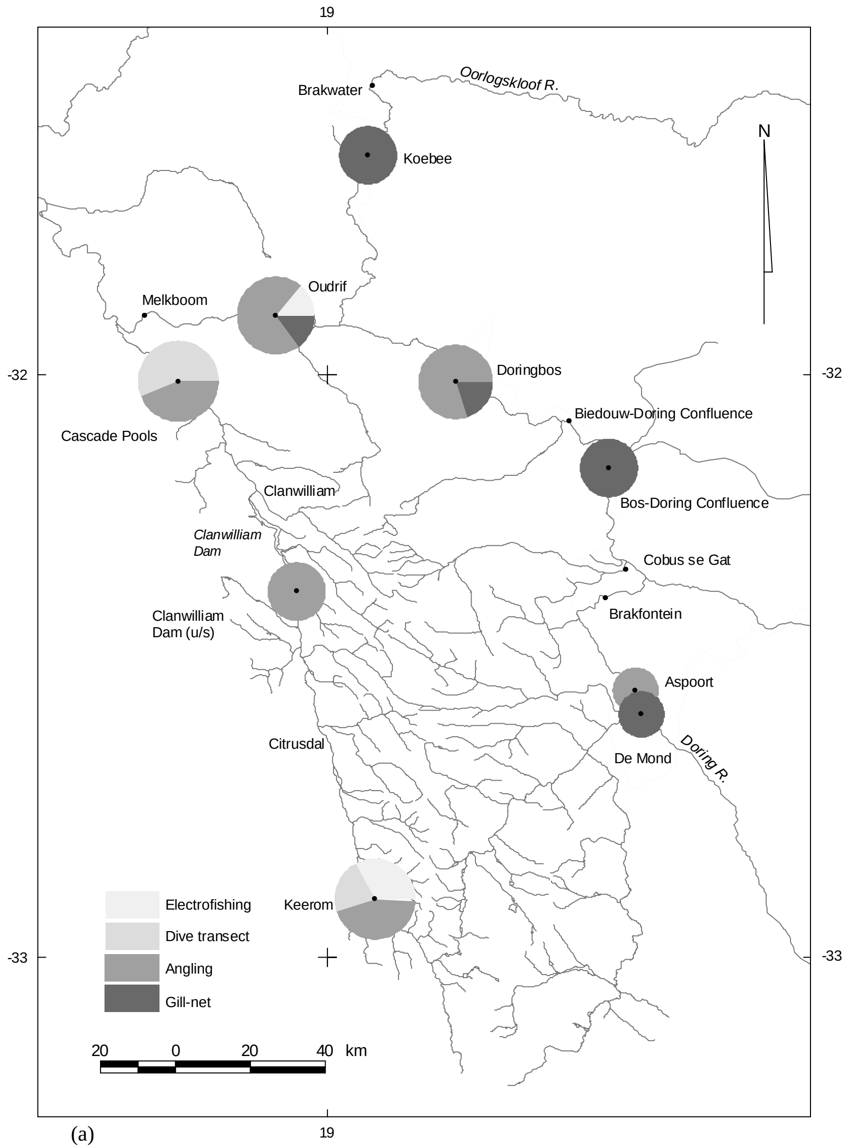


Figure 6.2.3. Map of the Olifants and Doring Rivers showing the distribution of *Labeo seeberi* sampled during (a) February and (b) October 2001. The size of the pie-chart represents the summed CPUE indices. Shaded regions of the pie chart represent CPUE indices for each sampling technique.



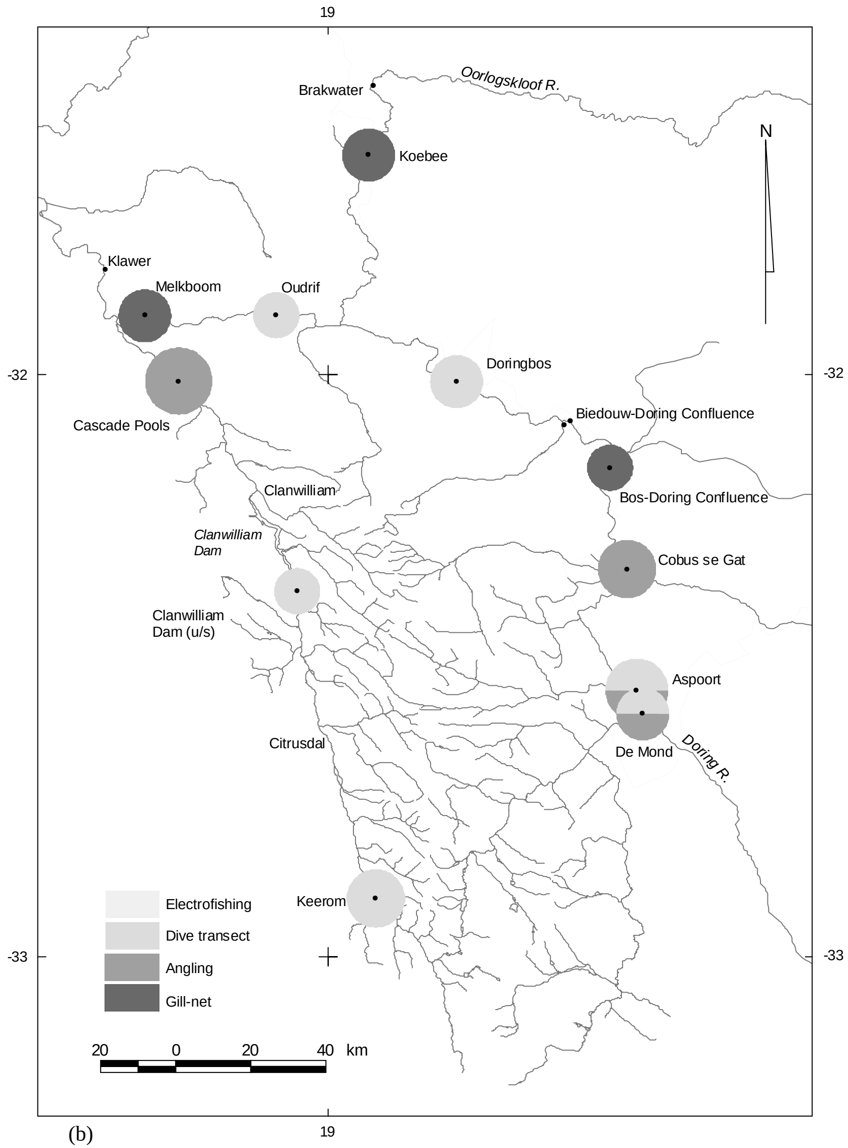


Figure 6.2.4. Map of the Olifants and Doring Rivers showing the distribution of *Micropterus dolomieu* sampled during (a) February and (b) October 2001. The size of the pie-chart represents the summed CPUE indices. Shaded regions of the pie chart represent CPUE indices for each sampling technique.

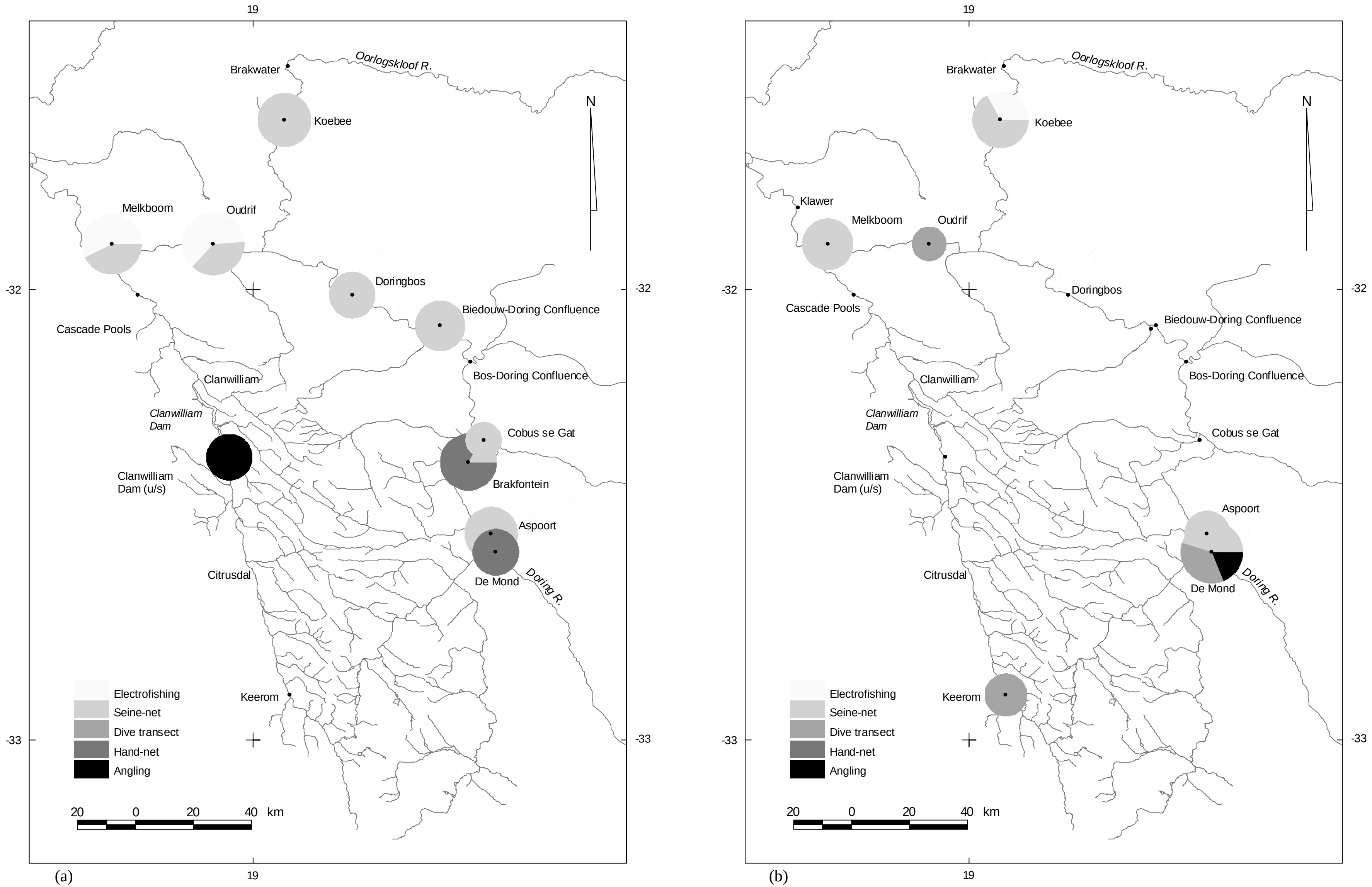


Figure 6.2.5. Map of the Olifants and Doring Rivers showing the distribution of *Lepomis macrochirus* sampled during (a) February and (b) October 2001. The size of the pie-chart represents the summed CPUE indices. Shaded regions of the pie chart represent CPUE indices for each sampling technique.

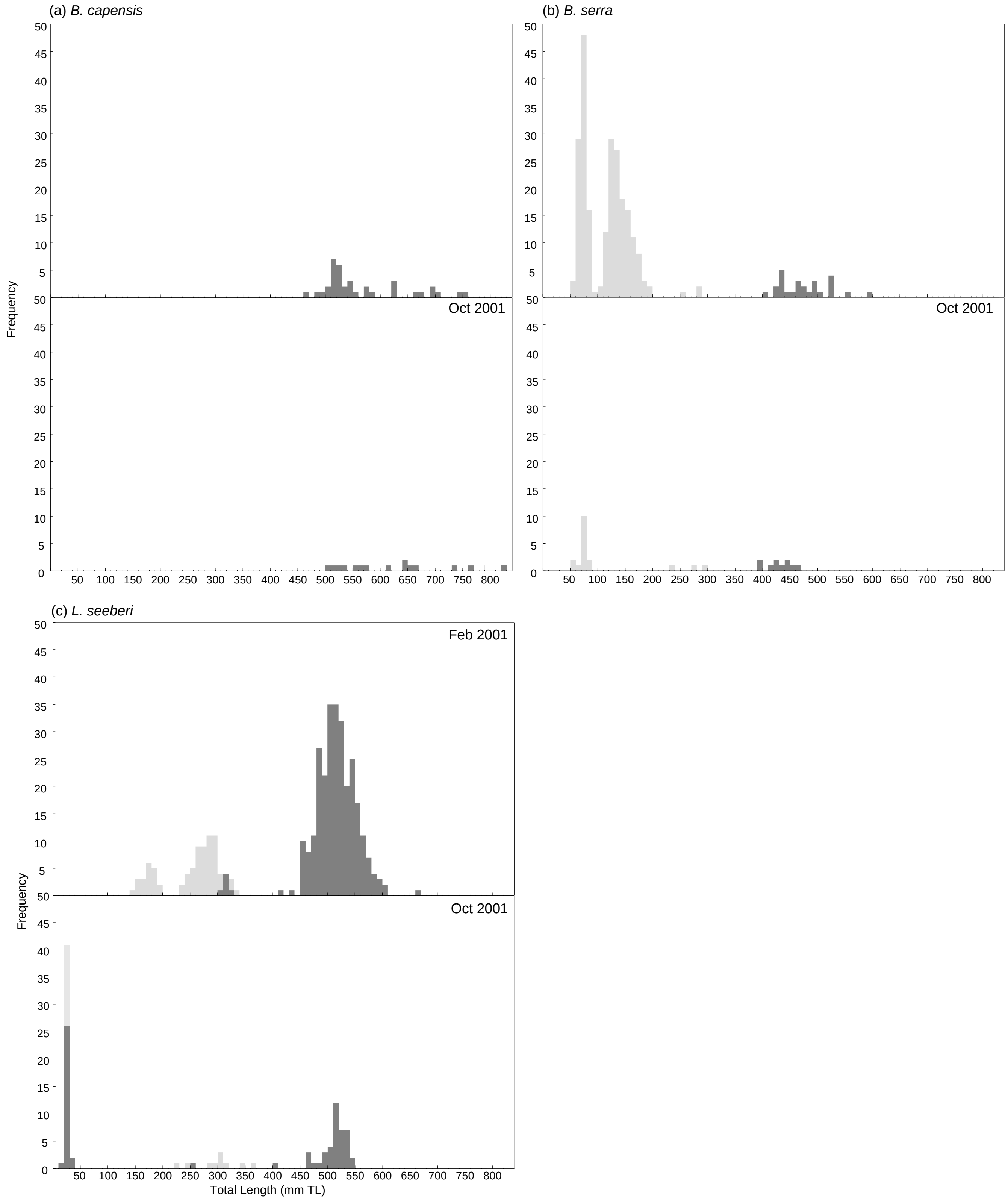


Figure 6.3.1. Length-frequency distributions for (a) *B. capensis* February 2001 and October 2001; (b) *B. serra* February 2001 and October 2001 and (c) *L. seeberi* February 2001 and October 2001. Light grey bars represent reaches free of invasion, darker bars represent areas where invasives have been recorded

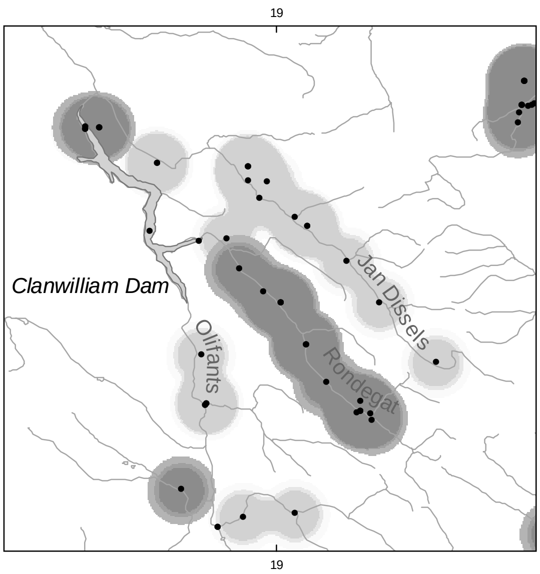


Figure 7.1.1. Distribution of ● *B. capensis* and ● *M. dolomieu* on the Jan Dissels, Rondegat and Olifants rivers based on RAI's.

APPENDIX B

Photographic Portfolio

Plate 1. Site 1 at Keerom on the upper reaches of the Olifants River looking downstream towards a mid-channel island and riffle (Feb 2001).

Plate 2. Site 2 on the Olifants River upstream of Clanwilliam Dam looking downstream (Oct 2001)

Plate 3. Site 3 on the Olifants River below the Bulshoek Dam, downstream of the Cascade Pools, looking upstream (Oct 2001).

Plate 4. Site 4 at Aspoort on the Doring River looking downstream from the gauging weir towards the gorge (Oct 2001).

Plate 5. Site 5 at Brakfontein, looking upstream from above the farm dam (Feb 2001)

Plate 6. Site 6 at the confluence of the Bos (upstream of the riffle) and the Doring Rivers. Looking upstream (Oct 2001)

Plate 7. Site 7 at upstream of the confluence with the Biedouw and Doring Rivers, looking upstream, sandspit is visible on the inside bend of a meander in the foreground (Oct 2001).

Plate 8. Site 8 at Doringbos on the middle reaches of the Doring River a mid-channel island and riffle is visible. Looking upstream (Oct 2001)

Plate 9. Site 9 at Ou Drif on the lower- Doring River looking upstream towards the rapid flowing into a run and bedrock/talus pool (Oct 2001).

Plate 10. Site 10 at Melkboom on the Doring River near its confluence with the Olifants River looking upstream towards a run below the gauging weir (Oct 2001)

Plate 11. Site 11 upstream of the campsite at De Mond on the Doring River, looking upstream (Oct 2001).

Plate 12. Site 12, Cobus se Gat on the lower reaches of Tra-tra river. The pool which was sampled is visible in the foreground (Oct 2001).

Plate 13. Site 13, the pool at the campsite Brakwater on the Oorlogskloof River in the nature reserve (Oct 2001).

Plate 14. Site 14, the Koebee River looking downstream (Feb 2001)

Plate 15. Site 15, looking downstream on the Biedouw River from where the road crosses the river (Oct 2001).

Plate 16 Site 16, below Klawer on the Olifants River downstream of the confluence with the Doring (Oct 2001).

Plate 17 Seining a pool at Melkboom (Feb 2001)

Plate 18 *L. macrochirus* and *Micropterus* spp. caught in a seine-net from in the Doring River upstream of the confluence with the Biedouw River (Feb 2001)

Plate 19 A *B. capensis* individual is weighed at De Mond (Feb 2001).

APPENDIX C
Physical and chemical variables

Table 1 Physical habitat measurements: temperature (temp, °C), pH, conductivity (cond, μS/cm) and turbidity (turb, NTU) at sites visited during the February and October 2001 surveys.

			February 2001								October 2001							
			Temp. °C		pH		Cond. μS/cm		Turb.		Temp. °C		pH		Cond. μS/cm		Turb. NTU	
1	Keerom		21.50	±0.73	7.30	±0.00	22.00	±0.00	-	-	18.23	±0.13	6.91	±0.01	25.23	±0.22	1.30	±0.00
2	Clanwilliam		22.20	±0.00	7.10	±0.00	386.00	±0.00	-	-	22.10	±0.00	6.98	±0.03	86.08	±0.15	2.88	±0.40
3	Cascade Pools		25.50	±0.00	6.56	±0.00	130.00	±0.00	-	-	20.78	±0.05	6.85	±0.01	152.98	±1.44	1.83	±0.05
4	Aspoort		29.00	±0.73	7.38	±0.09			-	-	24.65	±0.24	7.55	±0.10	90.33	±0.24	2.80	±0.38
5	Brakfontein		27.88	±0.08	7.76	±0.29	140.63	±8.19	-	-	-	-	-	-	-	-	-	-
6	Bos-Doring	upper pool	-	-	-	-	97.40	±10.09	-	-	23.50	±0	8.05	±0.00	127.43	±4.68	-	-
		lower pool	-	-	-	-	110.10	±0.65	-	-	-	-	-	-	143.98	±6.73	-	-
		backwater	-	-	-	-	-	-	-	-	23.90	±0.00	8.13	±0.19	153.88	±4.34	-	-
7	Biedouw-Doring Con		24.74	±0.11	8.74	±0.01	263.75	±22.50	-	-	19.23	±0.10	7.93	±0.01	190.43	±0.83	4.08	±0.17
8	Doringbos		27.80	±0.15	7.98	±0.46			-	-	19.80	±0.08	7.80	±0.01	187.18	±0.26	4.56	±0.38
9	Oudrif	upper pool	24.03	±0.05	8.72	±0.04	1425.13	±22.02	-	-	19.60	±0.00	8.05	±0.03	252.00	±1.83	3.46	±0.55
		mid pool	25.44	±0.40	9.11	±0.41	1919.20	±16.30	-	-	-	-	-	-	-	-	-	-
		lower pool	25.13	±0.87	8.57	±0.42	1072.75	±186.27	-	-	-	-	-	-	-	-	-	-
10	Melkboom	upper pool	28.16	±0.46	7.43	±0.58	1000.40	±13.43	-	-	21.10	±0.00	8.24	±0.15	318.25	±3.10	3.53	±0.13
		lower riffle	-	-	-	-	-	-	-	-	18.40	±0.00	8.04	±0.01	292.25	±8.54	3.82	±0.41
11	De Mond		27.82	±0.40	7.62	±0.20	137.00		-	-	21.38	±0.05	7.23	±0.02	113.75	±1.05	2.58	±0.21
12	Cobus se Gat				7.65	±0.37	287.17	±47.34	-	-	22.20	±0.00	7.49	±0.02	62.08	±1.35	2.28	±0.38
13	Brakwater		-	-	-	-	-	-	-	-	17.30	±0.00	7.71	±0.02	477.50	±10.21	4.68	±0.26
14	Koebee		-	-	-	-	-	-	-	-	22.20	±0.40	8.08	±0.05	337.75	±5.85	81.70	±1.13
15	Biedouw River		-	-	-	-	-	-	-	-	20.60	±0.00	7.68	±0.01	165.88	±0.51	3.10	±0.10
16	Klawer		-	-	-	-	-	-	-	-	22.70	±0.08	7.42	±0.00	349.25	±1.50	6.16	±0.75
		Mean	25.77	±2.43	7.84	±0.74	537.81	±611.31	-	-	21.04	±2.09	7.65	±0.45	195.90	±118.61	8.58	±20.26

Table 2 Physical habitat measurements: width, mean depth (δ_d), maximum depth (d_{max}), mean velocity (δ_v) and maximum velocity (v_{max})for each of pools, riffles and runs at each site visited during the February and October survey.

		February 2001							October 2001						
		Transect no.	Habitat	Width (m)	δ_d (m)	d_{max} (m)	δ_v ($m.s^{-1}$)	v_{max} ($m.s^{-1}$)	Transect No.	Habitat	Width (m)	δ_d (m)	d_{max} (m)	δ_v ($m.s^{-1}$)	v_{max} ($m.s^{-1}$)
1	Keerom	T1	Riffle	4.40	0.11	0.22	0.74	1.27	T1	Riffle	36.50	0.24	0.87	0.40	0.38
			Riffle	4.80	0.27	0.52	0.45	0.79			*	*	*	*	*
		T2	Pool	39	1.6	2.5	0.01	0.01		Pool	41.00	1.87	2.45	0.01	0.01
2	Clanwilliam Dam	T1	Riffle	0	0	0	0	0	T1	Riffle	8.00	0.86	1.30	1.94	2.78
		T2	Pool	15.00	1.25	2.40	0	0	T2	Pool	26.00	2.14	4.30	>0.01	
3	Cascade Pools	T1	Pool	50	4.05	6	0	0	T1	Pool	48.30	4.65	7.40	0.00	0
		T2	Pool	*	*	*	*	*	T2	Pool	37.00	2.96	5.20	0.00	0
4	Aspoort	T1	Pool	40.00	2.20	3.10	0	0	T1	Pool	51.00	1.42	1.90	0.01	0.01
		T2	Riffle	0	0	0	0	0	T2	Riffle	13.30	0.22	0.58	0.13	0.38
5	Brakfontein			34.00	1.15	1.49	0.00	0.00			*	*	*	*	*
6	Bos-Doring	T1	u/s pool	60.50	0.47	0.85	0	0	T1	Pool	57.00	1.30	1.85	0.01	0.01
		T2	d/s pool	24.00	1.23	2.45	0	0	T2	Pool	*	*	*	*	*
		T3	Riffle	0	0	0	0	0	T3	Riffle	24.00	0.19	0.26	0.69	0.91
7	Biedouw-Doring Confluence		Pool	18.00	0.33	0.70	0	0		run	40.00	1.27	1.70	0.01	0.01
8	Doringbos	T1		10.00	0.95	1.80	0	0	T1	Riffle	38.00	0.34	0.86	0.40	1.14
		T2							T2	run	22.00	1.03	1.40	0.17	0.31
9	Oudrif	T1		30.00	0.90	1.89	0	0	T1	run	24.00	1.07	2.18	0.18	0.75
		T2		*	*	*	*	*	T2	Pool	25.00	2.12	3.60	0.05	0.2
		T3		*	*	*	*	*		Riffle	25.00	0.38	0.76	0.71	1.56
10	Melkboom	T1	pool	52.00	0.96	2.39	0	0	T1		54.00	1.72	2.70	0.01	0.01
				0	0	0	0	0		bass hab	5.00	0.48	0.70	0.20	0.6
				0	0	0	0	0		bass hab	6.00	0.44	0.64	0.27	0.5
				0	0	0	0	0		bass hab	8.00	0.46	0.83	0.17	0.9
				0	0	0	0	0	T2	run	30.00	0.53	1.16	0.27	0.75
11	De Mond			44.80	5.64	8.70	0	0			58.00	3.04	4.82	0.01	0.01
12	Cobus se Gat	T1		30.00	0.60	0.92	0	0		Riffle	3.00	0.24	0.34	0.55	0.89
		T2		0	0	0	0	0		Pool	27.00	1.50	2.00	0.01	0.01
13	Brakwater		pool	11.00	0.81	1.70	0	0		Pool	12.10	1.03	1.50	0.01	0.01
			riffle	0	0	0	0	0		Pool	13.10	1.21	1.70	0.01	0.01
			riffle	0	0	0	0	0		Riffle	12.10	0.23	0.43	0.28	0.7
14	Koebee			27.50	1.26	2.12	0	0		Pool	29.00	2.03	3.05	0.01	0.01
				0	0	0	0	0		Riffle	22.00	0.22	0.32	0.38	0.73
15	Biedouw River			0	0	0	0	0		Riffle	9.50	0.22	0.80	0.49	1.17
16	Klawer			*	*	*	*	*		Pool	54.00	6.27	9.30	0.01	0.01

APPENDIX D
Regional Classification

Table 1. Total number of fish separate sample events (*n*), mean (δ_{R}) and Standard Deviation reported for *Barbus capensis*, *Labeo seeberi*, *Barbus serra*, *Micropterus dolomieu*, *Lepomis macrochirus* captured between 1882 - 1998 in each region: Olifants mainstem Upper (OU), Olifants mainstem Lower (OL), Olifants Tributaries (OT), Doring-Groot mainstem (DG), Doring Tributaries (DT) and Oorlogskloof-Koebee system (OK).

OLIFANTS MAINSTEM - UPPER (OU)				
	No.fish	***n***	δ_{R}	**SD**
B. capensis	18	20	0.900	0.553
L. seeberi	0	20	0.000	0.000
B. serra	7	20	0.350	0.587
M. dolomieu	4	20	0.200	0.523
L. macrochirus	3	20	0.150	0.489
OLIFANTS MAINSTEM - LOWER (OL)				
B. capensis	5	20	0.250	0.444
L. seeberi	7	20	0.350	0.745
B. serra	5	20	0.250	0.550
M. dolomieu	5	20	0.250	0.550
L. macrochirus	7	20	0.350	0.671
OLIFANTS TRIBUTARIES (OT)				
B. capensis	72	68	1.059	1.091
L. seeberi	0	68	0.000	0.000
B. serra	14	68	0.206	0.475
M. dolomieu	23	68	0.338	0.660
L. macrochirus	0	68	0.000	0.000
DORING-GROOT MAINSTEM (DG)				
B. capensis	20	38	0.526	0.603
L. seeberi	19	38	0.500	0.647
B. serra	6	38	0.158	0.437
M. dolomieu	17	38	0.447	0.602
L. macrochirus	17	38	0.447	0.686
DORING TRIBUTARY (DT)				
B. capensis	35	58	0.603	0.857
L. seeberi	5	58	0.086	0.388
B. serra	60	58	1.034	1.228
M. dolomieu	27	58	0.466	0.754
L. macrochirus	4	58	0.069	0.317
OORLOGSKLOOF-KOEBEE (OK)				
B. capensis	4	11	0.364	0.505
L. seeberi	10	11	0.909	0.831
B. serra	7	11	0.636	0.674
M. dolomieu	5	11	0.455	0.522
L. macrochirus	6	11	0.545	0.688

APPENDIX E
Abundance, CPUE and Index of CPUE

Table 1. Abundance, CPUE and index of CPUE for *B. capensis*, *B. serra* and *L. seeberi* recorded or caught by Electrofishing (E), Gill-netting (G), Angling (A), Seine-netting (S), Spearfishing (S), Visual observation (V) and Hand netting (H) during February 2001.

			Abundance								CPUE								Index of CPUE								
			E	G	A	S	Sp	T	V	H	E	G	A	S	Sp	T	V	H	E	G	A	S	Sp	T	V	H	Total
		Site Name	No. fish	No. fish	No. fish	No. fish	No. fish	No. fish	No. fish	No. fish	fish/hr	fish/m^2/hr	fish/hr	fish/m2	fish/hr	fish/m	fish/m^2	fish/hr									
Barbus capensis	1	Keerom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	2	Clanwilliam Dam (u/s)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	3	Cascade Pools	0	1	0	0	0	0	0	0	0	0.0005	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**1**
	4	Aspoort	0	3	0	0	0	0	0	0	0	0.008	0	0	0	0	0	0	0	3	0	0	0	0	0	0	**3**
	5	Brakfontein	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	6	Bos-Doring Confluence	0	15	0	0	0	0	0	0	0	0.031	0	0	0	0	0	0	0	4	0	0	0	0	0	0	**4**
	7	Biedouw-Doring Confluence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	8	Doringbos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	9	Ou Drif	0	3	0	0	0	0	0	0	0	0.005	0	0	0	0	0	0	0	3	0	0	0	0	0	0	**3**
	10	Melkboom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	11	De Mond	0	13	0	0	0	0	0	0	0	0.006	0	0	0	0	0	0	0	3	0	0	0	0	0	0	**3**
	12	Cobus se Gat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	13	Brakwater	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	14	Koebee	0	2	0	0	0	0	0	0	0	0.004	0	0	0	0	0	0	0	3	0	0	0	0	0	0	**0**
		Total	**0**	**37**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.06**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**17**	**0**	**0**	**0**	**0**	**0**	**0**	**14**
		Mean	**0**	**2.64**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.004**	**0**	**0**	**0**	**0**	**0**	**0**									
		SD	**0**	**4.955**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.008**	**0**	**0**	**0**	**0**	**0**	**0**									
Barbus serra	1	Keerom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	2	Clanwilliam Dam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	3	Cascade Pools	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	4	Aspoort	0	1	0	0	0	0	0	0	0	0.003	0	0	0	0	0	0	0	2	0	0	0	0	0	0	**2**
	5	Brakfontein	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	6	Bos-Doring Confluence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	7	Biedouw-Doring Confluence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	8	Doringbos	0	2	0	0	0	0	0	0	0	0.004	0	0	0	0	0	0	0	3	0	0	0	0	0	0	**3**
	9	Ou Drif	0	13	0	0	0	0	0	0	0	0.022	0	0	0	0	0	0	0	4	0	0	0	0	0	0	**4**
	10	Melkboom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	11	De Mond	0	6	0	0	0	0	0	0	0	0.003	0	0	0	0	0	0	0	2	0	0	0	0	0	0	**2**
	12	Cobus se Gat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	13	Brakwater	0	1	0	227	0	0	0	0	0	0.004	0	0.798	0	0	0	0	0	3	0	4	0	0	0	0	**7**
	14	Koebee	0	4	0	0	0	0	0	0	0	0.008	0	0	0	0	0	0	0	3	0	0	0	0	0	0	**3**
		Total	**0**	**27**	**0**	**227**	**0**	**0**	**0**	**0**	**0**	**0.04**	**0**	**0.8**	**0**	**0**	**0**	**0**	**0**	**15**	**0**	**4**	**0**	**0**	**0**	**0**	**21**
		Mean	**0**	**1.93**	**0**	**16.2**	**0**	**0**	**0**	**0**	**0**	**0.003**	**0**	**0.06**	**0**	**0**	**0**	**0**									
		SD	**0**	**3.668**	**0**	**60.67**	**0**	**0**	**0**	**0**	**0**	**0.006**	**0**	**0.213**	**0**	**0**	**0**	**0**									
Labeo seeberi	1	Keerom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	2	Clanwilliam Dam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	3	Cascade Pools	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	4	Aspoort	0	11	0	0	0	0	0	0	0	0.031	0	0	0	0	0	0	0	4	0	0	0	0	0	0	**4**
	5	Brakfontein	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	6	Bos-Doring Confluence	0	130	0	0	0	0	0	0	0	0.271	0	0	0	0	0	0	0	5	0	0	0	0	0	0	**5**
	7	Biedouw-Doring Confluence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	8	Doringbos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	9	Ou Drif	0	10	0	0	0	0	0	0	0	0.017	0	0	0	0	0	0	0	4	0	0	0	0	0	0	**4**
	10	Melkboom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	11	De Mond	0	41	0	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0	4	0	0	0	0	0	0	**4**
	12	Cobus se Gat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	13	Brakwater	0	55	0	24	0	0	0	0	0	0.229	0	0.084	0	0	0	0	0	5	0	2	0	0	0	0	**7**
	14	Koebee	0	86	0	0	0	0	0	0	0	0.179	0	0	0	0	0	0	0	5	0	0	0	0	0	0	**5**
		Total	**0**	**333**	**0**	**24**	**0**	**0**	**0**	**0**	**0**	**0.75**	**0**	**0.08**	**0**	**0**	**0**	**0**	**0**	**27**	**0**	**2**	**0**	**0**	**0**	**0**	**29**
		Mean	**0**	**23.8**	**0**	**1.71**	**0**	**0**	**0**	**0**	**0**	**0.05**	**0**	**0.01**	**0**	**0**	**0**	**0**									
		SD	**0**	**40.48**	**0**	**6.414**	**0**	**0**	**0**	**0**	**0**	**0.096**	**0**	**0.023**	**0**	**0**	**0**	**0**									

Table 2. Abundance, CPUE and index of CPUE *Micropterus dolomieu* and *Lepomis macrochirus* recorded or caught by Electrofishing (E), Gill-netting (G), Angling (A), Seine-netting (S), Spearfishing (S), Visual observation (V) and Hand netting (H) during February 2001.

			Abundance								CPUE								Index of CPUE								
			E	G	A	S	Sp	T	V	H	E	G	A	S	Sp	T	V	H	E	G	A	S	Sp	T	V	H	Total
		Site Name	No. fish	No. fish	No. fish	No. fish	No. fish	No. fish	No. fish	No. fish	fish/hr	fish/m^2/hr	fish/hr	fish/m2	fish/hr	fish/m	fish/m2	fish/hr									
Micropterus dolomieu	1	Keerom	5	0	4	0	0	3	0	0	10	0	4	0	0	0.03	0	0	3	0	4	0	0	2	0	0	**9**
	2	Clanwilliam Dam	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	3	0	0	0	0	0	**3**
	3	Cascade Pools	0	0	2	0	0	7	0	0	0	0	4	0	0	0.07	0	0	0	0	4	0	0	5	0	0	**9**
	4	Aspoort	0	0	0	7	0	0	0	0	0	0	0.016	0	0	0	0	0	0	0	1	0	0	0	0	0	**1**
	5	Brakfontein	0	0	0	4	0	0	0	0	0	0	0	0.028	0	0	0	0	0	0	0	2	0	0	0	0	**2**
	6	Bos-Doring Confluence	0	4	0	0	0	0	0	0	0	0.008	0	0	0	0	0	0	0	3	0	0	0	0	0	0	**3**
	7	Biedouw-Doring Confluence	0	0	0	36	0	0	0	0	0	0	0	0.126	0	0	0	0	0	0	0	2	0	0	0	0	**2**
	8	Doringbos	0	1	4	6	0	0	0	0	0	0.002	4	0.042	0	0	0	0	0	1	4	2	0	0	0	0	**7**
	9	Ou Drif	1	1	7	9	0	0	0	0	2	0.002	14	0.016	0	0	0	0	1	1	5	1	0	0	0	0	**8**
	10	Melkboom	0	0	0	5	0	0	0	0	0	0	0	0.018	0	0	0	0	0	0	0	1	0	0	0	0	**1**
	11	De Mond	0	2	0	0	0	0	0	0	0	1E-03	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**1**
	12	Cobus se Gat	0	0	0	1	0	0	0	0	0	0	0	0.004	0	0	0	0	0	0	0	1	0	0	0	0	**1**
	13	Brakwater	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	14	Koebee	0	2	0	0	0	0	0	0	0	0.004	0	0	0	0	0	0	0	3	0	0	0	0	0	0	**3**
		Total	**6**	**10**	**18**	**68**	**0**	**10**	**0**	**0**	**12**	**0.02**	**28**	**0.23**	**0**	**0.1**	**0**	**0**	**0**	**9**	**21**	**9**	**0**	**7**	**0**	**0**	**46**
		Mean	**0.43**	**0.71**	**1.29**	**4.86**	**0**	**0.71**	**0**	**0**	**0.86**	**0**	**2**	**0.02**	**0**	**0.01**	**0**	**0**									
		SD	**1.342**	**1.204**	**2.199**	**9.502**	**0**	**1.978**	**0**	**0**	**2.685**	**0.002**	**3.842**	**0.034**	**0**	**0.02**	**0**	**0**									
Lepomis macrochirus	1	Keerom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	2	Clanwilliam Dam	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	3	0	0	0	0	0	**3**
	3	Cascade Pools	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	4	Aspoort	0	0	0	109	0	0	0	0	0	0	0	0.255	0	0	0	0	0	0	0	5	0	0	0	0	**5**
	5	Brakfontein	0	0	0	1	0	0	0	84	0	0	0	0.007	0	0	0	168	0	0	0	1	0	0	0	5	**6**
	6	Bos-Doring Confluence	0	1	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**1**
	7	Biedouw-Doring Confluence	0	0	0	199	0	0	0	0	0	0	0	0.699	0	0	0	0	0	0	0	4	0	0	0	0	**4**
	8	Doringbos	0	0	0	29	0	0	0	0	0	0	0	0.204	0	0	0	0	0	0	0	3	0	0	0	0	**3**
	9	Ou Drif	14	0	0	282	0	0	0	0	28	0	0	0.495	0	0	0	0	0	0	0	3	0	0	0	0	**3**
	10	Melkboom	10	0	0	145	0	0	0	0	20	0	0	0.509	0	0	0	0	0	0	0	3	0	0	0	0	**3**
	11	De Mond	0	0	0	0	0	0	0	43	0	0	0	0	0	0	0	86	0	0	0	0	0	0	0	3	**3**
	12	Cobus se Gat	0	0	0	6	0	0	0	0	0	0	0	0.021	0	0	0	0	0	0	0	1	0	0	0	0	**1**
	13	Brakwater	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	14	Koebee	0	0	0	192	0	0	0	0	0	0	0	1.349	0	0	0	0	0	0	0	5	0	0	0	0	**5**
		Total	**24**	**1**	**1**	**963**	**0**	**0**	**0**	**127**	**48**	**0**	**2**	**3.54**	**0**	**0**	**0**	**254**	**0**	**1**	**3**	**25**	**0**	**0**	**0**	**8**	**37**
		Mean	**1.71**	**0.07**	**0.07**	**68.8**	**0**	**0**	**0**	**9.07**	**3.43**	**0**	**0.14**	**0.25**	**0**	**0**	**0**	**18.1**									
		SD	**4.428**	**0.267**	**0.267**	**97.48**	**0**	**0**	**0**	**24.42**	**8.855**	**6E-04**	**0.535**	**0.395**	**0**	**0**	**0**	**48.84**									

Table 3. Abundance, CPUE and index of CPUE *Barbus capensis*, *Barbus serra* and *Labeo seeberi* recorded or caught by Electrofishing (E), Gill-netting (G), Angling (A), Seine-netting (S), Spearfishing (S), Visual observation (V) and Hand netting (H) during October 2001.

			Abundance								CPUE								Index of CPUE								
			E	G	A	S	Sp	T	V	H	E	G	A	S	Sp	T	V	H	E	G	A	S	Sp	T	V	H	Total
		Site Name	No. fish	No. fish	No. fish	No. fish	No. fish	No. fish	No. fish	No. fish	fish/hr	fish/m²/hr	fish/hr	fish/m2	fish/hr	fish/m	fish/m2	fish/hr									
Barbus capensis	1	Keerom	0	1	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**1**
	2	Clanwilliam Dam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	3	Cascade Pools	0	1	0	0	0	0	0	0	0	0.003	0	0	0	0	0	0	0	2	0	0	0	0	0	0	**2**
	4	Aspoort	0	3	1	0	0	1	0	0	0	0.003	0.25	0	0	0.01	0	0	0	2	1	0	0	1	0	0	**4**
	6	Bos-Doring Confluence	0	4	0	0	0	0	0	0	0	0.003	0	0	0	0	0	0	0	2	0	0	0	0	0	0	**2**
	7	Biedouw-Doring Confluence	0	1	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**1**
	8	Doringbos	0	4	0	0	0	0	0	0	0	0.003	0	0	0	0	0	0	0	2	0	0	0	0	0	0	**2**
	9	Ou Drif	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	10	Melkboom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	11	De Mond	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	12	Cobus se Gat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	13	Brakwater	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	14	Koebee	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	15	Biedouw River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	16	Klawer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
		Total	**0**	**14**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0.02**	**0.25**	**0**	**0**	**0.01**	**0**	**0**	**0**	**10**	**1**	**0**	**0**	**1**	**0**	**0**	**12**
		Mean	**0**	**0.93**	**0.07**	**0**	**0**	**0.07**	**0**	**0**	**0**	**0**	**0.02**	**0**	**0**	**0**	**0**	**0**									
		SD	**0**	**1.486**	**0.258**	**0**	**0**	**0.258**	**0**	**0**	**0**	**0.001**	**0.065**	**0**	**0**	**0.003**	**0**	**0**									
Barbus serra	1	Keerom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	2	Clanwilliam Dam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	3	Cascade Pools	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	4	Aspoort	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	6	Bos-Doring Confluence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	7	Biedouw-Doring Confluence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	8	Doringbos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	9	Ou Drif	0	10	0	0	0	0	0	0	0	0.014	0	0	0	0	0	0	0	4	0	0	0	0	0	0	**4**
	10	Melkboom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	11	De Mond	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	12	Cobus se Gat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	13	Brakwater	0	3	0	15	0	0	0	0	0	0.003	0	0.236	0	0	0	0	0	2	0	3	0	0	0	0	**5**
	14	Koebee	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	15	Biedouw River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	16	Klawer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
		Total	**0**	**13**	**0**	**15**	**0**	**0**	**0**	**0**	**0**	**0.02**	**0**	**0.24**	**0**	**0**	**0**	**0**	**0**	**6**	**0**	**3**	**0**	**0**	**0**	**0**	**9**
		Mean	**0**	**0.87**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.02**	**0**	**0**	**0**	**0**									
		SD	**0**	**2.642**	**0**	**3.873**	**0**	**0**	**0**	**0**	**0**	**0.004**	**0**	**0.061**	**0**	**0**	**0**	**0**									
Labeo seeberi	1	Keerom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	2	Clanwilliam Dam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	3	Cascade Pools	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	4	Aspoort	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	6	Bos-Doring Confluence	0	12	0	0	0	0	0	0	0	0.008	0	0	0	0	0	0	0	3	0	0	0	0	0	0	**3**
	7	Biedouw-Doring Confluence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	8	Doringbos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	9	Ou Drif	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	10	Melkboom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	11	De Mond	0	15	0	0	0	0	0	0	0	0.014	0	0	0	0	0	0	0	4	0	0	0	0	0	0	**4**
	12	Cobus se Gat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	13	Brakwater	0	10	0	0	0	0	0	0	0	0.009	0	0	0	0	0	0	0	3	0	0	0	0	0	0	**3**
	14	Koebee	0	15	0	0	0	0	0	0	0	0.042	0	0	0	0	0	0	0	5	0	0	0	0	0	0	**5**
	15	Biedouw River	26	0	0	0	0	0	0	0	52	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	**5**
	16	Klawer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
		Total	**26**	**52**	**0**	**0**	**0**	**0**	**0**	**0**	**52**	**0.07**	**0**	**0**	**0**	**0**	**0**	**0**	**5**	**15**	**0**	**0**	**0**	**0**	**0**	**0**	**20**
		Mean	**1.73**	**3.47**	**0**	**0**	**0**	**0**	**0**	**0**	**3.47**	**0**	**0**	**0**	**0**	**0**	**0**	**0**									
		SD	**6.713**	**6.058**	**0**	**0**	**0**	**0**	**0**	**0**	**13.43**	**0.011**	**0**	**0**	**0**	**0**	**0**	**0**									

Table 4. Abundance, CPUE and index of CPUE *Micropterus dolomieu* and *Lepomis macrochirus* recorded or caught by Electrofishing (E), Gill-netting (G), Angling (A), Seine-netting (S), Spearfishing (S), Visual observation (V) and Hand netting (H) during October 2001.

			Abundance								CPUE								Index of CPUE								
			E	G	A	S	Sp	T	V	H	E	G	A	S	Sp	T	V	H	E	G	A	S	Sp	T	V	H	Total
		Site Name	No. fish	No. fish	No. fish	No. fish	No. fish	No. fish	No. fish	No. fish	fish/hr	fish/m^2/hr	fish/hr	fish/m2	fish/hr	fish/m	fish/m2	fish/hr									
Micropterus dolomieu	1	Keerom	0	0	0	0	0	5	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	**0**
	2	Clanwilliam Dam	0	0	0	0	0	1	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	1	0	0	**1**
	3	Cascade Pools	0	0	3	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	5	0	0	0	0	0	**5**
	4	Aspoort	0	0	4	0	0	2	0	0	0	0	1	0	0	0.02	0	0	0	0	2	0	0	2	0	0	**4**
	6	Bos-Doring Confluence	0	1	0	0	0	0	0	0	0	7E-04	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**1**
	7	Biedouw-Doring Confluence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	8	Doringbos	0	0	0	0	0	3	0	0	0	0	0	0	0	0.03	0	0	0	0	0	0	0	2	0	0	**2**
	9	Ou Drif	0	0	0	0	0	1	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	1	0	0	**1**
	10	Melkboom	0	1	0	0	0	0	0	10	0	0.001	0	0	0	0	0	20	0	1	0	0	0	0	0	1	**2**
	11	De Mond	0	0	1	0	0	1	0	0	0	0	0.333	0	0	0.01	0	0	0	0	1	0	0	1	0	0	**2**
	12	Cobus se Gat	0	0	4	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	3	0	0	0	0	0	**3**
	13	Brakwater	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	14	Koebee	0	1	0	0	0	0	0	0	0	0.003	0	0	0	0	0	0	0	2	0	0	0	0	0	0	**2**
	15	Biedouw River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	16	Klawer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
		Total	**0**	**3**	**12**	**0**	**0**	**13**	**0**	**10**	**0**	**0**	**9.33**	**0**	**0**	**0.13**	**0**	**20**	**0**	**4**	**11**	**0**	**0**	**7**	**0**	**1**	**23**
		Mean	**0**	**0.2**	**0.8**	**0**	**0**	**0.87**	**0**	**0.67**	**0**	**0**	**0.62**	**0**	**0**	**0.01**	**0**	**1.33**									
		SD	**0**	**0.414**	**1.521**	**0**	**0**	**1.457**	**0**	**2.582**	**0**	**8E-04**	**1.588**	**0**	**0**	**0.015**	**0**	**5.164**									
Lepomis macrochirus	1	Keerom	0	0	0	0	0	5	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	3	0	0	**3**
	2	Clanwilliam Dam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	3	Cascade Pools	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	4	Aspoort	0	0	0	98	0	0	0	0	0	0	0	0.772	0	0	0	0	0	0	0	4	0	0	0	0	**4**
	6	Bos-Doring Confluence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	7	Biedouw-Doring Confluence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	8	Doringbos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	9	Ou Drif	0	0	0	0	0	1	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	1	0	0	**1**
	10	Melkboom	0	0	0	273	0	0	0	0	0	0	0	2.15	0	0	0	0	0	0	0	5	0	0	0	0	**5**
	11	De Mond	0	0	1	80	0	6	0	0	0	0	1	1.26	0	0.06	0	0	0	0	2	5	0	4	0	0	**11**
	12	Cobus se Gat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	13	Brakwater	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	14	Koebee	8	1	0	46	0	0	0	0	8	0.003	0	0.724	0	0	0	0	2	2	0	4	0	0	0	0	**8**
	15	Biedouw River	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	16	Klawer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
		Total	**8**	**1**	**1**	**497**	**0**	**12**	**0**	**0**	**8**	**0**	**1**	**4.91**	**0**	**0.12**	**0**	**0**	**2**	**2**	**2**	**18**	**0**	**8**	**0**	**0**	**32**
		Mean	**0.53**	**0.07**	**0.07**	**33.1**	**0**	**0.8**	**0**	**0**	**0.53**	**0**	**0.07**	**0.33**	**0**	**0.01**	**0**	**0**									
		SD	**2.066**	**0.258**	**0.258**	**73.77**	**0**	**1.935**	**0**	**0**	**2.066**	**7E-04**	**0.258**	**0.639**	**0**	**0.019**	**0**	**0**									