ENVIRONMENTAL WATER REQUIREMENTS FOR NON-PERENNIAL SYSTEMS

FISH SPECIALIST REPORT

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December 2009

"Environmental Water Requirements in Non-perennial rivers"

WRC Project No**: K5/1587**

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EXECUTIVE SUMMARY

The Seekoei River is an ephemeral southern tributary of the upper Orange River. The Orange River system, with its sixteen indigenous fish species, is relatively species-poor compared to the rivers systems situated to the north, such as the Limpopo with 50 indigenous species and the Zambezi with 134 species (Skelton, 2001). Four endemic species are known to occur in the upper part of the Orange River (upstream of its confluence with the Vaal River), namely *Labeobarbus kimberleyensis* (Vaal-Orange largemouth yellowfish), *L. aeneus* (Vaal-Orange smallmouth yellowfish), *Labeo capensis* (Orange River mudfish), and *Austroglanis sclateri* (rock catfish).

During this study, five indigenous species, *L. aeneus, L. capensis, Labeo umbratus* (moggel), *Barbus anoplus* (chubbyhead barb) and *Clarias gariepinus* (sharptooth catfish), and two exotic species, *Cyprinus carpio* (carp) and *Micropterus salmoides* (largemouth bass), have been recorded.

Species richness and diversity increased in a downstream direction with only one species sampled at EWR1 (in the upper Seekoei) and seven species recorded at EWR4 (in the lower section of the river). Four and six species were recorded at EWR 2 and 3 respectively.

In the upper reaches only *Barbus anoplus*, a tolerant and widespread pioneer species (Cambray and Bruton, 1985; Skelton, 2001), was found in the isolated pool at EWR1. Considering the site's location in the catchment, the natural low degree of surface water connectivity and the natural high concentration of electrical conductivity, *B. anoplus* was also the only species expected to occur there.

At EWR2 four of the five expected indigenous fish species were recorded, namely *B. anoplus*, *L. capensis*, *L. umbratus* and *C. gariepinus* - *L. aeneus* was never found at this site. One exotic species, *Cyprinus carpio*, was also recorded. Species composition varied markedly between samples. *B. anoplus* was the species with the highest frequency of occurrence, found during eight of the eleven sampling visits. Two of the species, *L. capensis* and *C. gariepinus,* were only found once.

Five indigenous and one exotic species were recorded at EWR3. Two of the species expected at this site, endemics *L. kimberleyensis* and *A. Sclateri*, was never found. Species richness varied between one (in October 2007) and six (in September 2006).

EWR4 had the highest species richness (n = seven), the added species being the exotic *M. salmoides.* The lowest species richness and abundance at this site was recorded in October 2007 when only one *B. anoplus*, one *L. aeneus*, and one *C. gariepinus* individual were sampled. This followed a six month period during which most of the available habitats at the site were dry. During the June 2007 survey fish were already isolated in a few shallow pools with sandy bottoms. It is most likely that only the largest of these still persisted when flow resumed in October 2007.

River conditions and habitat diversity differed profoundly between sites EWR1 and 2 (situated in the upper and middle sections of the catchment) and EWR3 and 4 (both located in the lower part of the catchment). In the upper and middle catchment surface waters are connected for less than 10% of the time (Hughes, 2008; pers. obs.), resulting in the river mostly being a series of isolated pools. Especially in the upper and lower reaches the numbers of species is negatively impacted by the many impoundments which reduce surface water connectivity and restrict fish movement. Available habitat at these sites, therefore, comprised of only two velocity-depth classes (slow-deep and slow-shallow), compared to the four classes (slow-deep, slow-shallow, fast-deep and fast-shallow) present at EWR3 and 4 during periods of flow. Habitat diversity at EWR3 and 4 is, however, reduced when surface flow stops and isolated pools form as drying continues.

In conclusion: the fish community of the Seekoei River is dominated by cyprinid species and consists of hardy, tolerant species adapted to the unfavourable environmental conditions prevalent in the river. The river typically exhibits high degrees of hydrological variability and natural disturbance. It experiences a low degree of flow predictability and surface water connectivity, mainly as a result of unpredictable and variable rainfall, high rates of evaporation and flow modification due to weirs and small dams. The river is further characterised by frequent floods and droughts, marked fluctuations in water temperature and rather homogenous habitats, especially in the upper and middle parts. It is therefore not strange that most of the fish are opportunistic generalist species.

Variability of flow was found to have a large impact on the availability and diversity of fish habitat at the various sites, and therefore also, fish species distribution and richness. Species composition varied markedly between samples, especially at sites where pool persistence was low. This large variation in species richness and composition, together with the natural low number of species, the generalist nature of species and the absence of historical data, impeded the mere use of fish indices.

ACKNOWLEDGEMENTS

- Jurie du Plessis, Ockie Scholtz and Juan Potgieter for assisting with fish sampling.
- Tascha Vos, Jurie du Plessis and Marie Watson for assisting with habitat surveys.
- Jurie du Plessis for drawing the contour maps of the sites based on the habitat survey data and for writing section 4.3.4 explaining the habitat survey method followed.
- T.C. Niewoudt, Oom Joe Bishop and Oom Carools Venter for allowing us access to their farms in order to do sampling. Tannie Aletta for lifting our spirits with her delicious meals and picnic baskets delivered to the river.
- Frank Sokolic for the maps included here.
- Nico Avenant for his patience, support and assistance with finalizing the document.

1. Introduction

1.1 Overview of the study

The main objective of the fish study was to develop an understanding of the ecological nature and functioning of fish assemblages of the Seekoei River as an example of a non-perennial river in southern Africa with the objective of contributing to the development of a prototype Environmental Water Assessment Methodology for non-perennial systems.

The study deviated from its original objective to do field-sampling in each of the three types of non-perennial rivers recognised in Rossouw *et al.* (2005), namely Semi-permanent, Ephemeral and Episodic. A decision was taken, and approved by the project's Steering Committee, to rather concentrate the sampling effort on one non-perennial river system closer to Bloemfontein where most of the team members were based. This would allow team members frequent access to the river, enabling them to develop an in-depth knowledge of one system, rather than superficial knowledge of three systems. The Seekoei River was subsequently selected for study.

The Seekoei River is a southern tributary of the upper Orange River, flowing into the Orange River at Vanderkloof Dam. The Seekoei River catchment is situated in the Northern Cape Province but falls into the Upper Orange water management area (WMA) which is under the jurisdiction of the Free State Department of Water Affairs and Forestry. The entire Seekoei catchment falls in the Nama Karoo Level I Ecoregion and 26.03 Level II Ecoregion (Kleynhans *et al.* 2004).

1.2 Terms of reference

The terms of reference for the fish component of this study included 16 tasks:

- Liaise with the project coordinator who will provide any relevant general information with respect to the project.
- Liaise with other specialists on the team in order to develop an integrated understanding.
- Start an international and national literature search for relevant information on his/her specialist field. Also provide a synthesis report of all this literature with particular focus on the relationships between his/her speciality, flow, continuity of ecosystems and the presence of refugia.
- Prepare a preliminary report of the above synthesis, as well as a proposed work plan by 3 December 2005, with the objective of aiding specialists in other disciplines to gain an overall understanding of your specific field. The work plan should include an outline of the analytical and other techniques you intend to use. These will be used to prepare an integrated work plan for the field work. Bear in mind that field work will have to be coordinated in order to restrict unnecessary expenses.
- Attend Workshops as set out in Deliverables 2, 9, and 12-15. Note that in the third year, only one system will be the subject of a workshop and not three as indicated.
- Attend the site-selection visit (by a representative team consisting of the following: geohydrologist, instream geomorphologist, biologist and study leader) to the proposed sites and

share your understanding of the nature of each site with regard to your specialist field with the rest of the multi-disciplinary team by means of a concise report.

- Attend the first field visit as part of the full team. This first (wet season) visit, unlike the second, will be a common one to enable experts to share their views in the field. The second (dry season) visit will be less formal. Nevertheless, for budget purposes, the approved work plan should be followed.
- Attend a half day post mortem workshop directly after the wet season visit to facilitate integration of results.
- Prepare a brief interim report after the wet season field visit by 31 March 2006.
- Prepare a brief report after the dry season by 20 August 2006.
- Prepare a draft report (including literature and analyses of field data) as starter document for the workshop on trial methodology for reserve determination by 30 November 2006. This report will be reviewed and returned to you for correction.
- Attend the Workshop on Trial Methodology for Reserve Determination – second week in March 2007.
- Update the comprehensive report for the Workshop on Application of the trial methodology. This report will relate to flow scenarios as related to your special field. This means that you should be fully prepared to contribute and participate in the workshop.
- Attend the Workshop on Application of the trial methodology and take responsibility for providing and interpreting the information on your specialist field for the chosen scenarios at the chosen sites in a form that can be understood by the rest of the multi-disciplinary team.
- Submit the final (corrected) report.
- A possibility exists that further verification of principles might take place, with or without fieldwork, on one of the Limpopo-tributaries.

1.3 Timeline of the study

Water Research Commission project 1587 commenced April 1st 2005 and ended March 31st 2008. A year's extension was, however, granted to complete method development and report writing. The fish report will report on the field data collected between March 2006 and March 2008.

1.4 Limitations of the study

The Seekoei River catchment received above average rainfall in 2006. Flow measured at D3H015 downstream of sites EWR 3 and 4 for the first seven months of 2006 (34.865 million m^3; January to July 2006) was more than twice the yearly average over the last 25 years (16.073 million m^3; 1980-2006: DWAF flow data). Instead of decreasing as expected, water levels at the study sites remained high throughout the "dry" period. The "dry-season" field visitin September did, therefore, covered rather "wet" conditions. The dry period, however, started by November (also unexpectedly) and prevailed until June 2007.

1.5 Outline of the report

This specialist report is structured as follows:

- Section 3 gives a literature overview of international and national literature on the relationship between fishes, flow, continuity of ecosystems and the presence of refugia in the context of non-perennial rivers.
- In Section 3 the study area is described, and in
- Section 4 the methods applied during the study is explained.
- The results are presented and discussed in Section 5, with the
- Conclusions and References following in Sections 6 and 7.

2. Literature study

2.1 Introduction

Flow in dryland rivers (rivers in arid and semi-arid regions) is usually not only intermittent, but also highly variable (Boulton *et al.* 2000). These rivers are governed by stochastic events (disturbances) such as floods and droughts and often have low seasonal predictability (O'Keeffe 1986). About 40% of South Africa's total river length is subjected to natural interruptions of flow (Davies and Day 1998). A large proportion of South Africa's rivers is, therefore, event-driven and is considered to be amongst the most variable in the world (Poff *et al.* 2006). For example, the coefficient of variance (CV) of flow between 0.33 in the generally predictable rivers of the Western Cape compared to 2.58 in the generally unpredictable rivers of the northwest (King *et al.* 1992 as cited in Uys and O'Keeffe 1997). This hydrological variability is believed to have played an important role in establishing heterogeneity within South African rivers (Nel *et al.* 2005). It has also lead to river regulation and interbasin-transfers in an effort to supply water for domestic and industrial uses (Davies *et al.* 1994).

Hydrological conditions in river ecosystems form a continuum of variability (Uys and O'Keeffe, 1997). In an attempt to present a conceptual framework illustrating the range of temporary flow regimes in South Africa's non-perennial rivers, Uys and O'Keeffe (1997) proposed a classification based on the following gradients (see Figure 2.1):

- The degree that abiotic or biotic processes control ecological community structure,
- The connectivity of surface aquatic habitat,
- The degree of flow predictability,
- The degree of flow variability, and
- The degree of natural disturbance.

It is proposed that as flow intermittency increases, flow variability increases and flow predictability decreases. In moving towards episodic systems, community- structuring forces may switch from biotic to abiotic, natural disturbances may increase and the connectivity of surface water habitats may decrease (Uys and O'Keeffe 1997). Uys and O'Keeffe (1997) identified two important hydrological state changes in this process that may result in major biotic and abiotic changes in streams: the first when surface flow disappears but surface water is still present in the river, and the second when surface water disappears from the majority of the river channel. The ecological consequences of the loss of flow of surface water in temporary systems may be the most influential environmental parameter affecting the aquatic biota (Boulton 1989 as cited in Uys and O'Keeffe 1997).

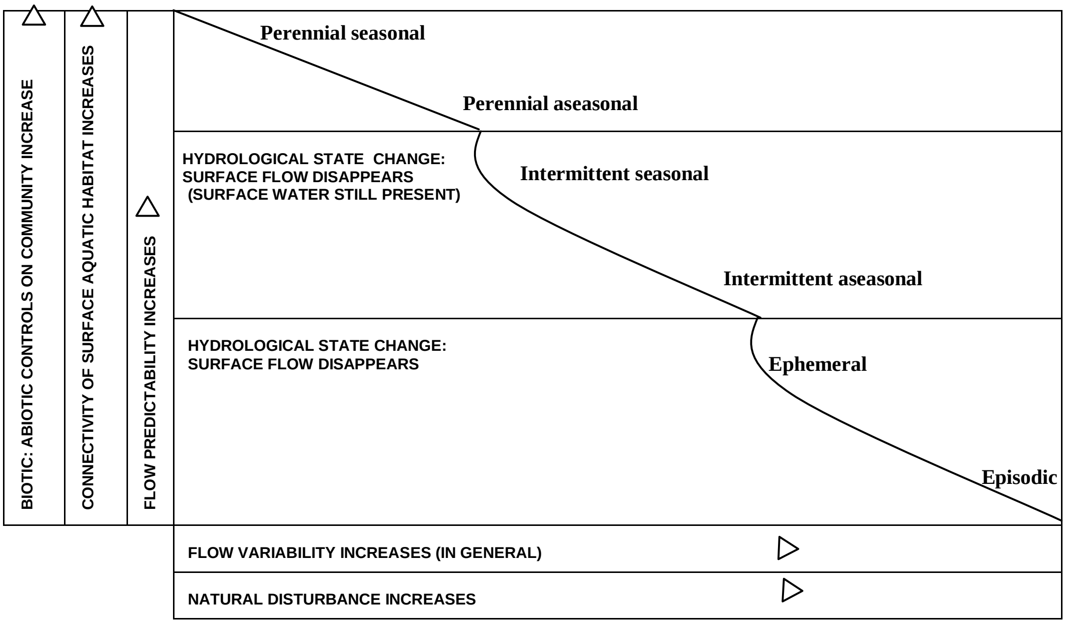

Figure 2.1: A conceptual illustration of the continuum concept (adapted from Uys and O'Keeffe, 1997).

It is evident from this discussion above that different aspects of the flow-regime may be relevant to a fish biologist considering the environmental water requirements for fish communities in non-perennial rivers, than those generally considered for communities in perennial rivers. Three such aspects will be considered in section 2.2: hydrological connectivity, water-depth and refugia. Fish communities may, however, also have an effect on the community structure of other riverine communities such as macroinvertebrates, zooplankton, algae and macrophytes. These effects may be more severe in drought years or during periods of isolation (e.g. in refuge pools) and is discussed below.

2.1. Roles of fish in river structure and functioning

Fish are a key biological component of riverine ecosystems and perform a number of important ecological functions. Matthews (1998) distinguished between direct and indirect effects of fish in freshwater ecosystems. Through predation, fish have a direct impact on the size structure and abundance of prey organisms (macroinvertebrates, zooplankton, algae and macrophytes); modify the physical structure of their ecosystems and play a significant role in nutrient cycling in stream ecosystems. Indirectly, fish do have the capacity to alter many aspects of the structure or function of ecosystems, and influence or change interactions that take place between organisms, or the organisms and the habitat (Matthews 1998).

Studies (reviewed by Matthew 1998) have indicated that invertivorous fishes directly affect the total abundance or biomass of stream insects, and can alter the size of prey populations as a result of size-selection. Gerking (1994) reported that predation of benthic invertebrates by fish eliminated certain prey species, changed prey-size distribution, and changed prey abundance and distributions. Strongly benthic fish species seem to have a more severe impact on benthic invertebrate species than visual predators like trout that effectively takes epibenthic and drifting invertebrates. From the literature it was also evident that a large number of small fish might have more impact on benthic or drift invertebrates than would a lesser number of larger fish (Allen 1982), and that fish predators may function synergistically with predatory invertebrates (Soluk and Collins 1988). Allen (1982) suggested that drift of invertebrates could ameliorate the effects of fishes on the density of their prey in a reach of a stream, replacing consumed or removing any surplus produced. It is not clear from literature exactly how important replacement by drifting is in a stream ecosystem. During periods of intermittence in ephemeral streams, the import of invertebrates by means of drifting would be unlikely as a result of disconnectivity. The severity of the impact of predacious fish on the macroinvertebrate community in an isolated pool is expected to be high but no studies could be found in the literature. Fish preying on macroinvertebrates have the potential to control all parts of the assemblage in littoral zones and lentic habitats (Matthew 1998), and expectedly even more so during periods of isolation.

Planktivorous fish can have strong effects on the size structure of zooplankton population (Brooks and Dobson 1965), with cascading effects to standing crops of phytoplankton (Matthews 1998). Size-selective predation by fish lowers the abundance of large zooplankton (which are more efficient grazers of algae), which leads to a shift to small-bodied taxa in the zooplankton assemblage (which are less efficient grazers of algae) resulting in an increase of the phytoplankton standing crop (Brooks and Dobson 1965; Matthews 1998). Responses of zooplankton populations to size-selectivity predation by fishes may, however, be more complex than illustrated above because life-history phenomena of the zooplankton may vary in an age-specific fashion (Taylor 1980). Also, the availability of nutrients in a food web may weaken the strength of the top-down effects of fish at trophic levels below zooplankton (McQueen *et al.* 1986). Generally, however, fish effects on zooplankton do include a reduction of the mean body size of zooplankton in the system, a lowering of the overall abundance and a change in the overall composition of zooplankton communities (Matthews1998). Larval fishes, typically in late spring and early summer, have a major influence on the decline in zooplankton abundance in lakes (Work and Gophen 1995) and the same could be expected for river ecosystems. Most studies reviewed by Matthews (1998) indicated that omnivorous fish enhanced total phytoplankton abundance and biomass (or primary productivity) by enhancing nannoplankton, which is too small to be grazed efficiently by fish.

Algae-grazing fish have the ability to control standing crops of algae (including periphyton) in their ecosystems (Power 1984). Power (1990) showed that at high densities fish could deplete algae but could enhance it at low densities by removal of sediments that, in the absence of fishes, became limiting to algae. Algivores and detrivores modify the structure of algae at small spatial scales, consequently reducing the quality of patches for invertebrates and indirectly influencing invertebrate densities (Flecker 1992). Heavy grazing in pools could result in a reduction in the standing crop of algae, change the dominant algae species, change the proportion of green, bluegreen and diatom cells at microscopic level, decrease net primary productivity per unit area, but increase net primary productivity per unit algal biomass, convert benthic particulate organic matter to smaller size fractions and lead to changes in C:N ratios (Matthews 1998). It can be expected that the impact of algivory and detrivory could be even more severe in a pool isolated for some time during the dry season. Bunn *et al.* (2003) found that the bands of algae along the shallow littoral zone of isolated turbid pools in an arid zone floodplain river (Coopers Creek) were the major source of energy for aquatic consumers, supporting large populations of crustaceans and fish.

Opportunistic cyprinid omnivores play an important role in ecosystem nitrogen dynamics in an intermittent desert stream (Grimm 1988). Ammonia excreted by the fish provided a rapid recycling of assimilable nitrogen to primary producers, which were often nitrogen limited. The fish switched to algae when the preferred taxon of insects (baetid mayflies) diminished, increasing their daily ingestion rate to compensate for the lower nitrogen content of algae. Grimm (1988) found that 3 to 6% of total nitrogen standing crop was stored in fish biomass and that excreted ammonia by the fish provided a rapid recycling of assimilable nitrogen to primary producers, which were often nitrogen limited.

Fish seem to have several kinds of potential impact on the nutrient relationships in aquatic ecosystems, including the transport of nutrients within their bodies and its subsequent release at a place different than the place where the materials were obtained, thereby altering the cycling of nutrients within a system (Matthews 1998). In fluvial systems the net upstream movement of fish biomass may compensate for downstream transport of nutrients in the system (Hall 1972). Partridge (1991) found that elevated flows are required to transport faeces downstream, otherwise it tends to accumulate on pool bottoms within the pool where fish are feeding at base flow. The rapid release of organic matter from cyprinid faeces indicates that fish contribute significantly to the metabolism of lake systems (Prejs 1984). Further, decomposition of fish carcasses in a temperate lake accounted for as much 10 to 20% of the phosphorus flux to sediments in littoral waters (Nriagu 1983). Benthic particulate organic matter dislodged by fish activity in flowing habitats are transported downstream until it settles from the water column in deeper or slower-flowing habitats, increasing food availability (Gelwick *et al.* 1997).

2.2 Aspects of the flow regime that may influence fish community structue

Introduction

Streams characterized by harsh physical conditions often host fish species that are tolerant of environmental stress, having passed through environmental or physiological evolutionary filters (Matthews and Marsh-Matthews 2003). Many of the fishes that are adapted to survive harsh environmental conditions, have generalized habitat, trophic, and reproductive requirements (Bramblett and Fausch 1991; Magoulick 2000). These fish communities do often show less impact of droughts than species in rivers with a more stable flow (Matthews and Marsh-Matthews 2003) and may be relatively resistant to thermal or oxygen stress (Matthews and Marsh-Matthews 2003). Magoulick (2000), however, cautions that regional factors, such as location in the catchment, are often neglected as factors structuring fish communities, but should be kept in mind.

2.2.1 Hydrological connectivity

Rivers have often been described as “corridors” or “linear landscapes in which water play a key role in connecting habitat patches” (see e.g. Junk *et al.* 1989; Ward 1998; Amoros and Bornette 2002). Hydrological connectivity can therefore be defined as “water-mediated transport of matter, energy and organisms within or between elements of the hydrologic cycle” (Freeman *et al.* 2007) and plays an important role in shaping the structure of aquatic communities.

Hydrological connectivity operates in four dimensions: longitudinal, lateral, vertical and temporal (Ward, 1989). While the longitudinal dimension refers to upstream-downstream linkages (a concept well described in the River Continuum Concept of Vannote *et al.* 1980), the lateral dimension refers to linkages between the river channel and the riparian/floodplain system and the vertical dimension incorporates interactions between the river channel and contiguous groundwaters (Ward 1989). The fourth dimension, which superimposes a temporal hierarchy on the other three dimensions, mainly relates to changes occurring on both annual (e.g. inter-annual hydrological variability) and historical scales (decades to centuries; Ward 1989; Amoros and Bornette 2002). According to Ward and Standford’s (1983; as cited in Jungwirth *et al.* 2000) extended serial discontinuity concept, the relative strength of the longitudinal connections is highest in the constrained headwaters, vertical interactions reach their maximum in the braided middle course of the river and lateral connectivity is most pronounced in alluvial floodplain rivers.

Important questions with regards to fish communities are, therefore, how connectivity (and by implication water depth/level) will influence:

- The availability of food,
- The availability of cover e.g. riparian vegetetation communities, substrate types and water depth, and
- Reproduction e.g. availability and accessibility of suitable spawning areas, cues for for spawning, the availability and accessibility of shallow nursery areas.

A study on the Cooper Creek, a dryland river in central Australia, indicated that in contrast with the more traditional view of the river continuum concept of Vannote et al (1980) that terrestrial carbon and nutrients imported from upstream are the most important energy source in lowland river reaches, that benthic algae in the shallow littoral zone of ephemeral pools was the primary energy source for consumers on the longterm (Bunn *et al.* 2003). The study indicated that the littoral zones were the major producers of carbon whereas the mid-channel habitat was a net consumer.

Stream fish assemblages have been shown to return to their pre-disturbance structure if colonization opportunities and habitat structure are left intact (Taylor, 1997). Barriers prohibiting fish movement (e.g. weirs and small dams that often lack fish ladders), could, therefore, have a detrimental impact on the re-establishment of fish communities after drought periods, thereby worsening the effects of the droughts. Especially small fishes in streams upstream from artificial reservoirs may be in danger of local extirpation during drought (Matthews and March-Matthews

2003). In-channel structures may become increasingly inaccessible barriers to fish during low-flow conditions, causing the fragmentation of populations.

2.2.2 Water depth

Water depth is a function of hydrological connectivity and may influence the community structure of aquatic communities such as the phytoplankton, zooplankton, macrophytes, macroinvertebrates and also fish (Kahl et al. 2008). Schlosser (1988) proposed that species richness should increase with increasing depth, habitat heterogeneity and temporal stability. This was supported by the work of Capone and Kushlan (1991) that indicated increasing species richness with increasing pool depth, pool persistence and channel size. Harvey and Stewart (1991) further demonstrated a strong positive relationship between pool depth and the size of the largest fish within a pool. This is also supported by the work of Magoulick (2000) who noted that large central stonerollers were positively related to pool depth. Pool depth can also markedly influence the survival of stream fishes (Harvey and Stewart 1991).

Spatial and temporal variation in water depth has been shown to affect biotic interactions among prey fish and their predators, in turn generating a dynamic mosaic of algal and macroinvertebrate habitat-patches with differing structural and functional ecosystem properties (Gelwick *et al.* 1997). Loricariid in a Panamanian stream were heterogeneously distributed on depth gradients in stream pools, avoiding depths < 20 cm, presumably to avoid avian predators (Power 1984). Harvey and Stewart (1991) reported that predation risk from wading or diving animals (such as herons, otters or water mongoose) is much higher for larger fishes in shallow water than for these fishes in deeper water or for smaller fish in shallow water. Gelwick *et al.* (1997) also found that benthic algivores abandoned habitats where predation risk became critical as water became shallow (<28cm). Fish larger than 50 mm (TL) avoided habitats that became shallow (< 30 cm) during low discharge (Gelwick *et al.* 1997). This avoidance was in accordance with increased body-size dependent predation risk from piscivorous fish and birds (Power 1984; Gelwick *et al.* 1997). Deep water column provide a spatial refuge from avian predators. Intermediate-size fish (30 – 100 mm TL) are usually vulnerable to fish predators in deep water and to bird predators in shallow water and were found in intermediate-depth microhabitats (Gelwick *et al.* 1997).

The work of Kahl et al. (2008) further showed that it is the fishes residing in the shallower littoral zones that are most vulnerable to fluctuations in water level. The littoral area is often used by juveniles as a place of refuge from predation and fluctuations in the water level could, therefore, have an impact on the recruitment success of some species. For example, in their study a sudden drop in water level shortly after the spawning period, led to the total loss of that year's offspring. A strong decrease in water level causes a loss of refuges from predation for the young fish. These young are "forced" into deeper areas where fish density had already increased as a result of the falling water leve, increasing predation risk.

Pool depth is an important consideration in non-perennial rivers. These rivers are often located in water-scarce areas, where they are seen as an important source of water. Water extraction has been cited by Gaigher *et al.* (1980) as one of the major factors causing the decline of fish species in the old Cape Province and Skelton (1977 as cited in Cambray 1990) considered it the main cause for the decline of six threathened fish species. According to Cambray (1990), it is not only the loss of habitat that is detrimental to fish fauna, but also the way in water is pump from the pools. He proposes that certain pools in the intermittent Groot River be identified as important refugia (or legislated pools) and that water abstraction be prevented below a certain level.

It is, however, not only pool depth that is important, but also pool persistence. Hay *et al.* (1996) found that fish production in the Okavango River is effected by the length of time that floodplains are inundated. The longer the period of inundation, the higher the survival rate of juveniles and fish production. It could be that a similar trend is evident in stream pools. Shallow habitat could be lost to juveniles prematurely as a result of water abstraction, forcing them to enter the deeper pools where they are more vulnerable to predation by other fish.

2.2.3 Refugia

The highly variable and unpredictable nature of the hydrological regimes of non-perennial rivers, make these rivers a very harsh environment for their biota. It is expected that as the variability of stream flow increases (moving from semi-permanent to episodic), it becomes the key factor in the shaping of the community structure of fluvial systems (Jacobson 1997). Aquatic biota in these systems have to negotiate not only variability in flow, but also habitat disconnectivity when surface flow disappears, disturbances like floods and droughts, and surviving low flow periods in pool refugia. Access to suitable refugia, therefore, increases a fish community's resistance and resilience to disturbance.

The response of biota to a disturbance consists of both resistance (capacity to withstand disturbance) and resilience (capacity to recover from disturbance). To many natural disturbances, stream biota have a low resistance but a great capacity for resilience (Lake 2005). This resilience come from species having evolved adaptations to with stand and recover, and these adaptations include attributes such as high mobility and recolonization capacity, short life cycles and the use of refugia (Lake 2000).

During periods of isolation, aquatic organisms in stream pools can be exposed to harsh abiotic and biotic factors because of drying, lack of flow, increased competition for resources and increased vulnerability to predation (Dekar and Magoulick 2007). The effects of these factors may become more pronounced as fish become congregated as the pool area decreases. Local abiotic, rather than biotic factors, have been found to govern community composition and species distribution under harsh physical conditions (Uys and O'Keeffe 1997). Dekar and Magoulick (2007) found that maximum depth was a consistently good predictor of central stoneroller and creek chubb densities in isolated pools. They also found that larger pools acted as refugia for more species compared with smaller pools that were less likely to persist.

During periods of isolation, the consumption of algae intensifies in local patches (Matthews and March-Matthews 2003). Also the byproducts of fish (faeces, nutrients and particulate organic matter tend to remain in the pool, whereas at higher flows such materials are likely to be flushed downstream (Matthews and March-Matthews 2003).

The survival of fish in isolated pools is an important ecological factor in intermittent rivers (Minshull 2008). It is, therefore, important to understand the hydrological processes that maintain these pools, especially in sand-bed rivers. The impact of the extraction of water from isolated pools, or from boreholes in or close to the river, for urban and agricultural practices is not always well understood as the link between sub-surface and surface water is not always known.

2.3 The role of fish in environmental water assessments

2.3.1 Background on environmental water assessments

Environmental flow methodologies aim to protect the ecological integrity of rivers in the light of increasing anthropogenic pressure, by trying to predict how much water can be harvested from a river without ecological damage (Pusey, 1998b). In order to predict how much water can be harvested, the quantity of water needed to maintain river integrity in a particular state need to be known (Acreman and Dunbar 2004). This state may be pre-determined or agreed upon based on a trade-off with other considerations. The methods used to assess the environmental water requirements of rivers must therefore be able to predict the consequences of varying degrees of alteration of the flow regime so that the implications for societies are understood (Acreman and Dunbar 2004). Society, in return, must clarify the goals for river management so that river scientists can determine appropriate flow recommendations.

Acreman and Dunbar (2004) recognise three steps in determining environmental water requirements. First the setting of broader objectives to indicate the type of river desired before defining the environmental water requirements. Secondly, defining environmental flow allocations by means of environmental flow approaches or methodologies and thirdly incorporating the environmental flow approaches into a wider assessment framework that identifies the problem, uses the best technical method and presents results to decision-makers.

2.3.1.1 Setting of objectives for flows

Two approaches are currently applied to achieve this goal, namely objective-based flow-setting where river flows are set to achieve specific pre-defined ecological, economic or social objectives, and scenario-based flow setting where various water allocation options or scenarios are examined. Both approaches have been applied in South Africa.

The Department of Water Affairs and Forestry (DWAF) uses a river-classification where objectives are set according to different ecological management targets (Acreman and Dunbar 2004). This implies that not all rivers would be managed for the same status. Four target classes are distinguished with Class A being the closest to natural conditions and Class D showing the highest degree of modification (Kleynhans 1999). Two additional classes (E and F) may describe the present ecological status but cannot be a target. Rivers falling into this category have to be managed as Class D rivers. The procedure of assigning these ecological classes (described in Kleynhans 1999; Louw 2005) includes determining the present status and importance of the rivers, whereafter a management class is set for the river (resource unit). Three biological components, fish, aquatic macro-invertebrates and riparian vegetation, are usually considered in determining the present ecological status (PES) of the river (resource unit). Specific procedures exist for determining the PES (as well as assigning a management category) for each component (fish, Kleynhans 1999, 2003 and Kleynhans and Engelbrecht 1999; Macro-invertebrates Thirion; riparian vegetation, Kemper 1999). Previously, a combined PES category was determined by reaching consensus between the specialists involved. In the new EcoClassification procedure (Kleynhans and Louw 2006) physical attributes (water quality, geomorphology and hydrology) are considered together with the biological components. Again different processes are followed to assign a category (A-F, where A=natural, and F=critically modified) to each component. The results for the different components are then integrated by means of the EcoStatus tool (Kleynhans and Louw 2006) to present a combined PES. The current status of the fish population (in relation to reference conditions) plays an integral part in the determination of the PES (present EcoStatus) and the Recommended Ecological Categories (RECs), as well as, in the evaluation of scenarios. The Ecoclassification procedure supports a scenario-based approach (Kleynhans and Louw 2006), implying a shift from setting objective for flows to considering a range of endpoints.

Scenario-based approaches were, among others, followed in the Lesotho Highlands Water Project (LHWP; Brown and King 2000; King *et al.* 2004) and the Thukhela River Reserve study (DWAF 2004; Tlou 2004). In these studies, various scenarios of environmental water releases from the dams were considered. This allowed decision-makers and stakeholders to assess trade-offs presented by different environmental flow options. For the majority of non-perennial rivers regulated by weirs and small dams in central South Africa, environmental water releases are not possible. Acreman and Dunbar (2004) gives an example (relevant to this study) where a scenario-based approached was used in the allocation of groundwater in the Wylye River catchment. A suite of abstraction scenarios ranging from “no abstraction” to “full abstraction” (including various combinations of different pumping rates levels in between) were considered in setting acceptable abstraction levels. For each scenario, the biophysical consequences impact on habitat for target fish species and implications for water supply to the public and industry were determined. These scenarios provided the basis for discussions between stakeholders of acceptable abstraction strategies.

2.3.1.2 Environmental flow approaches

Historically, fish were the centerpiece of most instream flow assessments (Arthington *et al.* 1999). The earliest environmental flow assessments were designed in North America to protect the habitat required particular fish species of recreational or commercial value. Since then, the emphasis has moved from the preservation of certain valued species to the protection of river ecosystems. Currently, more than 200 approaches for determining environmental flows (or environmental water requirements) exist (Arthington *et al.* 2004; Tharme 2003). Several authors have thoroughly discussed, evaluated and compared these approaches (Tharme 1996; Dunbar *et al.* 1998; Tharme 2002; Acreman and King 2003; Tharme 2003; Arthington *et al.* 2004; Acreman and Dunbar 2004; King *et al.* 2004) and would, therefore, not be repeated in this discussion. A short discussion on the different categories of approaches, with special reference to the role of fish (this section) and the kind of data used in the approaches (section 2.4) follows.

Four categories of environmental flow approaches are distinguished by King *et al.* (1999) and Tharme (2003): hydrological, hydraulic rating, habitat rating, and holistic methodologies. Differences in group definitions and classifications occur among authors (Tharme 2003; Acreman and King 2003; Acreman and Dunbar 2004).

Hydrological

This group of methods was developed in North America and represents the simplest set of techniques where, at a desktop level, hydrological data, as naturalized, historical monthly or average daily flow records, are analyzed to derive standard flow indices which then become the recommended environmental flows (Arthington *et al.* 2004). This type of methods yields only a fixed or minimum flow and not a whole regime (Acreman and Dunbar 2004). They are rapid methods generally used at the planning stage of water resource developments, or in situations where preliminary flow targets and exploratory water allocations trade-offs are required (Arthington *et al.* 2004).

Tennant (1976), who developed the frequently used Montana Method (Pusey 1998b), recognized congruence between discharge levels and the nature of instream fish habitat. He considered three factors as being crucial for fish well-being: wetted with, depth and velocity (Pusey 1998a) and used calibrated data from hundreds of sites on rivers in the mid-western states of the United States of America to propose flows that could achieve the maintenance of particular amounts of habitat (Acreman and Dunbar 2004). For example, Tennant stated that flows greater than or equal to 60% of the mean annual flow are needed to maintain excellent-to-outstanding habitat for fish. He observed that the greatest changes to habitat occurred between the flow range of 0-10% of the mean annual flow and concluded that short-term survival habitat for (salmonid) fishes could be maintained by preserving 10% of the mean annual flow (Pusey 1998a).

Advantages and disadvantages of hydrological methods have been recognized by several authors (Pusey 1998a, 1998b; Tharme 2003; Acreman and King 2003; Acreman and Dunbar 2004; Arthington *et al.* 2004). In an effort to apply the Montana Method in Australia, Richardson (1986 cited in Pusey 1998a) found that Australian rivers lack extensive flow records and are characterized by markedly different flow regimes and species of very different evolutionary histories. The relationship between habitat suitability and proportions of annual flow, which forms the basis of the Montana Method, has not been examined for Australian rivers. The same is true for rivers in southern Africa. For the majority of ephemeral rivers in the central part of South Africa, flow records are very poor, do not exist (Avenant 2004) or are suspect (Steÿn 2005), presenting a fatal flaw for the application of hydrological methods on these rivers. Further, implementing monthly percentile flows in rivers without storage facilities with outlets would also be not feasible. Fish assemblages in most of the non-perennial rivers and streams in the central part of the country have low fish species richness and comprise of generalist species.

Habitat discharge methodologies

This group of methodologies originated in North America (Tharme 2003), and seeks to define a quantifiable relationship between the discharge regime and the quality of an instream resource (e.g. the amount and type of fishery habitat; Pusey 1998a). Once this relationship is known, a modified flow regime can be constructed to maintain the habitat at either maximum suitability or at acceptable levels (Pusey 1998a). These methods examine the effects of specific increment in discharge on instream habitat, with most emphasis placed on the passage, spawning, incubation, rearing and other flow-related maintenance requirements of certain economically important fish species (Tharme 1996). Two groups of habitat discharge or transect based methodologies developed from this foundation, hydraulic rating and habitat rating (Tharme 2003).

Hydraulic rating

Hydraulic rating methodologies use changes in simple hydraulic variables, such as wetted perimeter or maximum depth, usually measured across a single, flow-limited river cross-section (commonly riffles), as a surrogate for habitat factors known or assumed to be limiting to target biota, in order to develop a habitat-discharge relationship for deriving environmental flow requirements (Arthington *et al.* 2004). Of the hydraulic rating methodologies, the “wetted perimeter” method has been most widely used, also in Australia (Pusey 1998a). It is based on a series of observations of changes in stream habitat structure with changing discharge and involves the placement of a single transect per site at a location on the river most responsive to flow changes (Pusey 1998a). Pusey (1998a) identified three important assumptions associated with this method. First, it is assumed that single transects per site are adequate to describe the changes within that site that occur with changing discharge. Second, since those locations that are most responsive to changes in discharge are riffles, studies tend to focus on this habitat. It is assumed, therefore, that consideration of one habitat type only is sufficient to fulfill the requirements of other biotopes. Third, it is assumed that stream area is a surrogate for many other factors or processes that determine overall ecological integrity. According to Pusey (1998a), these inherent assumptions result in a highly simplified perception of the stream environment encompassed within a single variable.

Pusey’s (1998a) comments are very valid, and should be considered when hydraulic rating methods are applied on non-perennial rivers. These rivers do not have continuous flow, implying that riffle-habitats are temporary. Pools usually provide the only “permanent” habitats, providing refuge to biota during the dry season. Although riffle-habitat may be important to some fish species during the breeding season, most species in the smaller non-perennial tributaries of the Orange River system do not prefer or inhabit riffles. By focusing on the species occurring in the riffles, the majority of fish could be ignored. In non-perennial rivers the relationship between the water level (and therefore also groundwater in most cases) and habitat structure or suitability in pools should also be investigated. At the onset of flow after a dry spell, riffle and rapid habitat provides critical connections between pools isolated during dry periods.

Habitat rating

Habitat rating or habitat simulation methodologies (also referred to as microhabitat or habitat modeling methodologies) make use of hydraulic habitat-discharge relationships, to provide more detailed, modeled analyses of both the quantity and suitability of the physical river habitat for the target biota (Arthington *et al.* 2004). [*In other words: Information from hydraulic simulations with data on the preferred physical micro-habitat requirements of individual fish species is used to assess how much of the preferred micro-habitat is available at different discharges].* In these methods multiple transects are used as an empirical means of determining changes in habitat with changing discharge (Pusey 1998a). Multiple transects are also an attempt to address the problems associated with reliance on a single transect and a single variable such as wetted perimeter (Pusey 1998a). Pusey (1998a) explains that a series of transects is implemented within a stream and variables such as depth, velocity, substrate and cover are measured at intervals across the transect. Changes in these variables with change can then be determined and modeled in various hydraulic programs (Arthington *et al.* 2004). If the habitat requirements of a certain species are known, then the change in suitability of an area at different discharges may be determined. Simulated information on available habitat is, therefore, linked with seasonal information on the range of habitat conditions used by target fish (or invertebrate) species by means of using habitat suitability index curves. The resultant outputs, in the form of habitat-discharge curves for specific biota or extended as habitat time and exceedence series, are used to derive optimum environmental flows (Arthington *et al.* 2004).

Pusey (1998a) provides a thorough discussion on the advantages and disadvantages of applying the method in Australian rivers. Habitat rating methods have been used in Victoria, Australia. In several of these studies the focus has been on identifying optimal flow (i.e. flows which result in the maximum amount of a particular habitat for a fish species). Some authors (see Hall 1989 cited in Pusey 1998a) suggested, however, that in order to impose an environmental flow allowance on the basis of whether they maintain certain proportions of fish habitat, river specific relationships between habitat levels and fish numbers (or biomass) need to be established. Four important fish habitat types were recognized in Victorian studies: (i) rearing; (ii) resting; (iii) spawning; and (iv) passage (see Table 2.1 for an explanation of the different habitat types). Hall (1989 cited in Pusey 1998a) proposed that rearing habitat is the most critical habitat to consider and that reductions in the size of rearing area may result in a reduction of the carrying capacity of a fish population. Mostly due to a lack of validation by research, the degree to which any one of these requirements takes precedence over the others is unknown. In Table 2.2 the habitat types were considered for the Seekoei River. Although the long-term flow record for the Seekoei River indicated that high flows generally occurs between February and March, short-term flows turned out to be much more variable and unpredictable, especially in the upper and middle reaches. This variability should be considered when the approach is followed.

Table 2.1. The four types of fish habitat recognized in Victorian (Australia) studies using habitat rating methods (see Pusey 1998a).

Fish habitat	**Description**
Rearing	Areas in which fish feed as well as those areas in which prey organisms are found
Resting	Areas of a river in which fish seek refuge and includes such areas as deep pools with low water velocities, woody debris and macrophyte beds
Spawning	Habitat attributes such as certain depths, water velocities and substrates, plus conditions necessary to cue reproduction or initiate movement.
Passage	Conditions that allow or prevent fish movement from one section to another.

Habitat rating methods assume that all complicated interactions between the responses to all variables are reflected in the fishes distribution (Ibbotson 2002). Habitat use by fishes is influenced by many factors, including habitat availability, past disturbance, temperature and the presence of predators and competitors (Pusey 1998a). Ibbotson (2002) cautions that habitat use will only reflect habitat quality correctly when the distribution of habitat availability is spread evenly across habitat types and is at carrying capacity. Also, Pusey (998a) indicates that it is not ideal to derive the habitat use of a fish population from literature reports on work done in other systems far removed. Poorly developed species-specific habitat requirements could increase the potential of errors in these methods.

Table 2.2: An example of how seasonal habitat use can be used for to identify habitat requirements for fishes in the Seekoei River.

Fish habitat	Winter (dry season)	Spring (dry season/start of wet season?)	Summer to autumn (Rain, flow and floods)	Autumn (rainy season/floods)
Rearing	Pools	Accessibility to new feeding areas	Rapids/riffles for some species Shallow nursery areas for young	Species feeding in rapids/riffles Shallow nursery areas for young.
Resting	Deep pools		Deep pools for larger fish, shallow areas for young Availability of fish cover	Refuge from floods
Spawning		Cues for spawning e.g. floods, water temperature	Cues for spawning e.g. floods, water temperature	
Passage	N/A?	Accessibility to spawning areas e.g. gravel and vegetation. Restocking of river after dry period.	Necessary during breeding season, as well as extending feeding grounds and exchange of genetic material.	Sub-adults need to move back into pools before winter.

With regards to the Seekoei River study, the following points were raised:

- With the exception of Arthington *et al.* (2004) who produced habitat preferences curves for four indigenous species (*Pseudobarbus quathlambae*; *Labeobarbus aeneus*; *Labeo capensis* and *Austroglanis sclateri*) in the upper reaches of the Orange River, no other similar research has been done on the fish community in the upper Orange (upstream of the Orange-Vaal confluence). Although very valuable work have been on the distribution and life cycles of fish species in this river section (notably that of Benade 1993a and b; Cambray 1983a and b, 1984, Cambray and Bruton 1984, 1985 etc.), a lot of the information that relates to habitat use are anecdotal. Is Pusey's (1998a) warning valid in that habitat preference curves for other river systems (e.g. Limpopo) should not be used? Would it be possible to use it within the same Level 1 or 2 ecoregions?
- To what extent would habitat use change seasonally? For obvious reasons, habitat use during the dry and wet seasons would be very different. Are shallow habitats mainly utilized by larval and juvenile fish until they are large enough to enter the deeper habitats? Are these "temporary" shallow habitats important for the survival of fish in these rivers? If so, why?
- Is it sufficient to divide the flow cycle into dry and wet seasons, or are further (finer) distinctions necessary?
- All the fish species occurring in the Seekoei River are generalist species. How would their generalist behaviour influence habitat preference curves? How much effort should be spent (is justified) on establishing river-specific habitat preference curves in a non-perennial river with a generalist fish assemblage (and without specialist species)? Would it be possible to find significant relationships between fish abundance and certain habitat types (except pools)?
- If farmers are required to stop pumping water from a pool in order to protect critical fish habitat, scientific proof is needed on how much water is needed for fish survival in the pools. How do you identify the critical pools in a river? How do you determine the critical level below which farmers would not be allowed to abstract water from a pool.

Holistic

Holistic methodologies aim to address the water requirements of the entire riverine ecosystem rather than the needs of only a few taxa (Arthington *et al.* 2004). The focus is on maintaining or restoring the flow-related biophysical components and ecological processes of instream and groundwater systems, floodplains and downstream receiving waters (e.g. estuaries; Arthington *et al.* 2004). Several ecosystems components, including geomorphology, hydrology, hydraulic habitat, water quality, riparian and aquatic vegetation, macroinvertebrates, fish and other vertebrates with some dependence upon the river/riparian ecosystem, are usually considered in these assessments. Each of these components is usually evaluated using a range of field and desktop techniques (see Arthington and Zalucki 1998; Dunbar *et al.* 1998; DWAF 1999; King *et al.* 2000; Tharme 2003; Arthington *et al.* 2004 for further details). The flow requirements of each component are then incorporated into the environmental water assessment recommendations, using various systematic approaches (Arthington *et al.* 2004).

More than 16 holistic methodologies have been developed since the early 1990s (representing nearly 8% of the global total of environmental flow approaches; Tharme 2003). Arthington *et al.* (1998) grouped these methods into two categories, namely “bottom-up” and “top-down” methods. “Bottom-up” methods (e.g. the Building Block Method, BBM; Tharme and King 1998; King *et al.* 2000) are designed to construct a modified flow regime by adding flow components to a baseline of zero flows. “Top-down” methods (e.g. the Downstream Response to Imposed Flow Transformations method, DRIFT; Brown and King 2000; King *et al.* 2003) consider how much a river’s flow regime can be altered before the aquatic ecosystem show noticeable changes or degradation.

The South African developed BBM (Tharme and King 1998; King *et al.* 2000) is currently the most frequently applied environmental flow approach with applications in South Africa, Australia, Swaziland and Zimbabwe (Tharme 2003). The method has also been modified for intermediate and comprehensive determinations of the ecological reserve as prescribed by the South African National Water Act (Act 36 of 1998; DWAF 1999). It was also recently incorporated in the Flow Stress-Response Methods (O’Keeffe and Hughes 2002) that is currently being developed (also see Kleynhans and Louw 2006).

Holistic methodologies consider a range of taxa other than just fish, and incorporate important ecological processes (Pusey 1998b). These methods recognize that the information base is sometimes deficient in some areas and allow for the incorporation of a range of methods to address particular issues. According to Pusey (1998b), one of the most important advantages of holistic methods is the fact that they are not constrained to accept the recommendations offered by any one method without an assessment of its advantages or disadvantages compared with a range of other methods and for other components of the riverine ecosystem. Determining the flow requirements for fish remains, however, integral to holistic environmental water assessments because fish are a key biological component of river ecosystems (Arthington *et al.* 1999).

Five levels of EcoStatus determinations are recognized in the South African EcoStatus determination procedure ranging from EcoStatus Desktop Level to EcoStatus Level 4 (see Table 2.3). Based on the level of EcoStatus determination, certain biological components (and corresponding EcoStatus tools) are prescribed. Field assessments for the fish component, using the Fish Response Assessment Index (FRAI), are to be included only in level 3 and 4 EcoStatus assessments (Kleynhans and Louw 2006). If information on the fish assemblage is known or available for a particular river (or resource unit), it may be included at Desktop level.

Table 2.3: Levels of EcoStatus determinations and corresponding Ecological Reserve methods (adapted from Kleynhans and Louw 2006).

Levels of EcoStatus determination	***Ecological Reserve methods***
EcoStatus Desktop Level	*Desktop Reserve assessment*
EcoStatus Level 1	*Rapid I Ecological Reserve method*
EcoStatus Level 2	*Rapid II Ecological Reserve method*
EcoStatus Level 3	*Rapid III Ecological Reserve method (and River Health Programme)*
EcoStatus Level 4	*Intermediate and comprehensive Reserve methods*

Several authors provide an in-depth evaluation of holistic methodologies (Pusey 1998a; Pusey 1998b; Tharme 1996, 2000, 2002, 2003; Arthington 1998; Arthington *et al.* 1998; Dunbar *et al.* 1998; Arthington and Zalucki 1998; Acreman and King 2003; Acreman and Dunbar 2004; Arthington *et al.* 2004).

2.3.1.3 Assessment frameworks

Environmental flow approaches are usually incorporated into wider assessment frameworks that identify the problem, use the best technical method and present the results to decision-makers (Acreman and King 2003; Acreman and Dunbar 2004). Examples are the Instream Flow Incremental Methodology (IFIM; Bovee 1982 cited in Acreman and Dunbar 2004; Bovee et al 1998), the Downstream Response to Imposed Flow Transformations (DRIFT; King *et al.* 2003), and the Catchment Abstraction Management Strategies (CAMS; Environment Agency 2002 cited in Acreman and Dunbar 2004).

2.3.2 The role of fish assessments in environmental water assessments

In the evolution of environmental flow approaches, fish moved from being the centerpiece, to being one of several biological components assessed. Being a key biological component in most river ecosystems, fish still remain integral in determining environmental water assessments.

Fish are generally considered as very useful biological indicators (Karr *et al.* 1986):

- Fish assemblages (usually) represent a wide variety of trophic levels and may therefore integrate the effect of detrimental environmental changes (Kleynhans 2003).
- Fish are good indicators of long-term effects and broad habitat conditions due to their relative longevity and mobility (Kleynhans 2003). Their greater mobility has the potential to integrate diverse aspects of relatively large-scale habitats and their longer life span includes a temporal dimension to the assessment of stream conditions (Karr *et al.* 1986).
- Fish use a wide range of habitats during their daily activities and different life-stages. These habitats may be seen as a function of base flow (Kleynhans and Engelbrecht 1999).
- Fish represent less identification problems than do aquatic invertebrates.

- The conservation status and distribution patterns of most fish species have been determined (Skelton 2001).
- The public at large tend to value fish and are usually more familiar with fish than with other forms of aquatic life (Karr *et al.* 1986).

In the South African context, fish are used as one of the key indicators in environmental water assessments (Louw 2003), in that:

- They are often the critical indicator due to factors such as size and more critical flow requirements.
- In determining environmental flow requirements, fish are used as one of the key indicators of the biological integrity of the system.
- Fish are used to define the objectives for which flows must be quantified.
- Together with other components, they are used to quantify the ecological reserve.
- Fish are used to set resource quality objectives for biota and habitat and as a monitoring tool to measure compliance and whether objectives are being achieved.

With regards to the role of fish in the assessment of environmental water requirements, Arthington *et al.* (1999) raise two important points[1]. First, that the needs of small-bodied fish species also be considered in the provision of water. According to Pusey *et al.* (1999), the inclusion of smaller fish species in environmental water assessments is essential to understand fish assemblage structure and dynamics, and may be particularly important in detecting the more subtle effects of impoundment and discharge regulation on stream habitat and ecological processes (Sparkes 1992 cited in Arthington *et al.* 1999).

Second, that exotic species also deserve careful consideration in environmental water assessments. Alien species may have a range of detrimental effects on indigenous fishes and other aquatic biota, including alteration of habitat and water quality, interspecific and predatory effects on species assemblages, alteration and degradation of local and regional genetic stocks, introduction of parasites and diseases and socio-economic effects (Arthington *et al.* 1999). Environmental flow allocations may serve to increase or decrease the suitability of stream habitats and resources for alien species.

[1] This must be seen in the light that the study of Arthington et al. 1999 was conducted in the upper reaches of the Orange River and that the fish assemblage included the critically endangered *P. quathlambae*.

2.3.3 The role of fish assessments in environmental water assessments in non-perennial rivers

Is it necessary to include fish assessments in environmental water assessments in ephemeral and episodic rivers? This may be a valid question, as some rivers lack sufficient permanent surface water to support a fish community (e.g. Kuiseb). As a result of the harsh environmental conditions (variability in flow, intermittency, turbidity, catastrophes etc.) that prevail in most of these rivers, fish assemblages generally comprise of hardy generalists able to cope with very variable flow (e.g. although *Labeobarbus aeneus* prefers to spawn during high flow conditions, they are known to produce young in dams and pools). Specialist species are often absent. This, together with, low species richness impede the application of most indices (for example see Kleynhans 1999, 2003). If fish are (or were historically), however, present in a system, it should be considered.

The disappearance of surface water from the majority of the river channel has major ecological consequences for aquatic biota, especially fish. According to Puckridge *et al.* (undated) the most important hydrological measures for biological communities in arid zone rivers, are: duration of drying, frequency of drying, duration of connection between water bodies, as well as the duration of no flow and multi-annual variation in pulse magnitude in a river reach. These measures may, however, be different for macroinvertebrates and fish, and even between the different subsets and age-classes of the fish assemblage. Puckridge *et al.* (undated) found that fish species richness per water body is positively related to long-term water body permanence. In some rivers, this absence or discontinuity of surface water proved to be unsuitable for sustaining a natural fish community. The transient nature of the pools, disconnectivity between pools, absence of refugia for surviving droughts, absence of aquatic macrophytes and other cover, all contributed to unsuitable conditions for the development and support of a natural fish fauna. In such river systems, the assessment of flow requirements for fish is not relevant and should rather focus on macroinvertebrates, riparian vegetation or other vertebrates like frogs, birds or small mammals.

It might be necessary to design a guideline according to which a decision can be made on when to include a certain biological component or when to use another vertebrate species. A possibility could be to prepare a matrix showing the different categories of non-perenniality (e.g. see Rossouw et al. 2005 and/or Uys and O'Keeffe 1997) together with possible biological indicators. Omitting or replacing components should not be a problem within existing methodologies (or decision frameworks). The only obstacle would be that no standardized methods for the consideration of other vertebrate species exist at present besides fishes. It would also be necessary to do a preliminary investigation of the catchment in order to identify any other vertebrate species that could be used (e.g. certain algae or macroinvertebrates could have a strong link to birds or amphibians). [The "temporary" occurrence of birds in ephemeral pans in the Northern Cape Province has been documented (Hermann et al. 2004; Mark Anderson, Northern Cape Department of Tourism, Environment and Conservation pers. comm)].

Table 2.3: An example of a matrix

Categories of non-perenniality: months with no-flow (%)	*Biological components*					
	Algae/ Diatoms	Riparian	Macro-invertebrates	Fish	Amphi-bians	Birds
Perennial (0)	X	X	X	X		
Semi-permanent (1-25%)	X	X	X	X		
Ephemeral (26-75%)	X	X	X	(X)		(X)
Episodic (>76%)	X	X	(X)			X

2.4 Kinds of fish data used in instream flow assessments

Many kinds of data are required for a scientific assessment of the environmental flow requirements for riverine fishes:

Pusey *et al.* (1999) have shown that the provision of water to sustain fish populations and assemblages is intimately linked to the maintenance of channel and floodplain morphology, hydraulic habitat conditions, opportunities for movement and migration, water quality conditions, food resources and energy flow, and other organism in the riverine and riparian environment. In the light hereof, they proposed a list of information requirements as part of a protocol for assessing the flow requirements for fish at various spatial scales within the landscape:

- Composition of the fish fauna, species distributions in the catchment and relationships between hydrology and distribution patterns.
- Quantitative data on the habitat requirements of each fish species and of each life history stage of each species and relationships with hydrology.
- Dietary requirements of fish species and the influence of hydrology on production and availability of food resources.
- An understanding of patterns of fish movement and their relationship to hydrology.
- The basic life history of each species and its relationship to hydrology.
- An understanding of inter-specific interactions between fish species and their relationship to hydrology, including the effects of exotic species.
- An understanding of ecological linkages between the surrounding landscape, hydrology and community metabolism in rivers.
- An understanding of the influence of freshwater flows on fish of estuarine and coastal systems.

2.5 The fish community of the Seekoei River

2.5.1 The Seekoei River as part of the Orange River system

The Orange River system falls largely in the semi-arid to arid zone of southern Africa and represents an extremely hostile physical environment for freshwater biota (Gaigher *et al.* 1980b). Rainfall is erratic and river flow quite unreliable (Bowmaker *et al.* 1978). Generally, the main runoff occurs from November to April, with a peak from January to April. The river is characterised by marked fluctuations of annual temperature and flow with devastating floods and episodic droughts (Allanson *et al.* 1990; Bowmaker *et al.* 1978). The water is furthermore heavily silt laden (especially during the rainy season), and virtually devoid of submerged macrophytes (Allanson *et al.* 1990). Physical habitat is, therefore, fairly homogenous with emergent vegetation, mainly *Phragmites* sp., occurring in sheltered bays or shallow areas.

The fishes of the Orange River system have over long periods of natural selection adapted to a riverine environment (Bowmaker *et al.* 1978; Gaigher *et al.* 1980b). These riverine fish species are mainly bottom feeders or predators (Du Plessis and Le Roux 1965; Bowmaker *et al.* 1978) that can benefit from the natural seasonal changes in environmental factors such as flow, temperature and turbidity (Tómasson and Allanson 1983). According to Bowmaker *et al.* (1978) the essential characteristic of riverine fish species is their generalisation. Conversely, any longterm stability in the environment would allow specialisation, hence speciation (Bowmaker *et al.* 1978). Opportunism therefore plays an important role in the seasonal or episodic colonisation of lentic habitats of riverine fish species (Allanson *et al.* 1990). Also, in an environment where mortality is high due to erratic flow, suitable conditions for spawning and hatching are of short duration and predation on juveniles heavy, successful recruitment depend to a large extent on high population fecundity (Gaigher *et al.* 1980). Fecundity increasing with an increase in mass and large average size in females would therefore be advantageous for survival.

2.5.2 Fish species expected to occur in the Seekoei River

The Orange-Vaal River system hosts a relatively species poor fish assemblage. Fifteen indigenous fish species (out of 94 indigenous fish species occurring in southern Africa), belonging to 11 freshwater fish families (compared to the 20 families present in the Zambesi system) have been recorded (Skelton 2001; De Moor and Bruton 1996). Six endemic species, *Labeobarbus kimberleyensis*, *L. aeneus*, *Labeo capensis*, *Austroglanis sclateri* and *B. hospes* (only present in the lower Orange River below Augrabies Falls; Skelton 2001) occur.

With regards to the Orange River, Jubb (1972) distinguished between the “highland” (above 1500 m) and the “lowland” (below 1600 m) zones. The tributaries of the Orange and Caledon Rivers in the Lesotho highlands have clearer cool waters inhabited by two minnows, *Barbus anoplus* and the critically endangered *Pseudobarbus quathlambae* (Maluti minnow), the Vaal-Orange smallmouth yellowfish (*Labeobarbus aeneus*) and a rockbarbel *Austroglanis sclateri* (Jubb 1965, 1972; Skelton 2001;). The warmer, turbid waters of the lowlands are inhabited by *B. anoplus* and *L. aeneus*, as well as another yellowfish species, *Labeobarbus kimberleyensis*, two labeos (*Labeo capensis* and *L. umbratus*) and two silurids, *A. sclateri* and the widespread sharptooth catfish *Clarias gariepinus* (Jubb 1964, 1972). The Augrabies Falls forms a geographical barrier to certain species separating the lower Orange from the rest of the system (Gaigher *et al.* 1980).

Several exotic fish species have been introduced to the Orange River. In the highland area two trout species, Salmo trutta and S. gairdneri, were introduced in 1935 into the upper reaches of the Orange and Caledon Rivers in Lesotho (Jubb 1972). In river sections and dams below 1 500 m.a.s.l., largemouth and smallmouth bass, Micropterus salmoides and M. dolomieu, a cichlid Tilapia sparrmanii (into the upper reaches of the Caledon River in 1964), and the bluegill sunfish, Lepomis macrochirus were released (Jubb 1972). Another exotic, Cyprinus carpio, moved in from the Vaal River and established itself in the upper Orange River (Jubb 1972).

Table 2.3: Fish species of the Orange River (Jubb 1964, 1972; Gaigher *et al.* 1980; Skelton and Cambray 1981; Cambray 1984; Benade 1993a and b; De Moor and Bruton 1996; Skelton 2001). Four distribution zones are indicated: RU, Upper reaches (above 1500 m); UO, Upper Orange (from below 1500 m to upstream of Vaal-Orange confluence; MO, Middle Orange (downstream of Vaal-Orange confluence to upstream of Augrabies Falls); LO, Lower Orange (downstream of Augrabies Falls).

Family	***Species***	***Common name***	***Natural distribution***	***Conservati on status***
Cyprinidae	*Barbus anoplus*	Chubbyhead barb	UO, MO	
	B. trimaculatus	Threespot barb	MO, LO	
	B. paludinosus	Straightfin barb	MO, LO	
	B. hospes	Namaqua bard	LO	Near threatened
	Pseudobarbus quathlambae	Maluti minnow	UR	Critically endangered
	Labeobarbus aeneus	Vaal-Orange smallmouth yellowfish	UR, UO, MO, LO	
	L. kimberleyensis	Vaal-Orange largemouth yellowfish	UO, MO, LO	Vulnerable
	Labeo capensis	Orange River mudfish	UO, MO, LO	
	L. umbratus	Moggel	UO, MO	
	Mesobola brevianalis	River sardine	LO	
Bagridae	*Austroglanis sclateri*	Rockbarbel	UR, UO, MO, LO	Least concern
Clariidae	*Clarias gariepinus*	Sharptooth catfish	UO, MO, LO	
Cichlidae	*Tilapia sparrmanii*	Banded tilapia	UO, MO, LO	
	Pseudocrenilabrus philander	Southern mouthbrooder	MO, LO	
	Oreochromis mossambicus	Mozambique tilapia	LO	

2.5.3 Life histories of the species expected in the Seekoei River

2.5.3.1 Barbus anoplus (Family: Cyprinidae)

General background and distribution

Barbus anoplus are successful in a wide range of habitats, varying from shallow streams to the shorelines of large impoundments (Jubb 1967; Cambray 1985; Skelton 2001). It is widespread in the Orange River system occurring from below the Lesotho highlands to Augrabies Falls (Jubb 1967; 1972) and is common in the southern tributaries of the upper Orange River (Skelton and Cambray 1981). The species has also been successful at colonizing shallow unstable rivers in southern Africa (Cambray 1985) due to their small size, rapid growth rate in the first year, early sexual maturity, distributional migration, high fecundity and tolerance of low water temperatures (Cambray 1983a). Also, their rapid embryonic development rate and the ability of some protolarvae to float while others adhere to surfaces, enable the species to endure harsh conditions associated with receding water levels and high silt loads (Cambray 1983a). *Barbus anoplus* can tolerate salinities up to and including 11g/L for a two week period (100% survival; De Bie, 1985).

Conservation status

Barbus anoplus is a common and widespread species.

Habitat preferences

Barbus anoplus prefers cooler waters and is frequently associated with cover or shelter such as fallen logs, brushwood or marginal vegetation (Skelton 2001). The widespread species occurs from clear rocky upland streams to turbid impoundments with silt substrata in the Karoo (Cambray undated). It is abundant in the marginal areas of Gariep and Vanderkloof Dams (Cambray *et al.* 1978) but is not abundant in the main channel of the Orange River (Benade 1993a).

Flow related aspects of biology

Feeding

Barbus anoplus are omnivorous, feeding on insects, zooplankton, seeds, green algae and diatoms (Skelton 2001). The species, however, exhibits wide trophic adaptability with riverine specimens living in small streams having a more varied diet than those living in open-water habitats (Cambray 1983b).

Breeding

This small, short-lived (males live two years, females two to three years) species has a high seasonal reproductive potential (reaching sexual maturity after one year at lengths of about 40 mm) (Cambray 1985; Cambray and Bruton 1985). Males display a bright yellow/ golden breeding colour, especially during the first spawning (Cambray and Bruton 1984; Skelton 2001). Adults migrate into shallow temporary areas prior to breeding and adhesive eggs are laid amongst vegetation (Skelton 2001; Cambray 1983a). Spawning migrations are, however, not necessary and fish may spawn locally if there is a rise in the water level and marginal vegetation is flooded (Cambray *et al.* 1978).

Barbus anoplus exhibits a multiple spawning habit with the first spawning in November - January and the second in February - March (Cambray and Bruton 1985). The delay in the second spawning is probably an adaptation to defer breeding (prolonging the number of summers the available stock would live, decreasing the chances of one or generations lost due to unavourable environmental conditions and reducing intra- and interspecific competition between fry) that evolved because of the unstable environment of the Orange River (Cambray and Bruton 1984; 1985). Cambray and Bruton (1985) consider this as very important in understanding the age and growth of the species and advise that offspring from the two spawning events be treated as different age groups when considering differences in length.

The reproductive cycle of *B. anoplus* is based on an annual periodicity (Cambray and Bruton 1984). According to Cambray and Bruton (1984) this recurring cycle is typical of fish that live in freshwater in the cold temperate zones, where habitats are dominated by annual cycles of environmental variables such as day-length, temperature and food availability.

2.5.3.2 Labeobarbus aeneus (Family: Cyprinidae)

General background and distribution

Labeobarbus aeneus is widely distributed throughout the Orange River system (Jubb 1967; Mulder 1971, 1973a) and is abundant in the Orange River (Mulder 1973a; Benade 1993a). This could be because of its omnivorous feeding habits, tolerance to turbidity and earlier maturity (Mulder 1973a).

Conservation status

Labeobarbus aeneus is widespread in the Orange-Vaal River system and is not listed on the IUCN Red list.

Habitat preferences

Labeobarbus aeneus prefers clear, fast flowing waters with sandy or rocky substrate (Benade 1993a; Mulder 1973a) within deeper pools, backwaters, runs and large and small dams (Du Plessis and Roux 1965). Clear water is of minor importance in determining the distribution of the species (Mulder 1971), but substrate requirements play an important role in the breeding success of the species (Benade 1993a). *L. aeneus* seems to be more abundant in the turbid Orange River with a gravel substrate, than in the clearer water of the Lower Vaal underlain by a silted substrate (Benade 1993a).

Labeobarbus aeneus in the upper reaches of the Orange River showed a preference for fine substrates (mud and sand). Abundances for the species correlated negatively with small and large cobble substrate and leaf litter (Arthington *et al.* 1999). On the use of microhabitat, Arthington *et al.* (1999) reported that the species showed a distinct preference for areas of zero mean water velocity. The species preferred depths greater than 100 cm, but was frequently collected in shallow water (10-40 cm).

Flow related aspects of biology

Feeding
Labeobarbus aeneus are opportunistic omnivorous feeders (Tómasson *et al.* 1983). Depending on availability, benthic invertebrates (including bivalve molluscs e.g. *Corbicula*), aquatic vegetation (e.g. macrophytes), algae (e.g. filamentous algae) and detritus are the major food items taken (Mulder 1971; Gaigher and Fourie 1984; Skelton 2001). Younger individuals (<200 mm in length) rely mainly on benthic and planktonic invertebrates including zooplankton, insects and insect larvae, while larger individuals (>200 mm) show a preference for filamentous algae and macrophytes (Mulder 1973a; Gaigher and Fourie 1984; Skelton 2001). Turbidity, especially during periods of higher flow, affects the vulnerability of prey other than plankton. Although smaller fish exist well on zooplankton, energy expenditure would force larger specimens to take prey which are less vulnerable in turbid water (Gaigher and Fourie 1984). Gaigher and Fourie (1984) found terrestrial insects are important to all size groups after flooding. Dörgeloh (1994) observed seasonal differences in the food taken by *L. aeneus* in Sterkfontein Dam: In winter fish consumed to large extent plant zoobenthos, with plant material (*Potamogeton* and *Lagarosiphon*) comprising the highest percentage mass of the stomach contents in spring, summer and autumn. All length groups (except ≥ 400 mm in summer) preferred zooplankton (Cladocera) throughout the year. Plant material (*Potamogeton* and *Lagarosiphon*) was especially important in summer and autumn. Gaigher and Fourie (1984) found turbidity to *L. aeneus* probably competes for food with *B. anoplus* (feeding facultatively on invertebrates), *C. carpio* (benthiphagous), and the predaceous *L. kimberleyensis* and *C. gariepinus* (Gaigher and Fourie 1984).

Breeding
Under natural flow conditions, *L. aeneus* breeds during the first post-winter floods (Tómasson and Allanson 1983) in spring, migrating upstream to spawn on gravel beds (Jubb 1967; Skelton 2001). Under regulated conditions, temperature most probably determine breeding time, with low temperatures retarding breeding as well as initial growth rates, and also leading to high mortalities (Tómasson and Allanson 1983). Males were found to be sexually mature after four years and the males after five years (Mulder 1973a). The length at which the species reach sexual maturity is usually 200 mm standard length (SL) for males and 240 mm SL for females (Skelton 2001), but varies between river systems. This could be due to general habitat differences, river section differences or inefficient sampling (Benade 1993a).

2.5.3.3 Labeobarbus kimberleyensis (Family: Cyprinidae)

General background and distribution
Labeobarbus kimberleyensis is an important species in the Orange River system because of its endemic status, and being one of only two predatory fish species in the system (Benade 1993b). The species is widely distributed throughout the Orange River system except for its absence from the Lesotho catchment (Jubb 1967) and intermittent southern tributaries of the Orange River (Skelton and Cambray, 1981). It is presently more abundant in the lower Vaal than the Orange River (Benade 1993a).

Conservation status

Concern about the species becoming increasingly scarce in the Orange River system has been expressed since the 1970s (Jubb 1972; Mulder 1973a; Benade 1993; Skelton 2001). This concern has been recognized and *L. kimberleyensis* is currently considered to be “vulnerable” on the IUCN Red list (Skelton 2001). Factors contributing to the paucity of *L. kimberleyensis* are river regulation (negatively impacting upon gonad development and reproduction; Benade 1993a)) and extremely turbid conditions in the Vaal (Mulder 1973a) and Orange Rivers (Benade 1993a), restricting the ability of the predatory species to see its prey. Another contributing factor is the slow growth-rate and the age at which both sexes reach sexual maturity (Mulder 1971, 1973a). Increasing angling pressure may contribute to a critical situation concerning *L. kimberleyensis* in the future (Mulder 1973a). Occasional hybridization between *L. aeneus* and *L. kimberleyensis* may occur (Mulder *et al.* 1990).

Habitat preferences

It prefers clear, fast-flowing deep water with a sandy to gravel substrate (Mulder 1973a). Adult *L. kimberleyensis* prefer larger permanent water bodies such as dams (Mulder 1971; Rossouw 1973; Skelton 2001) and deep pools (Du Plessis 2005) whereas juveniles are generally found in larger numbers in rapids (Mulder 1971).

Flow related aspects of biology

Feeding

Labeobarbus kimberleyensis is a visual predator from the juvenile stages with increasing piscivorous tendency with increasing age (Mulder, 1973a). Major prey items are insects (an important prey item for juveniles) crustaceans and fish (Mulder 1973a; Skelton 2001).

Breeding

Under natural flow conditions *L. kimberleyensis* breeds in and below rapids (Skelton and Cambray 1981) during the first spring floods (Mulder 1973a). Under regulated conditions, temperature probably becomes the determinant breeding factor, with low temperatures retarding breeding, initial growth rates and juvenile survival (Tómasson and Allanson 1983). Benade (1993a) found gonad development of *L. kimberleyensis* in the upper and middle Orange River to be linked to both flow and temperature. Males attain sexual maturity at an age of six years (350 mm) while the females reproduce at an age of eight years (460 mm) (Mulder 1971, 1973a).

2.5.3.4 Labeo capensis (Family: Cyprinidae)

General background and distribution

Labeo capensis is the most common large fish species in the Orange (Skelton and Cambray 1981), Caledon (Baird 1976, Baird and Fourie 1978) and Vaal (Mulder 1971, 1973b; Russell 1997) Rivers. Although this species prefers running waters of large rivers, it does not seem to be confined to certain habitat types, and seems to be utilizing all aquatic habitats in the Orange River system, including large impoundments (Mulder 1973b; Cambray 1984, 1985; Skelton 2001). *Labeo capensis* haemoglobin has a high oxygen affinity enabling the species to endure very low oxygen concentrations frequently present in stagnant waters (Frey and Van Aardt 1994). High fecundity and early maturation are important factors contributing to the success of the species in this river system (Mulder 1973b; Gaigher *et al.* 1980a). Gaigher *et al.* (1980a) concluded that sex ratios and spawning behaviour are important adaptations to ensure high maximum fecundity in an unfavourable environment for spawning, high juvenile predation and high intraspecific predation under low flow conditions. Two predacious fish species occur with *L. capensis*, *i.e. C. gariepinus* and *L. kimberleyensis*. Numerically, *C. gariepinus* is probably the most important predator on *L. capensis*, especially during periods of low flow, with *L. kimberleyensis* mainly restricted to capturing immature specimens (Gaigher *et al.* 1980a).

Conservation status

Labeo capensis is endemic to the Orange-Vaal River system. It is a common and abundant species and is not on the IUCN Red list.

Habitat preferences

Labeo capensis is known to prefer running waters in large rivers with muddy pools Jubb 1972; Skelton 2001). Although Arthington *et al.* (1991) sampled the *L. capensis* in habitats with a diverse range of substrate types, the species showed a preference for muddy substrates. The species also showed a preference for habitats between 31 and 40 cm deep with low velocities. It was often collected in areas of open water devoid of cover but usually in association with substrate and/or rocky undercut (Arthington *et al.* 1999). *Labeo capensis* is a schooling species aggregating in the mid to lower half of the water column (Arthington *et al.* 1999).

Flow related aspects of biology

Feeding

Labeo capensis is mainly a detritus feeder (Jubb 1967; Mulder 1973b), grazing from firm surfaces of rocks and plants (Skelton 2001).

Breeding

Males in the Vanderkloof Dam reach sexual maturity at lengths of 280 mm (four years of age; Gaigher *et al.* 1980a) to 320-350 mm (Tomasson *et al.* 1984), compared to 260 mm in the Hardap Dam (Van Zyl *et al.* 1995) and 160-250 mm in the Caledon River (Baird and Fourie 1978). Females only become sexually mature at lengths of 360 mm (six years of age; Gaigher *et al.* 1980a) to 370-400 mm (Tomasson *et al.* 1984) in Vanderkloof Dam. Spawning takes place in spring and early summer after the first floods (Mulder 1973b; Gaigher *et al.* 1980a; Skelton 2001). Jubb (1972) reported the spawning migrations to occur during the months of November to January when suitable conditions occur. Since the completion of the Gariep and Vanderkloof Dams, spawning seems to occur in October to November in the regulated river section between the two large dams (Gaigher *et al.* 1980) with several minor spawnings evident until January (Mulder 1973b; Gaigher *et al.* 1980a; Cambray 1985). The gonosamitic index (GSI) of female specimens in the Vaal River peaked during September, remaining high in October and November whereafter it declined to a minimum in January (Van der Merwe *et al.* 1987).

During spawning males and females move upstream in pairs (Mulder, 1973b) and spawn on inundated vegetation during flood periods (Gaigher *et al.* 1980a). Large numbers of individuals gather in rocky rapids, where eggs are also laid (Skelton 2001). Individual females seem to spawn all their eggs at once but all females do not breed at the same time (Gaiger *et al.* 1980; Van Zyl *et al.* 1995). Suitable conditions for spawning are of short duration and do not allow time for extended breeding behaviour - the success of fertilisation is therefore independant of the size of the males (Gaigher *et al.* 1980a). In the Gariep Dam, the species appears to spawn throughout the dam and do not have a specific spawning migration (Fairall and Hamman 1977). River regulation in the Orange River possibly offers a longer spawning season to *L. capensis*, and being less dependent on seasonal floods, they can now breed when water temperature, photoperiod and regulated flow provide a suitable combination of triggers (Cambray 1985). The study of Van Zyl *et al.* (1995) in Hardap Dam, Namibia, clearly showed that water temperature correlate with development of the gonads in both male and females; spawning was therefore not depended on flooding and took place in summer (October to March). In the light of the above it seems as if change in water in water temperature triggers gonad development in *L. capensis*.

Due to the fact that the flood periods last only for a few days, eggs must hatch rather quickly. Post-larvae and small fish remain in shallow areas where suitable food is probably available and they are relatively safe from predation (Gaigher *et al.* 1980), possibly moving to deeper waters after reaching a length of 180 mm (Cambray *et al.*, 1978) becoming relatively immune to predation at that length.

2.5.3.5 Labeo umbratus (Family: Cyprinidae)

General background and distribution

Labeo umbratus is widespread in the Orange-Vaal River system. Skelton and Cambray (1981) found the species to be rare in the main channel of the Orange River, but dominant in secondary tributaries. The species is tolerant to a wide range in both water temperature and quality (Jubb 1967), and can survive austere conditions in drying, muddy pools (Jubb 1972). It is not particularly successful in the lotic conditions (Skelton and Cambray 1981) suiting *Labeobarbus kimberleyensis*, *L. aeneus* and *Labeo capensis*, reducing competition (Mulder 1971). It is therefore not as abundant as the endemic *L. capensis* in the Orange River (Gaigher *et al.* 1980b).

Conservation status

This widespread species is not Red Data listed.

Habitat preferences

Labeo umbratus prefers standing or slow flowing water (including backwaters), thrives in impoundments (Mulder 1971; Rossouw 1973; Merron and Tómasson 1984; Skelton 2001) and is virtually absent from clear fast-flowing waters, except during spawning migrations (Mulder 1973b).

Flow related aspects of biology

Feeding

Labeo umbratus is a detrivore feeding on soft sediments and detritus (Jubb 1967; Skelton 2001).

Cambray (1990) reported on juveniles of this species migrating upstream during a period of high flow following on a period of intermittence in the Groot River (Gamtoos River system). The bulk upstream movement of *L. umbratus* specimens (ranging between 100 to 400 mm) took place during the day (11:00 to 19:00) possibly in an effort to reach new feeding habitat in order to optimize foraging possibilities before winter (Cambray 1990).

Reproduction
Males and females in the Vanderkloof Dam reach sexual maturity at 350-360 mm (three years) and 370-380 mm (four years), respectively (Tomasson *et al.* 1984) and breeds in summer after the rains, migrating upstream to suitable spawning sites over flooded grassy banks of rivers or within rocky stretches (Mulder 1973b; Tomasson *et al.* 1984; Skelton 2001). In years when floods are not high enough to inundate the surrounding grasslands, the species breed in fast-flowing water in the main river channel (Mitchell 1984, Mitchell and Jordaan 1985). Jubb (1972) also mentions the species to breed prolifically in large pools and dams, and that upstream spawning migrations are not essential for breeding. It, therefore, seems that *L. umbratus* depend on flood conditions at the right time of year for successful breeding, but that breeding takes place in different habitats (Tomasson *et al.* 1984). *Labeo umbratus* individuals in the Modder River were found breeding during successive floods indicating that not all fish in a population spawn at the same time (Mitchell 1984). The success of the species in highveld impoundments is ascribed to its high fecundity (large females producing up to 250 000 eggs), early maturity, and fast growth rate (Mulder 1973b; Skelton 2001).

2.5.3.6 Clarias gariepinus (Family: Clariidae)

General background and distribution

Clarias gariepinus is probably the most widely distributed fish in Africa, and is widespread in the Orange-Vaal River system (Jubb 1972; Skelton and Cambray 1981). It occurs in almost any habitat but favours floodplains, large slow flowing rivers, lakes and dams (Skelton 2001). Catfish is a pioneering fish species not only found in all permanent waters of its distribution range, but also inhabiting semi-permanent and seasonal water (Van der Waal 1998).

Clarias gariepinus can endure harsh conditions such as high turbidity, poorly oxygenated waters and desiccation (Skelton 2001; Frey and Van Aardt 1994; Van der Waal 1998). It has a branchial respiratory tree allowing the fish to obtain oxygen in stagnant and very poorly oxygenated waters (Frey and Van Aardt 1994). A normal physiological temperature range for *C. gariepinus* in tropical areas is 20-30°C, with an optimum of 27°C for juveniles and 28°C for adults (Viveen *et al.* 1985 cited in Hoffman *et al.* 1991). Catfish in drying pools are known to endure a daily temperature variation of 13.5-27.5° (Donelly 1973 cited in Van der Waal 1998). In temperate rivers like the Orange River, the species occur in waters where water temperatures could be as low as 5°C in winter. Hoffman *et al.* (1991) reported that juvenile catfish younger than 21 days are highly sensitive for sudden temperature drops.

Conservation status

Clarias gariepinus is widespread and common and is not Red Data listed.

Habitat preferences

Although they occasionally forage in rapids (Bell-Cross 1976 cited in Bruton 1978), the species prefer the placid part of their biotopes ranging from deep profundal habitats to shallow littoral areas (Bruton 1978). Their preference for shallow water habitats (adults included) are well documented (see Bruton 1978 for discussion), but Bruton's (1978) study found that *C. gariepinus* occupy definite zones in Lake Sibaya. Smaller individuals (<200 mm) inhabit well-vegetated inshore areas, whereas larger individuals inhabit more open and deeper habitats. Large adults (>600mm) were more often present in the deep profundal habitats (<40 m). Catfish in Lake Sibaya exhibit a diel feeding pattern, feeding in deeper areas during the day and migrating onshore to feed in shallow areas at night (Bruton 1978).

Flow related aspects of biology

Feeding

Clarias gariepinus is an opportunistic general carnivore (Bruton 1978) preying on virtually any available organic food including fish (the species is an important predator on *L. capensis*, especialliy during periods of low flow; Gaigher *et al.*1980), birds, small mammals, reptiles, snails, crabs, shrimps, insects, other invertebrates and plant matter such as seeds and fruit, and is even capable of straining fine plankton (Skelton 2001). They are, however, mainly piscivorous during the winter months (Mulder 1971; Gaigher 1973) and are able to hunt in packs, herding and trapping smaller fishes (Skelton 2001). Dörgeloh's (1994) study in the Sterkfontein Dam confirmed that the species takes a large variety of prey items during all seasons. Zooplankton (Cladocera and Copepoda) was consumed mainly in autumn and spring, while micronekton was preyed on to a large extent in autumn and summer. The growth rate of C. gariepinus appears to be affected by turbidity in the dam (Quick and Bruton 1983). According to Quick and Bruton (1983), conditions in the Vanderkloof Dam are unfavourable for smaller invertivorous fish (<500 mm) but favourable for larger piscivorous catfish (>500 mm).

Breeding

The species breed in summer after the rains, when large numbers of mature fish migrate to flooded shallow grassy verges of rivers and lakes (Skelton 2001). The species has a non-guarding open-substratum phytophillic spawning classification (Bruton and Merron 1990) and awaits suitable environmental conditions before spawning (Cambray 1985). The highly adhesive eggs, which remain in the spawning area, hatch within 25-40 hours (Cambray 1985; Skelton 2001). The larvae are free swimming and feed within two or three days, remaining inshore, adhering to vegetation (Skelton 2001). Individuals may reach maturity after four to six years at lengths of >740 mm (females) to 820-920 mm (males) in Vanderkloof Dam (Quick and Bruton 1983) and between >900 mm (females) and 800-850 mm (males) in Gariep Dam (Hamman 1981). The growth rate of *C. gariepinus* varies, however, markedly in different water bodies (Quick and Bruton 1983).

2.5.3.7 Austroglanis sclateri (Family: Austroglanididae)

General background and distribution

Although the small silurid was reported to be widely distributed in the Orange River system (Jubb 1967; Jubb 1972), it became technically extinct from the Gariep Dam (Gaigher *et al.* 1980b), the Orange River main channel between the South Africa/Lesotho border, and the lower Vaal River (Benade 1993b). Russell (1997) found *A. sclateri* to be abundant in the Vaalbos National Park, but the species is, however, not common, even in its preferred habitat (Skelton and Cambray 1981; Benade 1993a). The species have been sampled in the upper reaches of the Orange River both in Lesotho and South Africa (Niehaus *et al.* 1997; P. de Villiers pers. comm.).

Conservation status

This endemic species to the Orange-Vaal River system was previously listed in the South African Red Data Book (Skelton 2001) mainly as a result of a lack of knowledge concerning its general biology and ecology. The species is currently listed as “least concern” (Skelton 2001) as it is believed to be more abundant than previously thought. It has, however, become locally extinct in certain river stretches where they previously occurred, possibly as a result of flow regulation and siltation smothering substrates (Benade 1993a; Avenant 2001).

Habitat preferences

Austroglanis sclateri lives in rocky habitats, particularly rapids and flowing water (Jubb 1972; Skelton and Cambray 1981; Cambray 1984; Skelton 2001). Niehaus *et al.* (1997) sampled juveniles of this species (<45 mm) in backwater pools with a rubble substrate whereas adults (> 140 mm) were found in stickels to runs. Arthington *et al.* (1999) recorded the species to be abundant in wide, high gradient streams with large cobble or boulder substrates. The fish were collected in a wide range of water velocities but appeared to prefer mean velocities between 0.61-0.7 m/s and also velocities greater than 1 m/s. It preferred water depths between 11 and 30 cm but was also sampled at depths greater than 80 cm (Arthington *et al.* 1999).

Flow related aspects of biology

Feeding

Austroglanis sclateri is an omnivore, feeding primarily on invertebrates, especially aquatic insects, with large specimens taking small fish (Jubb 1967; Jubb 1972; Skelton 2001).

Breeding

Little is known about this species’ breeding habits (Jubb 1972; Benade 1993b).

Exotic species

2.5.3.8 Cyprinus carpio

Cyprinus carpio, a hardy tolerant species, has successfully invaded several species-poor, abiotically harsh environments in southern Africa (De Moor and Bruton 1996). It has been present in southern Africa for over 200 years (it was introduced to the Cape Province in 1896 from Asia and Eastern Europe) and has invaded most major catchments (Jubb 1967; De Moor and Bruton 1996). It has the widest distribution range of all exotic fish species in southern Africa, and is present in the Orange (Jubb 1967; Skelton and Cambray 1981; Benade 1993a) and the Vaal (Mulder 1971; De Moor and Bruton 1996) Rivers. The species generally prefers large water bodies with slow flowing or standing water with soft bottom sediments, and thrives in farm dams and turbid rivers (Skelton 2001).

This omnivorous species has a varied diet (Jubb 1967; Skelton 2001). Its habit of dredging its environment's bottom mud enables it to find food almost anywhere (Jubb 1967).

Cyprinus carpio breeds in spring and summer, laying sticky eggs in shallow vegetation (Skelton 2001). Larvae hatch after four to eight days, whereafter rapid growth occurs (Skelton 2001). In the upper Mississippi River 0+ carp are most abundant in shallow areas associated with flooded vegetation (Sheaffer and Nickum 1986 cited in Vilizzi and Walker 1999). The affinity of carp hatchlings and fingerlings for these shallow areas make them vulnerable to changes in water level; young fish abandon the nursery areas after attaining lengths of 75-100 mm (Vilizzi and Walker 1999).

According to Vilizzi and Walker (1999): 20-30 days after hatching: 20-25 mm SL – onset of juvenile period. After the onset of the juvenile phase the carp resemble adults in morphology, feeding habits, locomotion.

3. Study area

3.1 Introduction

The Seekoei River, an ephemeral southern tributary of the upper Orange River, was selected for study mainly due to its proximity to Bloemfontein and its reliable flow and stage record of more than 25 years.

The following section will only present a concise overview of the catchment and the selected study sites where fish sampling was conducted. A more detailed description is found in Chapter 2 of the Main report.

3.2 The Seekoei River catchment

The Seekoei River catchment, which falls in the Upper Orange Water Management Area (WMA), lies between 31.473 S and 24.1203 E (source) and 30.2895 S and 25.0187 E (junction with Orange River) in the D3 sub-drainage region and comprises quaternary catchments D32A to H and D32J to K (Figure 3.1). The main tributary is the Klein Seekoei River, which rises in the Sneeuberge in the Eastern Cape and joins the Seekoei main just upstream of gauging weir D3H001 (not operational) at the border of quarternary catchments D32C, D32E and D32F. Other tributaries that enter the Seekoei River are the Elandskloof River (D32A), Noupoortspruit (D32G), Elandsfonteinspruit (D32H), Elands River (D32J) and Gansgatspruit (D32K).

General climate

The catchment is situated in the dry central parts of South Africa and experiences large fluctuations in both diurnal and seasonal temperatures, with mean maximum summer temperatures in January above 30°C and mean minimum winter temperatures below 1°C (Schultz, 1980). Frost occurs frequently between May and October (average 158 d/yr; Venter *et al.*, 1986). The catchment receives mostly summer rainfall (October to March) with the mean annual rainfall ranging between 250 and 400 mm (Schulze, 1997). Rainfall could, however, be highly variable - not only between years, but also between months (Hughes, 2008a). Evaporation varies between 1900 mm in the high-lying areas to 2500 mm in the north-western parts of the catchment (Schulze, 1997). The potential mean annual evaporation (average of 1 911 mm/a) within the catchment exceeds the potential mean annual precipitation (average of 313 mm/a) by 6 times, resulting in a low gross mean annual runoff (MAR) and a high coefficient of variation in MAR (Dollar, 2005).

Gauge records from flow-measurement weir D3H015 (located at the outlet of quaternary catchment D32J) indicate that the Seekoei River experiences surface flow for approximately 45% of the time (Steÿn, 2005). Mean monthly stream discharge is highest in late summer (February-March) and lowest in winter (May-July; see Figure 3.1). During the study, however, it became evident that these flow characteristics were only relevant to the 8 km immediately upstream of the flow-measurement weir; the upstream channels experience flow less than 10% of the time. Most of the flow recorded at the measuring-weir was therefore generated in the high topography gorge area in the lower part of the catchment (Hughes, 2008b). This area covers only a small area of the total catchment, but has a major influence on the flow regime (Hughes, 2008a). Due to concentrated outflow at the base of a perched aquifer and/or distributed lateral flow, the lower Seekoei River experiences prolonged flow after rainfall events (Hughes, 2008a). In the drier upper and middle parts of the catchment, persisting pools are sustained by contributions through connections with groundwater (Van Tonder *et al.*, 2007).

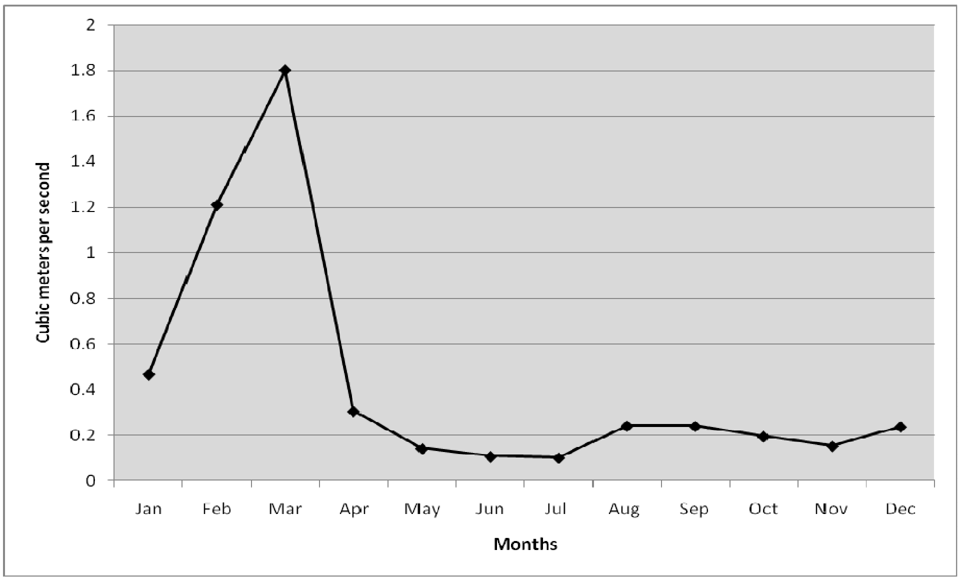

Figure 3.1: Mean monthly stream discharge (in m^3/s) at the D3H015 gauging station for the period October 1980 to June 2008 (adapted from Steÿn 2005).

Geology and topography

The catchment landscape is dominated by flat-lying Karoo Supergroup sediments that have been intruded by innumerable sills and dykes of dolerite (Dollar 2005). The upper and middle sections of the catchment are dominated by Adelaide Subgroup mudrocks and subordinate sandstones, with intrusions of dolerite (Cole *et al.* 2004), while the lower catchment comprise of Tierberg Formation shales, siltstones and sandstones and dolerite-capped koppies (Le Roux 1993). Dolerite sills and rings control the geomorphology and landscape of much of the Karoo basin (cf. Du Toit 1905; Cole *et al.* 2004). The bed of the Seekoei River is often just above the bedrock (and indeed, is often incised into/contacts bedrock) and is therefore strongly influenced by the relationship between the softer Karoo sediments and the position and breaching of dolerite sills and dykes. Valley form tends to be broad in the Karoo sediments and alluvium but confined where the river passes through dolerite and/or dolerite-capped Karoo sediments.

According to Dollar (2005), the river channel flows in alluvium for approximately 80% of its length. The alluvium consists mainly of medium-to fine-grained sand, together with pebbles and coarser-grained sand deposits (Cole *et al.* 2004). These alluvial deposits may date back as far as early Pleistocene or even Pliocene (De Wit 1993).

The catchment is situated between 1200 m to 1700 m above sea level. Its topography is mostly flat and has a mean catchment slope of 1 to 4% (Hughes 2008). Steeper slopes do however occur closer to the catchment boundaries, as well as in an isolated area in the lower part of the catchment, where the Seekoei River passes through a gorge (quaternary catchment D32J; see Figure 2.3). Here, the river channel is flanked by dolerite ridges, rising to a height of about 200 m close to the river, compared to less than 20 m for the rest of the catchment (Hughes 2008).

Ecoregions and the geomorphological regions of the Seekoei River
The Seekoei catchment is predominantly situated in the Nama Karoo Level I ecoregion (26) with only small patches in the south and south eastern part of the catchment falling in the Drought Corridor (18; Kleynhans *et al.*, 2004). Three Level II ecoregions are recognised: 26.03; 18.01 and 18.06 (see Figure 3.3). Level II ecoregions are based on a combination of altitude, rainfall, runoff variability, air temperature, geology and soil (Kleynhans *et al.* 2004).

The main stem of the Seekoei falls mainly in the Lower foothill longitudinal zone with only three stretches in the middle section being classified as Lowland river (see Figure 3.3). This classification, which is based on Rowntree and Wadeson's (2000) geomorphological zonation of river channels, implies that the Seekoei's main stem is a low-gradient alluvium channel with sand and gravel dominating the bed. The upper reaches of the Seekoei and the various small tributaries are classified as Upper foothills indicating steeper slopes (gradient of 0.005 – 0.019; Table 3.1).

Table 3.1: Geomorphological classification for the Seekoei River and its tributaries (based on Rowntree and Wadeson 2000).

River/tributary	***Quaternary catchment***	***Geomorphological zone/s***
Seekoei River mainstem	D32D	Upper foothills, lower foothills
	D32E	Lower foothills;
	D32F	Lowland river; lower foothills
	D32G	Lowland river
	D32J	Lower foothills
	D32K	Lower foothills; lowland river
Elandskloof River	D32A	Upper foothills, lower foothills
Klein-Seekoei River	D32B	Upper foothills, lower foothills
	D32C	Lower foothills
Noupoortspruit	D32G	Transitional; upper foothills, lower foothills
Elandsfonteinspruit	D32H	Transitional; upper foothills, lower foothills
Elands River	D32J	Transitional; upper foothills, lower foothills

Catchment condition

The Seekoei River is situated in a rural area. A large number of dams and weirs have been erected in the river course for irrigation abstraction, stock watering and for recreation, and its in-stream and riparian habitats are considered moderately modified mainly due to flow regulation and modification (Watson and Barker, 2006). No major towns draw water from, or discharge water into, the river. The socio-economic profile of the population utilizing the Seekoei River is made up of established commercial farmers and their staff. General farming activities are game and stock farming, or a combination of livestock, game and limited opportunistic irrigation agriculture.

Agriculture in the Seekoei catchment was established in the late eighteenth century and is reported to since have had severe ecological implications, such as the introduction of domestic mammal species, the deforestation of natural vegetation in order to plant crops like wheat, the degradation of Karoo veld as a result of the extensive wagon trail network (Neville and Sampson 1994), extensive rill, sheet and gully erosion in the upper catchment (Holmes 2001) and the erection of weirs and dams in the river channel. In early historical times the Seekoei River valley supported very large herds of game dominated by springbok, quagga and wildebeest, which congregated about the abundant natural springs (Bollong and Sampson 1999). Game and other food sources, such as birds, fish and crabs, were sufficient to support Bushmen communities in the headwaters and valley at least since the late Holocene (Plug and Sampson 1996). However, by the late 1870's the valley was entirely taken up by farms (Plug and Sampson 1996). Some of the early travelers described the Seekoei River and its tributaries as a seasonal river, consisting of a long chain of pools (zeekoegaten) during dry periods (Holmes 2001). These early accounts also frequently make mention of droughts or floods, giving testimony to the river's natural event driven flow regime.

3.3 Study sites

Four sampling sites were selected for study on the Seekoei River: EWR1 in the upper part of the catchment, EWR2 in the middle part and EWR 3 and 4 in the lower catchment (see Figure 3.2). Site-selection was primarily based on the information obtained from a macro-reach analysis which divided the river into distinct geomorphologic reaches based on the river's longitudinal profile, a habitat integrity assessment which evaluated the physical condition of the in stream channel and riparian zones of the river, and a recognizance visit to the river[2].

The location and physical characteristics of the four sampling sites are described below.

EWR1

EWR1 is situated southeast of Hanover on the main stem of the Seekoei River (quaternary catchment D32E) about 20 km upstream of the confluence of the Seekoei and the Klein Seekoei Rivers (see Figure 3.2). In this reach (macro-reach 3) the river meanders over alluvium which is underlain by mudstone and sandstone. It falls in the lower foothills longitudinal geomorphic zone

[2] The site-selection process is outlined and discussed in Chapter 5 of the Main report. Reports outlining the macro-reach analysis by Dollar (2005), habitat integrity assessment by Watson and Barker (2006) and recognizance visit by Avenant (2006) are also included on the CD and will provide further details on the methods followed and the results obtained.

with a gradient of between 0.001 and 0.005 (Rowntree and Wadeson 2000; see Figure 3.3). The dominant channel type comprises isolated pools and dry linear distributary channels. Both the in-stream and riparian zones are largely natural (Instream Habitat Integrity, IHI, Class B; Riparian Habitat Integrity, RHI, Class B) with flow regulation being the major impact in the reach.

The site is dominated by a persistent, but isolated, pool of approximately 90 m long, 7.4 m wide and approximately 70 cm deep (at the deepest point; see Plate 1, Photos 3-6). The pool's substrate consists mostly of sand to very fine sediment covered by extensive organic matter deposits and is fringed by sedges. The active channel is overgrown with sedges (Plate 1, Photos 1-2).

EWR2

EWR2 is located about 2 km downstream of the confluence of the Seekoei and the Klein Seekoei Rivers in macro-reach 4 (D32F), east of Hanover (Figure 3.2). The river channel, which corresponds a "lowland river" at this point (Rowntree and Wadeson 2000; Figure 3.3), consists mainly of a single thread channel flanked by reeds, and broken occasionally by pools and distributary channels (Dollar 2005). The in-stream and riparian habitats of the river is moderately modified in this reach (IHI Class C), mainly due to flow regulation (24 weirs and 1 dam wall) and reed encroachment in and along the riverbed.

The sampling site comprises a large pool (approximate pool length: 75 m; width: 12.92 m at the widest point) surrounded by reeds (*Phragmites australis*; see Plate 2, Photo 3-6). The pool has a shallower section of about 30 m long, which dried up during the study period. The pool has a sandy bottom with decomposing organic (mostly reeds) material. The channel at the site is very uniform with extensive reed growth on the terraces, benches and in the channel (Petersen and Dollar 2008).

The site is situated about 2 km downstream of a large weir (D3H001 - once used for measuring flow) which is not ideal due to the impact the weir might have on the natural flow patterns. The pool is, however, fairly natural. Although a number of large pools occur downstream of EWR2, the water levels of these pools are artificially managed for agricultural purposes, making them unsuitable for EWR assessments.

EWR3 and 4

Sampling sites EWR3 and 4 are both situated in macro-reach 5 in the lower Seekoei River (D32J). This lower section of the catchment is characterised by a much steeper topography, where the river flows over dolerite and shale, siltstone and sandstone. The river channel comprises mainly of alternating pools and rapids with riffles occurring only towards the upper end of the reach (Dollar 2005). The channel form (and hydraulics) is strongly controlled by local bedrock intrusions. Flow regulation as a result of the Vanderkloof Dam and several other impoundments, has a major impact in this reach of the Seekoei e.g. decreasing the variety of geomorphic features. The instream habitat is, therefore, considered to be largely modified (IHI Class D; Watson and Barker 2006). The riparian zone was rated as moderately modified (RHI Class C). Approximately 39% of the reach has reeds along the river, which could have a large impact on the flow, bed and channel of the river in this reach (Watson and Barker 2006).

Available habitats at EWR3 comprise a large pool (1 173 m long, 100-180 m wide, and 2.36 m deep at the deepest point when full) with a capacity of 32 517.46 m^3 when full[3] (see Plate 3a, Photos 1, 5 and 6) and when the river is flowing, a glide of 30 m and a riffle/rapid of about 70 m length (Plate 3a, Photo 4). The bottom of the pool consists mostly of coarse to fine sand, while the bed material of the run and riffle/rapid is typically coarser, consisting of cobbles and boulders (Petersen and Dollar 2008).

The channel-form at EWR4, situated approximately 2 km downstream of EWR3, is dominated by bedrock. Aquatic habitat consists mainly of a large shallow pool with a sandy, gravel bottom (Plate 4a, Photos 1 and 5). Several bedrock pools, rapids and a few riffle areas are present when the river is flowing (Plate 4a, Photos 2, 4 and 6).

The pool at EWR4 initially appeared to be fed by groundwater, in contrast to the pool at EWR3 which appeared to be fed by surface runoff water. EWR4 was therefore added as an extra site in order to investigate possible differences between pools fed by surface water and those maintained by sub-surface water.

[3] Volume surveys of the pools were done by Mr. J. Le Grange of DWAF, Free State region.

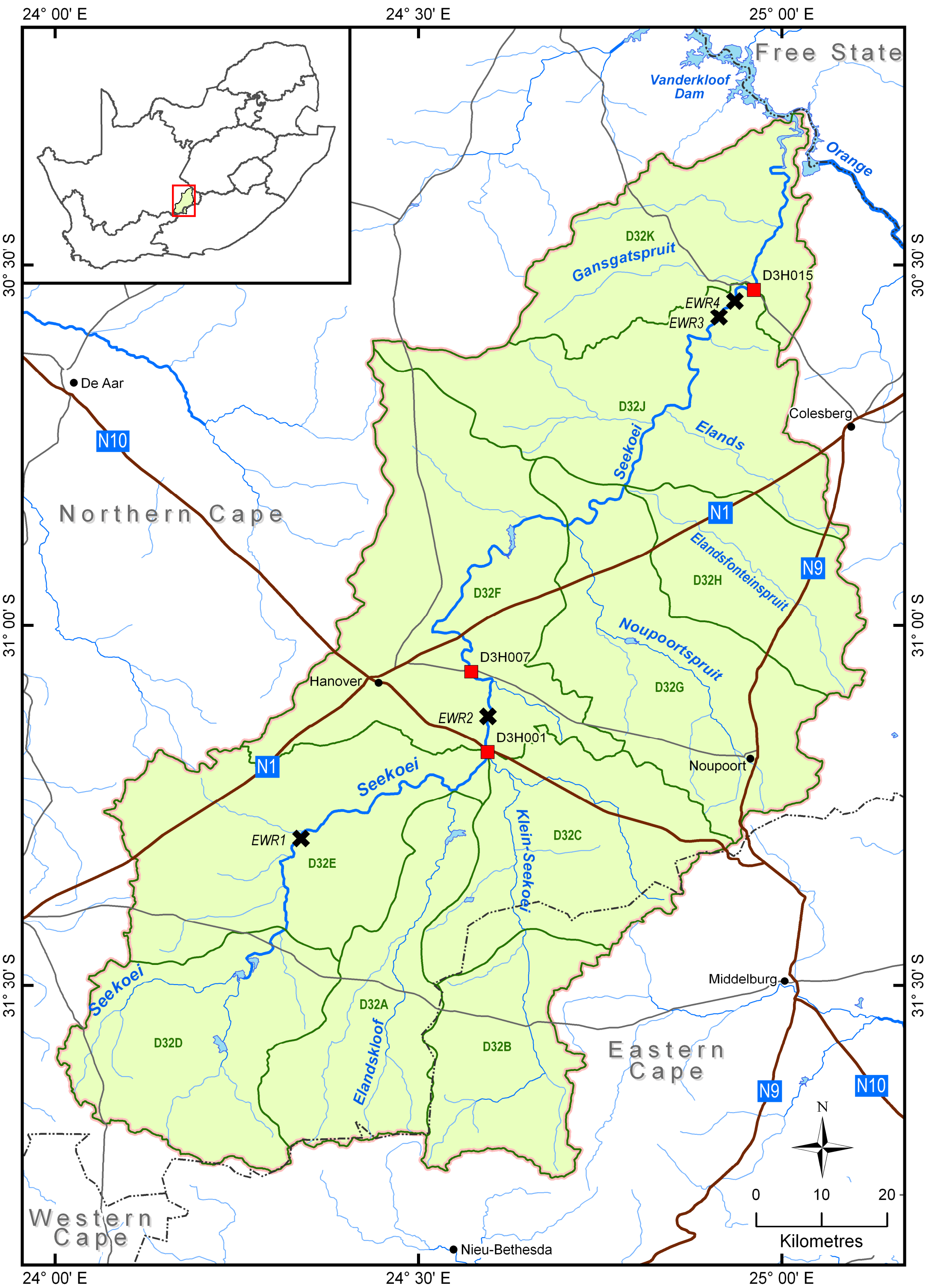

Figure 3.2: The Seekoei River catchment (sub-drainage D3). Main tributaries, quaternary catchments and gauging weirs are indicated. Sampling sites EWR1 to EWR4 are indicated by black crosses. (Data sources: Institute for Water Quality Studies (IWQS), DWAF and Chief Directorate of Surveys and Mapping).

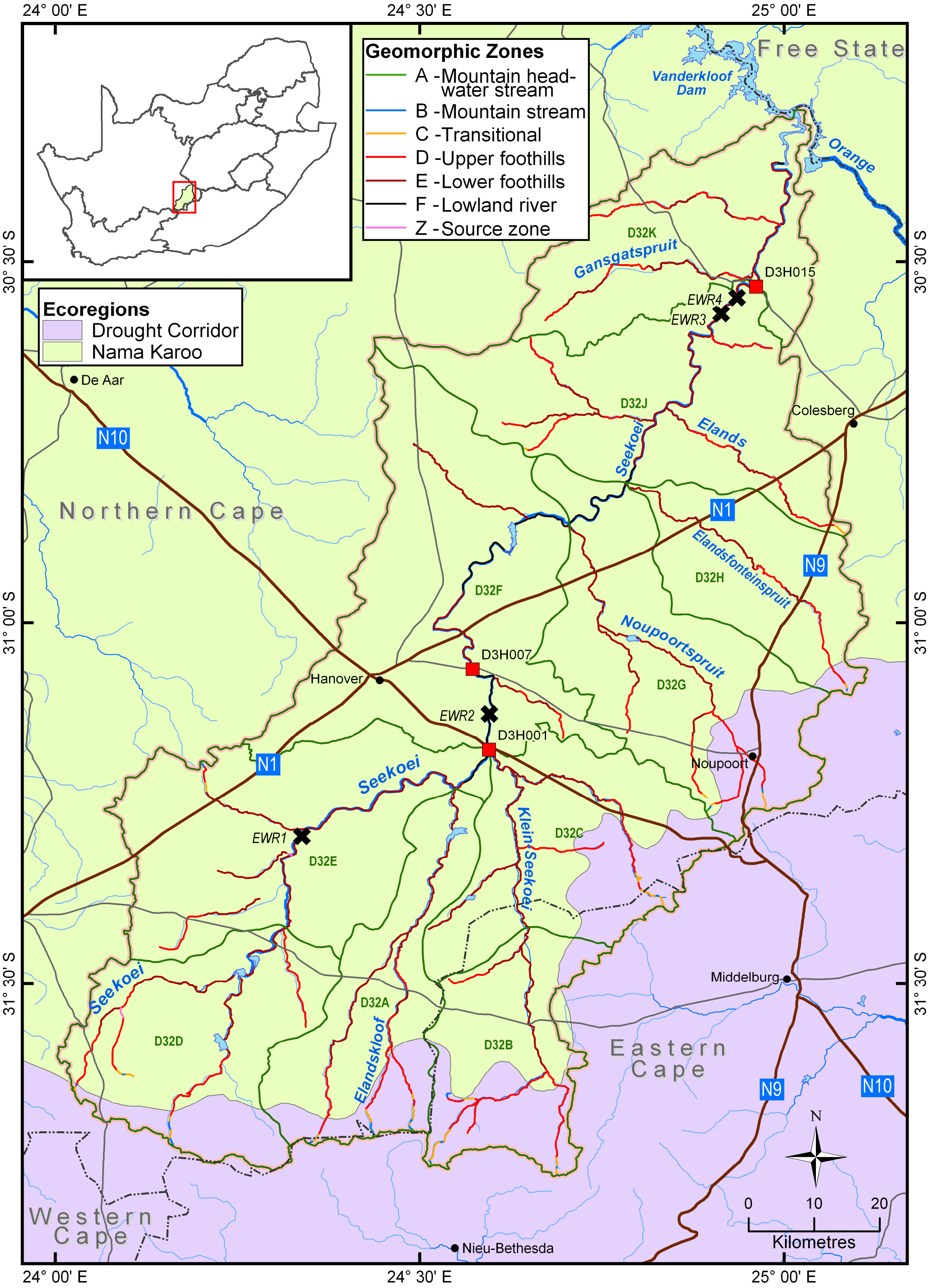

Figure 3.3: Ecoregions and geomorphological classification for the Seekoei River and tributaries. (Data sources: IWQS, DWAF and Chief Directorate of Surveys and Mapping).

4. Study methods

4.1 Introduction

The main aim of the fish study was to determine species richness, - composition, - distribution and fish abundance for a range of habitat types available at the sampling sites (representing the river reaches) over the course of the study. It also tried to provide quantitative data on the range of habitat types available to fish during periods of flow and intermittence in an attempt to develop relationships between habitat availability, water level and fish assemblage structure.

4.2 Sampling protocol and frequency

Twelve field visits were made to the river by the fish team between March 2006 and March 2008 (see Table 4.1). During most of these visits, the following actions were completed, following the sequence indicated below:

a) Recording gauge plate readings;
b) Taking photos from a set point;
c) Conducting in situ water quality measurements of the following variables: water temperature, pH, conductivity, secchi depth and percentage oxygen saturation;
d) Fish sampling;
e) Collecting data on fish microhabitat; and doing
f) Habitat surveys by means of transects.

Habitat surveys were not conducted during every field visit (Table 4.1) due to time and manpower limitations. Also, no habitat surveys were possible when the river bed was dry. The methods used for actions a, b, c, e and f will be discussed under section 4.2 “instream habitat assessments”, and those used for actions c and e in section 4.3 “fish sampling”.

4.3 Instream habitat assessment

An understanding of how the interaction between river flow and instream habitat may potentially influence the distribution and community structure of fish fauna is crucial for defining environmental water requirements (Arthington *et al.* 1999). An analysis of the relationships between fish assemblages and habitat structure, therefore, facilitates the identification of habitat variables that may be important determinants of the spatial and temporal variation in fish community structure. According to Arthington *et al.* (1999) habitat variables such as depth, velocity, substrate and fish cover, which are important determinants of fish assemblage structure, are often related to stream flow. Habitat availability is, therefore, often defined in terms of flow. In the Seekoei River where surface flow was absent for varying periods of time, habitat availability was defined in terms of water level or pool depth.

Table 4.1: Dates on which fish surveys and habitats assessments were conducted at EWR sites 1 to 4. (Gauge Plate readings, photos and water quality measurements were taken during every field visit and are not indicated here).

Date of sampling	EWR1				EWR2				EWR3				EWR4			
	Habitat assessment	Fish survey	Microhabitat	Habitat survey	Habitat assessment	Fish survey	Microhabitat	Habitat survey	Habitat assessment	Fish survey	Microhabitat	Habitat survey	Habitat assessment	Fish survey	Microhabitat	Habitat survey
28 Mar-1 Apr 06	X	X			X	X	X		X	X	X		X	X	X	
22-24 May 06	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
27-29 Jun 06	X	X*		X	X	X		X	X	X		X	X	X		X
15-17 Aug 06	X	X		X		X		X	X	X	X	X	X	X	X	X
26-29 Sep 06	X	X		X	X	X		X	X	X	X	X	X	X	X	X
13-15 Nov 06	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
11-12 Dec 06					X	X	X		X	X	X					
30 Jan – 1 Feb 07	X	X		X	X			X	X	X	X	Dry	X	X	X	Dry
20-22 Mar 07	X	X	X		X	X	X	X	X	X	X	Dry	X	X	X	Dry
12-14 Jun 07	X	X	X		X	X		X	X	X	X	X	X	X	X	Dry
9-11 Oct 07	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
31 Mar – 2 08	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X

* No data collected due to problems with sampling gear.

4.3.1 Gauge plate readings

Gauge plates were erected by the DWAF (Free State region) at each of the sampling sites (see Plates 1 to 4b). The gauge plates were placed in the sampling pools after the sites were surveyed. Gauge plate readings were recorded during each site visit and provided a set point against which changes in habitat availability could be measured.

4.3.2 Photographic record

Photos were taken of each sampling site from set positions during each field visit in order to record changes in habitat condition visually.

4.3.3 Fish habitat assessment

Introduction

The habitat potentially available to fish at each sampling site was assessed and described in terms of habitat diversity, diversity of fish cover, and habitat condition. An assessment of the habitats available to fish fauna at a specific site provides a framework against which the presence and absence of species can be interpreted.

A data sheet, based on Kleynhans (2005) and Dallas (2005), was prepared. This sheet was completed during field visits and required information under the following headings (see Appendix A):

- Site information;
- In stream use and surrounding land use;
- Flow conditions and water quality at the site;
- Gauge plate reading;
- Physical habitat description;
- Habitat-type/ percentage biotope composition;
- Substrate components;
- Fish velocity depth classes and fish cover; and
- Fish habitats sampled and sampling effort.

These forms (that were prepared at the start of the study) were not found to be that useful for the conditions encountered during the Seekoei River study and would be modified for the next phase of the study. Fish sampling was also not conducted in the four velocity-depth classes identified by Kleynhans (1999), but rather at a number of sampling points identified at each sites (see section 4.3.2).

The following definitions of Kleynhans (1999; 2008) were used to define depth and velocity:

In non-flowing or slow-flowing habitats:
Deep habitat >50 cm; shallow habitat < 50 cm;
Fast flow >0.3 m/s; slow flow < 0.3 m/s.

In flowing habitats (e.g. riffles, runs and rapids):
Deep habitat >30 cm; shallow habitat < 30 cm;
Fast flow >0.3 m/s; slow flow < 0.3 m/s.

4.3.3.1 Fish habitat surveys

The available habitat at each site was surveyed by means of transects, recording water depth, surface flow and substrate at each point along every transect. This allowed us to describe and to quantify the physical characteristics of the different habitat types available to fish at each site. The length of the river sections surveyed at the respective sites varied between 30 m (EWR2) and 96 m (EWR1), depending on the characteristics of each site.

Depth profiles were determined for each sampling site by measuring depth across predetermined transects perpendicular to the riverbank. At sites EWR 1 and EWR 2 transects were spaced evenly, while transects at site EWR 3 and EWR 4 were chosen to dissect prominent habitat features (such as rapid, riffle, run, pool etc.; see Table 4.2).

At sites EWR 1 and EWR 2, which both comprise isolated pools, the downstream ends of the pools were marked during the first survey to serve as a fixed point in subsequent surveys. In cases where the surface area increased due to higher water levels, the distance between the fixed point and the new edge of the water was noted as a negative distance. Transects at EWR 1 were 10 m apart and at EWR 2, 5 m. At sites EWR 3 and EWR 4, which were usually not isolated, fixed transects were identified, marked and used during subsequent surveys.

Table 4.2: Distances from the marked point at the downstream end of the site where transects were situated.

EWR 1	*EWR 2*	*EWR 3*	*EWR 4*
- 13.2 m*	- 25 m*	0 m	0 m
0 m	0 m	11.5 m	11.1 m
10 m	5 m	15.2 m	20.6 m
20 m	10 m	19.3 m	27 m
30 m	15 m	40 m	36.4 m
40 m	20 m	58.5 m	48.4 m
50 m	25 m	73.9 m	
60 m	30 m	88 m	
70 m		107.5 m	
80 m		117.2 m	
90 m			
96 m			

* Indicate the maximum distance downstream from the fixed (0 m) point; the distance was not fixed and changed according to the water levels.

The length of each site was determined by measuring the length between the first and last transect. The width of each transect was determined by measuring the distance from where moist on the right bank was evident to where it stopped on the left bank. A depth reading (cm) was taken every 1 m starting on the right bank.

Grid files of sites EWR1 to 3 were created for every survey based on the length, width and depth measurements, using surface mapping software (Surfer, 2004). The initial grids were too coarse, resulting in depth profiles being not representative of the sites. A finer grid was then generated manually by extrapolating extra data points from the available width and depth measurements. The extrapolations were based on the assumption that the differences in width and depth between concurrent transects increased, or decreased, progressively with a constant number. For example, if the measured width was 8 m at transect x and 6 m at transect y located 10 m further, the width inbetween was expected to decrease progressively every 1 m with 0.2 m (see Figure 4.2). Also, if the depth at the midpoint of transect x was 60 cm and 50 cm at the midpoint of transect y located 10 m further, the depth inbetween was expected to decrease by approximately 1 cm every 1 m. Additional transects, 1 m apart, were therefore created based on these extrapolations, with a width value and a depth value at the midpoints. New grid files, based on the extrapolated data, were therefore generated and used to create contour maps of the sites and to calculate their volumes.

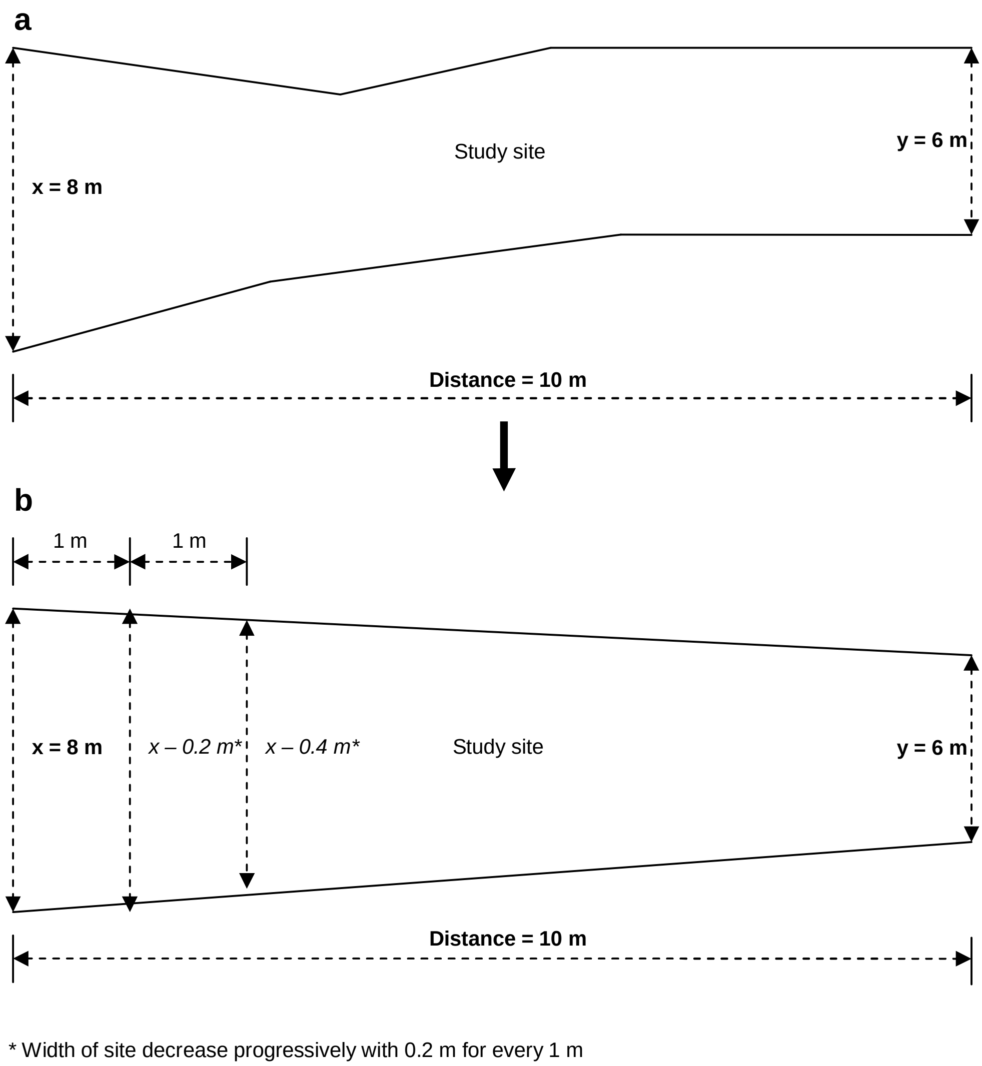

Figure 4.1: A schematic representation of how measured width data (a) were extrapolated (b) to generate a finer grid scale of the study site. Values in bold were measured during surveys, while values in italics were extrapolated

4.3.3.2 Fish microhabitat assessment

Measurements to describe the fish microhabitat were taken at each sampling point at the various sites at the exact spot where the fish specimens were collected (or where we sampled in the cases where no fish was found). Measurements were recorded at between 10 and 20 random points and included water depth, substrate and fish cover (available at that point).

Water depth was measured with a graduated stick. Six substrate classes were used: Mud (<0.063 mm), sand (0.063 – 2 mm), gravel (2 – 64 mm), cobbles (64 – 128 mm), boulders (>128 mm). The microhabitat categories were: Aquatic macrophytes, filamentous algae, organic debris, undercut banks, root masses, bedrock overhang, submerged vegetation, overhanging vegetation and substrate (see Appendix B).

Routine collection of data on microhabitat structure at different water depths allowed us to assess temporal variation in habitat characteristics and availability.

4.4 Fish surveys

Twelve fish sampling surveys were conducted between 27 March 2006 and 31 March 2008 (see Table 4.1). Most of the surveys coincided with the routine sampling visits to the river and comprised of electrofishing only. Gill and seine-netting were used additionally on two occasions at two sites (Table 4.3).

Table 4.3 Dates on which EWR1 to 4 sites were sampled between March 2006 and 2008. (E/S, Electro-narcosis; S/N, seine netting; G/N, gill netting). *Asterisks indicate the use of the new electroshocker.

Date of sampling	***Sampling sites***							
	EWR1	**EWR2**	**EWR3**			**EWR4**		
	E/S (min)	E/S (min)	E/S (min)	S/N (hauls)	G/N (hours)	E/S (min)	S/N (hauls)	G/N (hours)
Mar 06	65	35	70	2	-	78	2	12
May 06	30	25	88			76		
Jun 06	9	17	80			57		
Aug 06*	20	25	106			83		
Sept 06	20	45	96		12	62		12
Nov 06*	10	29	85			56		
Dec 06*		15	19			Not sampled		
Jan 07	13	12	28			27		
Mar 07*	7	12	27			14		
Jun 07*	10	13	84			25		
Oct 07*	10	14	43			32		
Mar 08*	12	19	75			47		

* New electrofishing gear used.

4.4.1 Field equipment and methods

A variety of fish collecting methods were applied depending on the habitat type to be sampled (see Table 4.3):

4.4.1.1 Seine and gill netting

The deep slow-flowing pools at EWR3 and 4 were sampled by means of seine and gill netting. A seine net 2 m deep, 1.5 m high and 30 m long with mesh sizes of 16 mm for the wings and 5 mm for the sac was used with one seine sample consisting of three consecutive hauls. Seven gill nets comprising mesh sizes of 45 mm, 57 mm, 68 mm, 73 mm, 93 mm, 118 mm, and 150 mm were lowered at 18:00 in the evening and cleaned at 06:00 the following morning.

For seine netting, the CPUE values are based upon the average number of fish captured per seine net haul and for gill netting CPUE was expressed as the average number of fish captured per hour.

4.4.1.2 Electro-narcosis

Electro-narcosis, conducting an electric current into the water, which immobilises the fish momentarily, was applied at all the available habitats at each site. Due to the non-perennial nature of the river, habitat availability varied markedly over the course of the study. The stretch of river sampled also varied between the sites, being longer for the two downstream sites that had higher habitat diversity.

The initial electroshocker, consisting of a wooden handle 100 cm long, parallel fork 100 cm long and 25 cm between parallel forks, with copper-cladtips and powered by a 220 V AC, 2 kva portable Yamaha generator, was replaced with a SAMUS 725G backpack-electroshocker from August 2006 onwards (see Figure 4.2). Two samplers with dipnets were used to collected fish stunned by the electrical current. The original electroshocker was not very effective at EWR1 due to the high electrical conductivity at the site which caused the power output to exceed the capacity of the generator. The duration of sampling was recorded at each sampling site in order to calculate the catch per unit effort (CPUE) and to ensure consistency during repetitive sampling. Sampling time depended on the number of habitats present at each site. These habitats included overhanging vegetation, spaces under rocks, pools and riffles. Electrofishing was chosen to maximise the number of microhabitats sampled within each site, especially shallower habitats.

Figure 4.2: The "old" parallel fork electroshocker powered by a 220 V AC, 2 kva Yamaha generator (left) and the "new" Samus 725G backpack-electroshocker used from August 2006 onwards (right).

4.4.1.3 Fish measurements

Each fish specimen sampled was identified to species level with the aid of Skelton's (2001) keys, weighed and the fork length noted. Fish were returned to the river after notes were taken on their general health, as well as, the presence of anomalies and external parasites. When there was any doubt of identification the specimens were preserved in a 10% formalin solution and later identified in the laboratory. Samples were also sent to the Albany Museum (Grahamstown) for verification.

Sampling data for each sampling point were kept separate in plastic buckets until identification and measurements were done.

Figure 4.3: Measuring body length (left) and weight (right).

4.3.2 Number of sampling points surveyed at study sites

The Seekoei River in the upper and middle reaches, where sites EWR1 and 2 are located, comprises a series of isolated pools. These pools are infrequently connected, even under natural conditions. The hydrological model prepared for the Seekoei River indicated that the frequency of surface water connection varied between 10% and 12% of the time under natural conditions (see Activity 16, Chapter 5 of the main report). The natural frequency of connectivity was, however, reduced by up to 50% due to increased water storage behind in-channel dams and weirs, resulting in pools being connected only 5% of the time at present. Only one sampling point per river section was sampled in these reaches.

In contrast with the upper and middle reaches, the lower Seekoei River is dominated by a pool/riffle/rapid channel type and has a frequency of channel flow connectivity of approximately 50% (see Activity 16, Chapter 5, main report). A higher diversity of biotopes was accordingly available for sampling and six and seven sampling points were surveyed at EWR3 and 4, respectively. This was, however, only when the river was flowing. When surface flow stopped, the available sampling points were reduced to two at each site.

EWR1
Fish sampling at EWR1 was done in the isolated pool (Plate 1, Photos 1-6), starting at the upstream end of the pool (Photo 4) and working systematically towards the downstream end (Photo 6).

Suitable sampling points were scarce in this section of the river due to the low level of hydrological connectivity (the river consists of a series of isolated pools for most of the time and surface flow was never witnessed by the team during the period of study), limited access to the river (farm gates are locked for security reasons as farmers often do not reside on the farm, blocking access to the river) and time limitations during routine sampling trips.

EWR2
Two sampling points were initially decided upon, a deeper trench where the gauge plate is situated (Plate 2, Photo 3) and the shallower pool at the downstream end of the site (Plate 2 Photos 4 and 6; also see the diagrammatic representation of the site in Figure 4.4). The fish team unsuccessfully tried several sampling methods on the deep pool: electro-narcosis (pool too deep and steep), seine-netting (no beach from where to launch the net, pool surrounded by thick reed patches) and gill-netting (the pool is very narrow, deep and surrounded by dense reed patches making it difficult to maneuver a boat). Sampling was therefore mainly done in the shallow pool. When pools were available upstream of the actual sampling site, they were also sampled.

Although a number of large pools occur approximately 6 km downstream of EWR2, the water levels of these pools are artificially managed for agricultural purposes, making them unsuitable for EWR assessments. One of these pools was sampled in September 2006.

EWR3
The number of points available for sampling at EWR3 was influenced by surface flow in the channel. When flow was present, the following six sampling points were sampled:

- Main pool (Plate 3b, Photo 1);
- Pool A (Plate 3b, Photo 2);
- Pool B (Plate 3b, Photo 3);
- Outflow (Plate 3b, Photo 4);
- Pool C (Plate 3b, Photo 5); and
- Rapid (Plate 3b, Photo 6).

The first three sampling points are situated in a large pool that dominates the site. Pool A and B were sampled during every visit, but the deep habitat in the Main pool were only sampled in March and September 2006 when the full team was present. The Outflow, Pool C and the riffle area could only be sampled when surface flow was present in the channel.

Unfortunately the names of the sampling points do not differentiate between flowing and non-flowing habitats (as flow was not always present in the flowing habitats) but were kept unchanged throughout the study. The location of the sampling points at the site is indicated in Figure 4.5, and a description of the sampling points is given in Table 4.4.

EWR4

Seven sampling points were surveyed at EWR4, depending on whether surface flow was present or not:

- Main pool (Plate 4b, Photo 1)
- Pool A (Plate 4b, Photo 2)
- Pool B (Plate 4b, Photo 3)
- Pool C (Plate 4b, Photo 4)
- Pool D (Plate 4b, Photo 5)
- Rapids/riffles A and B (Plate 4b, Photos 6 and 7)
- Pool E (Plate 4b, Photo 8)

Surface flow was recorded in Pool B (glide), the rapids and Pool D (glide). The main pool was only sampled in March 2006 and September 2006 when the full team was present.

Unfortunately the names of the sampling points do not differentiate between flowing and non-flowing habitats (as flow was not always present in the flowing habitats) but were kept unchanged throughout the study. The location of the sampling points at the site is indicated in Figure 4.6, and a description of the sampling points is given in Table 4.4.

4.5 Data analyses

Statistical analyses were conducted using the computer program STATISTICA for Windows (Statsoft Inc., Tulsa, OK, USA). The Shapiro-Wilk’s W-test was used to test for normality and parametric or non-parametric tests were used to compare groups and/or correlate variables. The 95% level ($p<0.05$) was regarded as statistically significant for all tests.

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Table 4.4: A physical description of the sampling points surveyed at sites EWR1 to EWR4.

Sampling sites	*Sampling points*	*Habitat description*	*Habitat type*	*Flow description**	*Dried up during the study?*	*Substrate*	*Dominant fish cover type*	*Sampling method*
EWR1	Pool	Predominantly deep isolated pool fringed by sedges	Pool	No flow	No	Sand to very fine sediment	Aquatic vegetation (shallow areas)	Electro-narcosis
EWR2	Pool	Predominantly shallow isolated pool feinged by reeds	Pool	No flow	Yes	Sand, silt	Emergent and submerged aquatic vegetation	Electro-narcosis
EWR3	Main pool	Large, deep pool	Pool	No flow	No*	Coarse to fine sand	Water column	Gill and seine netting
	Pool A	Littoral area, right bank of the main pool	Shallow pool habitat	No flow	No*	Coarse to fine sand	Aquatic vegetation	Electro-narcosis
	Pool B	Predominantly deep pool at the down-stream end of the Main pool in the left channel	Pool	No flow	Yes	Boulders, cobbles and gravel	Substrate cover	Electro-narcosis
	Outflow	Glide situated at the point of outflow in the right channel from the Main pool	Glide	Fast to slow/no flow	Yes	Boulders, cobbles and gravel	Substrate and overhanging riparian vegetation	Electro-narcosis
	Pool C	Predominantly shallow glide/riffle situated in the right channel between the outflow and the rapid	Glide	Fast to slow/no flow	Yes	Boulders, cobbles and gravel	Substrate and aquatic vegetation	Electro-narcosis
	Rapid	A 40 m rapid situated in the right channel at the downstream end of the site	Rapid	Fast to slow/no flow	Yes	Boulders, cobbles and gravel	Substrate cover	Electro-narcosis

Table 4.4: Continued.

Sampling sites	Sampling points	Habitat description	Habitat type	Flow description*	Dried up during the study?	Substrate	Dominant fish cover type	Sampling method
EWR4	Main pool	Large, deep pool	Pool	No flow	Yes, separated into series of small shallow pools	Coarse to fine sand	Water column	Gill and seine netting
	Pool A	Downstream end of the main pool	Pool	No flow	Yes	Boulders, cobbles and gravel	Substrate and aquatic vegetation	Electro-narcosis
	Pool B	Glide situated in the left channel; connects Pools A and D	Glide	Very slow flow	Yes	Boulders, cobbles, gravel and sand	Substrate and riparian vegetation cover	Electro-narcosis
	Pool C	Shallow bedrock pool	Shallow pool	No flow	Yes	Bedrock	Bedrock overhang	Electro-narcosis
	Pool D	Predominantly shallow glide between rapids	Glide	Fast to slow flow	Yes	Bedrock, cobbles and pebbles	Substrate	Electro-narcosis
	Pool E	Deep pool situated at the downstream end of the site	Deep pool	No flow	Yes	Bedrock, boulders, cobbles and gravel	Substrate cover	Electro-narcosis
	Rapid	Two rapids, one between Pools B and D and one between Pools D and E.	Rapid	Flow	Yes	Boulders, cobbles and gravel	Substrate cover	Electro-narcosis

*** According to the Mr. C. Venter (owner of the farm where EWR3 is situated), the pool dry out occasionally e.g. in December 2005.**

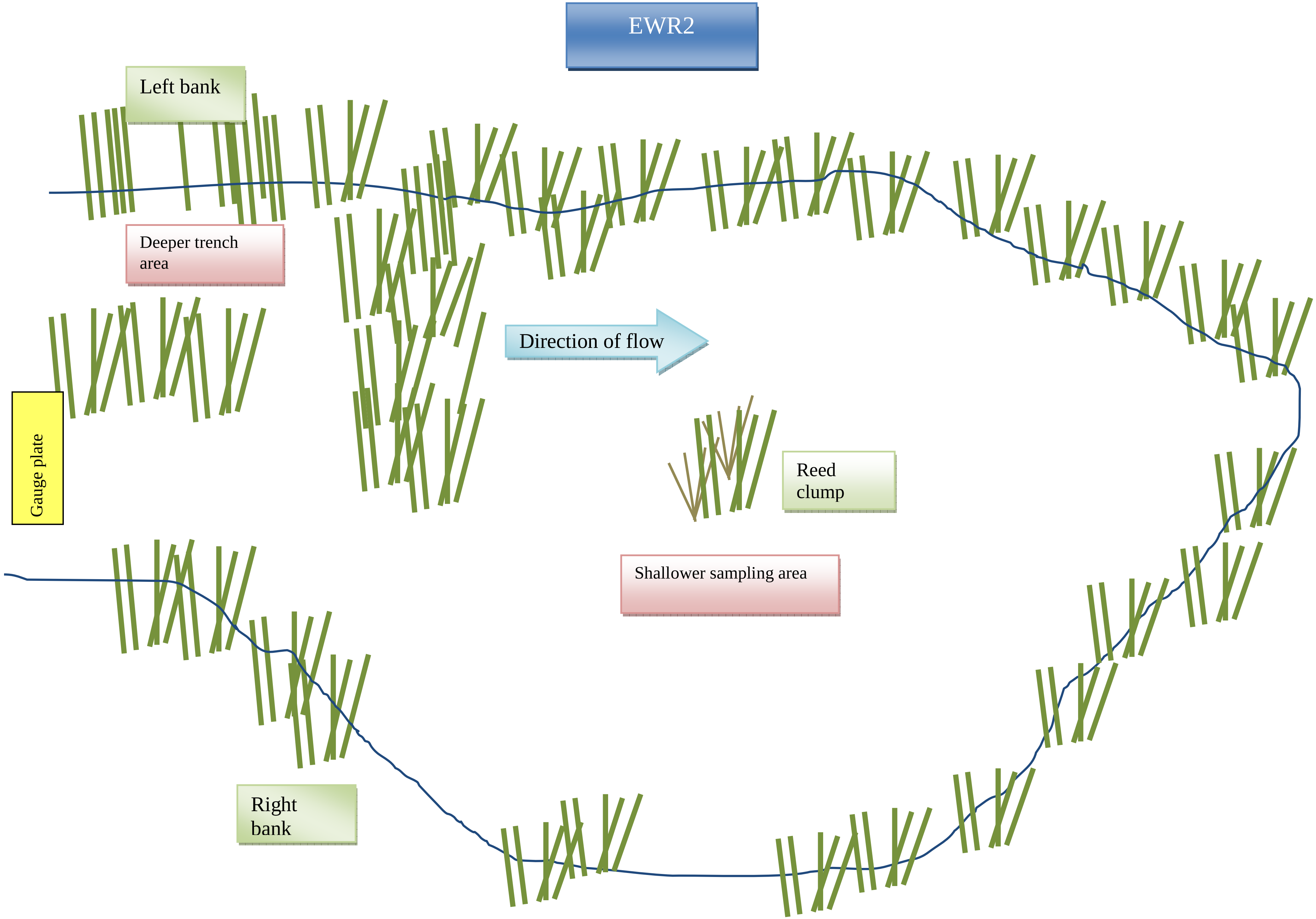


Figure 4.2.: Diagrammatic site-plan for EWR2 showing the sampling area surveyed during the study (note: diagram not to scale).

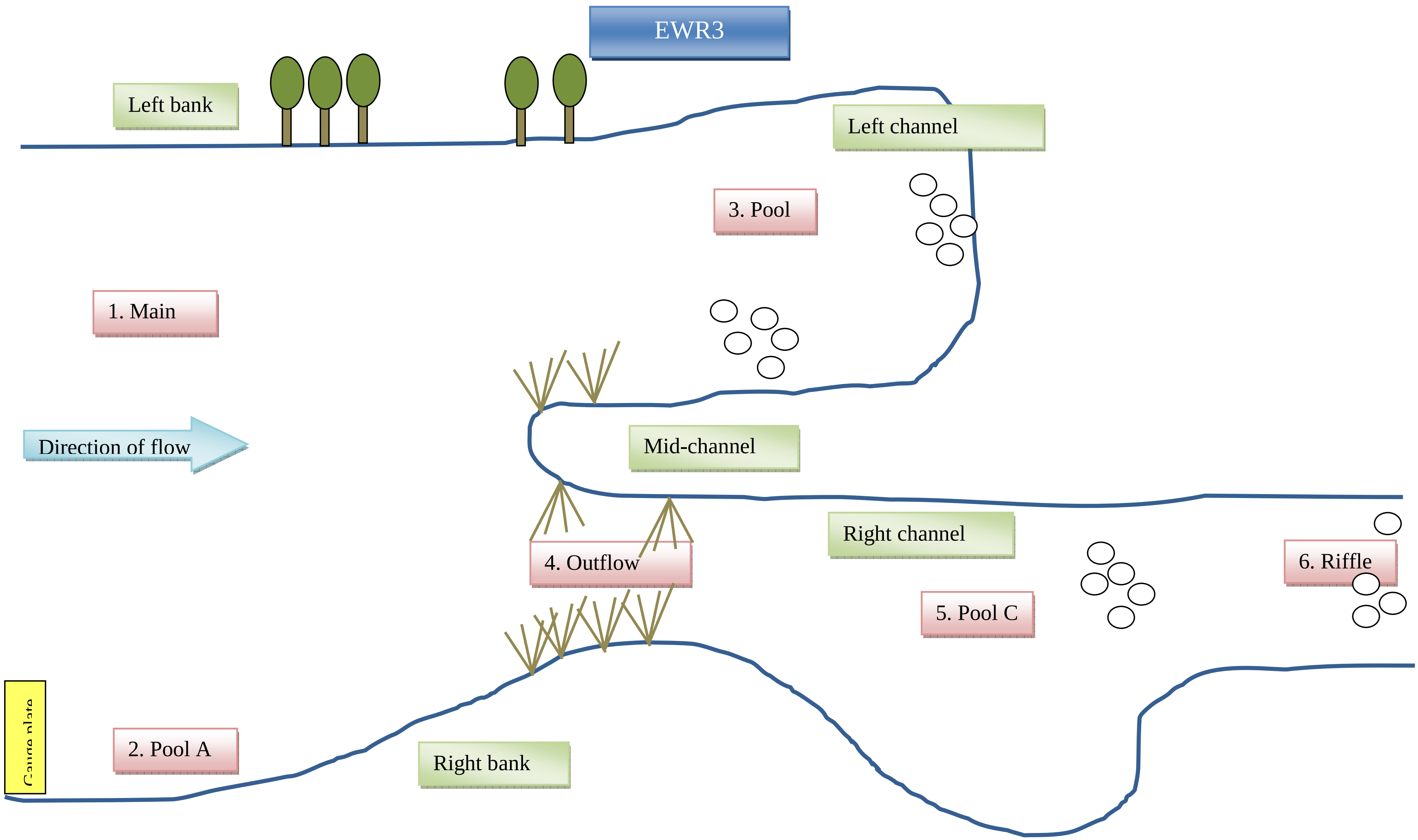


Figure 4.3.: Diagrammatic site-plan for EWR3 showing the 6 sampling points surveyed during the study (note: diagram not to scale).

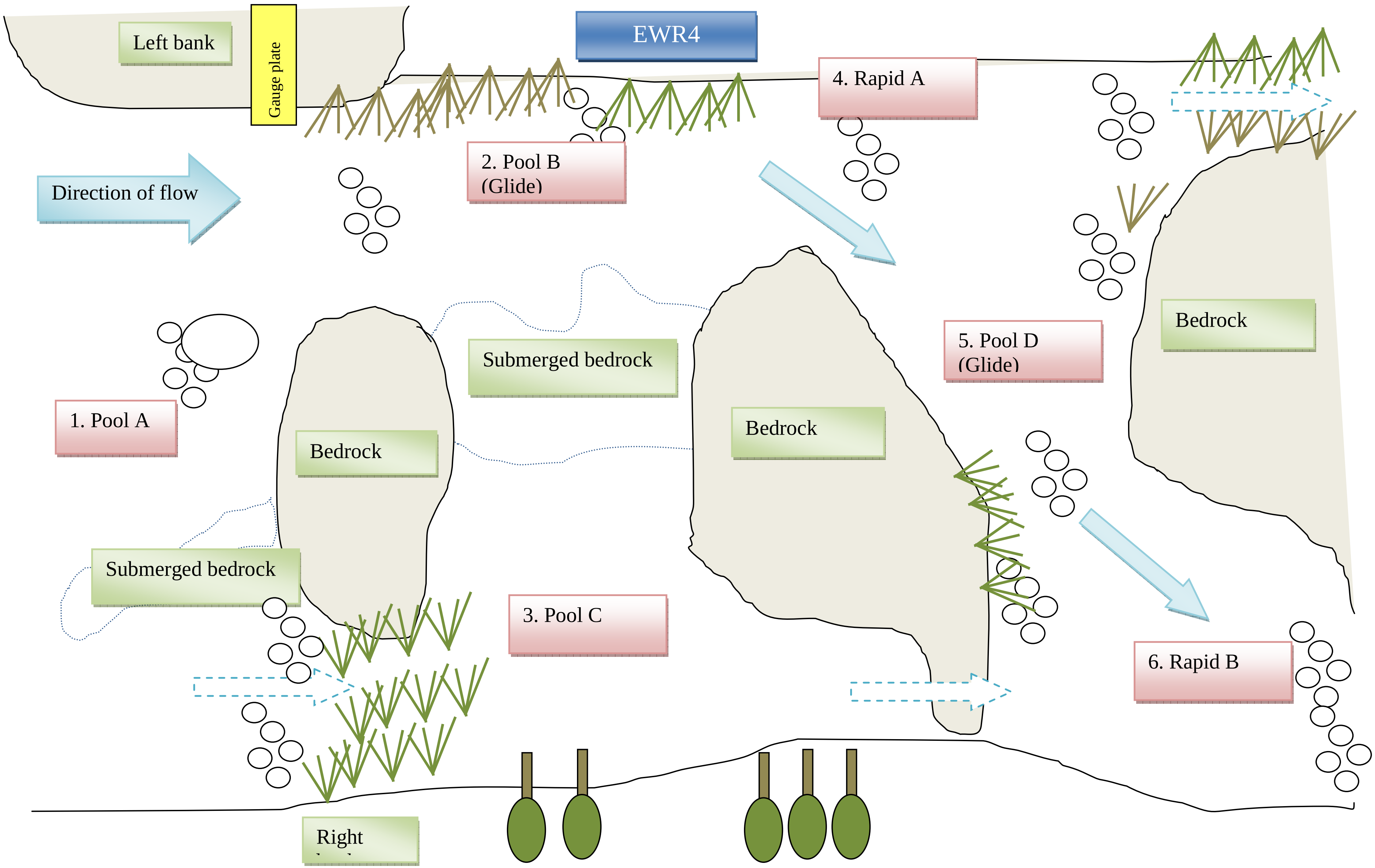


Figure 4.4.: Diagrammatic site-plan for EWR4 showing the 6 of the 7 sampling points surveyed during the study (note: diagram not to scale). Pool A1 id located upstream of Pool A and Pool E is located downstream of Rapid B. The perforated arrows indicate additional paths of surface flow under high flow conditions.

4.6 Determining the Present Ecological State of the fish community

The present ecological state (PES) of the Seekoei River fish community was calculated for the four river reaches represented by sites EWR1 to 4 by applying Kleynhans' (2006; 2008) Fish Response Assemblage Index (FRAI). The various steps, outlined and explained in Kleynhans (2006; 2008) were followed and will not be duplicated here. However, for the purpose of clarity, more information is provided for two of the steps: setting the reference condition for the Seekoei River fish community and the calculation of the frequency of occurrence ratings.

4.6.1 Setting reference conditions

The EcoStatus suite of models (see Kleynhans and Louw 2006; 2008) requires that the reference conditions, describing the condition of a river reach prior to anthropogenic impacts, are determined for each component (fish, aquatic invertebrates, riparian vegetation, water quality, geomorphology and hydrology). Two sources of information can be consulted in order to compile a list of fish species expected to be present under reference conditions: historical information (published and unpublished records and reports), and when not available, fish data from other river reaches or rivers in the same ecoregion could suffice (Kleynhans, 2008).

4.6.1.1 Historical information

As fish data were mostly lacking for the Seekoei River, the reference fish assemblages were mainly based on historical records for the Orange River, Vanderkloof Dam (situated at the confluence of the Seekoei and Orange rivers) and other southern tributaries of the Orange Rivers situated in the same Level II ecoregion (26.03). Literature sources consulted included for example Jubb (1964, 1967, 1972), Jubb and Farquharson (1965), Marshall (1972), Van Schoor (1972), Gaigher *et al.* (1980), Skelton and Cambray (1981), Hocutt and Skelton (1983), Cambray and Bruton (1984), Tómasson *et al.* (1984), Skelton (1986, 2001), Barkhuizen (1993), Benade (1993), DWAF (1995), Skelton *et al.* (1995), De Moor and Bruton (1996), Skelton (2001), SAIAB Database (2006), Albany Museum database (2003), and correspondence in 2005 and 2006 with Dr. J. Cambray (Curator: Freshwater Ichthyology, Albany Museum), Mr. C. Benade (previously from the Department of Environmental Affairs, Northern Cape) and local farmers (Messrs. TC Niewoudt, J. Bishop, A. Clarke and C. Venter). The fish habitat and cover available at each sampling site were also taken into account in the preparation of the list, relying on expert judgement and the team's previous experience of working in the Orange River system.

The following southern tributaries of the Orange Rivers fall into 26.03, the same Level II ecoregion as the Seekoei River (from east to west): Stormberg Spruit; Modderbrul Spruit; Oudagspruit; Broek Spruit; Brakspruit; Suurbergspruit; Oorlogspoort; Hondeblaf; lower part of the Brak River system, including the Klein Brak, Ongers and Visgat Rivers, and the lower parts of the Hartbees River system, including the Sak, Brak and Renoster Rivers. Four indigenous fish species, *B. anoplus*, *L. aeneus*, *L. capensis* and *L. umbratus* and two exotic species, *C. carpio* and *Carassius auratus*,

Table 4.5: Fish species recorded in the southern tributaries of the upper Orange River and Vanderkloof Dam located where the Seekoei River joins the Orange River (Sources: SAIAB Database 2003; Benade 1994; Skelton and Cambray 1981; Hocutt and Skelton 1983; Tómasson *et al.* (1984).

Fish species	***Broekspruit***	***Brakspruit***	***Suurberg-spruit***	***Hondeblaf***	***Brak River (Ongers)***	***Hartbees River***	***Vanderkloof Dam***
Indigenous species							
Barbus anoplus	X	X		X	X	X	X
B. paludinosus							
B. trimaticulatus							
Labeobarbus aeneus	X		X			X	
L. kimberleyensis							X
Labeo capensis		X		X		X	X
L. umbratus		X			X	X	X
Clarias gariepinus							
Austroglanis sclateri							X
Tilapia sparrmanii							
Pseudocrenilabrus philander							
Exotic species							
Cyprinus carpio		X				X	X
Carassius auratus						X	
Micropterus salmoides							

Table 4.6: Fish species recorded by Hocutt and Skelton (1983) in the Hartbees-Sak River system.

	Hartbees												
Fish species	**Vis**							**Sak**					
	Vis	**Vis – west**	**Renoster**	**Riet**	**Portugals**	**Rooikuils**	**Klein-Riet**	**Leendert**	**Sak**	**Brak**	**Gansvlei**	**Blomfontein**	**Sout**
Barbus anoplus	X	X	X	X	X		X	X	X	X		X	X
B. paludinosus													
B. trimaticulatus													
Labeobarbus aeneus	X		X	X			X		X	X	X	X	X
L. kimberleyensis													
Labeo capensis			X						X				X
L. umbratus			X	X									
Clarias gariepinus													
Austroglanis sclateri													
Cyprinus carpio							X			X	X	X	X
Carassius auratus							X				X		

have previously been recorded in some these tributaries (see Table 4.5). The same six species were also recorded in the Hartbees-Sak River system (an ephemeral southern tributary of the Orange River) by Hocutt and Skelton (1983; see Table 4.6). The cichlid *Tilapia sparrmanii* was introduced into the Caledon River in the 1960s (Jubb 1972) and was therefore initially added to the list of expected species.

4.6.2 Calculating Frequency of occurrence ratings (FROC) values

The fish sampling data for each sampling site were transformed to frequency of occurrence ratings (FROCs) based on Kleynhans' (2008) ratings where a FROC rating of "0" can be described as "fish species absent" and a rating of "5" as "fish species present at almost all sites". The model requires that three or more sampling points are sampled per river section. The fish data are then transformed into a FROC rating by the following calculation:

$$FROC = (Nsp/Ns) \times 5$$

Where:

FROC: Frequency of occurrence of a species
Nsp: Number of sampling points in a river section where a species was sampled
Ns: Number of sampling points sampled in a river section
5: Maximum frequency of occurrence of a species.

Due to the fact that the minimum number of sampling points was not always available, cumulative fish data (including all data accrued up to that date) were used to calculate a FRAI score for months and sites where fish were sampled at less than three sampling points (as suggested by Kleynhans pers. comm., 2008). The number of sampling points (Ns) was therefore substituted by the number of sampling repetitions done up to that point in time and the number of sampling points where a species was sampled (Nsp) was substituted by the number of sampling repetitions when a species was sampled up to that point. The FRAI scores calculated by using cumulative data are clearly indicated in the results.

5. Results and discussion

This chapter provides an overview of habitat conditions and the fish communities in the Seekoei River. Specific results are described and discussed for each of the four sampling sites, EWR1 to EWR4.

5.1 Overview of fish surveys – species composition, abundance and the distribution of fish in the river:

5.1.1 Species composition and distribution

A total of seven species have been recorded for the Seekoei River (see Table 5.1). Of these, five species occur naturally in the Orange-Vaal system. Two exotic species have been recorded, namely *Cyprinus carpio* which was found in the middle and lower Seekoei, and *Micropterus salmoides* which was recently introduced into the lower reach of the river (farmer Carools Venter, Holfontein; pers. comm.).

Species richness increased in a downstream direction with only one species recorded for EWR1 and seven species recorded at EWR4 (Table 5.1). *Barbus anoplus* was the most widespread species and was recorded at all four sampling sites. The four species recorded in both the middle and lower reaches are the two large cyprinids *Labeo capensis* and *L. umbratus*, the catfish *Clarias gariepinus* and the exotic *Cyprinus carpio*. The Smallmouth yellowfish *Labeobarbus aeneus* was only recorded in the lower Seekoei River.

Table 5.1: Fish species recorded in the Seekoei River, March 2006 to April 2008.

Fish species	***Common name***	***Conservation status***	***Distribution***			
			EWR1	EWR2	EWR3	EWR4
Cyprinidae						
Barbus anoplus (Weber, 1897)	Chubbyhead barb	Not threatened	X	X	X	X
Labeobarbus aeneus (Burchell, 1822)	Vaal-Orange smallmouth yellowfish	Not threatened			X	X
Labeo capensis (Smith, 1841)	Orange River mudfish	Not threatened		X	X	X
Labeo umbratus (Smith, 1841)	Moggel	Not threatened		X	X	X
Cyprinus carpio (Linnaeus, 1758)	Carp	Exotic		X	X	X
Clardiidae						
Clarias gariepinus (Burchell, 1822)	Sharptooth catfish	Not threatened		X	X	X
Centrarchidae						
Micropterus salmoides (Lacepède, 1802)	Largemouth bass	Exotic				X

5.1.2 Fish abundance

In total 7311 fish specimens have been collected and recorded at the four sampling localities (Table 5.2). The single species found at EWR1, Barbus anoplus, occurred in relatively high numbers here, but also occurred at all three other sites contributing >34% to the total catch. It was, therefore, the species with the widest dristribution, as well as, the most abundant fish sampled in the Seekoei River. Other abundant species were *L. capensis* (23.5% of the total catch) and the exotic *C. carpio* (20%). This implies that nearly 80% of all the fish recorded belonged to only three species, all in the family Cyprinidae. The remaining four species each contributed less than 10% to total abundance. Fish was more abundant in the lower part of the catchment than in the upper and middle reaches of the river, with 43.6% of the specimens collected at EWR4, 30.3% at EWR3, and 26.1% collectively at EWR1 and 2. At EWR2, where sampling was conducted in a shallow pool habitat, only 5.6% of the total number of fish was sampled.

Table 5.2: Fish abundance recorded in the Seekoei River, March 2006 to April 2008.

Fish species	***EWR1***		***EWR2***		***EWR3***		***EWR4***		***Total***	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**		**%**
Barbus anoplus	1501	100	353	86.5	530	23.97	116	3.64	**2500**	**34.2**
Labeobarbus aeneus					138	6.24	46	1.44	**184**	**2.5**
Barbus juveniles					168	7.6	5	0.16	**173**	**2.4**
Labeo capensis			2	0.49	515	23.29	1202	37.67	**1719**	**23.5**
Labeo umbratus			19	4.66	232	10.49	409	12.82	**660**	**9.0**
Labeo juveniles			4	0.98	247	11.17	224	7.02	**475**	**6.5**
Cyprinus carpio			3	0.74	330	14.93	1132	35.47	**1465**	**20.0**
Clarias gariepinus			27	6.62	51	2.31	45	1.41	**123**	**1.7**
Micropterus salmoides							12	0.37	**12**	**0.2**
Total number of individuals	**1501 (20.5%)**	**(20.5)**	**408 (5.6%)**		**2211 (30.3%)**		**3191 (43.6%)**		**7311**	**100**

A large number of juvenile fish (<45mm) were also sampled. Due to the difficulty of identifying these small fish to species level in the field, they were recorded to genus level as either *Barbus* juveniles (young of *B. anoplus* and *L. aeneus*) or *Labeo* juveniles (young of *L. capensis* and *L. umbratus;* Table 5.2). These unidentified juveniles, together, contributed 8.9% to total abundance, with the *Labeo* juveniles more abundant than the *Barbus* juveniles. The *Labeo* juveniles were mainly found during autumn (March to May), but the *Barbus* young was found in all four seasons (June and April) with the highest numbers recorded during spring and summer.

5.2 Results and discussion per study site

5.2.1 Results: Site EWR1

The frequency of surface water connection in the upper reach of the Seekoei River where EWR1 is situated is naturally low (about 10% of the time) and the river mainly comprises a series of isolated pools in this river section. The connectivity has, however, been greatly reduced from natural conditions as a result of increased water storage. It was proposed in the study (see Hughes, 2008) that the upstream inflow into the pool at EWR1 is approximately 50% lower than what it was before the erection of the large number of earth dams, weirs and dams in the upper Seekoei River. The large number of in-channel structures creates flow modifications that have a large impact on the instream habitat integrity of this reach in that it may cause the build-up of silt and increase habitat fragmentation. Due to the scarcilty of persistent pools in this river section (about 94% of the river channel in this reach was dry in October 2005 when the video survey of the river was done; Watson and Barker 2006) only one sampling point was surveyed for the study.

5.2.1.1 Instream habitat

Potential fish habitat

The available fish habitat at EWR1 was limited to an isolated pool, approximately 90 m long and 7.4 m wide, fringed with sedges (see Plate 1). The pool, which is fed by groundwater, persisted for the whole period of study. Pool depth (as measured by the gauge plate) remained fairly constant (mean=82.21 cm; std=4.42 cm), never dropping below 69 cm (Figure 5.1). The pool's surface area also remained relatively constant during the study, varying between 499 m^2 in May 2006 (gauge plate=83.5 cm) and 574 m^2 in November 2006 (gauge plate=85 cm; Figure 5.2). The mean surface area over this period was 534.33 m^2 (std=24.48 m^2).

The habitat surveys indicated that the sampling pool was dominated by shallow habitat (depth < 50 cm) that comprised more than 70% of the pool (see Figure 5.3). The deeper habitat (depth >50 cm) was mainly located towards the centre of the pool (Figures 5.4a and b). The ratio of shallow and deep habitat remained very similar throughout the study (Figure 5.3).

The pool's substrate comprised mainly silt and clay, covered by a thick (up to 30-50 cm) layer of fine black organic material. Silt and clay dominated in the shallow pool areas (<50 cm), while silt, gravel and cobbles occurred in the deeper parts of the pool (41-80 cm; see Figure 5.5).

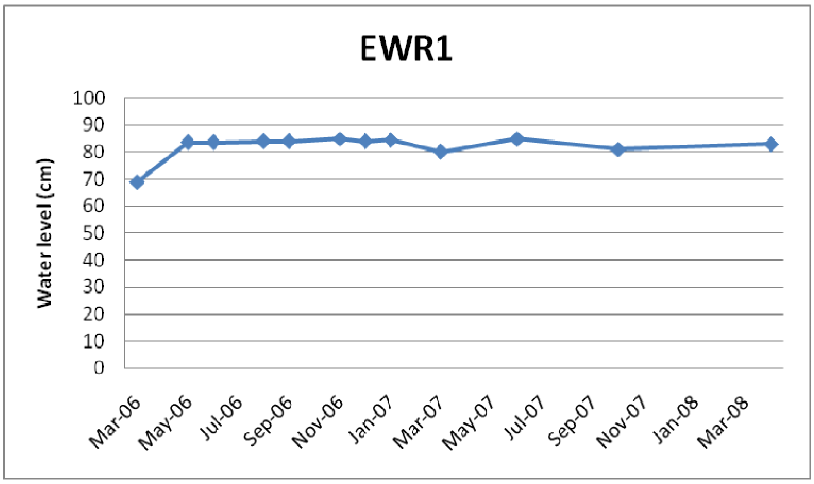


Figure 5.1: Gauge plate readings for EWR1, March 2006 to March 2008.

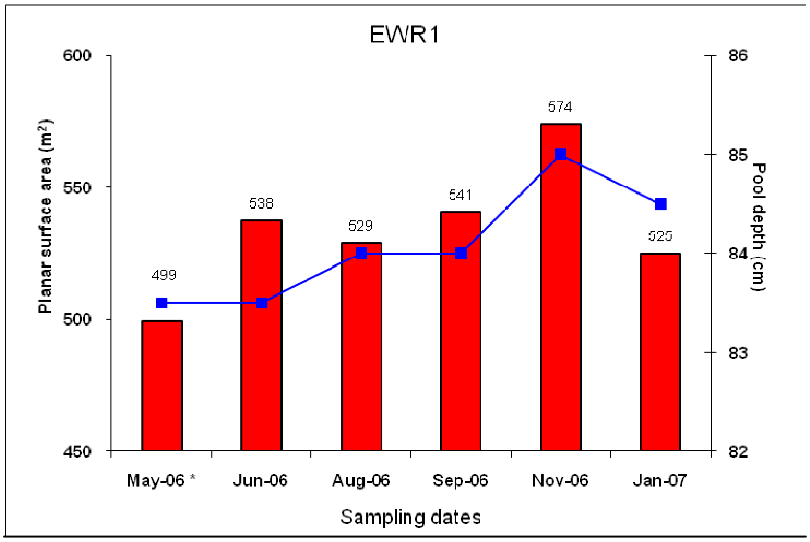


Figure 5.2: Pool surface areas for EWR1, May 2006 to January 2007 (surface area calculated from habitat survey measurements made on site).

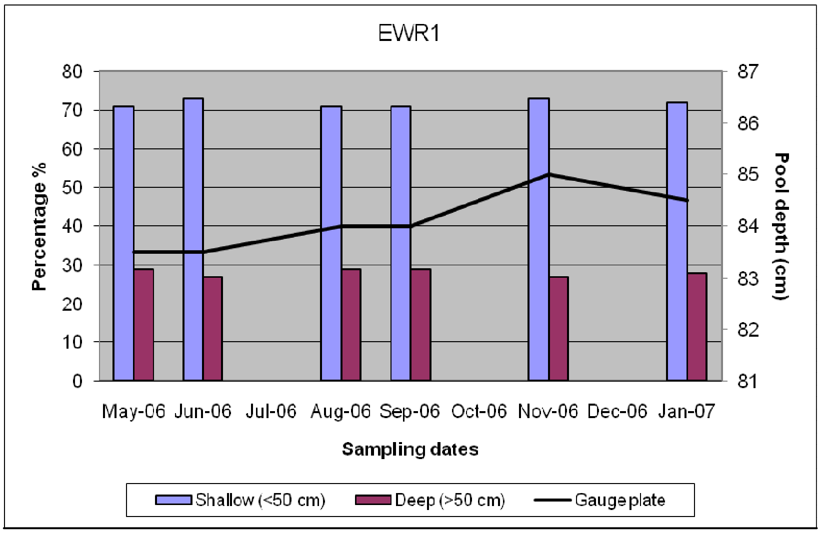


Figure 5.3: The distribution of shallow (<50cm) and deep (>50cm) habitat for EWR1, May 2006 to January 2007 (based on data from habitat surveys).

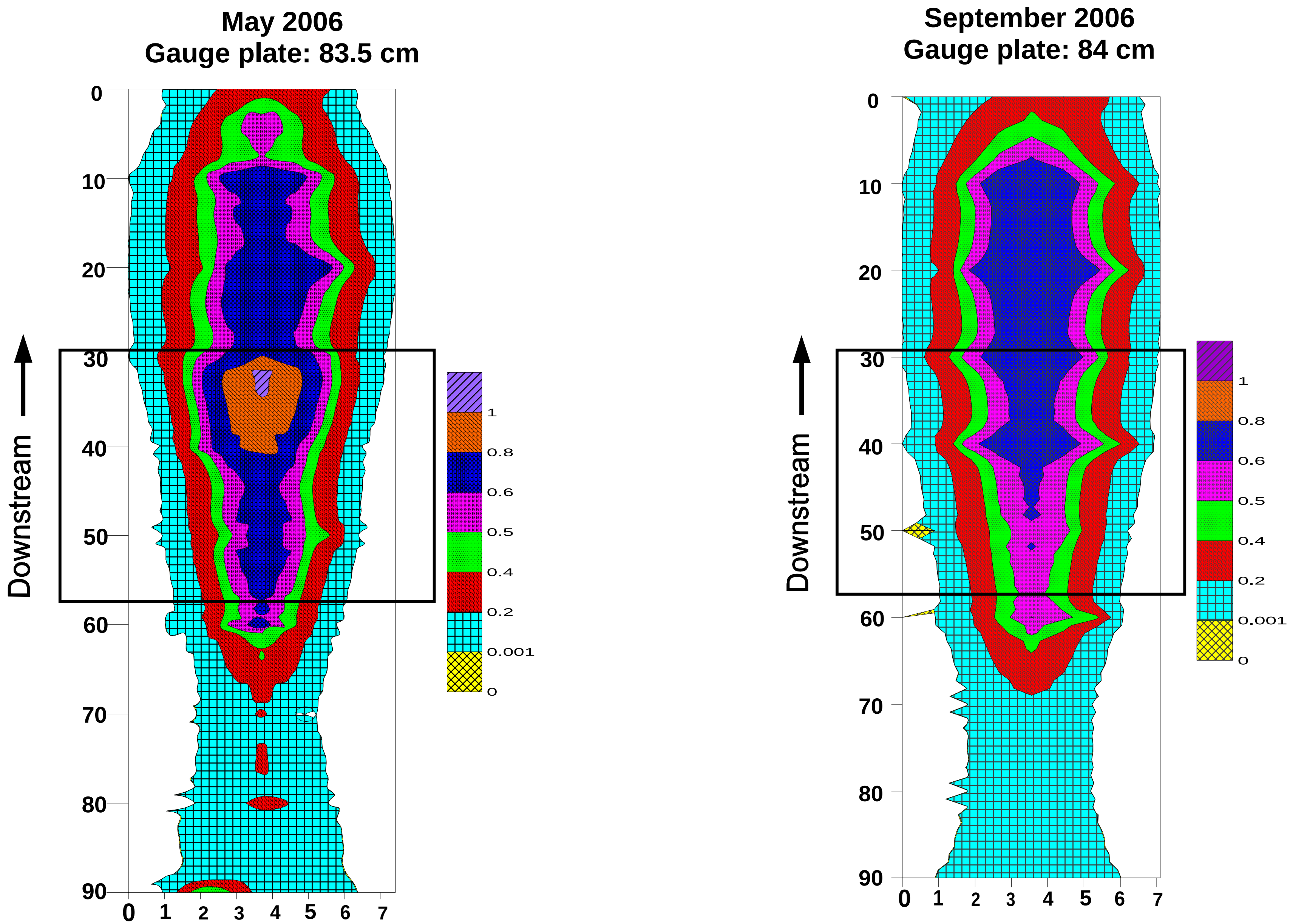


Figure 5.4: The distribution of depth interval classes (m) for sampling pool at EWR1 for May 2006 and September 2006. (The main sampling area is indicated by a black box). The gauge plate is located at 36 m.

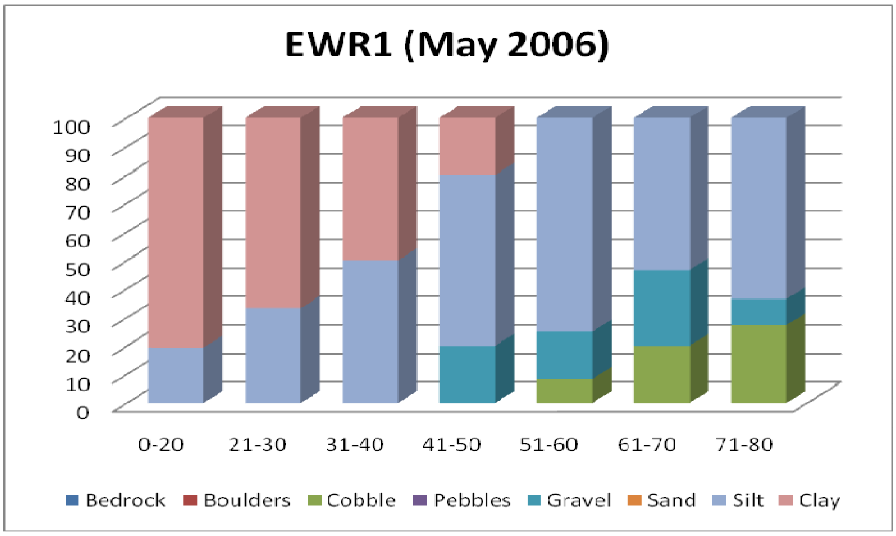


Figure 5.5: The percentage contribution of the different substrate classes for EWR1 based on data obtained from the habitat survey done in May 2006.

Water quality

The pool at EWR1 represented fairly harsh environmental conditions to fish. Water temperature measured in the isolated pool varied between 4.6ºC in winter (June 2007) and 26ºC in summer (November 2006; see Table 5.3). Conductivity in the pool remained relatively high over the study period, varying between 109/1 mS/m (March 2006) and 271.40 mS/m (November 2006). The electrical conductivity of the groundwater feeding the pool increased towards the pool. Measurements taken at boreholes increased from 61 mS/m (furthest from the river channel) to 197 mS/m (closest to the river channel; see Van Tonder *et al.* 2007). The higher conductivity prevailing in the pool was mainly as a result of water lost to evaporation and evapotranspiration.

Table 5.3: Selected physical properties for EWR1, March 2006 to March 2008.

Date of sampling	*Time of samp-ling*	*Pool depth (cm)*	*Flow description*	*Water temp (°C)*	*pH*	*Conducti-vity (mS/m)*	*Diss. O_2 (mg/l)*	*O_2 %*	*Turbidity (NTU)*
Mar-06	09:30	69	No flow	12.3	8.35	109.10	5.22	52.1	29.0
May-06	14:00	83.5	No flow	8.90	8.15	161.00	5.55	49.0	7.30
Jun-06	11:12	83.5	No flow	5.10	8.01	236.00	5.10	61.1	2.50
Aug-06	10:48	84	No flow	7.70	8.17	235.10	7.70	78.8	8.60
Sep-06	10:00	84	No flow	10.6	7.94	199.10	8.64	78.3	27.00
Nov-06	14:00	85	No flow	26.0	8.31	271.40	8.10	103.3	26.00
Dec-06	13:15	84	No flow	22.8	8.42	264.10	6.89	80.3	-
Jan-07	10:17	84.5	No flow	22.8	8.18	249.00	2.91	34.4	14.20
Mar-07	17:10	80	No flow	20.2	8.54	256.60	4.95	56.2	38.00
Jun-07	10:00	85	No flow	4.60	8.31	195.40	7.80	62.8	2.20
Oct-07	10:40	81	No flow	10.8	8.80	256.20	14.75	130.8	17.60
Mar-08	11:20	83	No flow	18.0	8.09	245.70	5.36	42.9	9.20

5.2.1.2 Fish survey

Fish species expected

No literature or information could be found on the fish community in this section of the river. However, based on the fish habitat and cover available and recognising the position of the site in the catchment, only two species were expected to occur in the sampling pool namely *Barbus anoplus* and *Clarias gariepinus* (see Table 5.4). In the light of the uncertainty due to the lack of historical data, *L. capensis* and *L. aeneus* were initially added to the expected list but were removed as the study progressed.

Table 5.4: List of fish species expected at EWR1.

Fish species	Expected	Confidence level
Indigenous fish species		
Barbus anoplus	√	95%
Labeobarbus aeneus	?	5%
Labeo capensis	?	10%
Clarias gariepinus	√	60%

Fish species observed

Barbus anoplus was the only species collected at EWR1. It was relatively abundant at the site, and a total of 1501 specimens were recorded during the 196 minutes of sampling done over the period of study (Table 5.5). Even though the water level at the pool remained relatively stable during the study, fish abundance varied between 24 (captured in May 2006), and 557 specimens (sampled in November 2006). Fish abundance further varied markedly between seasons, and even within the same season (Figure 5.6). During the first year of study, *B. anoplus* was more abundant in spring than in autumn - an average of 415 specimens was recorded in September and October 2006, compared to March and May 2006 when an average of 39 specimens were sampled. This could, however, be as a result of the less efficient sampling gear that was used at the start of the study (coinciding with the autumn samples). During the second year seasonal abundances were fairly similar with *B. anoplus* being slightly more abundant in summer (30.7% of the year's total number of specimens) and autumn (28.8%) than in winter (19.8%) and spring (20.7%).

A large difference in the total abundance of *B. anoplus* was evident between the spring samples of 2006 and 2007. In 2007, only 85 specimens were captured compared to the average of 415 specimens captured in September and November 2006. There was also a marked difference in the yield of the two autumn samples. The total abundance in March 2006 (53 specimens) was nearly half that of March 2007 (118 specimens) but again, the difference in sampling gear could have had an effect. The total abundance of the two winter samples (August 2006 and June 2007) was very similar, with 83 and 81 fish specimens sampled respectively.

It appeared as if *B. anoplus'* abundance was lowest at the start of the study (when the water level in the pool was the lowest recorded over the study period – 69 cm), increased to their highest level in spring 2006 (water level in the pool: 84-85 cm), dropped to 126 specimens in summer 2007 (water level: 84.5 cm), but remained fairly constant until autumn 2007 when 118 specimens were recorded. A slight drop in fish numbers occurred in winter 2007, but again remained stable during the subsequent spring (2007) and autumn (2008) samples.

The highest catch per unit effort (CPUE) was recorded in November 2006, when 55.7 fish specimens were sample per minute (Table 5.2). The lower CPUE recorded in March and May 2006 may be attributed to the fact that the original electroshocker was not very effective due to the high electrical conductivity at the site which caused the power output to exceed the capacity of the generator.

Table 5.5: List of observed fish species at EWR1, March 2006 to March 2008. (FL, fork length; CPUE, catch per unit effort. CPUE calculated as number of fish captured per minute).

Date of sampling	*Fish species*	*Pool depth*	*Abun-dance*	*Length range* (FL in mm)*	*Mean length (FL in mm)*	*Standard deviation*	*Sampling effort (min)*	*CPUE*
Mar-06	*B. anoplus*	69	53	18-87	22.07	13.99	65	0.8
May-06	*B. anoplus*	83.5	24	32-72	39.00	10.47	30	0.8
Jun-06*	*B. anoplus*	83.5	0				9	0
Aug-06+	*B. anoplus*	84	83	12-63	31.64	7.86	10	8.3
Sep-06	*B. anoplus*	84	273	20-48	31.85	4.04	20	10.6
Nov-06	*B. anoplus*	85	557	17-65	30.24	5.61	10	55.7
Jan-07	*B. anoplus*	84.5	126	25-45	33.51	4.65	13	9.7
Mar-07	*B. anoplus*	80	118	25-45	36.00	5.61	7	16.9
Jun-07	*B. anoplus*	85	81	22-52	37.56	5.24	10	8.1
Oct-07	*B. anoplus*	81	82	32-58	44.20	6.72	10	8.2
Mar-08	*B. anoplus*	83	104	22-70	46.06	10.29	12	8.7
Total			**1501**				**196**	

* No data collected due to problems with sampling gear.

+ Start using new electroshocker.

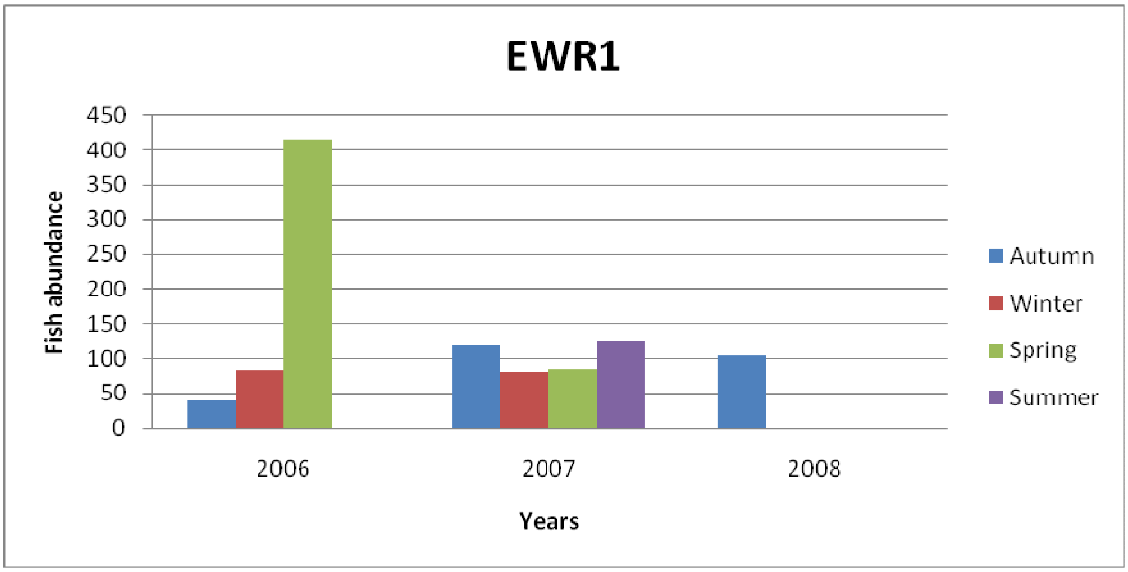


Figure 5.6: Total fish abundance recorded for the various seasons, 2006 to 2008. (Autumn: March, April, May; Winter: June, July, August; Spring: September, October, November; Summer: December, January, February. Note: where two or more field visits were made in the same season, the average abundance was calculated).

Population structure and recruitment

The body length (fork length, FL) of the sampled specimens ranged between 12 mm and 87 mm, while the mean body length varied between 22.07 mm (std=13.99 mm) in March 2006 and 46.06 mm (std=10.29 mm) in March 2008 (Table 5.5).The distribution of size classes for all the fish sampled at EWR1 is represented in Figure 5.7, while changes in size distribution between sampling visits are presented in Appendix C.

The body length of the majority of the fish (84.2%) was equal or less than 40 mm – the biggest proportion of these (50.53%) falling in the 31 to 40 mm size class (Figure 5.7). *B. anoplus* males and females reach sexual maturity between 38-41 mm and 38-40 mm, respectively, in Vanderkloof Dam (Cambray 1983; Cambray and Bruton 1985). This implies that the majority of the fish sampled during this study were juveniles.

In the March 2006 sample, nearly 91% of fish specimens fell into the 11-20 mm length mode, indicating that spawning possibly occurred in early February 2006. *B. anoplus* is a multiple spawner with the first spawning occurring over an extended period from November to December/January, and the second in February to March (Cambray and Bruton 1985). The March sample exhibit the lowest mean length 22.07 mm (std=13.99) with the widest range (18-87 mm), indicating that offspring from the second spawning and sexually mature individuals were present. Strangely, the 21-30 mm cohort representing the recruits from the first spawning, were absent.

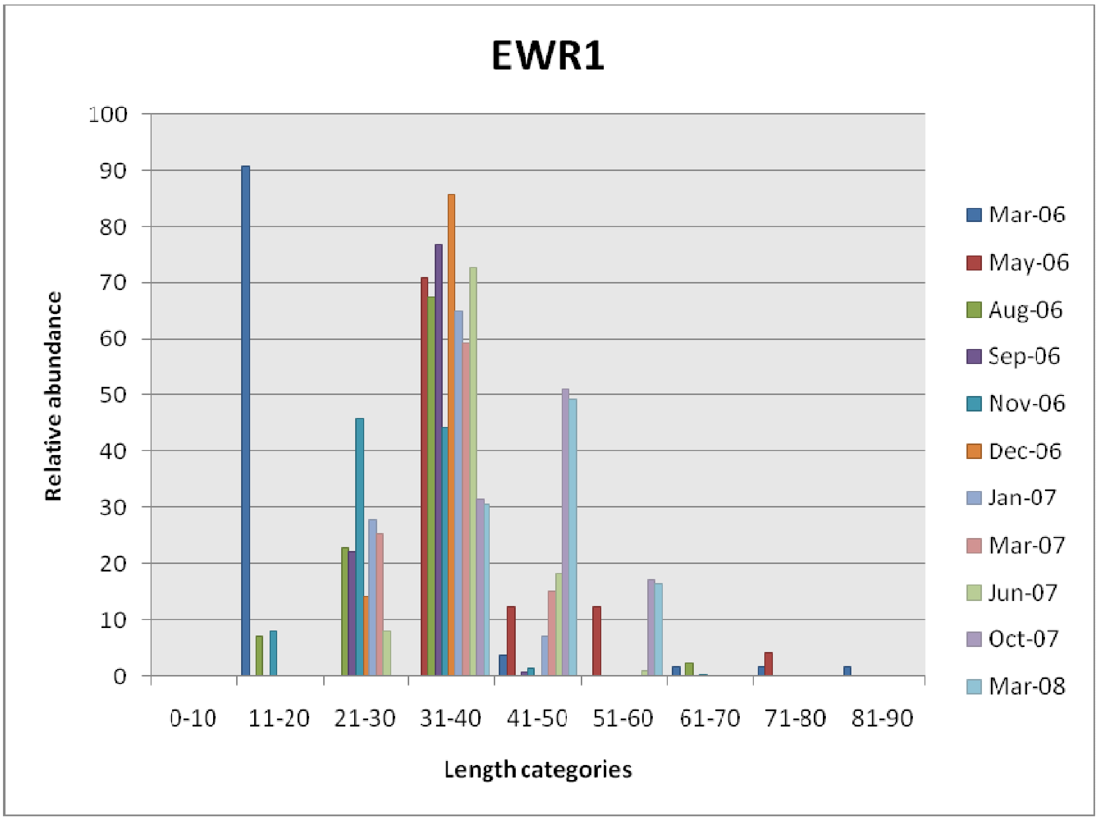
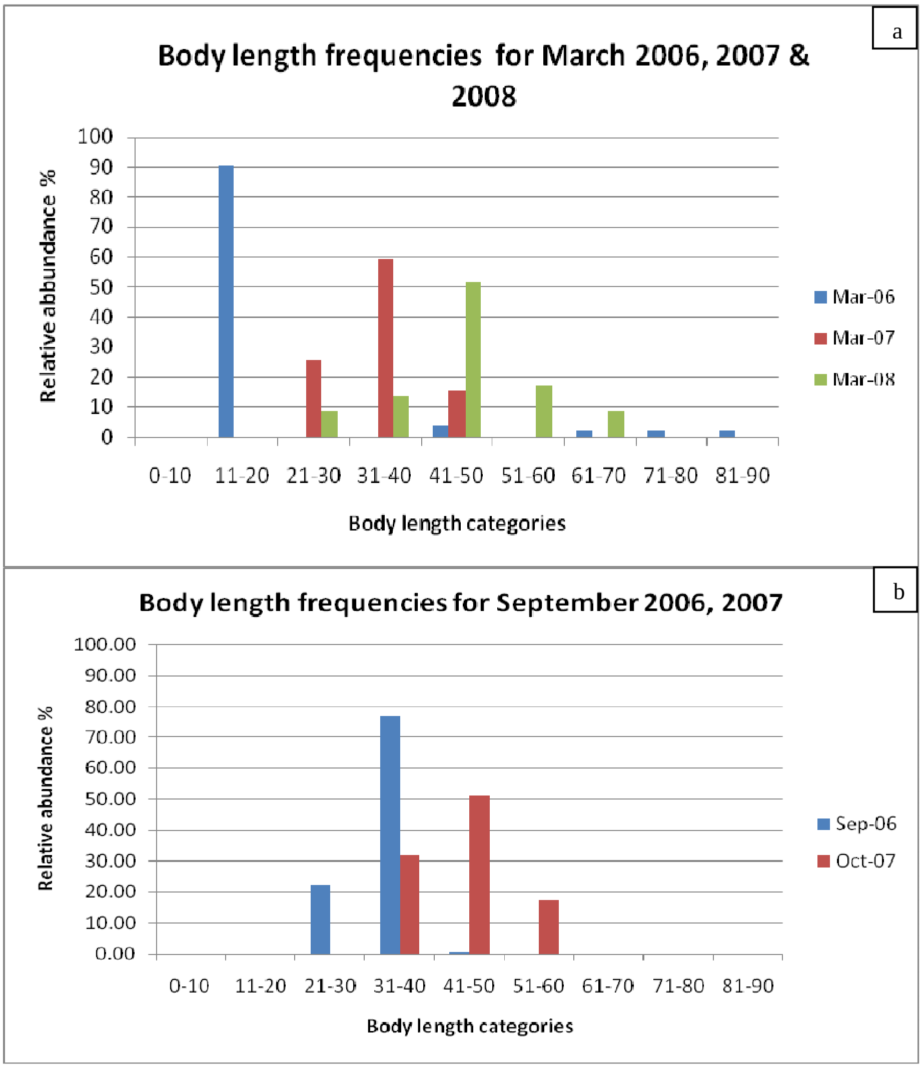


Figure 5.7: The percentage length frequency distributions of all *B. anoplus* specimens collected at EWR1, March 2006 to March 2008.

The percentage length frequency distributions of *B. anoplus* for the subsequent field visits (Appendix C) indicated that two spawnings took place between September 2006 (first spawning of the 2007 season) and February 2007 (second spawning of the 2007 season), as well as a spawing in September/October 2007 (first spawning of the 2008 season; Figure 5.8b). Strangely, no evidence of a second spawning in early 2008 was found in the March 2008 sample (see Figure 5.7). Also of interest is the presence of individuals in the 11-20 mm size class in the August 2006 sample, which means that a spawning event possibly took place late July/early August 2006.

When the three March samples are compared, it is clear that the 11-20 mm cohort found in 2006 is missing from both the 2007 and 2008 samples (see Figure 5.8a). (Note that 165.5 mm of rain was recorded for Hanover in February 2006 compared to 16 mm and 36 mm for February 2007 and 2008, respectively). Although there is evidence that two spawning events took place in the 2007 season (represented by the 21-30 mm cohort, second spawning, and the 31-40 mm cohort, first spawning), it appeared as if only one spawning occurred in the 2008 season.



Figures 5.8: The percentage length frequency distributions of *B. anoplus* specimens for the Autumn (a) and Spring (b) samples taken at EWR1.

5.2.1.3 Microhabitat

Bteween November 2006 and March 2008 the measurements for the description of the fish microhabitat were taken where fish specimens were collected.These measurements, recorded for 10 and 20 random points, included water depth, substrate and fish cover.

Water depth

The water level in the pool (based on the gauge plate readings) varied between 85 cm (in November 2006 and June 2007) and 80 cm (in March 2007) (see Table 5.6). The mean pool depth over this period was 82.8 cm (std=2.28), compared to a mean depth of 57 cm measured for the microhabitats where the fish were sampled.

Fish specimens at EWR1 were recorded between 27 cm (mean minimum depth=34.6 cm; std=9.07) and 84 cm (mean maximum depth=76.8 cm; std=6.14). Mean water depth in the microhabitat generally increased with an increase in pool depth.

Table 5.6: A description of microhabitat depths and in relation to fish abundance and catch per unit effort (CPUE) for EWR1 for selected months.

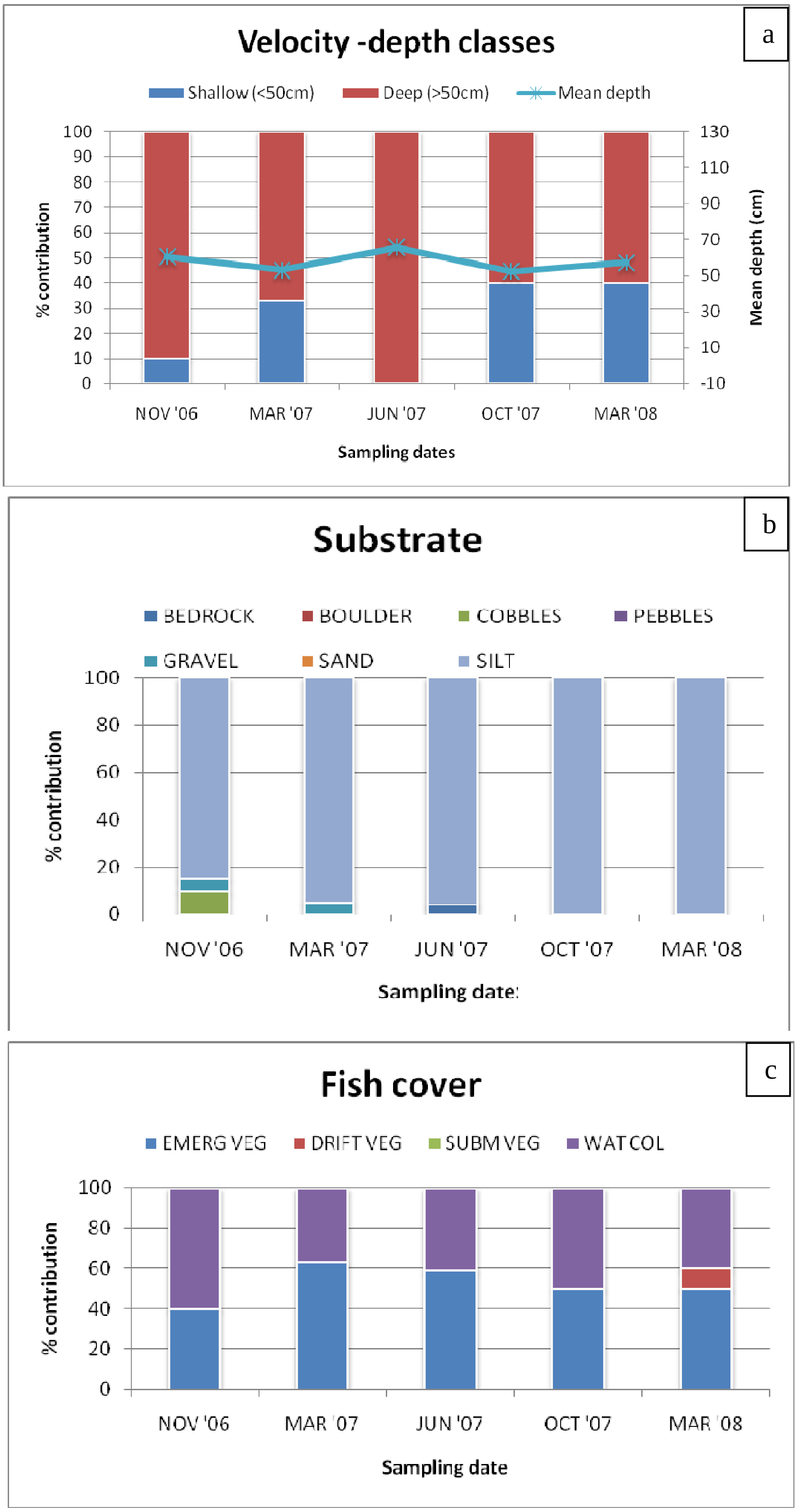
Sampling date	*Gauge plate*	*Mean depth*	*Minimum depth*	*Maximum depth*	*Fish abundance*	*CPUE (fish/min)*
Nov-06	85	60.65	27	81	557	55.7
Mar-07	80	53.1	34	71	118	16.86
Jun-07	85	65.7	50	84	81	8.1
Oct-07	81	52.5	29	70	85	8.5
Mar-08	83	57.2	33	78	83	6.92
Mean	**82.80**	**57.83**	**34.60**	**76.80**	**184.8**	**19.22**
Standard deviation	**2.28**	**5.50**	**9.07**	**6.14**	**208.62**	**20.77**

The fish specimens were predominantly sampled in the deeper parts of the pool (>50cm) over a silt substrate (Figure 5.9a and b). Fish cover was mainly provided by the sedges which fringed the pool and the water column in the deeper parts of the pool (Figure 5.9c).

5.2.1.4 Discussion: Site EWR1

Barbus anoplus was the only fish species collected at EWR1. The pool is a rare (natural) aquatic environment in a dry landscape (94% of the river channel is dry in this river section) in the upper parts of the catchment. Despite the fact that it is isolated most of the time (it only experiences surface water connection for about 5% of the time), it persisted throughout the dry period, presenting aquatic biota with a fairly stable habitat. The water level in the pool showed relatively little variance over the two years of study and comprised slow-deep and slow-shallow habitats (Figure 5.3).

B. anoplus is a pioneer species known to occur in a wide range of habitats including small, shallow streams (Skelton 2001) and isolated pools (Jubb 1967; Cambray *et al.* 1978; Avenant 1999; Skelton 2001). It was known to occur in the southern tributaries of the Orange River (such as the Seekoei River; Skelton and Cambray 1981) and is especially well adapted to the unstable riverine environment with its erratic flows, droughts and floods, and high silt loads (Kriel 1972 as cited in Cambray and Bruton 1985). It has been reported that the species can tolerate low temperatures and relatively high electrical conductivity (De Bie 1985). In this study, their resilience was also illustrated by their presence and abundance in EWR1 where electrical conductivity readings of up to 271.4 m/s were recorded.



Figures 5.9: The distribution of velocity-depth classes (a), substrate composition (b) and fish cover (c) for EWR1 based on microhabitat measurements taken between November 2006 and March 2008.

B. anoplus was predominantly sampled in the deeper parts of the pool (>50cm) at a mean depth ranging between 52.5 cm and 65.7 cm (Figure 5.9a). They were found over a silt substratum (the dominant substrate-type in the pool) and were mainly associated with cover provided by the sedges fringing the pool. Specimens were, however, often sampled in the open water towards the middle of the pool. Although the species generally inhabit sheltered areas, it is known to occur in the open waters of impoundments where they feed on zooplankton (Cambray, 1983b). It should also be noted that fish predators are absent from the pool.

Large variations in fish abundance occurred at the site, with abundances varying not only between seasons but also within seasons. Significant correlations were found between Catch Per Unit Effort (CPUE) and the water temperature (Pearson product-moment $r=0.69$; $p=0.018$). This correlation was highly significant in the period March 2006 to November 2006 ($r=0.94$; $p=0.006$), but not thereafter (November 2006 to March 2008; $p>0.19$) (see Figure 5.10). No correlations between CPUE and water level were found ($p>0.3$), nor between CPUE and turbidity (NTU; $p>0.4$).

Although abundances in 2006 were higher in spring than in autumn and winter, seasonal abundances were more similar in 2007. In 2006, fish abundance at EWR1 increased with temperature (see above). Over the same period mean minimum body lengths dropped, indicating that recruitment took place. This trend was not evident in 2007, indicating that recruitment is influenced by a combination of factors; in this case the absence of rainfall might have had an effect (see below). No significant correlations could be found between mean or minimum fork length and any of the variables water temperature, pool depth or turbidity ($p>0.1$) (Figure 5.11).

The study confirmed that *B. anoplus* is persisting and breeding in the pool at EWR1. The species is known to be very well adapted to persist in arid areas by maturing early, having a high productive rate and the ability to produce multiple clutches per season, growing rapidly during the first year as well as the ability to to tolerate low temperatures (Cambray, 1983). Multiple clutches decrease the chance of one or more generations being lost due to unfavourable environmental conditions (Cambray and Bruton, 1984) - an important adaptation in ephemeral rivers with a variable and unpredictable flow-regime.

Cambray and Bruton (1985) reported that in Vanderkloof Dam (situated at the confluence of the Seekoei and the Orange Rivers) the first spawning occurs over an extended period from November to December, while the second spawning occurs in February or March. Offspring of the first spawning then typically reaches a body length of 36 to 42 mm by March/April of the following year (Cambray and Bruton 1985). The fish data observed at EWR1 indicate that multiple spawnings took place during both years of the study. Interesting was the presence of the 11 to 20 mm cohort in August 2006, which indicated very early spawning that specific year. According to Cambray and Bruton (1984), *B. anoplus* usually spawn after periods of steady rainfall with the first spawning occurring when water temperatures reach approximately 20°C. 64

mm of rain was recorded for Hanover (located about 20 km from EWR1) in August 2006, but in the present study water temperatures above 20°C were only recorded later, between November and March.

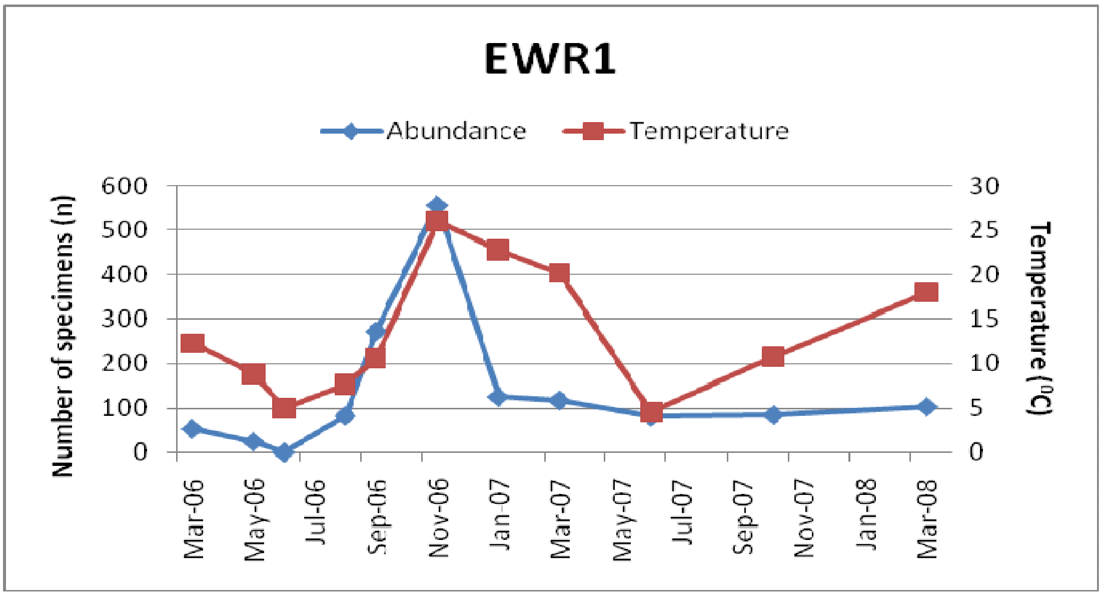


Figure 5.10: Fish abundance and water temperature recorded at EWR1, March 2006 to March 2008.

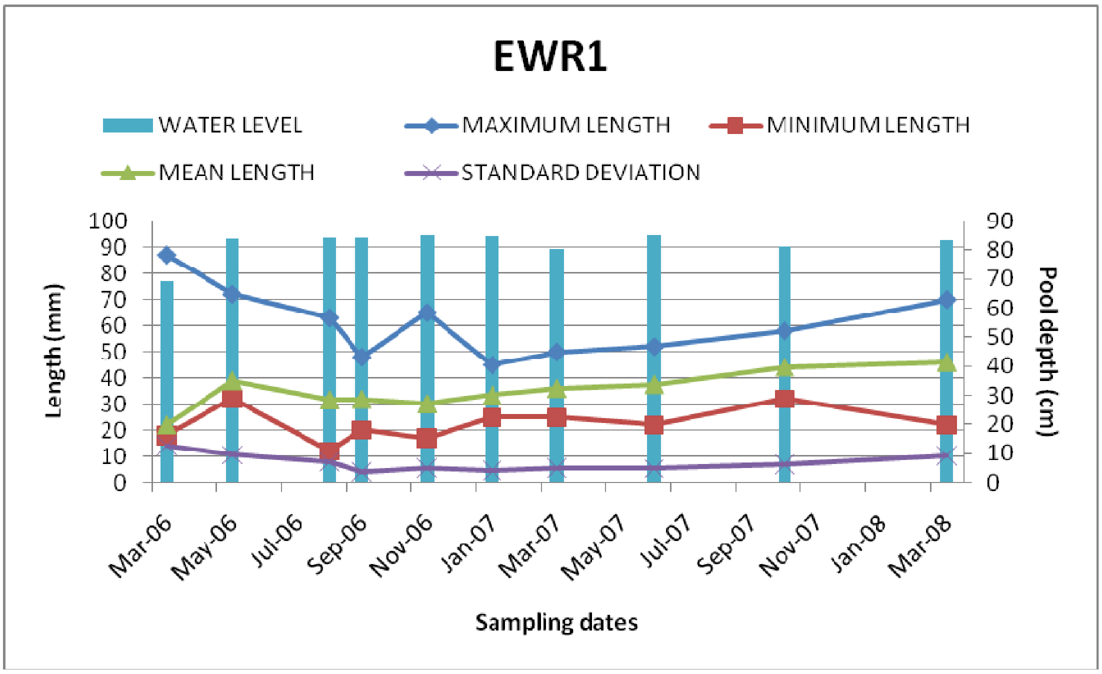


Figure 5.11: Mean fork length (FL) of *B. anoplus* specimens recorded at EWR1, March 2006 to March 2008. Mean maximum FL, mean minimum FL and standard deviations are also indicated.

5.2.2 Site EWR2

EWR2 is located approximately 2 km downstream of the Seekoei River's confluence with the Klein Seekoei River. Although the natural frequency of surface water connection in this reach was slightly higher than for upstream sections, it was still very low (12% of the time) and has been further reduced (to less than 5% of the time) since agricultural development started in the catchment. Instream storage in the Seekoei is greater than in the Klein Seekoei (see Table 5.15, Chaper 5, Main report), and a large number of in-channel structures (±30 have been noted by Watson and Barker 2006) are present in this section of the main channel. Suitable sampling sites were limited in the reach and a large section of the river channel (approximately 41%, according to Watson and Barker 2006) is overgrown with reeds.

5.2.2.1 Instream habitat

Potential fish habitat

The sampling site comprises a large pool (approximate pool length: 75 m; pool width: 12.92 m at the widest point) fringed by *Phragmites australis* reeds. The aquatic habitat at the site consisted of a deeper trencsh (where the gauge plate is situated) and a shallower section of approximately 30 m long at the downstream end of the site. Fish sampling was mainly done in the shallower parts of the pool (hereafter referred to as the sampling pool; see discussion under section 4.3.2) and therefore the habitat surveys also focused on this area.

The water level at EWR2 was much more variable than at EWR1. The gauge plate readings fluctuated between 36 cm (March 2007) and 151 cm (March 2008; Figure 5.15) with a mean depth of 87 cm over the period of study (std=32.82 cm). The surface area of the sampling pool also varied with fluctuations in pool depth and during 2006 it shrunk from 566.49 m^2 in September 2006 (gauge plate: 135 cm) to 34.99 m^2 in January 2007 (gauge plate: 45 cm; see Figure 5.16), drastically reducing the available fish habitat at the site.

The sampling pool provided predominantly shallow habitat (<50 cm). For May, June and August 2006 the ratio between shallow and deep (>50 cm) habitats was approximately 80:20 (Figure 5.17). This ratio decreased to about 60:40 in September 2006 when the pool depth increased to 135 cm, but increased to about 90:10 in January 2007 when the pool depth shrunk to 45 cm. Shallow habitat, therefore, became more abundant as the water level in the pool dropped.

The distribution of shallow and deep habitats in the sampling pool are presented in Figure 5.15. The shallow habitat is mostly located at the periphery of the pool with the deeper habitat towards the centre. (The start of the deeper trench area is visible at the 25 m line in Figure 5.12a). The large difference in habitat availability is evident when Figure 5.15a, representing habitat availability at a gauge plate reading of 135 cm (September 2006), is compared with Figure 5.15b when the gauge plate reading was 45 cm (January 2007).

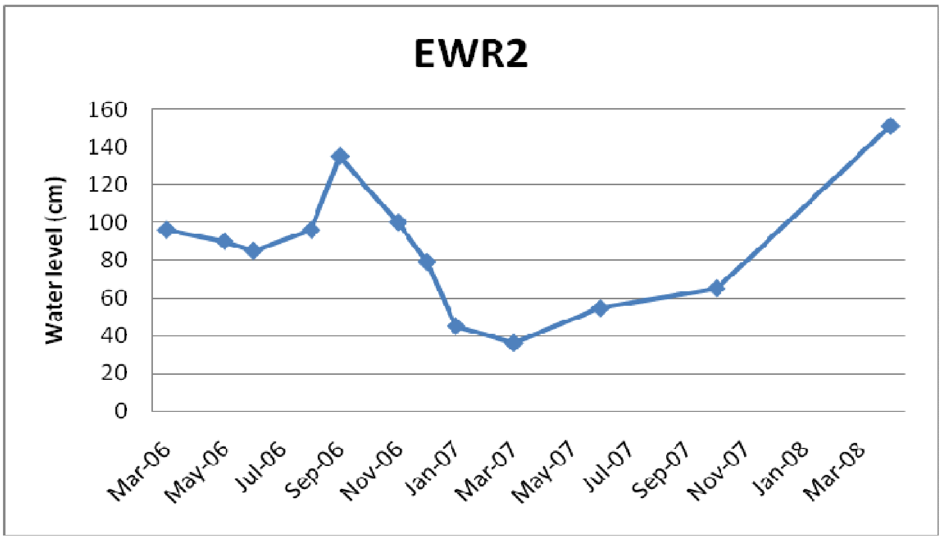


Figure 5.12: Gauge plate readings for EWR2, March 2006 to March 2008.

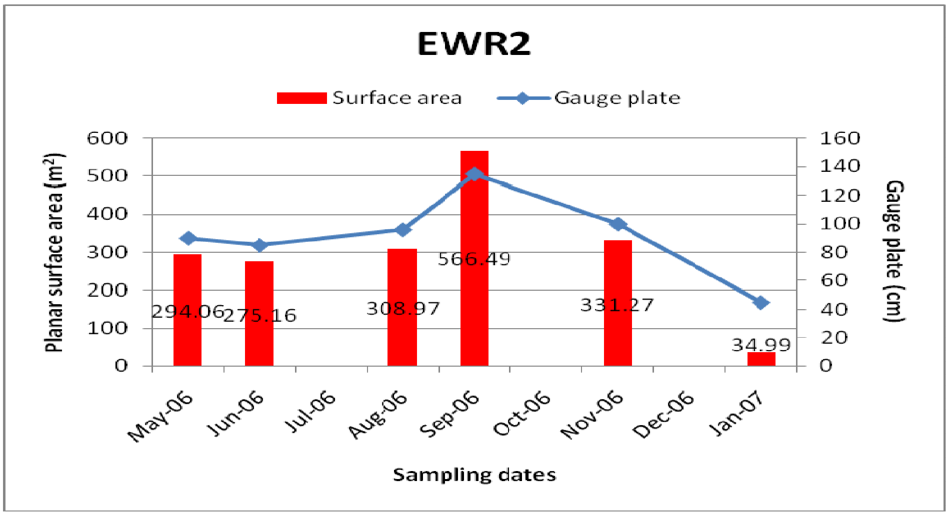


Figure 5.13: Pool surface area (m^2) for EWR2, May 2006 to January 2007 based on habitat survey data.

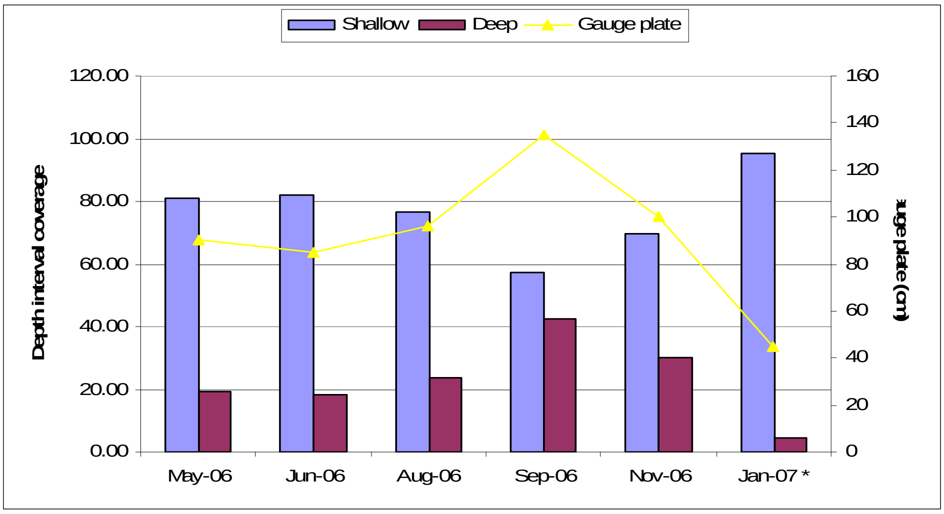


Figure 5.14: The distribution of shallow (<50 cm) and deep (>50cm) habitat for EWR2, May 2006 to January 2007.

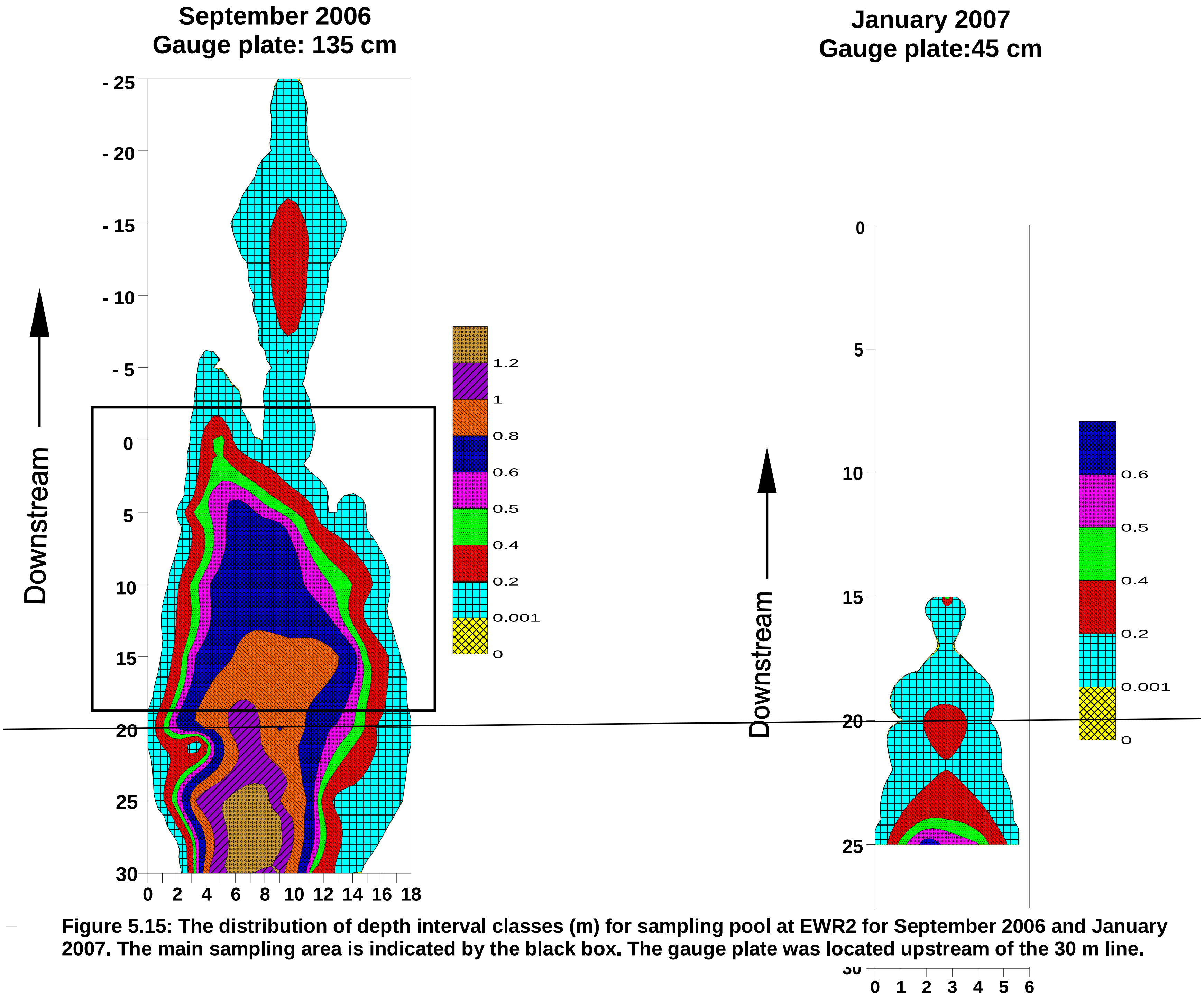


Figure 5.15: The distribution of depth interval classes (m) for sampling pool at EWR2 for September 2006 and January 2007. The main sampling area is indicated by the black box. The gauge plate was located upstream of the 30 m line.

Over a period of four months the surface area of the pool was reduced by about 93%, resulting in a substantial loss of both shallow and deep, but especially deep, habitat. In January 2007 no habitat deeper than 70 cm was available, compared to 140 cm in September 2006 (Figure 5.16).

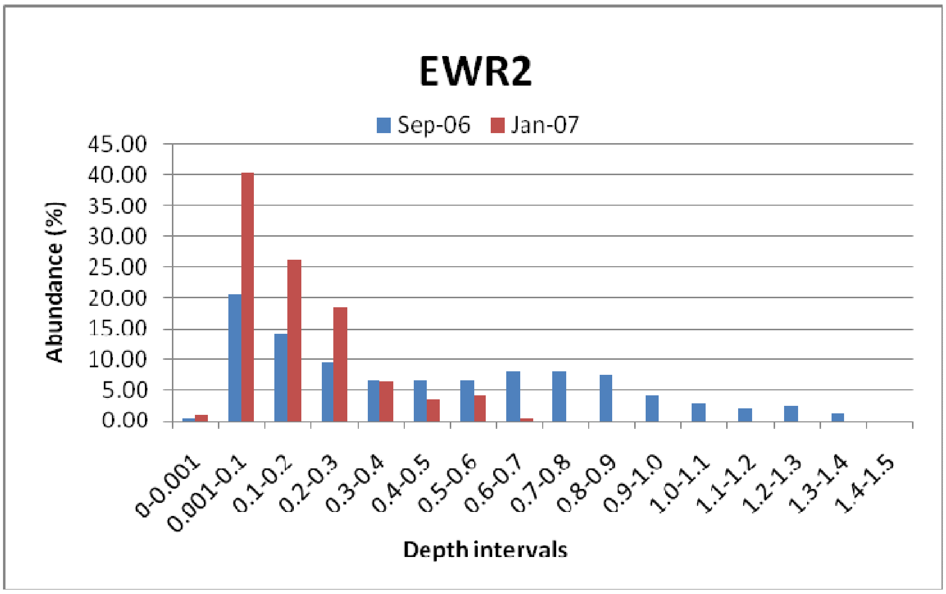


Figure 5.16: The distribution of depth intervals at EWR2 for September 2006 and January 2007.

The pool's substrate comprised mainly of clay, silt and organic material (see Figure 5.17). Substrate cover was very scarce in the pool, and reeds and reed stubbles were expected to provide the most cover for fish at the site. Reeds were more abundant in the shallower depth classes than in the deep (Figure 5.18) – even more so in January 2007 when the water level in the pool was very low (45 cm).

Water quality

Water temperatures at EWR2 ranged between 7.1°C (June 2006) and 29.1°C (December 2006; Table 5.7). Both the minimum and maximum temperatures were higher than that measured at EWR1, but could be attributed to the fact that sampling at this site usually took place at midday compared to early mornings at EWR1. Seasonal differences in water temperatures occurred, with the mean water temperature being highest in summer (28.3°C) and lowest in winter (9.1°C). The mean water temperatures for autumn and spring samplings were very similar, at 18.3°C and 17.3°C, respectively.

Electrical conductivity at EWR2 was considerably lower than at EWR1, varying between 21.46 mS/m (March 2008) and 99.3 mS/m (September 2007). Turbidity ranged between 91 NTUs (March 2008) and 3.4 NTUs (September 2006), with the turbidity generally being lower in spring and winter than in summer and autumn (Table 5.7).

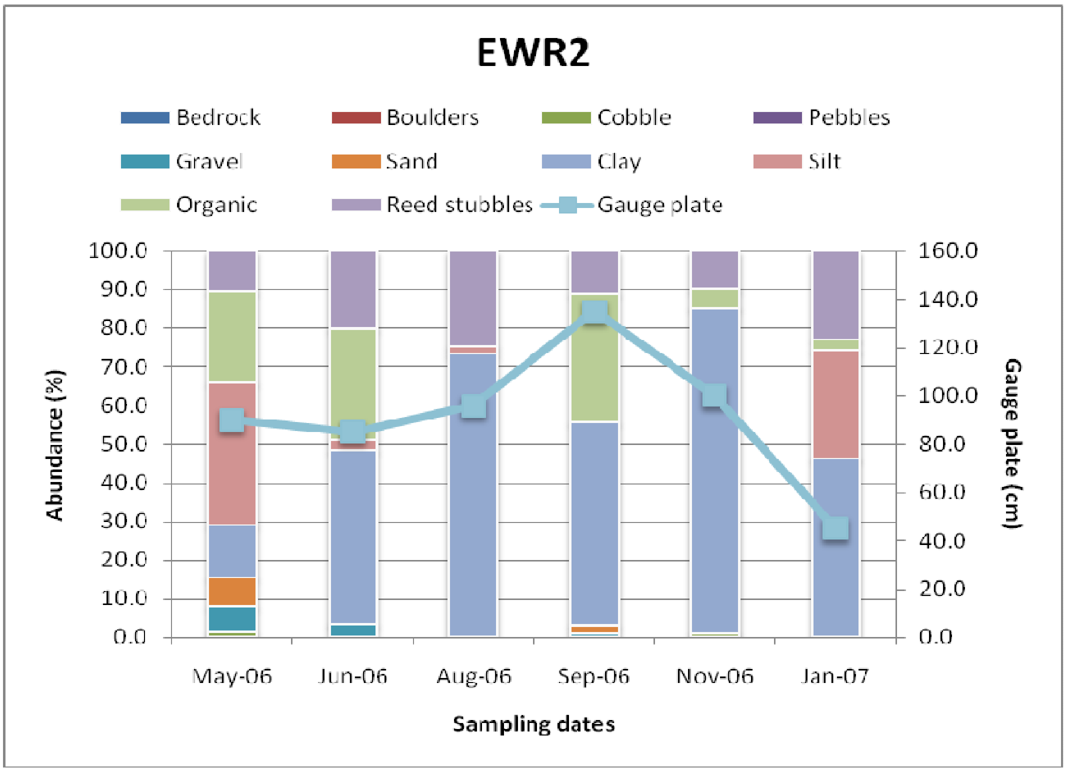


Figure 5.17: The percentage contribution of the different substrate classes for EWR2 based on habitat survey data for May 2006 to January 2007.

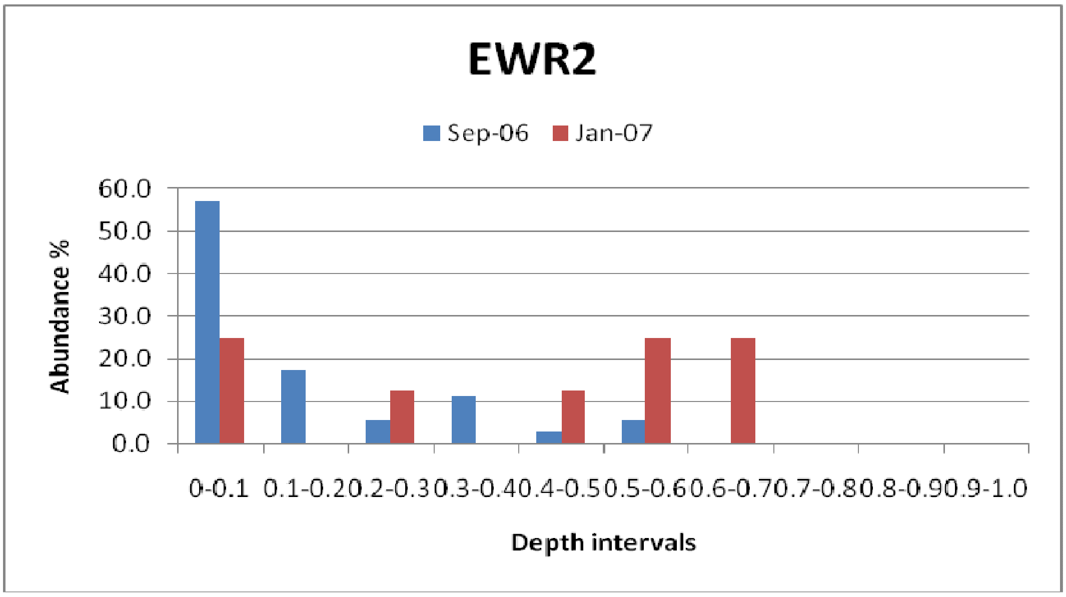


Figure 5.18: The distribution of reeds over the depth classes for EWR2 based on habitat survey data for September 2006 and January 2007.

Table 5.7: Selected water quality variables for EWR2, March 2006 to March 2008.

Date of sampling	*Time of samp-ling*	*Pool depth (cm)*	*Flow description*	*Water temp (°C)*	*pH*	*Conductivity (mS/m)*	*Diss. O_2 (mg/l)*	*O_2 %*	*Turbidity (NTU)*
Mar-06	14.45	96	No flow	19.8	6.92	27.0	1.2	13.2	15.8
May-06	09:40	90	No flow	9.0	7.30	26.0	2.1	18.8	9.7
Jun-06	14:40	85	No flow	7.1	7.69	26.2	8.1	68.7	6.4
Aug-06	14:35	96	No flow	8.0	7.74	34.7	11.3	97.7	7.2
Sep-06	13:50	135	No flow	15.6	8.34	45.1	11.4	113.5	3.4
Nov-06	10:00	100	No flow	21.1	7.70	59.2	6.9	78.8	5.2
Dec-06	16:40	79	No flow	29.1	9.07	70.5	7.9	103.2	-
Jan-07	14:40	45	No flow	27.5	7.92	89.8	4.5	56.7	28.0
Mar-07	09:15	36	No flow	20.4	7.55	85.8	6.5	73.7	23.0
Jun-07	13:00	73	No flow	12.2	7.70	54.5	4.34	39.7	27.0
Oct-07	13:50	65	No flow	15.4	8.48	99.3	14.69	148.7	4.1
Mar-08	13:00	151	No flow	24.1	7.01	21.46	4.1	41.1	91.0

5.2.2.2 Fish survey

Fish species expected

No information or historical data could be found in the literature for this river section. However, based on discussions with local farmers, an evaluation of the available fish habitat and cover at the site and previous experience, five indigenous fish species were expected, with varying degrees of confidence, to occur in this river section: the minnow, *B. anoplus;* the two *Labeos*, *Labeo capensis* and *L. umbratus*; the catfish *Clarias gariepinus*; and the yellowfish *Labeobarbus aeneus* (Table 5.8). The local farmers also confirmed the presence of the exotic carp, *Cyprinus carpio*, in the river reach.

Table 5.8: List of fish species expected at EWR2.

Fish species	**Expected**	**Confidence level**
Indigenous fish species		
Barbus anoplus	√	95%
Labeobarbus aeneus	√	60%
Labeo capensis	√	75%
Labeo umbratus	√	75%
Clarias gariepinus	√	95%
Exotic fish species	√	
Cyprinus carpio	√	95%

Fish species observed

A total of four indigenous and one exotic species were recorded at EWR2 between March 2006 and April 2008 (Table 5.9). The fish assemblage at the site was dominated by the family

Cyprinidae with *B. anoplus*, *L. capensis*, *L. umbratus* and *C. carpio* being recorded. *Labeobarbus aeneus*, which was expected, was not recorded during the study. *Clarias gariepinus*, one of five tropical species to be found in the Orange River system, was recorded on two occasions (March 2006 and 2008).

The number of species recorded at the site was generally low, with 2 or less species sampled during 10 of the 12 of the sampling visits (83.3% of visits; see Table 5.9). The highest number of species was recorded during March 2006 and March 2008 when 3 and 4 species were recorded respectiviely. In contrast, the March 2007 sample only produced 1 species, presumably coupled to the low water level in the pool at the time.

Species composition varied markedly between samples (see Figure 5.19). *Barbus anoplus* was the dominant species at the site: the most abundant (the species contributed 86.5% to the total abundance recorded at the site), but also had the highest frequency of occurrence (the species was present in 75% of the samples taken). It was also the only species recorded during the four sampling visits between December 2006 and June 2007. Most of the other species were present in low numbers and had a low frequency of occurrence. For example, *C. gariepinus,* that was the second most abundant, contributed 6.6% to the total abundance and was only present in two samples. The third most abundant species, *L. umbratus*, occurred in only 3 (25%) of the samples. *Labeo capensis* and *C. carpio* were the least abundant with only 2 and 3 specimens recorded, respectively.

The site yielded 408 fish specimens in total (contributing only 5.6% to the total number of fish sampled during the Seekoei River study), compared to the 1501 fishes recorded at EWR1. Large differences in total abundance also occurred at the site, ranging between 0 specimens in October 2007 and 231 in November 2006 (Table 5.9). Also, two thirds of the sampling efforts yielded a total of 20 specimens or less.

The CPUE was generally low and varied quite markedly between sampling visits (see Table 5.10). The highest CPUE was recorded in November 2006 when 7.97 specimens were sampled per minute. However, during six of the twelve sampling visits, less than one specimen was sampled per minute.

Table 5.9: Number of observed fish species at EWR2 (BAEN, *Labeobarbus aeneus*; BANO, *Barbus anoplus*; LCAP, *Labeo capensis*; LUMB, *Labeo umbratus*; Labeo, *Labeo* juveniles; CGAR, *Clarias gariepinus*; CCAR, *Cyprinus carpio*).

Sampling date	*Gauge plate*	*BAEN*	*BANO*	*LCAP*	*LUMB*	*Labeo*	*CGAR*	*CCAR*	*Species richness*	*Total abun-dance*
Mar-06	96	0	0	0	0	3	13	2	3	18
May-06	90	0	6	0	0	1	0	0	2	7
Jun-06*	85	0	11	0	9	0	0	0	2	20
Aug-06[+]	96	0	0	1	0	0	0	0	1	1
Sep-06	135	0	2	0	0	0	0	1	2	3
Nov-06	100	0	226	0	5	0	0	0	2	231
Dec-06	79	0	36	0	0	0	0	0	1	36
Jan-07	45	0	27	0	0	0	0	0	1	27
Mar-07	36	0	20	0	0	0	0	0	1	20
Jun-07	54.5	0	1	0	0	0	0	0	1	1
Oct-07	65	0	0	0	0	0	0	0	0	0
Mar-08	151	0	24	1	5	0	14	0	4	44
Total		**0**	**353**	**2**	**19**	**4**	**27**	**3**	**5**	**408**
Rel. abundance			**86.5**	**0.5**	**4.7**	**1.0**	**6.6**	**0.7**		**100**

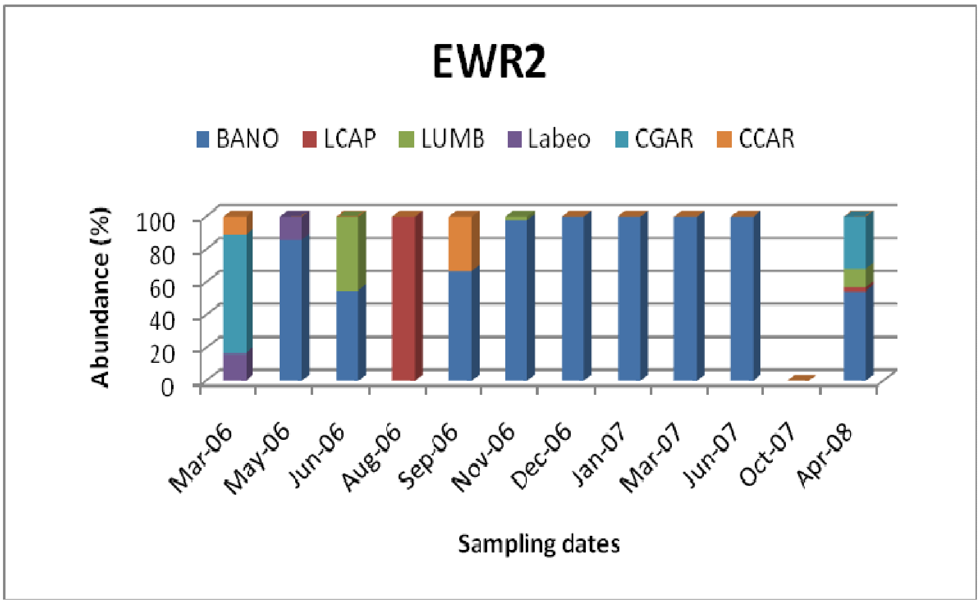


Figure 5.19: Species composition for the samples taken at EWR2, March 2006 to March 2008.

Table 5.10: Sampling effort, catch per unit effort (CPUE) and mean body lengths for fish sampled at EWR2, March 2006 to March 2008. (E/S, electroshocker powered by Yamaha generator; B E/S, backpack electroshocker powered by batteries).

Sampling date	*Pool depth*	*Sampling Method*	*Total abundance*	*Sampling effort*	*CPUE*	*Mean length*	*Min. length*	*Max. length*	Std
Mar-06	96	E/S	18	35	0.51	93.2	31	158	40.4
May-06	90	E/S	7	25	0.28	32.6	27	42	5
Jun-06	85	E/S	20	17	1.18	34.5	22	45	6.9
Aug-06	96	B E/S	1	25	0.04	128			
Sep-06	135	B E/S and E/S	3	45	0.07	59.7	25	119	51.63
Nov-06	100	B E/S	231	29	7.97	48.6	20	70	10.21
Dec-06	79	B E/S	36	15	2.4	44	30	65	10.77
Jan-07	45	B E/S	27	7	3.86	47.1	34	68	10.1
Mar-07	36	B E/S	20	12	1.67	51.9	40	60	6.06
Jun-07	54.5	B E/S	1	13	0.08	34			
Oct-07	65	B E/S	0	14	0				
Apr-08	151	B E/S	44	19	2.32	85.7	27	252	53.34

With the exception of *B. anoplus,* for which both juvenile and mature specimens were recorded, all of the fish sampled at EWR2 were sexually immature. The range of body lengths recorded for the various fish species are presented in Table 5.11.

The recorded body lengths for *B. anoplus* varied between 20 mm (November 2006) and 70 mm (also November 2006; see Table 5.11). The presence of juveniles (body length <38 mm) in the samples indicated that successful recruitment took place during the spring/summer of 2006, 2007 and 2008. The distribution of size classes in Figure 5.20, for example, indicates that an early spawning took place in September/October 2007. Sexually mature specimens (body length >38 mm) were only present in the samples taken between November 2006 and March 2007.

The *C. gariepinus* specimens recorded in March 2006 and April 2008 were immature individuals measuring between 70 mm and 252 mm. This species is known to reach a body length of about 200 mm (SL) within a year (Skelton 2001) and in the Vanderkloof Dam only reaches sexual maturity after four to six years, at lengths of more than 740 mm (Quick and Bruton 1983). Juveniles of less than 200 mm have previously been reported to enter shallow, well-vegetated areas to forage (Bruton 1978).

The other species reached sexual maturity as follows: *L. capensis* at 160 to 250 mm in the Caledon River (Baird and Fourie 1978) and at 320 to 350 mm in Vanderkloof Dam (Tomasson *et al.* 1984); *L. umbratus* at 350 to 380 mm in Vanderkloof Dam (Tomasson *et al.* 1984).

Table 5.11: Range of body lengths recorded for fish species at EWR2, March 2006 to March 2008. (The mean fork length for each species is indicated in brackets).

Sampling date	*Pool depth*	*Total abundance*	*Barbus anoplus*	*Labeo capensis*	*Labeo umbratus*	*Labeo*	*Clarias gariepinus*	*Cyprinus carpio*
Mar-06	96	18	31				70-158 (100mm)	34
May-06	90	7	27-33 (31 mm)			48		
Jun-06	85	20	22-33 (29.4mm)		32-45 (40.8mm)			
Aug-06	96	1		128				
Sep-06	135	3	25-35 (30mm)					119
Nov-06	100	231	20-70 (48.6mm)		43-54 (49mm)			
Dec-06	79	36	30-65 (44mm)					
Jan-07	45	27	34-68 (47.1mm)					
Mar-07	36	20	40-60 (51.9mm)					
Jun-07	54.5	1	34					
Oct-07	65	0						
Apr-08	151	44	27-69 (51.4mm)	133	51-67 (59.2mm)		99-252 (150.6mm)	

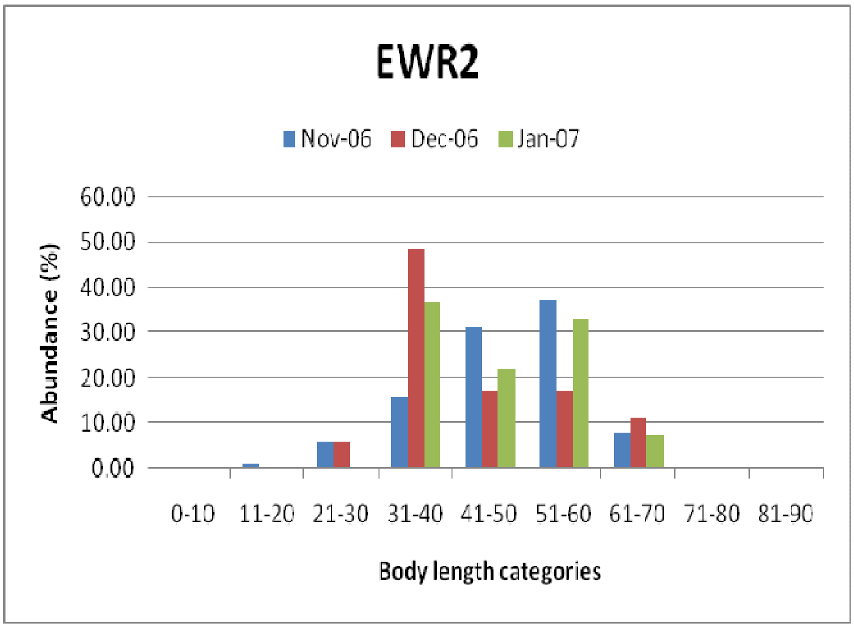


Figure 5.20: The percentage length frequency distribution of *B. anoplus* specimens at EWR2, November 2006 to January 2007.

5.2.2.3 Microhabitat

Measurements to describe the fish microhabitat were taken in the sampling pool at the exact spot where the fish specimens were collected (or where we sampled in the cases where no fish was found). Measurements were recorded at between 10 and 20 random points and included water depth, substrate and fish cover (available at that point).

Water depth

Most of the fish were sampled towards the middle of the sampling pool at depths ranging between 9 cm (mean minimum depth=21.8 cm; std=10.3 cm) and 100 cm (mean maximum depth=73.4; std=20.5 cm; Table 5.12 and Figure 5.15a). The sampling pool at EWR2 represented a very unstable habitat for fish, as indicated by the mean depth that ranged between 26 cm (March 2007) and 60.85 cm (March 2008). The mean depth of the area where we sampled was 43.3 cm (std=10.9) compared to a mean of 88.2 cm (std=35.8; Figure 5.21) for the gauge plate readings over the same period. The mean depth of the fish microhabitats generally increased with an increase in pool depth (as reflected by the gauge plate readings; see Figure 5.21).

The pool's surface area increased and shrunk as the water level in the pool fluctuated (Table 5.12). For example, the pool's surface area decreased from 566.49 m^2 in September 2006 when the pool was 135 cm deep to a mere 34.99 m^2 in January 2007 and a maximum depth of 45 cm measured. More specimens were sampled in January 2007 (CPUE=3.86 fish/minute) when the pool's volume was reduced than in September 2006 (CPUE=0.07). Although it appears as if the reduction in pool volume enhanced sampling success, it should also be noted that the team spent 45 minutes sampling the relatively small pool in September 2006, thoroughly covering all available habitats.

Table 5.12.: Depth measurements of fish microhabitats at EWR2, March 2006 and March 2008. Fish abundance, CPUE and pool surface area are also indicated. CPUE, catch per unit effort; Std, standard deviation.

Sampling date	*Gauge plate (cm)*	*Mean depth (cm)*	*Minimum depth (cm)*	*Maximum depth (cm)*	*Fish abundance (n)*	*CPUE (fish/min)*	*Surface area of pool (m^2)*
Mar-06	96	47.2	29	82	18	0.51	
May-06	90	39.7	37.5	41	7	0.28	294.06
Jun-06	85	44.4	20	100	20	1.18	275.16
Sep-06	135	59.9	29	93	3	0.07	566.49
Nov-06	100	45.3	28	78	231	7.97	331.27
Dec-06	79	33.0	10	59	36	2.4	
Jan-07	45	38.8	9	66	27	3.86	34.99
Mar-07	36	26.0	10	45	20	0.6	
Oct-07	65	37.2	15	75	0	0	
Mar-08	151	60.9	30	95	44	2.32	
Mean	**88.2**	**43.3**	**21.8**	**73.4**	**40.6**	**1.92**	**300.4**
Std	**35.8**	**10.9**	**10.3**	**20.5**	**68.3**	**2.5**	**189.0**

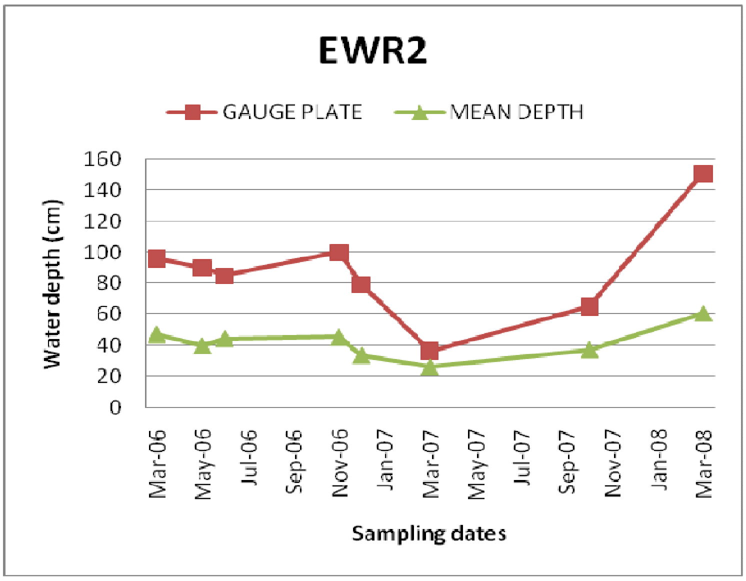


Figure 5.21: Mean depth in relation to water level (gauge plate readings) at EWR2, March 2006 to March 2008.

Velocity-depth classes

The sampling pool at EWR2 was isolated from surface water in the rest of the river channel during each field visit and surface channel flow was never witnessed at the site.

The fish were predominantly sampled in shallow (<50 cm) habitat. Shallow habitat was the dominant depth classduring all the visits, except in September 2006 and March 2008 when the water level in the pool was high (Figure 5.22a). In September 2006 (gauge plate reading=135 cm) and March 2008 (151 cm) the ratio between shallow and deep habitats was 40:60 and 25:75, respectively.

Fish cover and substrate

The pool's substrate is mainly composed of silt, as reflected in the microhabitat measurements (Figure 5.22b). Substrate cover in the form of boulders, cobbles and pebbles was rare at the site. Fish cover was mainly provided by reeds and reed stubbles (emergent aquatic vegetation), aquatic grasses (submerged aquatic vegetation), algal masses, water column and drifting macrophytes (*Azolla* sp.) (see Figure 5.22c).

Reeds occurred not only along the periphery of the pool at EWR2, but have also intruded into the channel. Reeds and reed stubbles were the main source of fish cover at the site, especially for *B. anoplus* which was often found between the reeds in the shallow peripheral areas of the pool (e.g. May 2006, September 2006 and April 2008) or between the reed clumps in the middle of the sampling pool (May 2006 and June 2006).

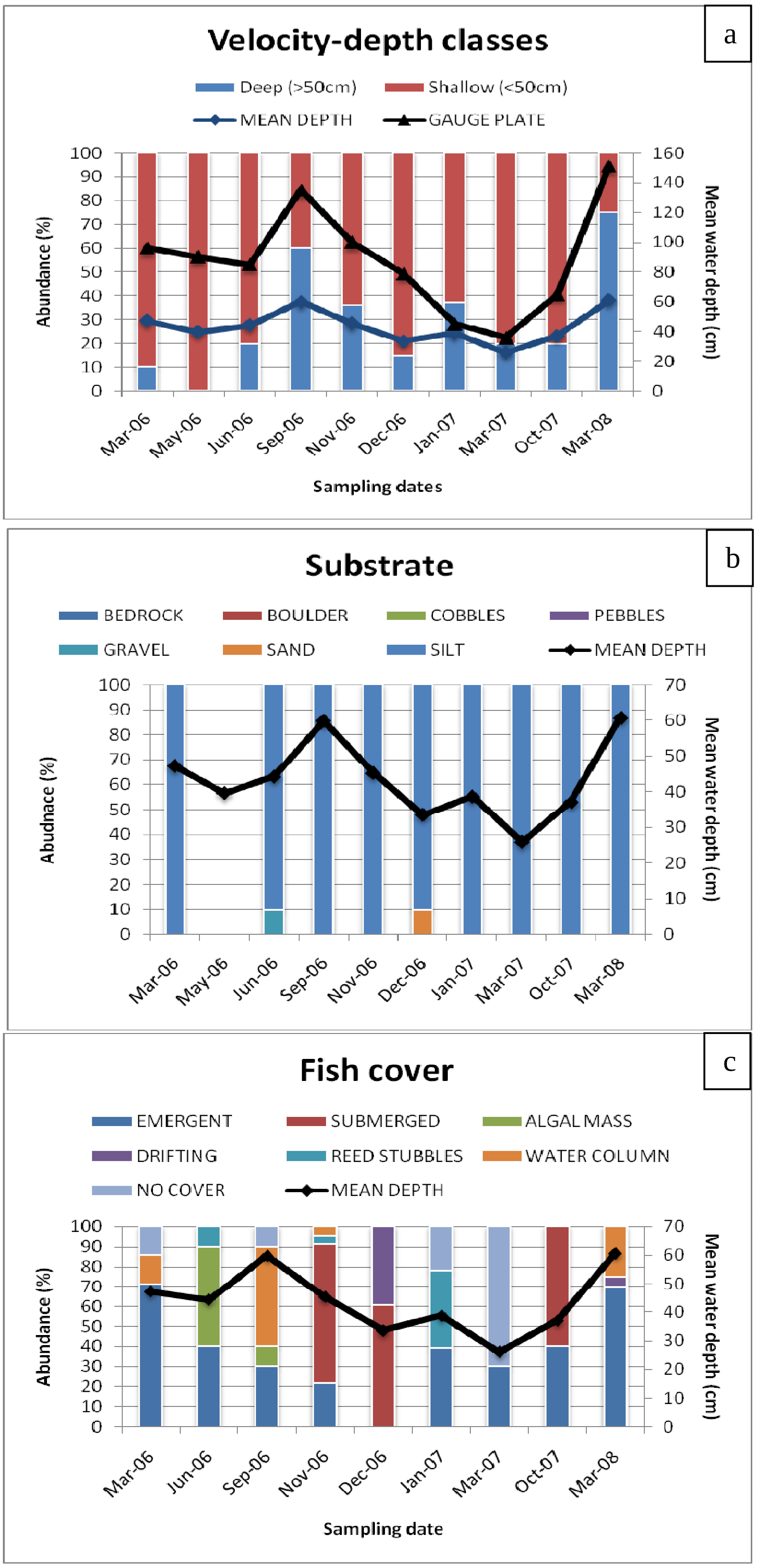


Figure 5.22: The distribution of depth classes (a), substrate composition (b) and fish cover (c) for EWR2 based on microhabitat measurements between March 2006 and March 2008.

The indigenous fine oxygen weed *Lagarasiphon muscoides* was especially abundant at the site in November and December 2006, when it was an important source of cover for *B. anoplus* specimens (Figure 5.22c). Masses of algal growth was present on the pool bottom during the 2006 winter samples and provided cover for *B. anoplus*, *L. umbratus* (juveniles) and *L. capensis* (FL=128 mm) specimens. The fish were found “hiding” underneath the algal masses at the bottom of the pool.

The water column mainly provided cover when the pool was deeper, such as in September 2006 and March 2008 when the mean water depth was more than 40 cm (see Figure 5.22c). Then the *C. carpio* specimens were found in the deeper areas towards the middle of the pool.

5.2.2.4 Discussion for EWR2

Compared to EWR1, EWR2 represented a relatively unstable habitat for fish. The naturally low frequency of surface water connection in this river reach has been further reduced by a large number of weirs and small dams erected on the river. As a result, the pool at EWR2 is estimated to experience surface water connection for only 5%, or less, of the time. Indeed, water level at the site fluctuated considerably over the two years. The gauge plate was however placed in a deeper trench area at the site and did not accurately reflect the conditions in the sampling pool. Large fluctuations in the surface area and volume of the sampling pool occurred, especially in the first year of the study when the sampling pool’s surface area was reduced by 93.8% between September 2006 and January 2007.

The sampling pool comprised predominantly shallow habitat, but the ratio between shallow and deep habitat changed continually in response to the changing water level. The substrate consisted mainly of silt and clay covered by organic material and reeds and reed stubbles were expected to provide the most cover to fishes. The pool generally exhibit good water quality and the electrical conductivity were markedly lower than at EWR1.

Five fish species were recorded at EWR2: *B. anoplus*, *L. capensis*, *L. umbratus*, *C. gariepinus* and the exotic *C. carpio*. The site had the lowest yield of the four sites - only 5.6% of the total number of fish sampled in the Seekoei, which may be a reflection of the variable habitat conditions prevailing in the sampling pool. Catch per unit effort was generally low (compared to EWR1) and varied markedly between samples. For example for half of the samples taken at the site, less than one specimen was sampled per minute. Species richness and composition, as well as total abundance, also varied markedly between samples. Fausch and Bramblett (1991) also found that species composition and relative abundances changed markedly at sites with shallow, simple habitat in the intermittent Purgatoire River (Colorado, USA), compared to deep, complex pools where these parameters remained relatively constant.

Barbus anoplus was both the most abundant and the most frequently sampled species and comprised nearly 87% of the total number of fish sampled at the site. It was also the only species recorded more than three times. *Barbus anoplus*’ small size enables it to utilize new food sources in highly variable environments inaccessible to other species (Cambray undated). Its life-history traits enables the species to colonize temporary and unstable habitats with alternating booms and busts in population size (Cambray and Bruton 1985), and may be the reason why the species was able to persist at EWR2. Both adults and juveniles were recorded at the site and the data showed that successful recruitment did occur at the site.

Catch per unit effort was not statistically related to any of the physical characteristics measured for the pool. Water level did, however, have an influence on the number of species sampled; the correlation indicating that the number species increase with water level ($r=0.747$; $p<0.01$). A similar relationship between species richness and water depth has also been shown in other studies (e.g. see Schlosser 1988, Capone and Kushlan 1991; Harvey and Stewart 1991).

Neither total abundance, nor *B. anoplus* abundance, was related to CPUE ($p>0.9$; see Fig. 5.23). It was, however, connected to the recruitment of young *B. anoplus* (correlation pool depth and minimum FL: $r=-0.65$; $p<0.05$), but not to the recruitment of any of the other species. It therefore seems as if the shallower habitat of the sampling pool was used as a nursery area by *B. anoplus*. Also for the other species present at the site, only juveniles and sub-adults were recorded here. *Labeo umbratus* young were recorded at three opportunities (June 2006, November 2006 and early April 2007), albeit in low numbers, while immature *C. gariepinus* specimens were recorded twice in autumn, namely in March 2006 and 2008. (No C. gariepinus young were recorded in March 2007, but the low water level is expected to have restricted access in the latter).

It is well-known that smaller fish again often reside in shallow areas in order to evade piscivorous fishes (e.g. see Power 1984; Schlosser, 1988; Harvey and Stewart 1991; Gelwick et al. 1997). Larger fish (e.g. >50 mm TL as indicated by Gelwick et al. 1997), however, are again more vulnerable to predation risk from wading or diving predators (e.g. herons, otters and water mongoose) in shallow water and seem to avoid waters less than 30 cm deep (Gelwick et al. 1997; Harvey and Stewart 1991). At EWR2, most of the sampled fish were smaller than 70 mm, the exception being *L. capensis* (length range: 128-133 mm) and *C. gariepinus* (length range 70-252 mm). Juvenile *C. gariepinus* individuals are known to enter shallow, well vegetated areas to forage (Bruton, 1978) and might have only entered the sampling pool temporarily to feed.

The fish were sampled predominantly in shallow habitat at mean depths ranging between 26 cm and 60.9 cm. The pool's substrate is mainly composed of silt. Substrate cover in the form of boulders, cobbles and pebbles was very rare at this site and fish cover comprised mainly reeds, reed stubbles, aquatic grasses, algal masses, and drifting macrophytes (*Azolla* sp.). *Barbus anoplus* was often associated with the reeds, water grasses (in summer) and algal masses (in winter). A thick mat of algae covered the bottom of the pool between June and September 2006 and fish (*L. umbratus* and *L. capensis*) were often sampled from beneath this algal layer. *Cyprinus carpio* specimens were sampled in the open water.

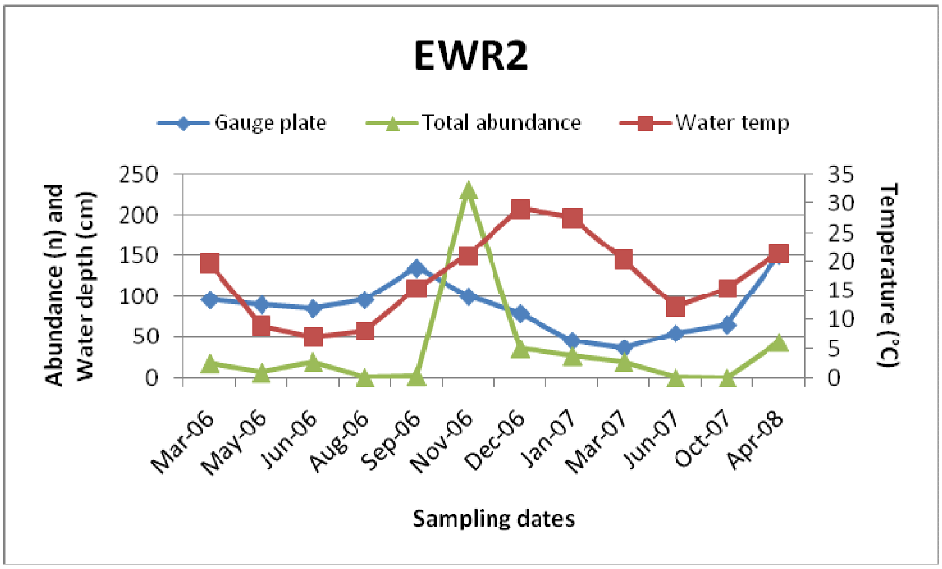


Figure 5.23: Total fish abundance, water level (gauge plate readings) and water temperatures for EWR2, March 2006 to April 2008.

5.2.3 Site EWR3

EWR3 is situated in quaternary catchment D32J approximately 2 km upstream of EWR4, and 6 km upstream of gauging station D3H015. In contrast to the rest of the catchment, which is relatively flat (except for the upper reaches in the Sneeuberge), the river passes through a gorge in this area. Runoff from the dolerite ridges flanking the river contributes to baseflow, resulting in a higher natural frequency of surface water connection (approximately 50% of the time) in this river section. The impacts of flow regulation also appear to be less than for the other macro-reaches and a decrease of only 2% in the natural frequency of channel flow was indicated by the hydrological model (Hughes 2008). Flow regulation in the river does have a relatively large impact on the flood regime, specifically the 1:2 and 1:5 year floods. Hughes (2008) indicated that very little outflow is experienced from D32F, severely curtailing 1:5 year floods at this point.

5.2.3.1 Instream habitat

Potential fish habitat

The sampling site comprises of a large pool, a glide and a downstream rapid/riffle. Downstream of the pool, the river has two channels separated by a vegetated mid-channel bar (see Figure 4.3). The hydraulic survey indicated that the flow in the right channel is expected at a maximum pool depth of 2.469 m (at a gauge plate reading of approximately 76 cm), while flow in the left channel would occur at a maximum pool depth of 3.39 m (at a gauge plate reading of approximately 168 cm; Dollar, 2007). In 2006 the gauge plate readings gradually decreased from 115 cm in May to 83.5 cm in November (see Figure 5.24). Between November and December it further dropped to below 76 cm and surface flow stopped. The pool was still isolated in March 2007 when a gauge plate reading of 15.5 cm was recorded. As a result, the number of sampling points was reduced to four in December 2006 (due to the rapid being dry), and to two in January and March 2007 (when the Outflow and Pool C also dried up). Between March and June 2007 the river started flowing again and kept flowing until April 2008.

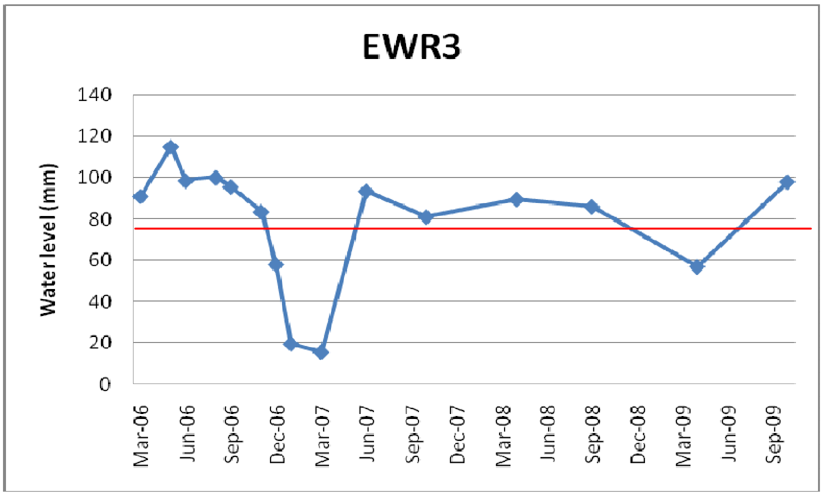


Figure 5.24: Gauge plate readings for EWR3 between March 2006 and September 2009. The red line indicates a depth of 76 cm, the point at which surface flow is expected to occur at the site.

Pool habitat

The pool at EWR3 is more than a kilometer long at full supply level (FSL) and about 1.9 m deep at the deepest point. A volume survey by the Department of Water Affairs (Free State) in December 2006 indicated that the pool reaches FSL at a gauge plate reading of 79 cm. When full, it has a volume of approximately 32517.46 m^3 and covers an area of c. 26508 m^2. At a gauge plate reading of 40 cm, pool volume is expected to decrease to 22775.85 m^3 and to cover an area of 23991.0 m^2. At 20 cm, the pool's surface area is expected to cover about half the area it covers at FSL. The pool's substrate is composed of coarse to fine sand.

Flowing habitats

The habitat surveys conducted at EWR3 focussed on the rapid/riffle habitat in the right channel. Three points were sampled in this section, the outflow of the pool into the right channel (a glide of ±10 m long; referred to as Outflow), a wider shallower section of ±60 m connecting the outflow to the rapid (referred to as Pool C), and a rapid of ±40 m long (see Figure 5.25a and b).

In an attempt to show how habitat availability and characteristics changed in this river section as the water level dropped, results from the habitat surveys conducted in May 2006 (gauge plate reading: 115 cm) and November 2006 (gauge plate reading: 83.5) are compared in Table 5.13 and Figure 5.25. In December 2008 the water level in the main pool dropped to 58 cm (this was not a scheduled visit and no habitat survey was done). During the field visits in January and March 2007, this section of the river was dry.

Outflow

In May the mean width of the wetted area was 9.8 m with water depths ranging between 6 and 60 cm (mean water depth=36.92 cm; Table 5.13). Flow measurements varied between 0.039 m/s and 0.284 m/s (mean flow=0.13 m/s). By November, the mean width decreased to 7.2 m and the mean water depth was reduced by 15 cm to 21.92 cm. No flow was detected by the flow meter.

Slow-deep habitat dominated the available habitat in both May and November (see Figure 5.26a). Based on the May survey, the substrate in this river section was composed of sand (31.8%), gravel (23.68%), cobbles (28.95%), boulders (10.53%), pebbles (2.63%) and organic material (2.63%; Figure 5.26b). In November boulders were the most abundant of the substrate categories, followed by gravel (30%), cobbles (15%) and pebbles (5%). The substrate (70%) and sedges (25%) was expected to provide the most cover to fish in May (Figure 5.26c). However, as the water edge receded, terrestrial grasses became more abundant, contributing about 30% of total cover in November.

Pool C

In this habitat, the mean width of the wetted area was reduced by about 40% between May and November. The mean water depth decreased by 44% from 16.96 cm to 9.46 cm, while maximum flow measurements dropped from 1.379 m/s to 0.407 m/s.

All four velocity-depth classes were represented in this river section in May, with slow-shallow being the most abundant (see Figure 5.26a). As the water level dropped, the deeper habitat was lost and by November only slow-shallow (92%) and fast-shallow (8%) habitat remained. The substrate was composed of mainly boulders, cobbles and gravel, which also provided the most fish cover (Figures 5.26b and c). In November filamentous algae became quite abundant in this section, contributing nearly 30% to total cover.

Rapid

The wetted area in the rapid decreased from 6.3 m to 4.3 m between May and November (Table 5.13). The average depth of the water was reduced by more than 50% from 21.39 cm to 10.23 cm, and the mean flow changed from fast (0.32 m/s) to slow flow (0.19 m/s; based on the definition of Kleynhans, 1999).

In May all four velocity-depth classes were present in the rapid section, with shallow habitat being more abundant than deep habitat. By November, three of the four classes disappeared and only slow-shallow habitat remained (Figure 5.26a). The rapid’s substrate was dominated by boulders both in May and November (Figure 5.26b) and accordingly substrate cover was expected to be the most important source of fish cover. Filamentous algae were also present in the rapid in November, and were present at 50% of the points surveyed (see Figure 5.26c).

Table 5.13: Water depths and surface flow based on habitat survey data for EWR3 for May and November 2006.

Date	*Gauge plate (cm)*	*Wetted area – mean width (m)*	*Water depth*			*Surface flow (measured at 1/3 of the water column)*		
			Mean depth (cm)	Minimum depth (cm)	Maximum depth (cm)	Mean flow (m/s)	Maximum flow (m/s)	Minimum flow (m/s)
Outflow								
May-06	115	9.8	36.92	6	60	0.13	0.284	0.039
Nov-06	83.5	7.2	21.92	1	40	0	0	0
Pool C								
May-06	115	15	16.96	1	44	0.29	1.379	0.032
Nov-06	83.5	8.7	9.46	2	25	0.21	0.407	0.05
Rapid								
May-06	115	6.3	21.39	6	43	0.32	0.7	0.028
Nov-06	83.5	4.3	10.23	1	19	0.19	0.445	0.062

Water quality

Water temperatures at EWR3 ranged between 7.7°C (June 2006) and 26°C (December 2006; Table 5.14). Temperatures were highest in summer (mean for summer samples = 25.6°C) and lowest in winter (mean for winter samples = 8.6°C). The mean water temperatures for autumn and spring were very similar at 17.13°C and 17.7°C, respectively.

Electrical conductivity varied between 40.4mS/m (in May 2006) and 116.4 mS/m (in December) 2006 (Table 5.14). The electrical conductivity readings taken from November 2006 to March 2007 when surface flow stopped were about 20 mS/m higher than the average conductivity (82.39 mS/m) recorded during the study. Turbidity readings were also higher in January and March 2007 when the pool was isolated. The dissolved oxygen levels in January and March 2007 were 5.11 mg/l (62.1% saturated) and 6.1 mg/l (67.8% saturated), respectively.

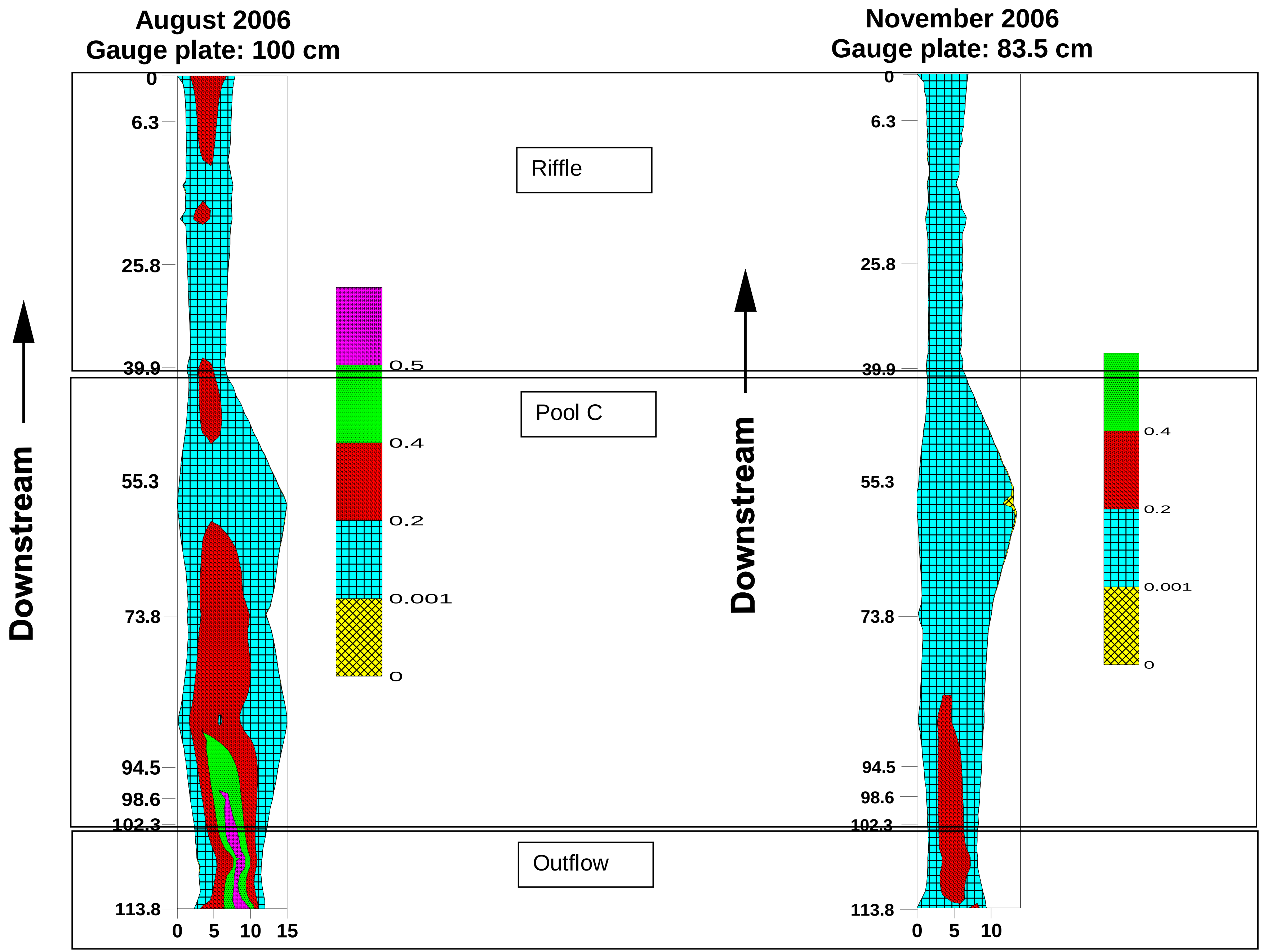


Figure 5.25: The distribution of depth interval classes (m) for the glide/riffle/rapid at EWR3 for (a) August 2006 (gauge plate reading: 100 cm) and (b) November 2006 (gauge plate reading: 83.5 cm). The three sampling points downstream of the main pool are indicated.

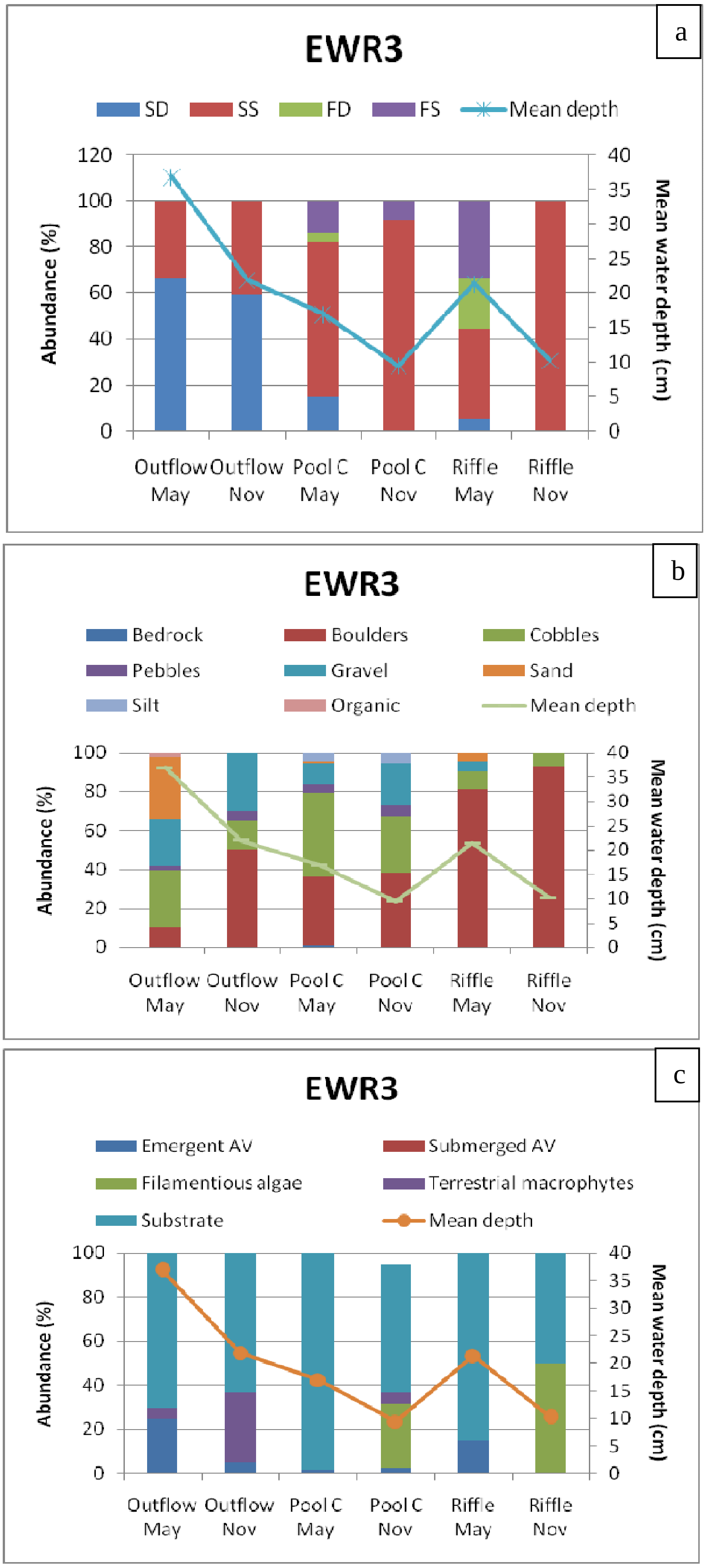


Figure 5.26: The distribution of velocity-depth classes (a; based on Kleynhans 1999), substrate composition (b) and fish cover (c) for EWR3 based on habitat survey measurements taken in May and November 2006.

Table 5.14.: Selected water quality variables for EWR3, March 2006 – April 2008 (measurements taken in main pool).

Date of sampling	*Time of samp-ling*	*Pool depth (cm)*	*Water temp (°C)*	*pH*	*Conduc-tivity (mS/m)*	*Diss. O_2 (mg/l)*	*O_2 %*	*Turbidity (NTU)*
Mar-06	10:50	91.0	19.9	8.24	61.4	3.44	38.0	5.6
May-06	09:30	115.0	10.2	7.84	40.4	7.24	65.4	10.0
Jun-06	09:35	98.5	7.5	8.54	60.7	9.38	79.4	5.8
Aug-06	09:40	100.0	10.7	8.81	80.3	8.34	79.3	3.6
Sep-06	10:20	95.5	15.4	8.49	87.2	9.25	94.9	6.5
Nov-06	08:50	83.5	21.3	8.57	101.9	6.41	76.0	5.2
Dec-06	12:00	58.0	26.0	8.70	116.4	-	-	-
Jan-07	09:15	19.5	25.1	9.30	114.0	5.11	62.1	27.0
Mar-07	09:15	15.5	18.5	9.40	97.9	6.1	67.8	20.0
Jun-07	09:15	93.5	7.7	8.18	79.6	5.78	48.8	5.3
Oct-07	08:55	81.0	16.4	8.75	88.7	8.21	83.7	6.2
Apr-08	08:40	102.0	19.7	8.27	60.2	5.6	51.6	4.1

5.2.3.2 Fish survey

Fish species expected

Eight indigenous species were expected at EWR3 (Table 5.15). No information could be found of previous fish surveys done in this section of the river. The list was, therefore, based on an evaluation of the available fish habitat and cover and local knowledge. Local information did not indicate the presence of *A. sclateri* or *T. sparmanii* but were added to the list based on the fact that the species do occur in the upper Orange River and habitat conditions suited the requirements of the mentioned species. Although Hocutt and Skelton (1983) indicated that *L. kimberleyensis* does not occur in the southern tributaries of the Orange River, it was added to the list based on the following reasons. Firstly, the species is known to migrate into the lower section of the river for spawning (Dr. J. Cambray, Albany Museum, pers. comm.). Secondly, in years with higher rainfall, such as 2006, it might be possible for the species to exist at sites satisfying their habitat requirements. The local farmer, Mr. C. Venter, confirmed the presence of the exotic *C. carpio*.

The habitat integrity of the instream and riparian zones in this river section was considered to be largely natural and moderately modified, respectively. Flow regulation was again regarded as a major impact factor.

Table 5.15: List of fish species expected at EWR3.

Fish species	*Expected*	*Confidence level*
Indigenous fish species		
Barbus anoplus	√	95%
Labeobarbus kimberleyensis	?	10%
L. aeneus	√	95%
Labeo capensis	√	95%
L. umbratus	√	95%
Clarias gariepinus	√	95%
Austroglanis sclateri	?	10%
Tilapia sparrmanii	?	10%
Exotic fish species		
Cyprinus carpio	√	95%

Fish species observed

Overview of site

A total of 2211 fish specimens, 30.3% of the total number of fish sampled in the Seekoei River, were collected at site EWR3. Six species were collected: *B. anoplus*, *Labeobarbus aeneus*, *L. capensis*, *L. umbratus*, *Clarias gariepinus* and the exotic *C. carpio* (Table 5.16). Of these, *B. anoplus* and *L. capensis* were the most abundant, contributing 23.97% and 23.29% to the total number of fish sampled at the site, respectively. These species also had the highest frequency of occurrence with *B. anoplus* being recorded during every sampling visist and *L. capensis* during 11 of the 12 visits. *Clarias gariepinus* was the least abundant species sampled at the site – only 51 individuals (2.31% of the total catch at the site) were captured (Table 5.16). The species had the lowest frequency of occurrence and was only recorded at four occasions.

The highest fish abundance and species richness were recorded between September 2006 and January 2007 when the water level began to drop, with nearly 60% of the total number of fish recorded at the site sampled during this period. All six species were recorded in September and November 2006, while five species were present in the December 2006 and January 2007 samples. A total of 583 fish, representing all six species recorded at EWR3, was captured in November 2006 (gauge plate reading 83.5 cm). The bulk of the November sample comprised of *C.carpio* juveniles (37%), *B. anoplus* (34.1%) and *L. capensis* (13.7%) specimens (Figure 5.27). The other species, *L. aeneus*, *L. umbratus* and *C. gariepinus* respectively contributed 9.3%, 4.8% and 1% to the total abundance. The lowest number of individuals was recorded in October 2007, when only five *B. anoplus* specimens were captured.

Table 5.16: Number of observed species at EWR3, March 2006 to April 2008. (BAEN, *Labeobarbus aeneus*; BANO, *Barbus anoplus*; LCAP, *Labeo capensis*; LUMB, *Labeo umbratus*; Labeo, *Labeo* juveniles; CGAR, *Clarias gariepinus*; CCAR, *Cyprinus carpio*).

Sampling date	*Gauge plate*	*BAEN*	*BANO*	*Barbus juveniles*	*LCAP*	*LUMB*	*Labeo juveniles*	*CGAR*	*CCAR*	*Total abundance*	*Sp. richness*
Mar-06	91	2	13	0	85	0	229	27	0	356	4
May-06	115	0	40	0	40	2	9	0	0	91	**3**
Jun-06	98.5	0	4	0	40	7	4	0	0	55	**3**
Aug-06	100	0	2	2	25	9	0	0	0	38	**3**
Sep-06	95.5	3	11	2	76	108	0	8	5	213	**6**
Nov-06	83.5	54	199	0	80	28	0	6	216	583	**6**
Dec-06	58	5	27	61	9	1	0	0	46	149	**5**
Jan-07	19.5	32	158	0	97	28	0	0	61	376	**5**
Mar-07	15.5	6	32	9	39	16	0	0	0	102	**4**
Jun-07	93.5	34	16	0	21	2	0	0	0	73	**4**
Oct-07	81	0	5	0	0	0	0	0	0	5	**1**
Apr-08	89.5	2	23	94	3	31	5	10	2	170	**6**
Total		**138**	**530**	**168**	**515**	**232**	**247**	**51**	**330**	**2211**	**6**
Relative abundance		**6.24**	**23.97**	**7.60**	**23.29**	**10.49**	**11.17**	**2.31**	**14.93**		
Frequency of occurrence (%)		**8/12 (66.7)**	**12/12 (100)**	**5/12 (41.7)**	**11/12 (91.7)**	**10/12 (83.3)**	**4/12 (33.3)**	**4/12 (33.3)**	**5/12 (41.7)**		

Overview of sampling points

The three sampling points in the pool (Main pool, Pool A and Pool B) together yielded 65.9% of the fish sampled at the site. Of these, Pool B had the highest abundance contributing 32.9% to the total catch (see Figure 5.28 and Table 5.17). The three remaining sampling points, Outflow, Pool C and Rapid contributed 8%, 16.7% and 9.5% to the total catch, respectively. These habitats were distinguished from the pool habitats in that stream flow occurred at these habitats at certain times of the year and that they dried out first after surface flow ceased. After surface flow stopped in December 2006, the Rapid was the first to dry out, followed by Pool C and the Outflow.

Species richness was very similar for all the sampling points with five species recorded at each point, except for Pool B where six species were sampled (Figure 5.38). With the exception of *C. gariepinus*, all other fish species were recorded at all the sampling points. *Clarias gariepinus* was absent from Pool A and the Outflow, and only one individual was recorded in Pool B. Nearly half of the *C. gariepinus* individuals were juveniles captured in the faster flowing habitats at Pool C and the Rapid (42.8%); the other 51% were adults which were captured in the gill nets in the Main pool (September 2006).

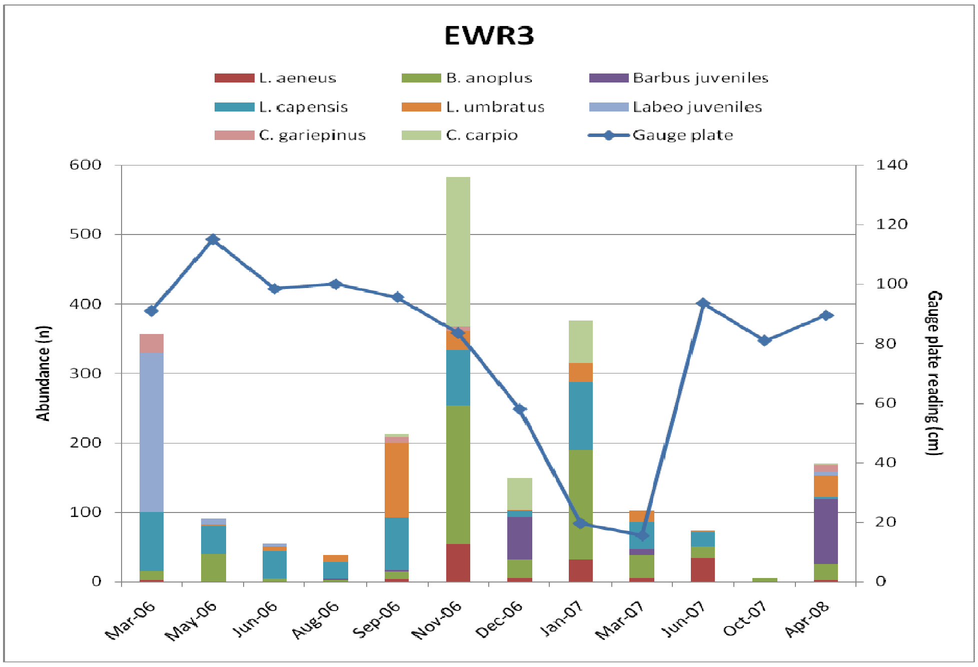


Figure 5.27: Species composition and abundance (n) at EWR3, March 2006 and April 2008.

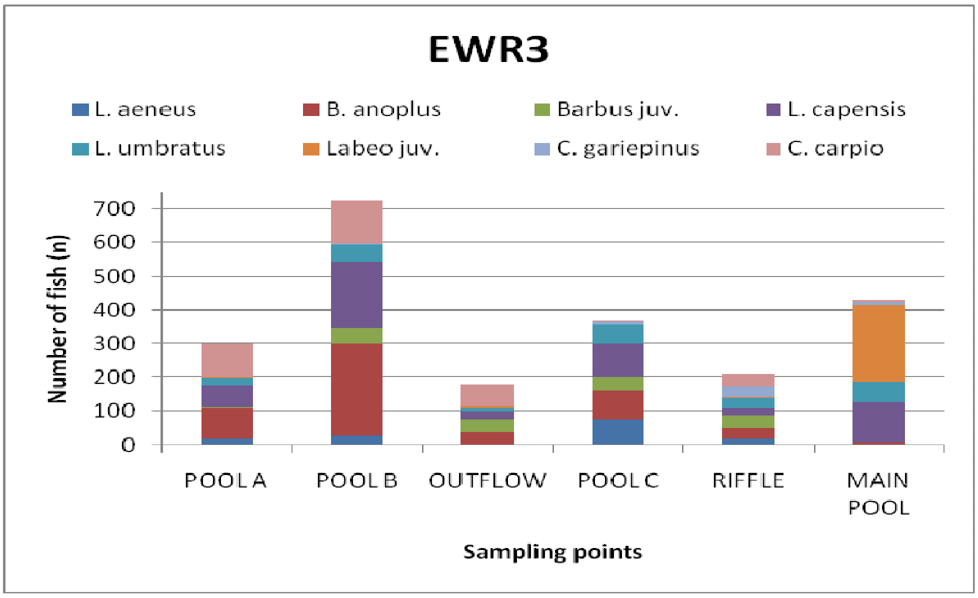


Figure 5.28: Species composition and abundance for the sampling points at EWR3, March 2006 and April 2008.

Table 5.17: Fish abundance and species composition for the various sampling points surveyed at EWR3, March 2006 to April 2008. (CPUE, Catch per unit effort were calculated as the number of fish sampled per minute).

HABITAT TYPE	*SAMPLING DATE*	*SAMPLING METHOD*	*BAEN*	*BANO*	*Barbus Juv.*	*LCAP*	*LUMB*	*Labeo Juv.*	*CGAR*	*CCAR*	*Species richness*	*Total abundance*	*CPUE*
POOL A	2006-05-22	E/S	0	0	0	0	0	0	0	0	**0**	**0**	**0**
(Main pool-shallows)	2006-06-28	E/S	0	0	0	1	2	1	0	0	**3**	**4**	**0.27**
	2006-08-16	B E/S	0	0	0	0	3	0	0	0	**1**	**3**	**0.38**
	2006-09-27	B E/S	0	1	1	5	0	0	0	0	**2**	**7**	**3.30**
	2006-11-14	B E/S	0	12	0	2	0	0	0	44	**3**	**58**	**4.83**
	2007-01-31	B E/S	17	73	0	51	17	0	0	55	**5**	**213**	**10.38**
	2007-06-13	B E/S	0	0	0	0	0	0	0	0	**0**	**0**	**0**
	2007-10-10	B E/S									**0**	**0**	**0**
	2008-04-01	B E/S	0	8	3	0	1	3	0	0	**3**	**15**	**1.50**
	Total		**17**	**94**	**4**	**59**	**23**	**4**	**0**	**99**		**300**	
	Relative abundance	**5.7**	**31.3**	**1.3**	**19.7**	**7.7**	**1.3**	**0.0**	**33.0**		**100.0**		
POOL B	2006-05-22	E/S	0	40	0	35	0	2	0	0	**3**	**77**	**1.27**
(Sloep-left)	2006-06-28	E/S	0	4	0	21	1	3	0	0	**3**	**29**	**1.93**
	2006-08-16	B E/S	0	2	2	23	6	0	0	0	**3**	**33**	**1.38**
	2006-09-27	B E/S	0	4	1	13	13	0	0	0	**3**	**31**	**2.96**
	2006-11-14	B E/S	0	68	0	9	0	0	0	79	**3**	**156**	**6.78**
	2006-12-13	B E/S	5	23	30	8	1	0	0	42	**5**	**109**	**7.27**
	2007-01-31	B E/S	15	85	0	46	11	0	0	6	**5**	**163**	**10.38**
	2007-03-21	B E/S	6	32	9	39	16	0	0	0	**4**	**102**	**6.80**
	2007-06-13	B E/S	0	2	0	0	1	0	0	0	**2**	**3**	**0.19**
	2007-10-10	B E/S		4							**1**	**4**	**0.25**
	2008-04-01	B E/S	0	9	7	0	2	0	1	1	**4**	**20**	**1.25**
	Total		**26**	**273**	**49**	**194**	**51**	**5**	**1**	**128**		**727**	
	Relative abundance	**3.6**	**37.6**	**6.7**	**26.7**	**7.0**	**0.7**	**0.1**	**17.6**		**100.0**		

Table 5.17: Continued.

HABITAT TYPE	*SAMPLING DATE*	*METHOD*	*BAEN*	*BANO*	*Barbus*	*LCAP*	*LUMB*	*Labeo*	*CGAR*	*CCAR*	*Species richness*	*Total abundance*	*CPUE*
OUTFLOW (Glide)	2006-05-22	E/S	0	0	0	4	0	6	0	0	**1**	**10**	**0.67**
	2006-06-28	E/S	0	0	0	12	2	0	0	0	**2**	**14**	**1.40**
	2006-08-16	B E/S	0	0	0	0	0	0	0	0	**0**	**0**	**0**
	2006-09-27	B E/S	0	3	0	4	8	0	0	0	**3**	**15**	**1.50**
	2006-11-14	B E/S	0	21	0	1	1	0	0	56	**4**	**79**	**7.17**
	2006-12-13	B E/S	0	4	31	1	0	0	0	4	**3**	**40**	**10.0**
	2007-01-31	B E/S	DRY								**0**	**0**	**0**
	2007-03-21	B E/S	DRY								**0**	**0**	**0**
	2007-06-13	B E/S	1	5	0	0	0	0	0	0	**2**	**6**	**0.60**
	2007-10-10	B E/S									**0**	**0**	**0**
	2008-04-01	B E/S	0	5	6	0	0	2	0	0	**2**	**13**	**2.60**
	Total		**1**	**38**	**37**	**22**	**11**	**8**	**0**	**60**		**177**	
	Relative abundance	**0.6**	**21.5**	**20.9**	**12.4**	**6.2**	**4.5**	**0.0**	**33.9**		**100.0**		
POOL C (Glide)	2006-03-31	E/S	0	9	0	0	0	0	9	0	**2**	**18**	**0.26**
	2006-06-28	E/S	0	0	0	6	2	0	0	0	**2**	**8**	**0.80**
	2006-08-16	B E/S	0	0	0	2	0	0	0	0	**1**	**2**	**0.20**
	2006-09-27	B E/S	0	0	0	14	27	0	0	0	**2**	**41**	**1.95**
	2006-11-14	B E/S	52	68	0	66	27	0	0	0	**4**	**213**	**24.42**
	2006-12-13	B E/S	DRY								**0**	**0**	**0**
	2007-01-31	B E/S	DRY								**0**	**0**	**0**
	2007-03-21	B E/S	DRY								**0**	**0**	**0**
	2007-06-13	B E/S	21	9	0	6	1	0	0	0	**4**	**37**	**2.47**
	2007-10-10	B E/S									**0**	**0**	**0**
	2008-04-01	B E/S	2	1	39	3	2	0	2	1	**5**	**50**	**5.0**
	Total		**75**	**87**	**39**	**97**	**59**	**0**	**11**	**1**		**369**	
	Relative abundance	**20.3**	**23.6**	**10.6**	**26.3**	**16.0**	**0.0**	**3.0**	**0.3**		**100.0**		

Table 5.17: Continued.

HABITAT TYPE	*SAMPLING DATE*	*METHOD*	*BAEN*	*BANO*	*Barbus*	*LCAP*	*LUMB*	*Labeo*	*CGAR*	*CCAR*	*Species richness*	*Total abundance*	*CPUE*
RAPID	2006-03-31	E/S	2	0	0	2	0	0	18	0	**3**	**22**	**0.3**
	2006-05-22	E/S	0	0	0	1	2	1	0	0	**2**	**4**	**0.09**
	2006-06-28	E/S	0	0	0	0	0	0	0	0	**0**	**0**	**0**
	2006-08-16	B E/S	0	0	0	0	0	0	0	0	**0**	**0**	**0**
	2006-09-27	B E/S	0	3	0	2	1	0	0	0	**3**	**6**	**0.20**
	2006-11-14	B E/S	2	30	0	2	0	0	6	37	**5**	**77**	**2.96**
	2006-12-13	B E/S	DRY								**0**	**0**	**0**
	2007-01-31	B E/S	DRY								**0**	**0**	**0**
	2007-03-21	B E/S	DRY								**0**	**0**	**0**
	2007-06-13	B E/S	12	0	0	15	0	0	0	0	**2**	**27**	**0.73**
	2007-10-10	B E/S	0	1	0	0	0	0	0	0	**1**	**1**	**0.13**
	2008-04-01	B E/S	0	0	39	0	26	0	7	0	**3**	**72**	**2.12**
	Total		**16**	**34**	**39**	**22**	**29**	**1**	**31**	**37**		**209**	
	Relative abundance	**7.7**	**16.3**	**18.7**	**10.5**	**13.9**	**0.5**	**14.8**	**17.7**		**100.0**		
MAIN POOL (Main pool-deep)	2006-03-31	S/N	0	4	0	83	0	229	0	0	**2**	**316**	
	2006-09-27	G/N	3	0	0	38	59	0	8	5	**5**	**113**	
	Total		**3**	**4**	**0**	**121**	**59**	**229**	**8**	**5**		**429**	
	Relative abundance	**0.7**	**0.9**	**0.0**	**28.2**	**13.8**	**53.4**	**1.9**	**1.2**		**100.0**		
	Total		**138**	**530**	**168**	**515**	**232**	**247**	**51**	**330**		**2211**	
	Relative abundance	**6.2**	**24.0**	**7.6**	**23.3**	**10.5**	**11.2**	**2.3**	**14.9**		**100.0**		

Main Pool

The deeper parts of the main pool at EWR3 were only sampled on two occasions: in March 2006 with a seine net and in September 2006 with a set of gill nets. The March sample were dominated by juvenile fish (mean fork length = 33.23 mm) of the genus *Labeo* (Figure 5.29a). In contrast to this, the gill nets yielded mostly adult fish representing the following five species: *L. aeneus*, *L. capensis*, *L. umbratus*, *C. gariepinus* and *C. carpio*. Of these the two Labeo species were the most abundant, collectively contributing nearly 86% to the total sample.

Pool A

B. anoplus and *C. carpio* young were the most abundant fish in the shallow littoral areas of the main pool (Figure 5.29b). This sampling point yielded mostly small samples sizes (≤15), except for November 2006 and January 2007 when 58 and 213 specimens were recorded respectively. In November the majority of the fish were young of the year with body lengths ranging between 12 and 63 mm (mean FL=32.41 mm; std=10.52 mm). In January however, body lengths varied between 22 and 385 mm (mean FL=49.69 mm; std=41.21), implying the presence of both juvenile and adult fish. By January the water level in the main pool had dropped to 19.5 cm (gauge plate reading) and the water's edge had retracted considerably.

Pool B

Fish samples taken at Pool B differed both in species composition and abundance (see Figure 5.29c). The habitat was dominated by two species, *B. anoplus* and *L. capensis*, which collectively contributed 64.3% to the total number of fish recorded in Pool B (Table 5.17). These two species were also the most frequently sampled fish, and were present in every sample taken at the sampling point. *Labeo umbratus* was also frequently sampled in this habitat (8 out of 11 samples), but was generally present in low numbers (<20). Although *C. carpio* contributed 17.6% to the total number of fish sampled at Pool B, they were mostly juveniles recorded between November 2006 and January 2007.

Outflow

This habitat contributed only 8% to the total fish abundance recorded at EWR3, the lowest of all sampling points. Sample sizes were generally low (<20), except in November and December 2006 when 79 and 40 specimens were recorded, respectively. Both these samples were dominated by juvenile fish, *C. carpio* in November and *B. anoplus* and/or *L. aeneus* young in December 2007 (Figure 5.29d). The sampling point was during the January 2007 and March 2007 field visits and could not be sampled.

Pool C

Large differences in species composition and fish abundance were recorded at this sampling point (Figure 5.29e). Sample sizes varied between 0 (June 2007) and 213 (November 2006). *Labeo capensis* was both the most abundant and most frequently recorded species in this habitat. The highest number of *L. aeneus* individuals (20.3% of all *L. aeneus* specimens sampled at EWR3) recorded for any of the sampling points at EWR3, was recorded here

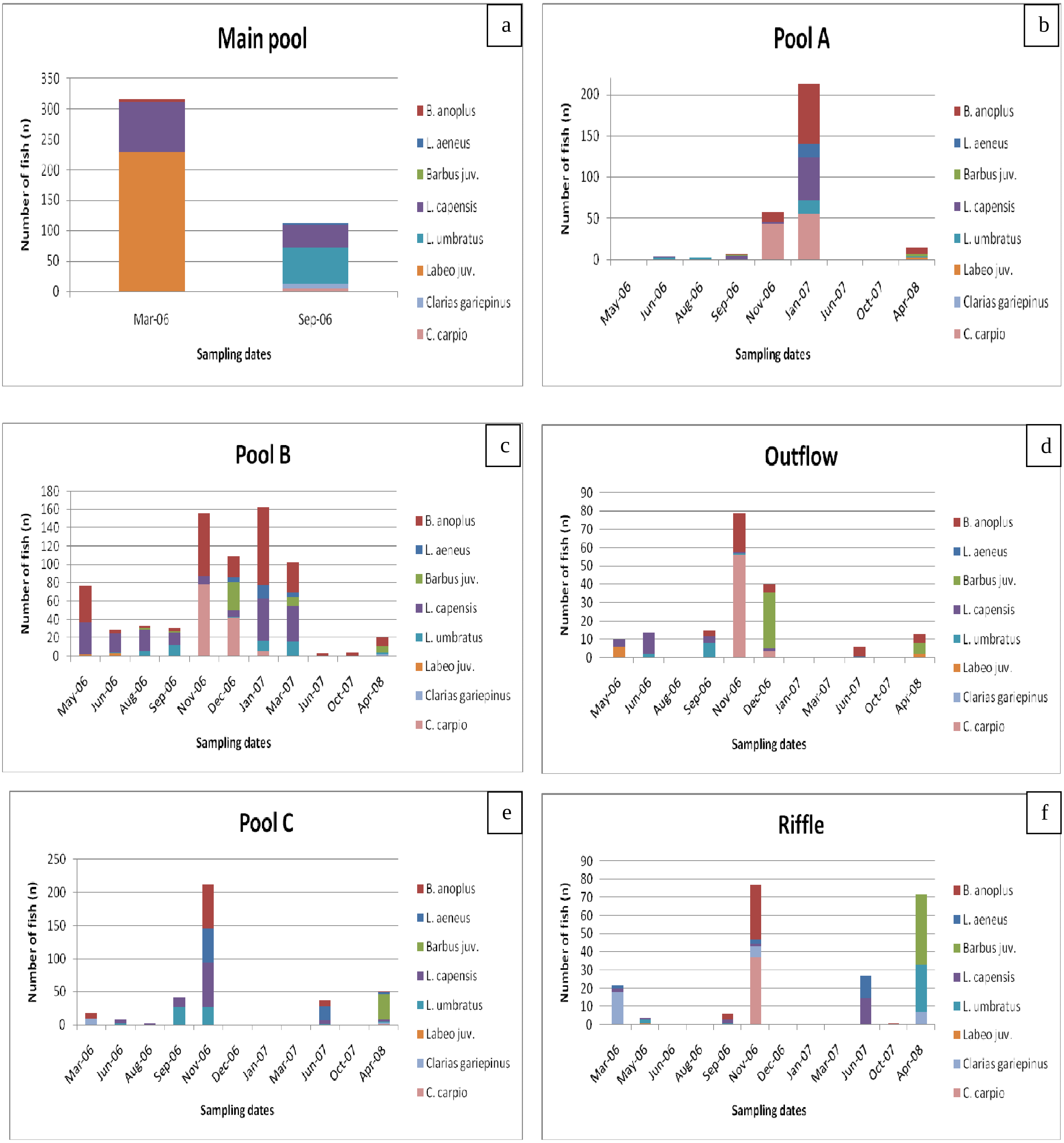


Figure 5.28: Fish abundance and species composition for the sampling points surveyed at EWR3, March 2006 to April 2008 .

despite being dry during three consecutive field visits (December 2006, January and March 2007).

Rapid

Labeo capensis was the species most frequently sampled in the rapid/riffle habitat, followed by *C. gariepinus*, *L. aeneus*, *L. umbratus* and also *B. anoplus*. As for the other sampling points, large variations in fish abundance and species composition occurred. The highest number of fish was sampled in November 2006 when 77 specimens were recorded in the rapid/riffle habitat (see Figure 5.29f).

5.2.3.3 Microhabitat

Water depth

The mean water depth of the sampling points fluctuated quite dramatically during the study, mainly in response to changes in the water level of the main pool (see Figure 5.30). Surface flow at the site ceased when the water level in the main pool dropped below 76 cm. After the onset of intermittence, the Rapid habitat was the first habitat to run dry, followed by Pool C and the Outflow. For example, surface flow at EWR3 stopped sometime between late November and early December 2006. At the time of the field visit in mid-December, the Rapid and Pool C were dry, while water depths of between 10 cm and 22.5 cm (mean = 15.05 cm) were recorded in the Outflow habitat (Table 5.18).

It is clear from Figure 5.30 that the mean depths recorded in the two pool habitats (Pools A and B) were higher than those measured in the "flowing" habitats (Outflow, Pool C and Rapid). It is also interesting to note that fluctuations in the mean water depths at the two pool habitats followed a similar pattern (as was the case for the "flowing" habitats), but that the pattern was different to that of the three "flowing" habitats. While the mean depths in the "flowing" habitats dropped to nil during intermittence, mean depths increased in the pool habitats.

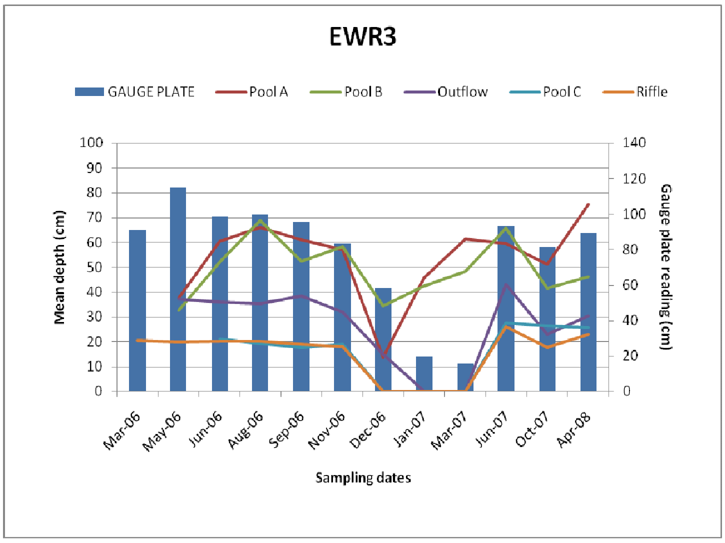


Figure 5.30: The mean depths recorded for the six sampling points at EWR3 in relation to the gauge plate readings, March 2006 to April 2008.

Table 5.18: Random depth measurements taken in each of the sampling points at EWR3, March 2006 to March 2008. Fish abundance, mean body length and body length range are also indicated.

Samp-ling date	*Flow descript-tion*	*Gauge plate (cm)*	*Mean depth (cm)*	*Minimum depth (cm)*	*Maximum depth (cm)*	*Fish abund-ance (n)*	*Mean body length (FL; mm)*	*Body length range*	*Body length* **Std**
Pool A									
May-06	No flow	115	37.67	30	50	0			
Jun-06	No flow	98.5	60.5	17	90	4	29	21-34	5.94
Aug-06	No flow	100	66.13	30	87	3	30.33	24-34	5.51
Sep-06	No flow	95.5	61.1	23	87	7	29.29	20-43	9.27
Nov-06	No flow	83.5	57	26.5	170	58	32.41	12-63	10.52
Dec-06	No flow	58	13.65	6	20	0			
Jan-07	No flow	19.5	45.95	15	92	213	49.69	22-385	41.21
Mar-07	No flow	15.5	61.5	19	96	154	46.98	25-260	31.72
Jun-07	No flow	93.5	59.68	39.5	76.5	0			
Oct-07	No flow	81	51.3	28	76	0			
Apr-08	No flow	89.5	75.3	35	101	15	52.27	31-176	36.21
Pool B									
May-06	No flow	115	32.67	28.5	36.5	77	32.57	17-47	5.21
Jun-06	No flow	98.5	52.1	30	68	29	33.14	22-42	5.31
Aug-06	No flow	100	68.9	41	95	33	34	25-47	4.22
Sep-06	No flow	95.5	52.4	35	99	31	31.16	20-43	5.96
Nov-06	No flow	83.5	58.29	20	114	156	32.61	11-64	9.37
Dec-06	No flow	58	34.52	12	68	109	38.25	11-320	31.29
Jan-07	No flow	19.5	42.35	12	77	163	51.78	22-355	35.6
Mar-07	No flow	15.5	48.5	24	81	102	64.22	15-135	33.56
Jun-07	No flow	93.5	65.73	29	104	3	41.33	26-70	24.85
Oct-07	No flow	81	41.5	31	57	4	38.25	34-40	2.87
Apr-08	No flow	89.5	46.1	27	81	20	57.95	38-216	43.48
Outflow									
May-06	Slow flow	115	37.38	28	53	10	24.4	18-34	8.26
Jun-06	Slow flow	98.5	36.07	2	60	14	37.71	34-41	1.86
Aug-06	Slow flow	100	35.31	1	59	0			
Sep-06	Slow flow	95.5	38.5	26	53	15	37.13	20-55	11.23
Nov-06	No flow	83.5	32.05	16.5	50	79	34.31	11-57	7.86
Dec-06	No flow	58	15.05	10.00	22.5	40	19.25	9-68	14.6
Jan-07	Dry	19.5	0	0	0				
Mar-07	Dry	15.5	0	0	0				
Jun-07	Slow flow	93.5	43.1	31	53	6	36.67	30-55	9.46
Oct-07	No flow	81	22.9	10	34	0			
Apr-08	Slow flow	89.5	30.5	9	45	13	37.15	35-45	3.98

Table 5.18 (continued).

Sampling date	*Flow description*	*Gauge plate (cm)*	*Mean depth (cm)*	*Minimum depth (cm)*	*Maximum depth (cm)*	*Fish abundance (n)*	*Mean body length (FL; mm)*	*Body length range*	**Std**
Pool C									
Mar-06		91	12.65	4.5	19	18	68.78	46-130	25.42
Jun-06	Fast flow	98.5	21.08	3	41	8	35.38	34-40	1.92
Aug-06	Fast flow	100	19.36	2	41	2	38	36-40	2.83
Sep-06	Fast flow	95.5	17.57	2	42	41	35.33	33-38	3.68
Nov-06	Fast flow	83.5	18.95	9	29.5	213	39.42	18-65	8.56
Dec-06	Dry	58	0	0	0				
Jan-07	Dry	19.5	0	0	0				
Mar-07	Dry	15.5	0	0	0				
Jun-07	Fast flow	93.5	27.7	15.5	40.5	37	53.14	28-86	16.29
Oct-07	No flow	81	26.5	13	41	0			
Apr-08	Fast flow	89.5	25.9	15	35	50	48.3	30-149	25.54
Rapid									
Mar-06		91	20.47	6	34	22	129.33	78-163	20.37
May-06	Fast flow	115	19.88	6	43	4	78.75	20-144	60.64
Jun-06	Fast flow	98.5	20.13	4	40	0			
Aug-06	Fast flow	100	20.32	2	37	0			
Sep-06	Fast flow	95.5	18.94	2	33	6	44.33	33-63	11.09
Nov-06	Slow flow	83.5	17.93	6	31	77	52.36	17-210	36.04
Dec-06	Dry	58	0	0	0				
Jan-07	Dry	19.5	0	0	0				
Mar-07	Dry	15.5	0	0	0				
Jun-07	Fast flow	93.5	25.94	12	45	27	68.63	47-111	14.85
Oct-07	No flow	81	17.7	6	17.7	1	44		
Apr-08	Fast flow	89.5	22.9	12	32	72	51.79	31-216	29.43

The mean minimum and maximum depths recorded in the Rapid were very similar to those in Pool C. For example the mean minimum and maximum depths for the Rapid were 20.5 cm and 26.1 cm respectively, compared to 21.2 cm and 26.3 cm for Pool C. This was also true for the Pools A and B for which the mean minimum and maximum depths were 24.5 cm and 53.6 cm and 26.3 cm and 49.4 cm, respectively. Despite this similarity, Pool B yielded more fish than Pool A (see Table 5.18).

Substrate and fish cover

Pools A and B

The substrate in Pool A was dominated by gravel - the most abundant substrate type in all but two cases, May 2006 and December 2006 (Figure 5.31a). In May, when the water level in the main pool was at its highest (gauge plate reading of 115 cm), sand was the most abundant substrate type. In December (gauge plate reading=58 cm) cobbles and pebbles were the most abundant substrate type. The mean water depth recorded in December was 13.65 cm, the lowest during the study. Submerged vegetation (mostly water grasses) and the substrate provided the most fish cover in Pool A (Figure 5.32a). Filamentous algae occurred between November 2006 and March 2007.

The substrate, which comprised of boulders, gravel, cobbles and pebbles (Figure 5.31b), was the predominant fish cover in Pool B (Figure 3.32b). Submerged vegetation in the form of water grass also provided fish cover as the water's edge gradually receded between November 2006 and March 2007.

Outflow, Pool C and Rapid
The composition of the Outflow's substrate differed from that in Pool C and the Rapid in that gravel was the most abundant, followed by boulders and pebbles (Figure 5.31c). The substrates in Pool C and the Rapid were strongly dominated by boulders and cobbles, with gravel becoming less abundant in a downstream direction (see Figures 5.31c-e). The substrate was an important source of fish cover in all three habitats, but more so for Pool C and the Rapid. Sedges and water grasses provided additional cover in the Outflow (Figure 5.32c).

5.2.3.4 Discussion for EWR3
The lower section of the Seekoei River differs from the upper and middle sections in that the surface water is connected for approximately 50% of the time, compared to less than 10% of the time in the upstream sections. Accordingly, EWR3 exhibits more habitat heterogeneity than EWR1 and 2, and six points were sampled at the site: three points in the main pool that dominates the site (Main pool, Pool A and Pool B), two glides (Outflow and Pool C) and a rapid (Rapid). Based on the data provided by a hydraulic survey of the site, surface flow in the left channel downstream of the pool is expected at a gauge plate reading of 76 cm and higher. This implies that surface flow was only present in the "flowing habitats" when the water level in the main pool was equal or higher than 76 cm. The microhabitat measurements taken at the various sampling points, however, indicated that no surface flow could be detected at a gauge plate reading of 81 cm, even though the surface water was still connected. The longterm flow record indicates that high flows are generally expected in late summer/autumn (February, March), with low flows prevailing in winter (June, July). However, during the first year of the study, surface flow persisted throughout the winter and drying only started in September, continuing until March the next year. The water level at EWR3 dropped from 95.5 cm in September to 15.5 cm in March over this period. Surface flow stopped sometime between November and December, reducing the number of sampling points to four in December and to two in January and March 2007. Surface flow was restored at some point between March and June and kept flowing until April 2008.

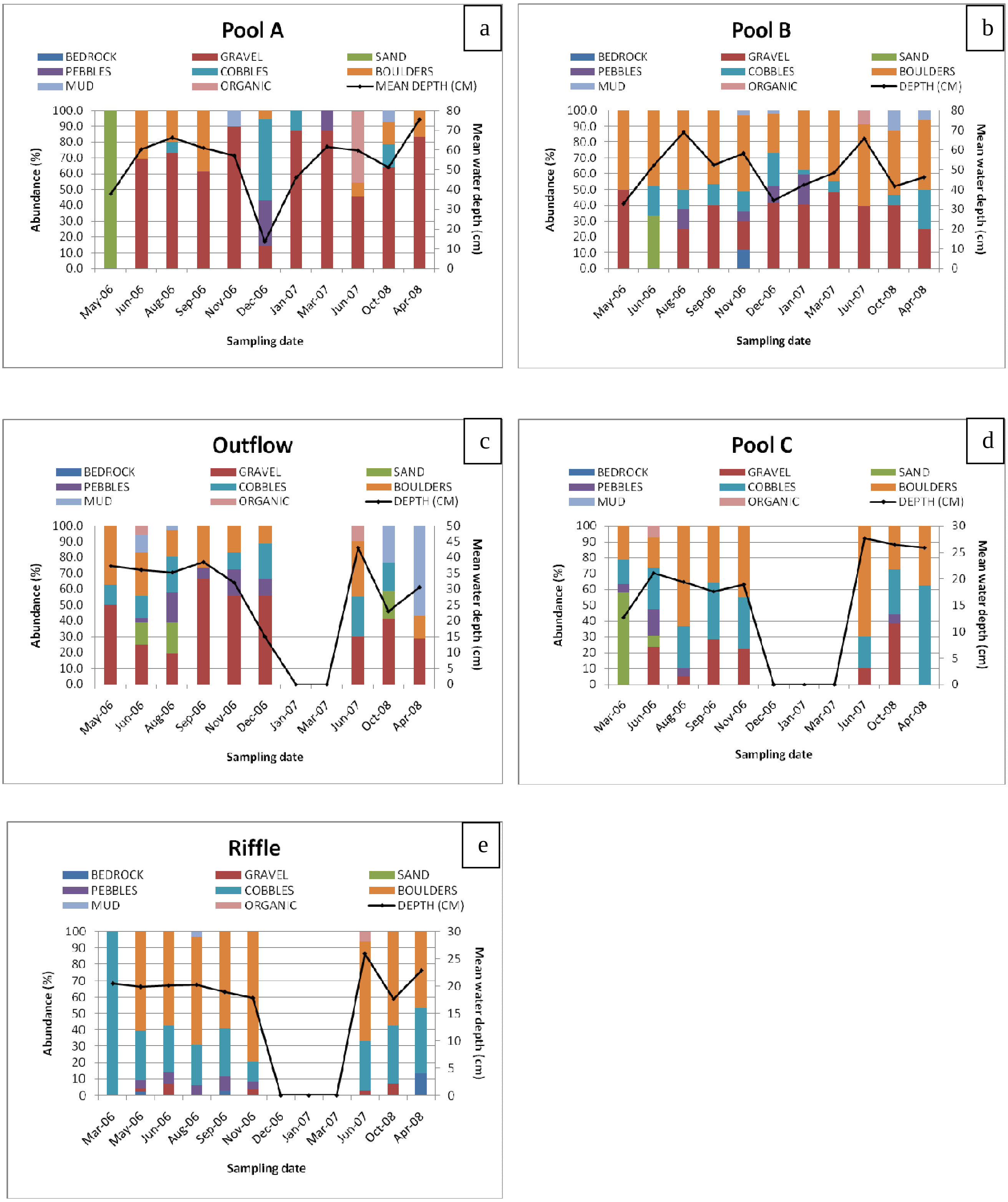


Figure 5.31: Substrate composition based on the microhabitat measurements taken in five of the sampling points at EWR3 during field visits, March 2006 to April 2008.

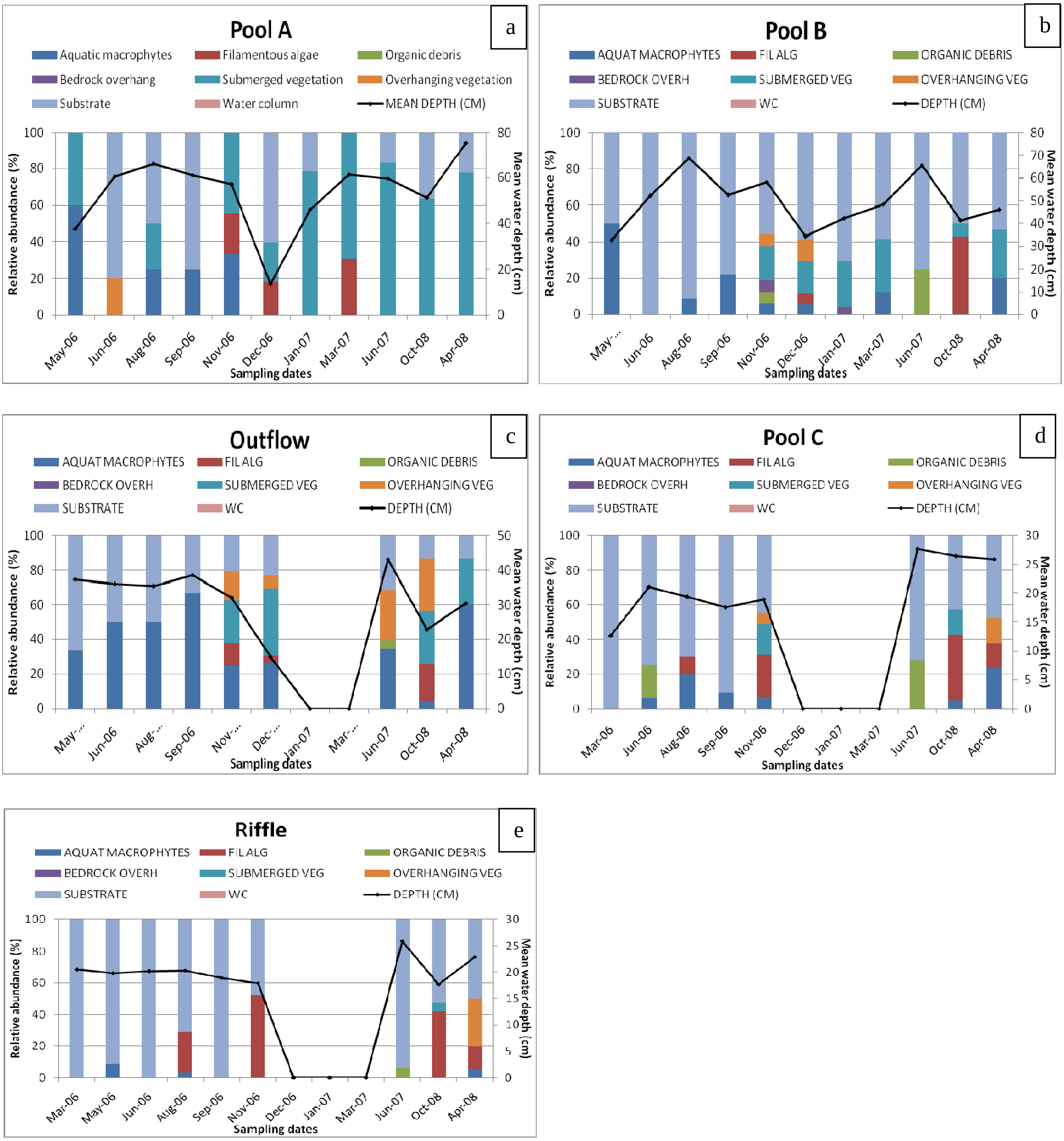


Figure 5.32: Fish cover composition based on the microhabitat measurements taken in five of the sampling points at EWR3 during field visits, March 2006 to April 2008.

Six fish species were recorded at EWR3, one more than at EWR2. *Labeobarbus aeneus* was added to the list of species found at EWR2 and 138 individuals of this species was recorded at the site, the bulk of these in the "flowing habitats" (especially Pool C and the Rapid). Fish was more abundant at EWR3 than at EWR4, with the catch at EWR3 comprising 75% of the total number of yellowfish (*L. aeneus*) recorded in the river. Overall (for all EWR3 sampling points combined), water level (gauge plate readings) was positively correlated with species richness observed ($r=0.747$; $p=0.005$). The number of *Barbus* juveniles increased with temperature ($r=0.674$; $p<0.05$). In turn, the abundance of *B. anoplus*, as well as *Barbus* juveniles, were positively correlated with total abundance ($p<0.001$).

The three pool habitats, Main pool, Pool A and Pool B, yielded nearly two thirds of the fish sampled at the site, with the flowing habitats Outflow, Pool C and Rapid contributing the remaining third. Species richness and composition were very similar for all sampling points, the exception being Pool B where six species were recorded. Pool B also yielded the most fish, contributing 32.9% to EWR3's total catch. Species richness and fish abundance were related in Pool B ($r=0.662$; $p<0.05$) and both these parameters were seemingly influenced by water temperature. Both correlated positively with water temperature ($p<0.05$). Water temperature, in turn, was negatively influenced by mean depth in this habitat ($r=-0.713$; $p<0.05$).

Barbus anoplus was not only numerically the most abundant species, but also the species most frequently sampled at EWR3. It was, furthermore, recorded at all the sampling points over the course of the study, but it was not necessarily present in every sample at every point. The species was most abundant in the two pool habitats (Pool A and B) and was present in every sample taken in Pool B during the study. With the exception of one record in March 2006 in Pool C, *Barbus anoplus*, that is generally associated with slow-flowing habitats (Kleynhans 2003), was first recorded in the flowing habitats at the start of the drying period in September 2006. In November 2006 the species was present at all three these habitats and in higher numbers. It seems as if the drop in water level, and slower flows as a result of that, increased the suitability of the "flowing habitats" for the species. For example, maximum flows recorded in the Outflow, Pool C and the Rapid respectively changed from 0.284 m/s, 1.379 m/s and 0.7 m/s at a water level of 115 cm (in May 2006) to 0.167 m/s, 0.891 m/s and 1.252 at a water level of 95.5 cm (in September 2006), and further to 0 m/s, 0.407 m/s and 0.445 m/s at a water level of 83.5 cm (in November 2006). Fish species that are generally associated with slow- or no-flowing conditions could, therefore, gain access to "flowing habitats" when habitat conditions change during the dry season.

Of the flowing habitats, *B. anoplus* was most abundant in the glide, Pool C. At higher water levels (such as in May 2006), this habitat represented a mosaic of shallow and deep, and fast and slow habitats over a substrate consisting of boulders, cobbles, pebbles and gravel (Figure 5.31). Much of this heterogeneity was, however, lost when the water level (and the mean water depth at the sampling point) decreased. This was also true for the other two "flowing habitats" where a reduction in the number of velocity-depth classes also coincided with a drop in water level. As flow slowed down in this habitat, filamentous algae and water grasses became more abundant, providing additional cover in this habitat.

The two large *Labeos* (*L. capensis* and *L. umbratus*) were also relatively abundant and frequently sampled at EWR3, collectively contributing 45% to the total number of fish recorded at the site. Both these species were recorded at all the sampling points, with *L. capensis* being more abundant at all points, except for the rapid where *L. umbratus* was slightly more abundant. The highest number of *L. capensis* individuals was recorded in Pool B, accounting for more than a third of all *L. capensis* specimens captured at EWR3. Pool B comprised slow-deep and slow-shallow habitat over a substrate comprising boulders, cobbles, pebbles and gravel. Fish sampled here was most often associated with the abundant substrate cover present at the sampling point. As the water level in the pool started to drop, the presence of water grasses and filamentous algae increased (Figure 5.32) and *C. carpio* was recorded for the first time at this point.

The water level at EWR3 started to drop in August 2006, resulting in a gradual decrease in the mean depths of the flowing habitats. Soon after surface flow stopped, these habitats ran dry: first Pool C and the rapid (by mid December 2006), and then the outflow (by January 2007), leaving Pools A and B isolated. During this period of intermittence fish abundance and CPUE increased in the remaining pool habitats, showing an increase in fish density. The loss of habitat (mostly the shallows) also appeared to “force” fishes of different sizes together and the range of body sizes, as well as standard deviations in body length, increased in Pool A and B over this period. Overall, the pool depth was negatively correlated to mean mean body length ($r=-0.692$; $p<0.05$). Pool depth correlated positively with both total abundance and the abundance of B. anoplus.

In turn, no correlations between any of the fish variables and physical characteristics could be found at Pool A.

5.2.4 Site EWR4

EWR4 is situated approximately 2 km downstream of EWR3 in the same quaternary catchment (D32J). The site, therefore, has a similar flow regime than that of EWR3 and experiences surface water connection for about 50% of the time. A weir about 3.5 m high is situated between EWR3 and 4 which could potentially impact surface water connectivity. Due to the similarity in the modeled hydrological regime for EWR3 and 4, an hydraulic survey was not done for EWR4.

5.2.4.1 Instream habitat

Potential fish habitat

The available habitat at EWR4, when there is surface flow, comprise a large pool with a sandy, gravel bottom, two glides (in the left channel), a bedrock pool, two short rapid/riffles, and another pool at the downstream end of the site. The marginal vegetation consists mostly of reeds with indigenous trees on the river banks. EWR4 represented the most complex habitat of the four study sites.

The water level at EWR4 showed the highest variability of the four sites (see Figure 5.33), and fluctuated between 0 and 105 cm (mean=68.55 cm; std=42.87 cm). The site was dry for the first six months of 2007. During this time the main pool was reduced to a series of isolated shallow pools (see discussion under section 5.2.4.3) and fish sampling was limited to some of these pools. At higher water levels (gauge plate reading ≥85.5 cm), flow was recorded in five of the seven sampling points (see Table 5.19). The highest flows were measured in the two rapid/riffles in May 2006 when the water level was at its highest. By November 2006 the water level dropped to 85.5 cm and the flow slowed down to such an extent that the only recorded flow occurred in the shallow Rapid B.

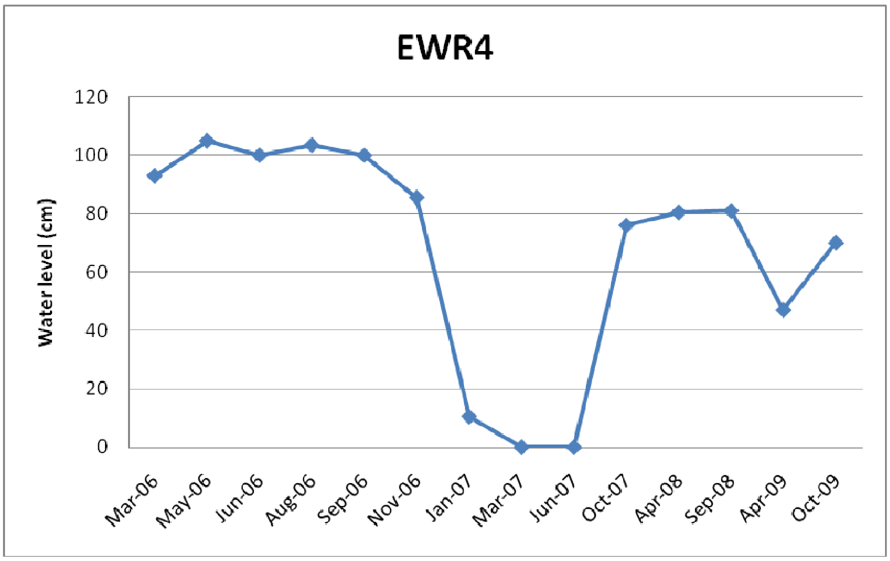


Figure 5.33: Gauge plate reading for EWR4, March 2006 to October 2009.

Pool habitat

Main pool

The main pool (where the gauge plate is situated) is 970.73 m long and about 2 m deep at the deepest point (DWAF, 2006b). The pool has a volume of 15735 m^3 and covers an area of 19035.3 m^2 at full supply level. Based on the volume survey, full supply level is reached at a gauge plate reading of 60 cm (DWAF, 2006b). At a gauge plate reading of 1 m, the volume is expected to increase to 23464.32 m^3. The pool's substrate consisted mainly of coarse sand and gravel.

Pool C

Pool C is a shallow bedrock pool (see Figure 34a-c) – mean depths varied between 10 cm in May 2006 and 3 cm in November 2006, drying soon after. The pool was dry for most of 2007, and fish samples could only be taken in March 2008.

Table 5.19: Water depths and surface flow based on habitat survey data for EWR4 for May 2006, November 2006 and October 2007.

			Water depth			*Surface flow (measured at 1/3 of the water column)*		
Date	*Gauge plate (cm)*	*Wetted area – mean width (m)*	Mean depth (cm)	Minimum depth (cm)	Maximum depth (cm)	Mean flow (m/s)	Maximum flow (m/s)	Minimum flow (m/s)
Pool B								
May-06	105	16	58.53	9	106	0.08	0.137	0.023
Nov-06	85.5	13.54	48.92	8	75	0	0	0
Oct-07	76	11.4	36.18	2	56	0	0	0
Pool C								
May-06	105	10	25.67	15	53	0		
Nov-06	85.5	3	16	3	16	0		
Oct-07	76	DRY						
Rapid A								
May-06	105	11	19.55	3	33	0.22	0.628	0.032
Nov-06	85.5	9	8	1	15	0	0	0
Oct-07	76	4	11	6	16	0	0	0
Pool D								
May-06	105	18.9	23.94	3	51	0.19	0.598	0.035
Nov-06	85.5	14.5	12.67	1	19	0	0	0
Oct-07	76	9.4	11	2	14	0	0	0
Rapid B								
May-06	105	3	12.5	4	26	0.98	1.736	0.163
Nov-06	85.5	1	11			0.378		
Oct-07	76	DRY						
Pool E								
May-06	105	16	58.53	9	106	0.08	0.137	0.023
Nov-06	85.5	13.54	48.92	8	75	0	0	0
Oct-07	76	11.4	36.18	2	56	0	0	0

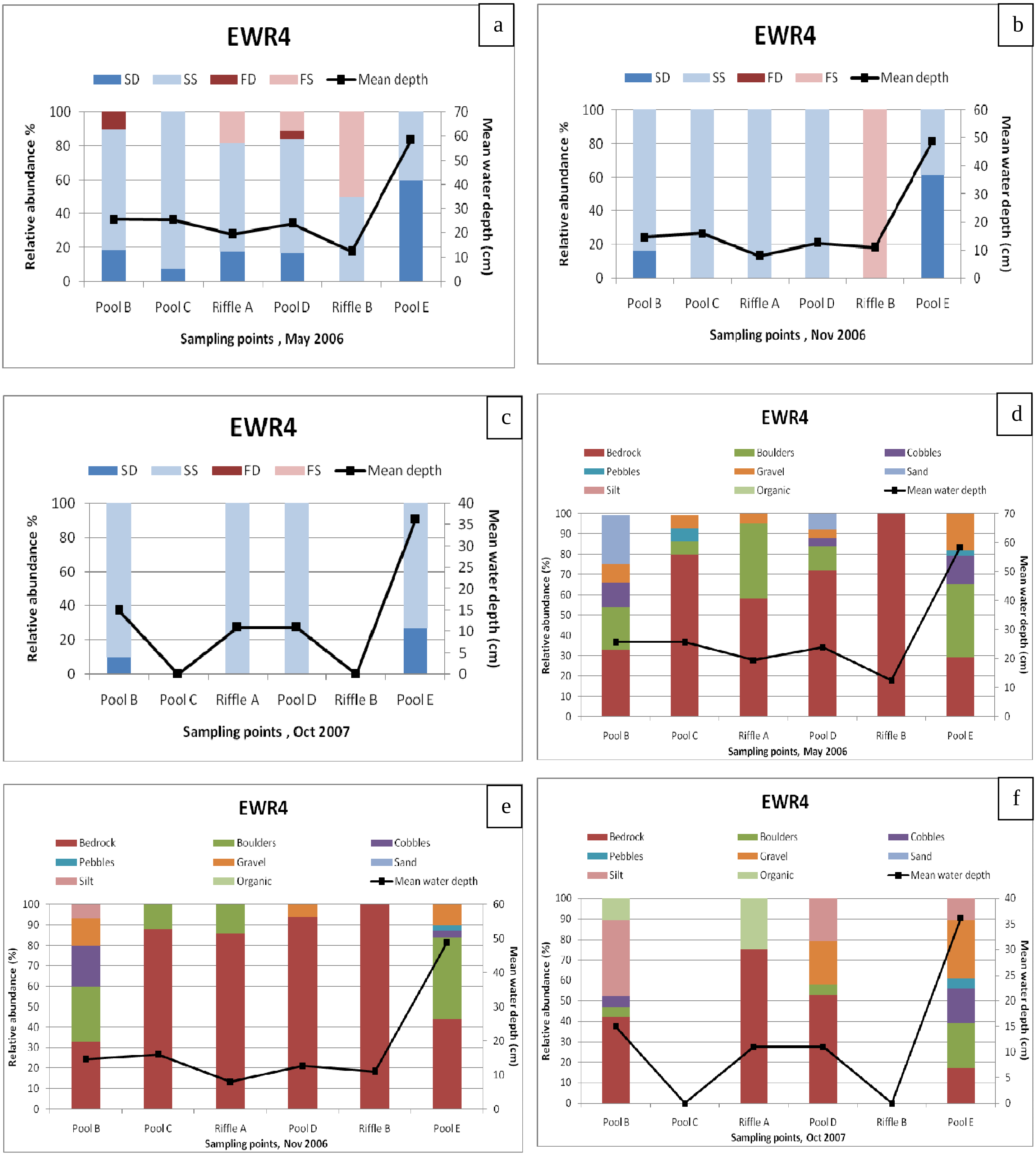


Figure 5.34: The abundance and distribution of velocity-depth classes (a to c) and substrate types (d to f) for the various sampling points at EWR4 for May 2006, November 2006 and October 2007.

Flowing habitats

Pool B (Glide)

Pool B is situated in the left channel and connects the main pool with Rapid A and Pool D. Although fast-deep habitat was present at higher water levels, it is dominated by slow-shallow habitat (Figure 34a-c). The substrate consisted of bedrock, boulders, cobbles, gravel and sand (Figure 34d-f) and was a major source of fish cover. As water levels dropped aquatic macrophytes and filamentous algae also provided cover, together with the sedges fringing the habitat.

Rapid/riffles

Rapid A connects Pools B and D (left channel) and Rapid B connects Pools D and E (right channel). Both comprise predominantly shallow habitat (see Table 5.19) and bedrock substrate (Figure 34a). Mean water depths in Rapid A decreased from 19.55 cm (std=9.69 cm) in May 2006 to 8 cm (std=9.09cm) in November 2006. Over the same period flows decreased from a maximum of 0.628 m/s (mean=0.22 m/s; std=0.23 m/s) to no-flow; no flow measurements were recorded when the water level in the pool were ≤85.5 cm. This was not true for Rapid B, where flow was still present in November 2006. Both rapids were, however, dry between January and October 2007.

Pool D (Glide)

The mean water depth in Pool D comprised mostly shallow habitat - in May 2006 when the highest gauge plate reading was recorded (Table 5.19), this habitat had a mean water depth of 23.94 cm (std=13.18 cm). Although slow-shallow habitat dominated in May, all four velocity-depth classes were present. However, as the water level dropped, surface flow disappeared and by November 2006 only slow-shallow habitat was left (Figure 5.34a-b). Substrate cover was the most important source of fish cover, with filamentous algae becoming especially abundant in November 2006 and October 2007 (see Figure 5.35b-c). The pool was dry for the first six months of 2007.

Pool E (Downstream end pool)

Pool E, situated at the downstream end of the site, was 16 m wide and had a mean water depth of 58.53 cm (std=33.38) in May 2006. Flow measurements taken along the right bank where Rapid B pours into the pool varied between 0.023 m/s and 0.137 m/s (Table 5.19). No flow could, however, be detected in November 2006 when the gauge plate reading and mean depth dropped to 85.5 cm and 48.92 cm, respectively. The available habitat was therefore dominated by slow-flowing water over a substrate of bedrock, boulders and cobbles (Figure 5.34a-c).

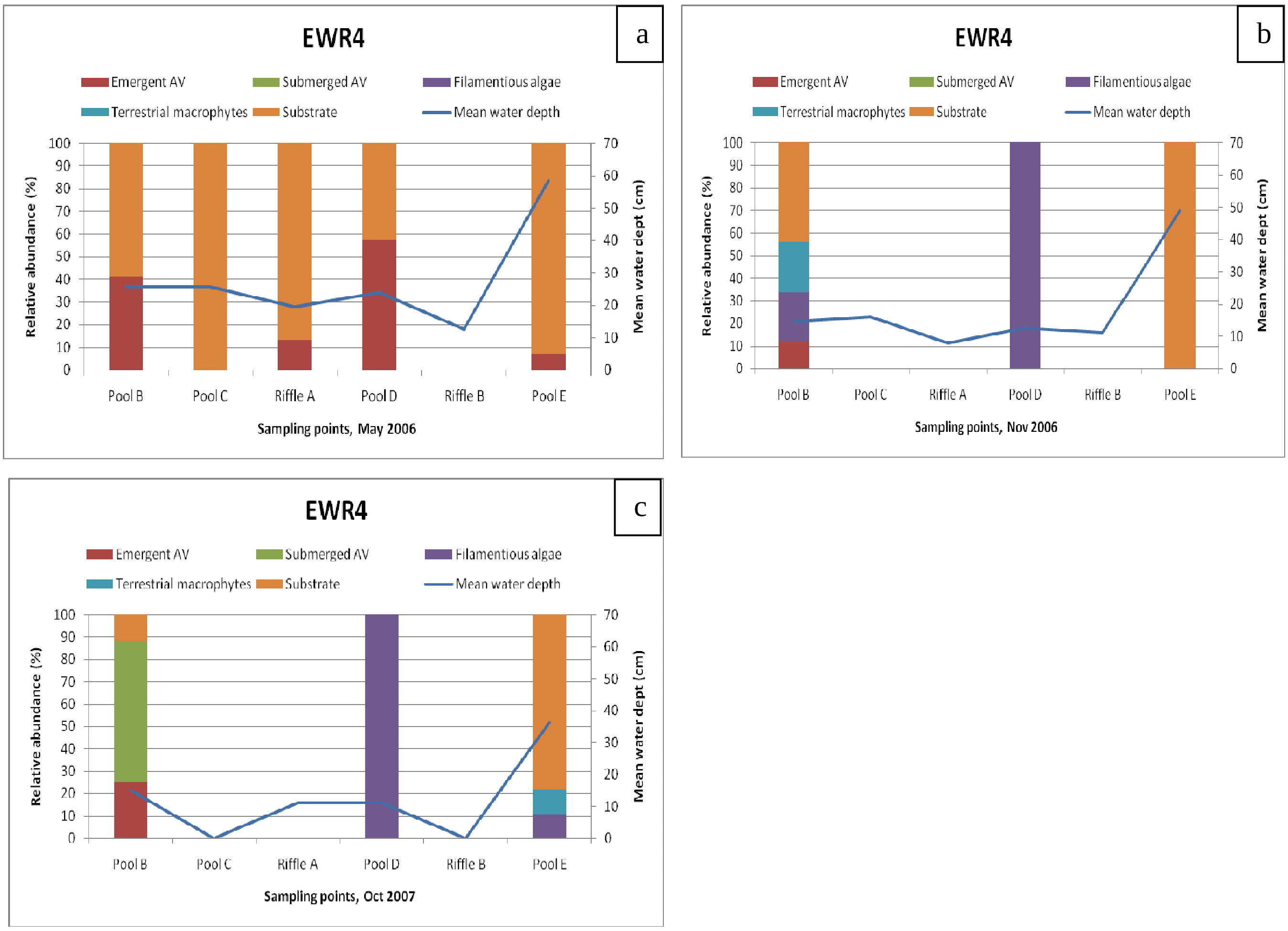


Figure 5.35: The abundance and distribution of cover types at the sampling points at EWR4 in May 2006, November 2006 and October 2007.

Water quality

Water temperatures varied between 5.2°C (June 2007) and 27.2°C (February 2007) and were, as expected, higher in summer (mean=27.2°C) and lower in winter (mean=7.4°C). The mean water temperatures recorded during the autumn and spring samples were 17.78°C and 19.0°C, respectively (Table 5.20).

Electrical conductivity readings at EWR4 (mean=79.8 mS/m; std=34.94 mS/m) was very similar to those taken at EWR3 (mean=82.39; std=23.39 mS/m), although the variability was slightly higher at EWR4. Turbidity fluctuated between 4.5 NTUs (August 2006) and 39 NTUs (February and March 2007) and was generally higher at EWR4 (mean=20.67 NTUs) than at EWR3 (mean=9.03 NTUs; see Table 5.20). It also appeared to be higher in early autumn as three of the four highest readings were recorded during the March-samples.

Table 5.20: Selected physical properties for EWR4, March 2006 to March 2008.

Date of sampling	*Time of samp-ling*	*Pool depth (cm)*	*Flow description*	*Water temp ℃*	*pH*	*Conductivity (mS/m)*	*Diss. O_2 (mg/l)*	*O_2 %*	*Turbidity (NTU)*
Mar-06	15:30	93.0	Slow flow	20.2	8.44	50.5	7.0	78.7	25.0
May-06	09:35	105.0	Fast flow	9.7	8.41	38.5	7.64	67.9	15.0
Jun-06	09:20	100.0	Fast flow	6.9	8.48	85.4	9.07	75.2	7.70
Aug-06	09:30	103.5	Fast flow	10.1	8.91	74.6	9.4	86.1	4.5
Sep-06	12:35	100.0	Fast flow	17.3	8.59	88.5	8.49	89.9	18.0
Nov-06	09:10	85.5	Slow flow	24.6	8.55	104.8	4.97	63.7	7.9
Feb-07	09:25	10.5	No flow	27.2	9.91	112.9	4.14	50.4	39.0
Mar-07	09:20	0	Site dry	20.5	9.64	138.1	5.72	64.8	39.0
Jun-07	09:40	0	Site dry	5.2	7.68	34.94	7.68	60.3	16.3
Oct-07	09:10	76.0	No flow	15.1	8.79	99.0	6.78	68.6	24.0
Apr-08	09:05	80.5	Slow flow	20.7	8.27	50.6	3.96	44.3	31.0

5.2.4.2 Fish survey

Fish species expected

The same eight indigenous species expected at EWR3 are expected to occur at EWR4 (Table 5.21). No information could be found of previous fish surveys done in close vicinity of the site. The list was, therefore, based on an evaluation of the available fish habitat and cover and local knowledge. The presence of the exotic *C. carpio* was confirmed by the farmer, Mr. C. Venter.

Table 5.21: List of fish species expected at EWR4.

Fish species	**Expected**	**Confidence level**
Barbus anoplus	√	95%
Labeobarbus kimberleyensis	?	5%
L. aeneus	√	90%
Labeo capensis	√	95%
L. umbratus	√	95%
Clarias gariepinus	√	95%
Austroglanis sclateri	?	20%
Tilapia sparrmanii	?	20%
Exotic fish species		
Cyprinus carpio	√	95%

The condition of the instream zone was described as largely modified (Class D) and that of the riparian zone as moderately modified. Flow regulation was the major impact.

Fish species observed

Overview of site

Five indigenous and two exotic species were recorded at EWR4 (see Table 5.22). *Micropterus salmoides* (Largemouth bass) was recorded for the first time in September 2006 and was apparently introduced into the lower Seekoei by a recreational angler (Venter, pers. comm.). The species was not recorded at EWR3, which means that it was possibly introduced downstream of the large weir halfway between the two sites. It was again found in February and in June 2007.

EWR4 had the highest fish abundance of the four sites and contributed 43.6% to the total number of fish recorded in the Seekoei River. *Labeo capensis* and *C. carpio* were the two most abundant species, respectively contributing 37.57% and 35.47% to the total catch. *Labeo capensis* was further the most abundant species sampled during eight of the eleven times it was recorded at the site (see Figure 5.35). Although *C. carpio* adults were poorly represented in the samples taken at the site, their young numerically dominated the samples of November 2006 and February 2007 (Figure 5.35). The three large indigenous cyprinid species, *L. aeneus*, *L. capensis* and *L. umbratus,* and the minnow *B. anoplus,* were frequently sampled at the site (see Table 5.22). Despite being frequently sampled, *L. aeneus* was only present in low numbers and the species only contributed 1.41% to total abundance.

Table 5.22: Number of observed species at EWR4, March 2006 to April 2008. (BAEN, *Labeobarbus aeneus*; BANO, *Barbus anoplus*; LCAP, *Labeo capensis*; LUMB, *Labeo umbratus*; Labeo, *Labeo* juveniles; CGAR, *Clarias gariepinus*; CCAR, *Cyprinus carpio*).

Sampling date	*Gauge plate*	*BAEN*	*BANO*	*Barbus juv*	*LCAP*	*LUMB*	*Labeo juv*	*CGAR*	*CCAR*	*MSAL*	*Total abun-dance*	*Sp. Rich-ness*
Mar-06	93	1	7	0	42	56	205	19	4	0	334	6
May-06	105	0	2	0	261	3	18	0	0	0	284	3
Jun-06	100	3	7	3	160	63	0	1	0	0	238	5
Aug-06	103.5	2	23	1	238	69	0	8	0	0	341	5
Sep-06	100	1	24	27	210	109	0	7	6	2	386	7
Nov-06	85.5	4	33	0	66	18	0	4	914	0	1039	6
Feb-07	10.5	1	7	0	44	16	0	1	182	8	259	7
Mar-07	0	11	7	0	77	11	0	0	8	0	114	5
Jun-07	0	7	0	0	33	25	0	0	1	2	68	5
Oct-07	76	1	1	0	0	0	0	0	1	0	3	3
Apr-08	80.5	14	5	0	68	16	1	5	16	0	125	6
Tot. abun-dance		**45**	**116**	**31**	**1199**	**386**	**224**	**45**	**1132**	**12**	**3191**	
Rel. abun-dance (%)		**1.41**	**3.67**	**0.97**	**37.57**	**12.10**	**7.02**	**1.41**	**35.47**	**0.38**		
Frequency of occurrence		**10/11**	**10/11**	**3/11**	**10/11**	**10/11**	**3/11**	**7/11**	**8/11**	**3/11**		

The highest number of species was recorded between September 2006 and February 2007 when the water level at the site started to drop. By February 2007 all of the flowing habitats were dry and the main pool became isolated from the rest of the remaining surface water in the channel. By March and June 2007 the pool had separated into a series of isolated shallow pools. A survey of some of the deeper pools in June 2007 yielded 68 specimens representing five species. Of these, the two *Labeo* species were the most abundant.

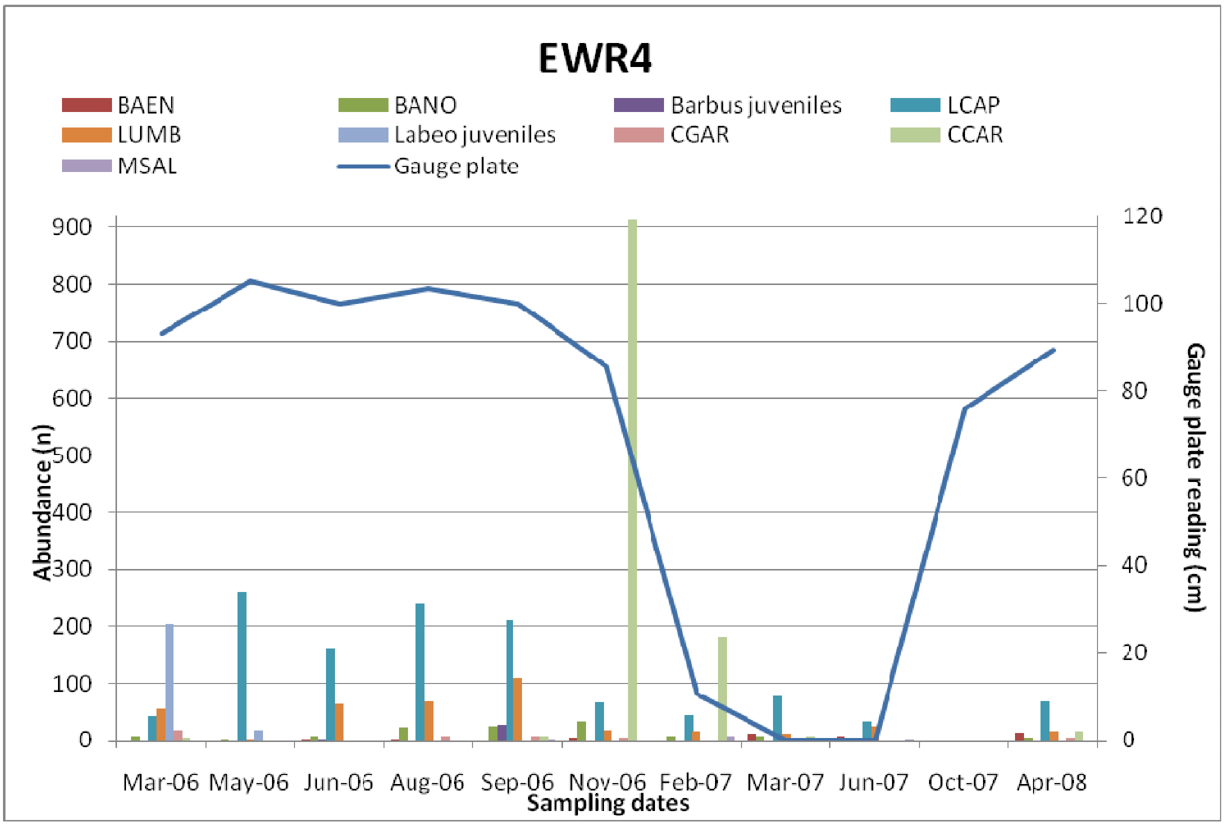


Figure 5.35: Species composition and abundance at EWR4, March 2006 to April 2008.

Overview of sampling points

The main pool (Pool A) at EWR4 yielded the most fish; contributing 31.96% to the total catch (Figure 5.37). Of these, 19.27% of the specimens were captured in the gill nets during the March 2006 and September 2006 samples; the remaining 12.69% were sampled with the electroshocker (Pool A1 in Figure 5.36 represent the fish captured by gill nets). Of the “flowing-habitats”, Pools B, C and D yielded the most fish, contributing 23.19%, 18.68% and 13.7% respectively (Figure 5.37). Very few fish were sampled in the rapid/riffles.

Pool A was the only sampling point where all seven species were recorded (*M.salmoides* was only found in the main pool). The shallow bedrock pool, Pool C, the rapids and Pool E at the downstream end of the site, yielded five species each (see Figure 5.37 and Table 5.23).

Three species, *L. capensis*, *C. gariepinus* and the exotic carp were recorded at all the sampling points. *Labeobarbus aeneus* was present at all the sampling points, except the shallow Pool C, while *L. umbratus* was not recorded in the rapids.

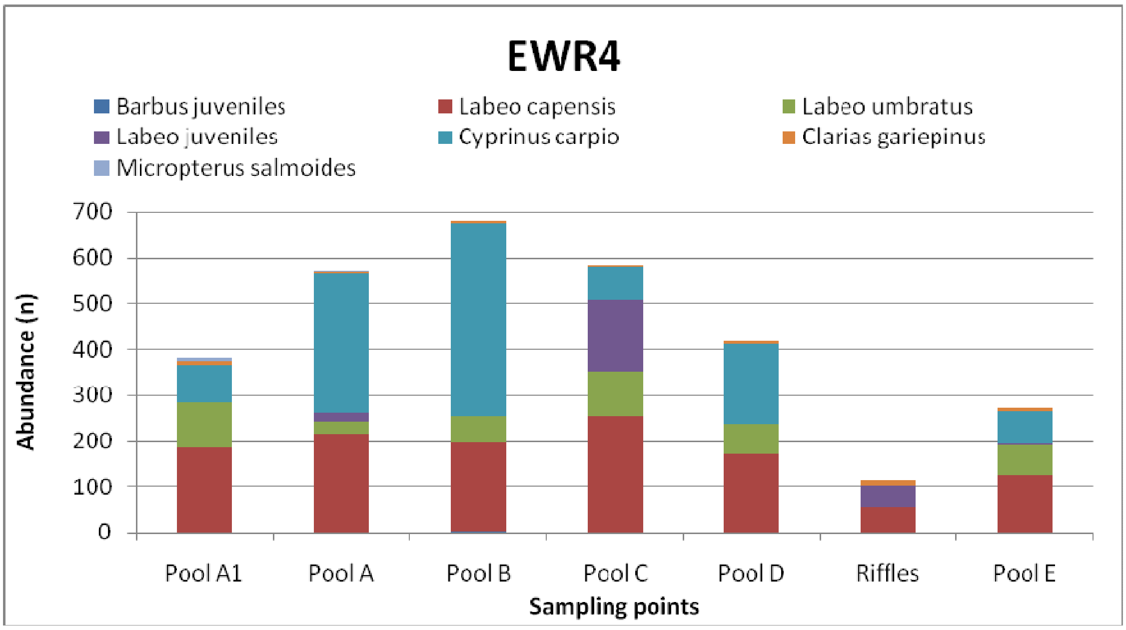


Figure 5.37: Species composition and abundance for the sampling points at EWR4, March 2006 to April 2008.

Pool A

The results from the fish surveys conducted in the main pool at EWR4 were split into two, Pool A1 and Pool A, for the following reasons:

- During March and September 2006 gill nets were used to sample the deeper parts of the pool (situated about a 100 m upstream from the gauging plate); the shallower parts of the pool closer to the gauging plate were sampled with the electroshocker. To keep these results apart, we referred to the deeper parts as Pool A1 and to the shallower parts as Pool A;
- When the site started to dry after November 2006, the water level receded to such an extent that the main pool splitted into two separate pools by February 2007: an upstream pool where the gill nets were used (Pool A1) and a downstream pool where the electroshocker was applied during the preceding surveys (Pool A).

Labeo capensis and *L. umbratus* dominated the samples taken with the gill nets (in Pool A1), with *L. aeneus*, *C. gariepinus* and *C. carpio* being present in low numbers (Table 5.23). In Pool A *L. capensis* and *B. anoplus* were the species most frequently sampled, while *C. carpio* was the most abundant. The high abundance was as a result of a large number of *C. carpio* young being present in the pool in November 2006 and February 2007. It is expected that the bulk of these young did not survive the dry period between March and June 2007 when the pool dried out completely.

Pool B

Of the six species that were recorded in this habitat, *C. carpio* and *L. capensis* were the most abundant, respectively contributing 56.9% and 26.2% to the total catch. While *L. capensis* was regularly sampled in this habitat, *C. carpio* was only recorded after surface flow slowed down from November 2006 onwards (see Tables 5.19 and 5.23). The large number of carp recorded in November 2006 comprised juveniles. Other species recorded in Pool B included *L. aeneus* (2.3% of the total catch), *B. anoplus* (5.5%), *L. umbratus* (7.7%) and *C. gariepinus* (0.9%) (see Table 5.23 and Figure 5.38).

Pool C

This shallow bedrock pool was dominated by *L. capensis* and *L. umbratus* young which collectively comprised 75% of the fish sampled (see Table 5.23). The pool was, however, dry between February 2007 and October 2007 and no fish were found in the pool in April 2008 (see Figure 5.38).

Pool D

Pool D that comprised mainly shallow habitat (see Table 5.19), was also dominated by *L. capensis* and *L. umbratus* juveniles (Figure 5.38). Although *C. carpio* was numerically the most abundant, the species was only recorded once (November 2006; Table 5.23). The habitat was also dry for the period between February and October 2007, but 17 specimens (representing 6 species) were found here in April 2008 when surface water returned.

Rapid/riffles

L. capensis was not only the most abundant in the rapids, but also the species most frequently sampled (see Table 5.23 and Figure 5.38). Ten juvenile *C. gariepinus* specimens were recorded here in March 2006, similar to EWR3 where juveniles of this species were also recorded in the rapid in March 2006. No fish was, however, recorded at this sampling point after September 2006 - in November 2006 the water depth was already very low in the rapid/riffle area (Table 5.19) and by February 2007 it was completely dry.

Pool E

Five species were recorded in Pool E (Figure 5.38). The species most frequently found were *L. capensis*, *L. umbratus* and *C. gariepinus*. The two *Labeo* species were also the most abundant, collectively contributing nearly 70% to the total catch recorded in the pool (Table 5.23). *B. anoplus* and *M. salmoides* were the two species that were absent from the site.

Table 5.23: Fish abundance and species composition for the various sampling points surveyed at EWR4, March 2006 to April 2008.

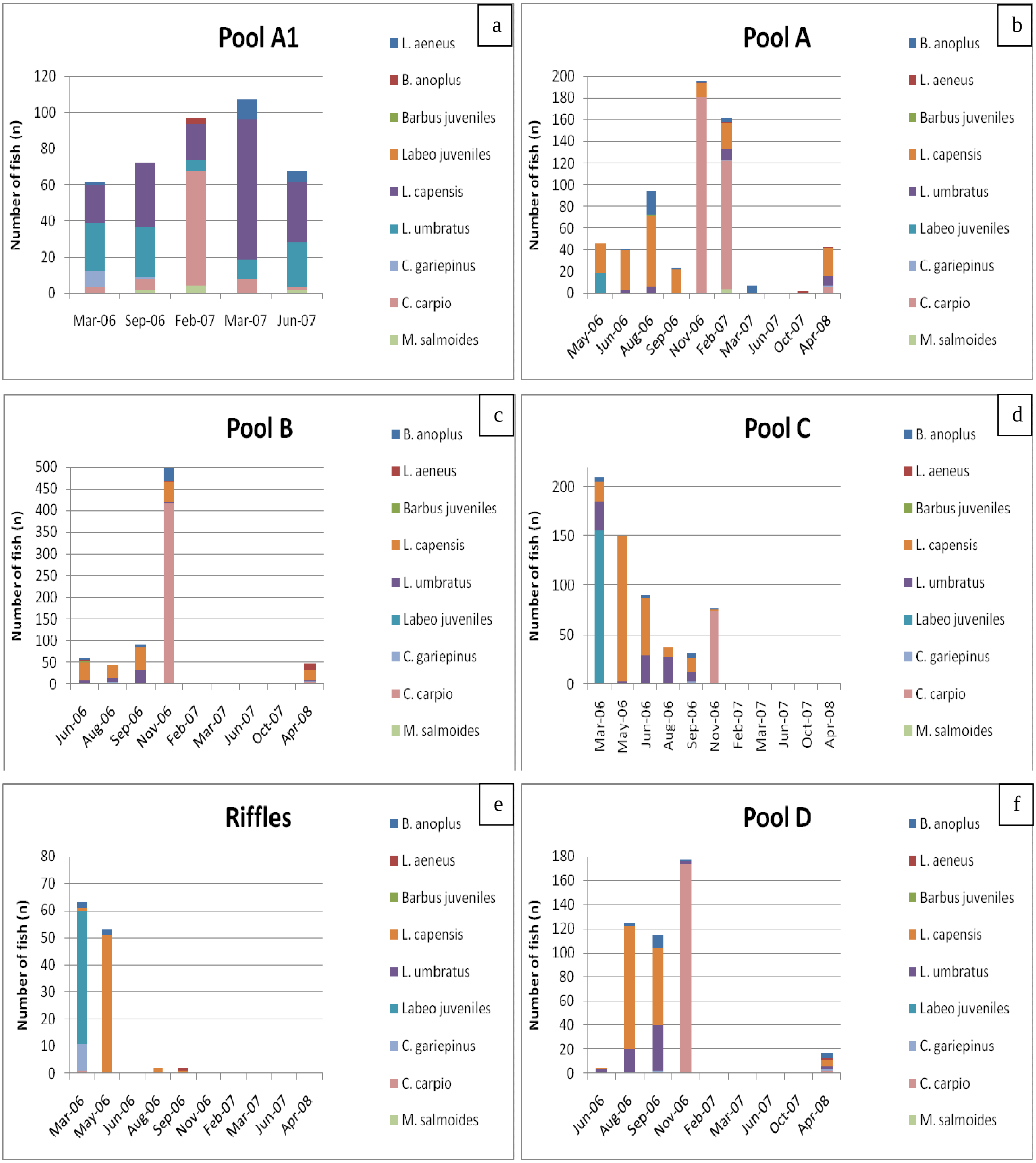
Sampling points	*Sampling Date*	*Samp-ling method*	*Gauge plate*	*BAEN*	*BANO*	*Barbus*	*LCAP*	*LUMB*	*Labeo*	*CGAR*	*CCAR*	*MSAL*	*Sp. richness*	*Total abundance*	*CPUE*
POOL A1 (main pool)	Mar-06	GN	93	1			21	27		9	3		5	61	
	Sep-06	GN	100				35	28		1	6	2	5	72	
	Feb-07	B E/S	10.5		3		20	6			64	4	5	97	6.47
	Mar-07	B E/S	0	11			77	11			8		4	97	9.73
	Jun-07	B E/S	0	7			33	25			1	2	5	107	2.72
	TOTAL			**19**	**3**	**0**	**186**	**97**	**0**	**10**	**82**	**8**		**405**	
	REL ABUNDANCE														
POOL A	May-06	E/S	105				28		18				2	46	2.23
	Jun-06	E/S	100		1		37	3					3	41	2.73
	Aug-06	B E/S	103.5		21	1	66	6					3	94	5.22
	Sep-06	B E/S	100		2		22						2	24	2.18
	Nov-06	B E/S	85.5	1	2		12				181		4	196	16.33
	Feb-07	B E/S	10.5	1	4		24	10		1	118	4	7	162	13.50
	Mar-07	B E/S	0		7								1	7	2.33
	Jun-07	B E/S	0										0	0	0
	Oct-07	B E/S	76	1							1		2	2	0.15
	Apr-08	B E/S	80.5	1	0	0	26	9	0	2	5	0	5	43	3.58
	TOTAL			**4**	**37**	**1**	**215**	**28**	**18**	**3**	**305**	**4**		**615**	
	REL ABUNDANCE			**0.7**	**6.0**	**0.2**	**35.0**	**4.6**	**2.9**	**0.5**	**49.6**	**0.7**		**100.0**	
POOL B (Glide)	Jun-06	E/S	100	3	4	3	41	9					4	60	6.67
	Aug-06	B E/S	103.5				28	11		4			3	43	2.15
	Sep-06	B E/S	100		7		51	33		1			4	92	9.20
	Nov-06	B E/S	85.5	2	29		48	1		1	416		6	497	45.18
	Feb-07		10.5											0	0
	Mar-07		0											0	0
	Jun-07		0	DRY										0	0
	Oct-07	B E/S	76		1								1	1	0.20
	Apr-08	B E/S	80.5	12	0	0	26	3	0	1	5	0	5	47	3.62
	TOTAL			**17**	**41**	**3**	**194**	**57**	**0**	**7**	**421**	**0**		**740**	
	REL ABUNDANCE			**2.3**	**5.5**	**0.4**	**26.2**	**7.7**	**0.0**	**0.9**	**56.9**	**0.0**		**100.0**	

Table 5.23: Continued

Habitat	Sampling date	Method	Gauge plate	BAEN	BANO	*Barbus*	LCAP	LUMB	*Labeo*	CGAR	CCAR	MSAL	Sp. richness	Total abundance	CPUE
POOL C (Shallow bedrock pool)	Mar-06	E/S	93		5		20	29	156				3	210	4.38
	May-06	E/S	105				148	2					3	150	9.06
	Jun-06	E/S	100		2		59	29					3	90	18
	Aug-06	B E/S	103.5				10	27		1			3	38	3.80
	Sep-06	B E/S	100		4	1	14	10		2			4	31	3.10
	Nov-06	B E/S	85.5		1		2				74		3	77	5.57
	Feb-07		10.5	DRY										0	0
	Mar-07		0	DRY										0	0
	Jun-07		0	DRY										0	0
	Oct-07	B E/S	76	DRY										0	0
	Apr-08	B E/S	80.5											0	0
	TOTAL			**0**	**12**	**1**	**253**	**97**	**156**	**3**	**74**	**0**		**596**	
	REL ABUNDANCE			**0.0**	**2.0**	**0.2**	**42.4**	**16.3**	**26.2**	**0.5**	**12.4**	**0.0**		**100.0**	
POOL D (Glide)	Jun-06	E/S	100				2	3					2	5	0.63
	Aug-06	B E/S	103.5		2		102	19		1			4	124	10.33
	Sep-06	B E/S	100		11		64	38		2			4	115	16.43
	Nov-06	B E/S	85.5		1			2			174		3	177	17.70
	Feb-07	B E/S	10.5	DRY										0	0
	Mar-07		0	DRY										0	0
	Jun-07		0	DRY										0	0
	Oct-07	B E/S	76										0	0	0
	Apr-08	B E/S	80.5	1	5	0	5	2	0	2	2	0	5	17	2.14
	TOTAL			**1**	**19**	**0**	**173**	**64**	**0**	**5**	**176**	**0**		**438**	
	REL ABUNDANCE			**0.23**	**4.34**	**0.00**	**39.50**	**14.61**	**0.00**	**1.14**	**40.18**	**0.00**		**100.0 0**	

Table 5.23: Continued.

Habitat	Sampling date	Method	Gauge plate	BAEN	BANO	*Barbus*	LCAP	LUMB	*Labeo*	CGAR	CCAR	MSAL	Species richness	Total abundance	CPUE
RAPIDS/ RIFFLES	Mar-06	E/S	93		2		1		49	10	1		4	63	1.31
	May-06	E/S	105		2		51						2	53	1.73
	Jun-06	E/S	100										0	0	0
	Aug-06	B E/S	103.5				2						1	2	0.22
	Sep-06	B E/S	100	1			1						2	2	0.29
	Nov-06		85.5											0	0
	Feb-07		10.5	DRY										0	0
	Mar-07		0	DRY										0	0
	Jun-07		0	DRY										0	0
	Apr-08	B E/S	80.5										0	0	0
	TOTAL			**1**	**4**	**0**	**55**	**0**	**49**	**10**	**1**	**0**		**120**	
	REL ABUNDANCE			**0.8**	**3.3**	**0.0**	**45.8**	**0.0**	**40.8**	**8.3**	**0.8**	**0.0**		**100.0**	
POOL E (downstream-end pool)	May-06	B E/S	105				34	1					2	35	5.0
	Jun-06	B E/S	100	1			21	19		1			4	42	4.20
	Aug-06	B E/S	103.5	2			30	6		2			5	40	2.93
	Sep-06	B E/S	100				26	23		1			3	50	5.0
	Nov-06	B E/S	85.5	1			4	15		3	69		5	92	8.36
	Feb-07		10.5	DRY										0	0
	Mar-07	B E/S	0	DRY										0	0
	Jun-07	B E/S	0	DRY										0	0
	Oct-07	B E/S	76										0	0	0
	Apr-08	B E/S	80.5	0	0	0	11	2	1	0	4	0	3	18	1.38
	TOTAL			**4**	**0**	**0**	**126**	**66**	**1**	**7**	**73**	**0**		**277**	
	REL ABUNDANCE			**1.4**	**0.0**	**0.0**	**45.5**	**23.8**	**0.4**	**2.5**	**26.4**	**0.0**		**100.0**	
	TOTAL			**46**	**116**	**5**	**1202**	**409**	**224**	**45**	**1132**	**12**		**3191**	
	REL ABUNDANCE			**1.5**	**3.7**	**0.2**	**38.1**	**13.0**	**7.1**	**1.4**	**35.9**	**0.4**		**101.1**	


Pool A1
a
L. aeneus
B. anoplus
Barbus juveniles
Labeo juveniles
L. capensis
L. umbratus
C. gariepinus
C. carpio
M. salmoides
Number of fish (n)
0
20
40
60
80
100
120
Mar-06
Sep-06
Feb-07
Mar-07
Jun-07
Pool A
b
B. anoplus
L. aeneus
Barbus juveniles
L. capensis
L. umbratus
Labeo juveniles
C. gariepinus
C. carpio
M. salmoides
Number of fish (n)
0
20
40
60
80
100
120
140
160
180
200
May-06
Jun-06
Aug-06
Sep-06
Nov-06
Feb-07
Mar-07
Jun-07
Oct-07
Apr-08
Pool B
c
B. anoplus
L. aeneus
Barbus juveniles
L. capensis
L. umbratus
Labeo juveniles
C. gariepinus
C. carpio
M. salmoides
Number of fish (n)
0
50
100
150
200
250
300
350
400
450
500
Jun-06
Aug-06
Sep-06
Nov-06
Feb-07
Mar-07
Jun-07
Oct-07
Apr-08
Pool C
d
B. anoplus
L. aeneus
Barbus juveniles
L. capensis
L. umbratus
Labeo juveniles
C. gariepinus
C. carpio
M. salmoides
Number of fish (n)
0
50
100
150
200
Mar-06
May-06
Jun-06
Aug-06
Sep-06
Nov-06
Feb-07
Mar-07
Jun-07
Oct-07
Apr-08
Riffles
e
B. anoplus
L. aeneus
Barbus juveniles
L. capensis
L. umbratus
Labeo juveniles
C. gariepinus
C. carpio
M. salmoides
Number of fish (n)
0
10
20
30
40
50
60
70
80
Mar-06
May-06
Jun-06
Aug-06
Sep-06
Nov-06
Feb-07
Mar-07
Jun-07
Apr-08
Pool D
f
B. anoplus
L. aeneus
Barbus juveniles
L. capensis
L. umbratus
Labeo juveniles
C. gariepinus
C. carpio
M. salmoides
Number of fish (n)
0
20
40
60
80
100
120
140
160
180
Jun-06
Aug-06
Sep-06
Nov-06
Feb-07
Mar-07
Jun-07
Oct-07
Apr-08

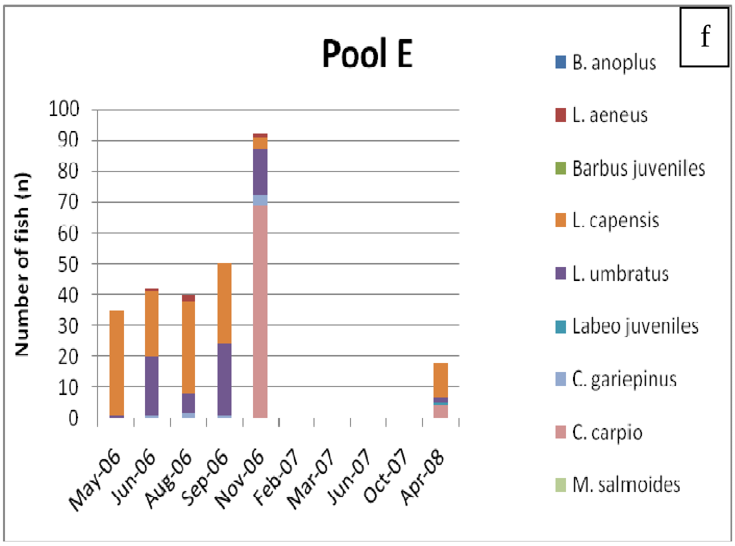


Figure 5.38: Species composition and abundance recorded at the various sampling points at EWR4, March 2006 to April 2008.

5.2.4.3 Microhabitat

Water depth

The water level (based on the gauge plate readings) at EWR4 showed the highest variability of all the sites (mean=68.5 cm; std=42.8 cm). This variability was reflected in the mean water depths measured at the various sampling points (see Figure 5.39).

Two of the sampling points, Pools A and E, represented predominantly deep habitat (>50 cm) with slow- or no-flow, while the remaining four points represented predominantly shallow habitat (<30 cm; see Table 5.24). Of the predominantly shallow habitats, flow was recorded at three: Pool B, Pool D and the Rapids/riffles. At these points, fast flows (>0.3 m/s) were only recorded when the gauge plate was ≥100 cm; slow flows (<3 m/s) occurred between 80 cm and a 100 cm, but ceased when the gauge plate reading reached 76 cm (Table 5.24).

The mean water depth of all the sampling points decreased as the water level at the site dropped (see Figure 5.39) and by February 2007 all were dry except for the main pool (Pool A). Three of the habitats, Pools B, D and E, remained dry until June 2007, but Pool C and the Rapids/riffles only became inundated by October 2007. It is interesting to note that by June 2007, surface flow was already present at EWR3. Surface flow at EWR4 was only restored when the weir situated between the sites overtopped.

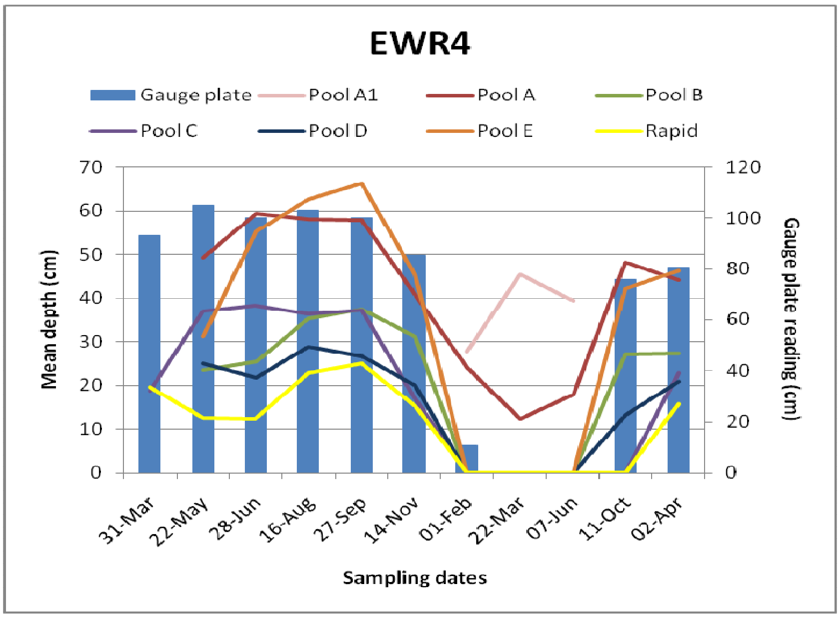


Figure 5.39: Mean depths recorded for the sampling points at EWR4 in relation to the gauge readings, March 2006 to April 2008.

The main pool was the only sampling point that retained some water between January and June 2007. As the water level receded, the main pool first separated into two pools (February 2007): Pool A where the gauge plate was located, and Pool A1 where the gill nets were used in March and September 2006. By June 2007, Pool A had markedly shrunk in size and depth and Pool A1 had separated into a series of small, shallow pools between 17 m and 65 m apart. Six pools were sampled for fish and surveyed (including Pools A and A1).

The pools were between 13 and 118.5 m long and the mean depths varied between 10.3 and 39.4 cm (see Table 5.25). Most of the pools had a substrate of coarse sand and mud, while cover was provided by aquatic grasses and reeds. Fish was, however, only found in the largest of these pools (Pool A1), which had a mean depth of 39 cm (Table 5.25).

Substrate and fish cover

Bedrock underlies most of the habitats sampled at EWR4, Pool A1 being the only exception. Pool A1, which comprises the deeper upstream habitat of the main pool at EWR4, has a gravel or coarse sand substrate compared to Pool A's substrate that comprise bedrock, gravel, boulders and cobbles (Figure 5.40). The substrate and overhanging rocks provided the most cover towards the middle of the pool, while sedges and reeds provided cover along the river banks. However, as the pool's surface area decreased, much of the substrate cover was "lost" to fishes and aquatic grasses and reeds became more important as a source of cover.

Table 5.24: Random depth measurements taken in each of the sampling points at EWR4, March 2006 to March 2008. Fish abundance, mean body length, minimum and maximum body lengths are alos indicated.

Samp-ling date	*Flow descript-tion*	*Gauge plate (cm)*	*Mean depth (cm)*	*Minimum depth (cm)*	*Maximum depth (cm)*	*Fish abund-ance (n)*	*Mean body length (FL; mm)*	*Body length range*	**Body length Std**
Pool A									
May-06	No flow	105	49.21	37.5	64	46	34.9	34-38	1.69
Jun-06	No flow	100	59.25	27.5	90.5	41	34.44	30-44	3.28
Aug-06	No flow	103	58	39	90	94	36.55	20-55	5.53
Sep-06	No flow	100	57.7	37	88.5	24	37	24-46	5.02
Nov-06	No flow	85.5	40.88	16.5	80	196	33.84	12-70	10.5
Feb-07	No flow	10.5	23.95	14	45	162	73.6	24-275	32.45
Mar-07	No flow	0	12.2	7	18	7	37.14	35-40	2.67
Jun-07	No flow	0	17.78	7	34	0	0	0	0
Oct-07	No flow	76	48	16	71	2	298.5	112-485	186.5
Apr-08	No flow	80.5	44.1	20	77	43	75.56	32-168	29.93
Pool B									
May-06	Fast flow	105	23.46	10	41				
Jun-06	Slow flow	100	25.36	9	55	60	40.02	28-87	8.35
Aug-06	Fast flow	103	35.24	2	60	43	48.79	28-195	31.39
Sep-06	Slow flow	100	37.34	8	59	92	41.27	28-147	12.18
Nov-06	No flow	85.5	31.05	18.5	36	497	36.18	20-165	11.85
Feb-07	Dry	10.5	0			0	0	0	0
Mar-07	Dry	0	0			0	0	0	0
Jun-07	Dry	0	0			0	0	0	0
Oct-07	No flow	76	27	17	62	1	45	0	0
Apr-08	Slow flow	80.5	27.3	20	38	47	57.02	29-191	24.55
Pool C									
Mar-06	No flow	93	18.63	4	51	210	43.27	40-73	6.49
May-06	No flow	105	36.93	17.5	53	150	35.98	34-45	3.82
Jun-06	No flow	100	38.3	22	51	90	36.29	28-53	3.75
Aug-06	No flow	103	36.3	24	45	38	38.58	28-128	16.33
Sep-06	No flow	100	37.25	17.5	55.5	31	43.52	30-137	20.3
Nov-06	No flow	85.5	17.1	6	32	77	32.38	18-40	4.1
Feb-07	Dry	10.5	0			0	0	0	0
Mar-07	Dry	0	0			0	0	0	0
Jun-07	Dry	0	0			0	0	0	0
Oct-07	Dry	76	0			0	0	0	0
Apr-08	No flow	80.5	22.8	17	36	0	0	0	0

Table 5.24: Continued.

Samp-ling date	*Flow descript-tion*	*Gauge plate (cm)*	*Mean depth (cm)*	*Minimum depth (cm)*	*Maximum depth (cm)*	*Fish abund-ance (n)*	*Mean body length (FL; mm)*	*Body length range*	***Body length** Std*
Pool D									
May-06	Fast flow	105	24.88	3	51				
Jun-06	Fast flow	100	21.72	3	48	5	41.4	38-45	3.29
Aug-06	Fast flow	103	28.79	6	50	124	38.43	28-150	10.92
Sep-06	Fast flow	100	26.73	5	45	115	43.64	28-170	25.32
Nov-06	No flow	85.5	20.08	10	31	177	37.34	25-72	7.02
Feb-07	Dry	10.5	0			0	0	0	0
Mar-07	Dry	0	0			0	0	0	0
Jun-07	Dry	0	0			0	0	0	0
Oct-07	No flow	76	13	11	18	0	0	0	0
Apr-08	Slow flow	80.5	20.9	13	26	17	63.13	37-158	39.16
Rapid B									
Mar-06	Slow flow	93	19.75	14	29	63	57.87	38-220	41.12
May-06	Fast flow	105	12.5	4	26	53	38.25	25-150	16.17
Jun-06	Fast flow	100	12.33	3	24	0	0	0	0
Aug-06	Fast flow	103	23	5	37	2	38	34-42	5.66
Sep-06	Fast flow	100	25.08	5	64	2	146.5	38-255	153.44
Nov-06	Slow flow	85.5	15.32	3	30	0	0	0	0
Feb-07	Dry	10.5	0			0	0	0	0
Mar-07	Dry	0	0			0	0	0	0
Jun-07	Dry	0	0			0	0	0	0
Oct-07	No flow	76	0			0	0	0	0
Apr-08	Slow flow	80.5	15.8	8	25	0	0	0	0
Pool E									
May-06	No flow	105	31.17	9	50	35	37	34-73	7.09
Jun-06	No flow	100	55.1	27	70	42	40.76	32-157	19.82
Aug-06	No flow	103	62.6	50	77	40	43.1	27-145	26.58
Sep-06	No flow	100	66.15	56	75	50	47	30-140	26.12
Nov-06	No flow	85.5	45.3	25.5	59.5	92	47.67	13-170	25
Feb-07	Dry	10.5	0			0	0	0	0
Mar-07	Dry	0	0			0	0	0	0
Jun-07	Dry	0	0			0	0	0	0
Oct-07	No flow	76	42	14	75	0	0	0	0
Apr-08	No flow	80.5	46.1	22	73	18	64	42-89	11.64

Table 5.24: Continued.

Samp-ling date	*Flow descript-tion*	*Gauge plate (cm)*	*Mean depth (cm)*	*Minimum depth (cm)*	*Maximum depth (cm)*	*Fish abund-ance (n)*	*Mean body length (FL; mm)*	*Body length range*	*Body length* **Std**
Pool A1									
Mar-06	No flow	93				61	376.55	180-690	94.17
Sep-06	No flow	100				72	358.51	165-545	80.76
Feb-07	No flow	10.5	27.75	12	47	97	74.85	26-165	29.48
Mar-07	No flow	0	45.35	24	70	107	108.06	60-130	11.49
Jun-07	No flow	0	39.4	17	63	68	135.4	93-518	51.49

Table 5.25: Habitat description of the isolated pools present at EWR4 in June 2007.

Pool	*Length (m)*	*Width (m)*	*Mean depth (cm)*	*Distance to next pool (m)*	*Dominant substrate type*	*Fish cover*	*Fish abun-dance (n)*	*Sp. rich-ness*
Pool 1	20.67	10.7	17.78	25	Bedrock, silt	Substrate	0	0
Pool 2	13.7	6.1	13.6	46	Mud	Aquatic grass	0	0
Pool 3	118.55	19.7	39.4	20	Coarse sand, mud	Aquatic grass, reeds	68	5
Pool 4	96	20	31.05	17	Coarse sand, mud	Aquatic grass, reeds	0	0
Pool 5	20.1	3.1	10.3	40	Mud		0	0
Pool 6	27.1	10.5	19.3	64	Mud	Reeds, aquatic grass, fila-mentous algae	0	0
Pool 7	±300			Weir			Not sampled	0

In Pool B the substrate consisted mainly of bedrock, boulders, cobbles and sand (Figure 5.40). Important sources of fish cover in this habitat included the substrate, bedrock overhangs and sedges along the water's edge.

The substrates of the three predominantly shallow habitats, Pool C, D and the Rapids, were also dominated by bedrock. In Pool C a backwater area that did not experience surface flow, bedrock overhang (of between 15 to 30 cm) and crevices were the only source of cover and shade for the juvenile fish found there. In Pool D boulders, cobbles and pebbles provided additional fish cover to the bedrock crevices present. In the shallow rapid, the substrate was again the most important source of fish cover.

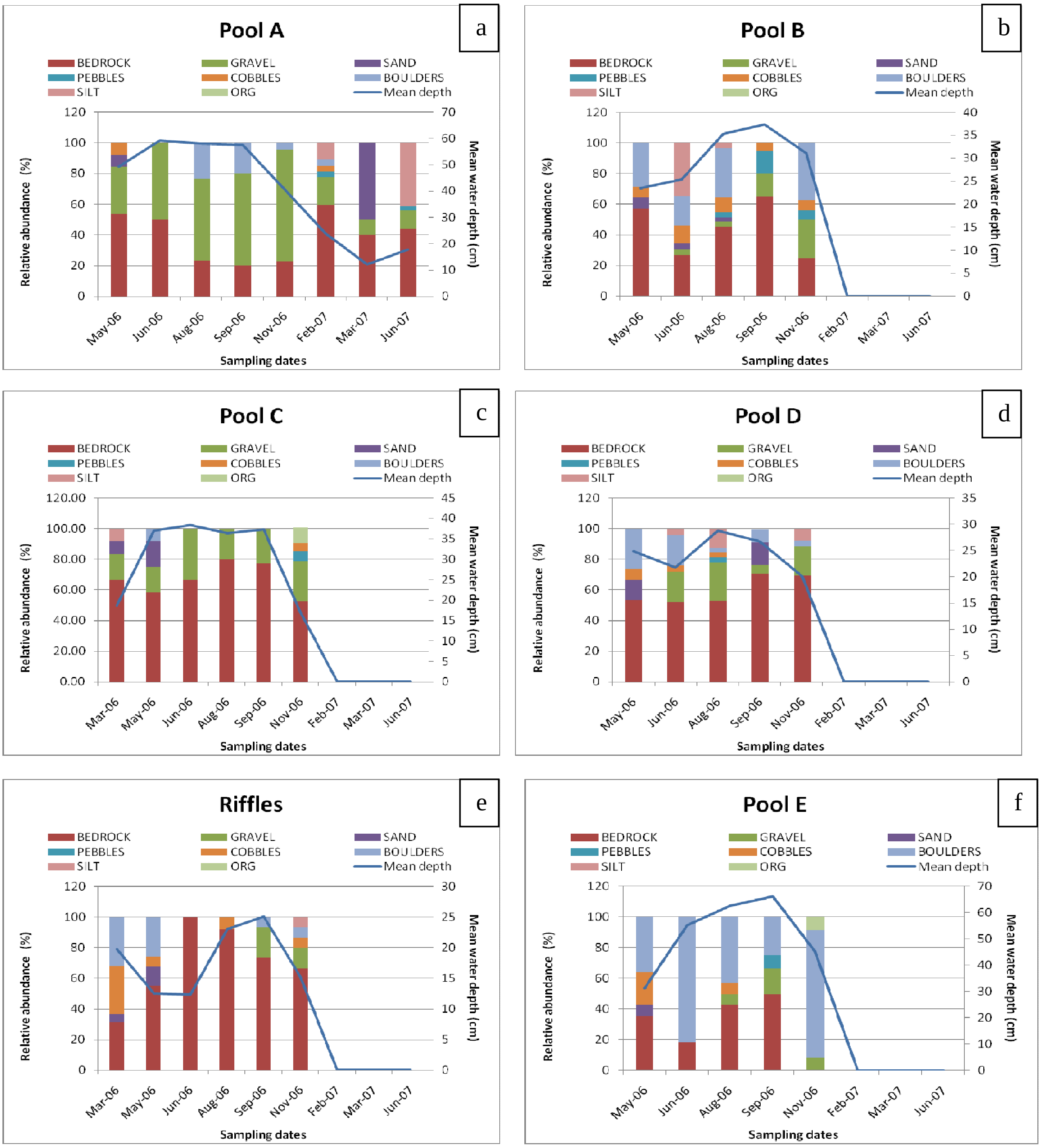
Pool E at the downstream end of the site, has a bedrock substrate covered with boulders, cobbles and pebbles. Again, substrate cover was very important, with sedges providing additional cover closer to the left river bank.

5.2.4.4 Discussion for EWR4

The available habitat at EWR4 exhibited the greatest heterogeneity of the four sampling sites in the Seekoei River. Seven points were sampled, including some deep and shallow pools, two glides and two short rapids. Most of this heterogeneity is, however, lost when surface flow stops and the habitat starts to dry (e.g. the period between November 2006 and June 2007). Despite the fact that the longterm flow record indicates that high flows generally occurs in March, followed by a period of lower flow in winter, this was not the case in 2006 when surface flow continued during the whole winter. Only in November 2006 did the flow started to slow down and the water level (based on the gauge plate readings) dropped. By early February 2007 all the shallow bedrock pools, runs and rapids had disappeared and only the large main pool persisted. The downstream end of this pool, of nearly a kilometer long, had separated into two pools with coarse sandy bottoms. This process continued and by June all that was left of the pool were a series of seven isolated pools varying in size and depth. This had a marked influence on the composition and abundance of substrate types at all sampling points (Figure 5.40).

The weir situated between EWR3 and 4 had a marked impact on the flow regime at EWR4: e.g. although surface connectivity at EWR3 was restored by June, EWR4 was still dry. The exact time when surface flow resumed at EWR4 is unknown, but by October 2007 the water level at the site had risen to 76 cm. This drying had an important impact on fish sampling in the sense that habitat characteristics (e.g. mean depth, maximum depth, flow, available cover, etc.) changed in response to fluctuations in the water level; and fish results should be interpreted against this variability. Also, the number of sampling points dropped to two under severe dry conditions, influencing the application of biological indices such as the Fish Response Assemblage Index (FRAI, see Kleynhans 2008).

The fish assemblage at EWR4 was dominated by the two large *Labeo* species, *L. capensis* and *L. umbratus*. Collectively they contributed 57.5% to the total number of fish recorded at the site; 90% if the large number of juvenile carp recorded in the summer of 2006/2007 is ignored. A number of observations indicated that the conditions at EWR4 suit these two species well: nearly 70% of *L. capensis* specimens and 61.2% of *L. umbratus* specimens recorded in the Seekoei River were found at this site; both species were represented in ten of the eleven samples taken over the two year period; *L. capensis* was recorded at all the sampling points, while *L. umbratus* was found at all but the rapid/riffle areas.


a
Pool A
BEDROCK
GRAVEL
SAND
PEBBLES
COBBLES
BOULDERS
SILT
ORG
Mean depth
Relative abundance (%)
Mean water depth (cm)
May-06
Jun-06
Aug-06
Sep-06
Nov-06
Feb-07
Mar-07
Jun-07
Sampling dates
b
Pool B
BEDROCK
GRAVEL
SAND
PEBBLES
COBBLES
BOULDERS
SILT
ORG
Mean depth
Relative abundance (%)
Mean water depth (cm)
May-06
Jun-06
Aug-06
Sep-06
Nov-06
Feb-07
Mar-07
Jun-07
Sampling dates
c
Pool C
BEDROCK
GRAVEL
SAND
PEBBLES
COBBLES
BOULDERS
SILT
ORG
Mean depth
Relative abundance (%)
Mean water depth (cm)
Mar-06
May-06
Jun-06
Aug-06
Sep-06
Nov-06
Feb-07
Mar-07
Jun-07
Sampling dates
d
Pool D
BEDROCK
GRAVEL
SAND
PEBBLES
COBBLES
BOULDERS
SILT
ORG
Mean depth
Relative abundance (%)
Mean water depth (cm)
May-06
Jun-06
Aug-06
Sep-06
Nov-06
Feb-07
Mar-07
Jun-07
Sampling dates
e
Riffles
BEDROCK
GRAVEL
SAND
PEBBLES
COBBLES
BOULDERS
SILT
ORG
Mean depth
Relative abundance (%)
Mean water depth (cm)
Mar-06
May-06
Jun-06
Aug-06
Sep-06
Nov-06
Feb-07
Mar-07
Jun-07
Sampling dates
f
Pool E
BEDROCK
GRAVEL
SAND
PEBBLES
COBBLES
BOULDERS
SILT
ORG
Mean depth
Relative abundance (%)
Mean water depth (cm)
May-06
Jun-06
Aug-06
Sep-06
Nov-06
Feb-07
Mar-07
Jun-07
Sampling dates

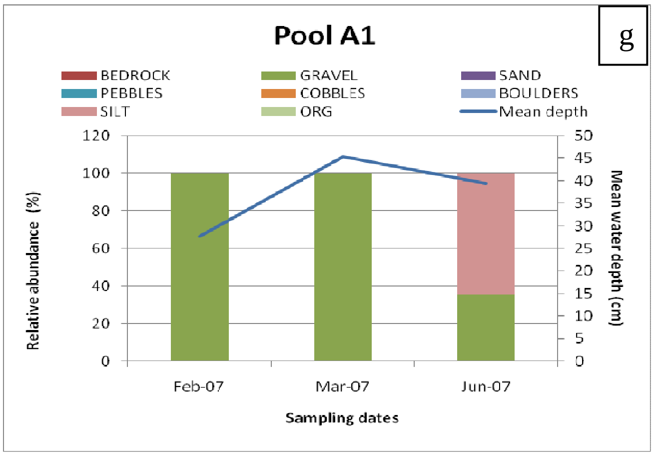


Figure 5.40: Composition and abundance of substrate types at the various sampling points at EWR4 based on microhabitat measurements, March 2006 to April 2008.

The seven sampling points represented a range of habitat conditions over the study period varying from no-flow to fast flow, and from shallow to deep. While surface flow was recorded in four of the habitats, pool conditions prevailed in the remaining three. These pool habitats yielded approximately 59% of the total number of fish recorded at the study site. It was also obvious that larger fish avoided the shallow areas.

Flowing habitats

Surface flow was only detected when the water level at the site was 80 cm or higher. At this level only slow flows (<3 m/s) were recorded; fast flows (>0.3 m/s) occurred when the water level was 100 cm or higher.

The highest flows at EWR4 were recorded in the two rapids: maximum flows of up 0.628 m/s and 1.736 m/s in Rapids A and B, respectively. Both these rapids were predominantly shallow (mean depths <30 cm), with substrate being the dominant cover-type. Habitat conditions, however, changed in response to changes in the water level. For example, where three velocity-depth classes (fast-shallow, slow-shallow and slow-deep) were present in Rapid A at a gauge plate reading of 105 cm (May 2006), only one (slow-shallow) remained when the gauge plate reading dropped to 85.5 (November 2006). *Labeo capensis* was not only the species most frequently recorded in the rapids, but also the most abundant in this habitat. Juveniles from this species contributed nearly 87% to the total number of fish sampled in this habitat. Species composition and abundance was variable in the rapids with differences found during all consecutive visits when fish were found. As no fish were found in the rapid during the first winter sample (June 2006) and the rapid was dry during the second winter sample, no comparisons were possible.

All five indigenous species were recorded in the two glides (Pools B and D) that collectively yielded approximately 37% of the total number of fish sampled at EWR4. Both these glides were dry from January to June 2007. At a gauge plate reading of 105 cm (May 2006) three (fast-deep, slow-deep and slow-shallow) and four (fast-deep, fast-shallow, slow-deep and slow-shallow) velocity-depth classes were present in Pool B and Pool D, respectively. The availability of velocity-depth classes decreased with a drop in water level. At a gauge plate reading of 85.5 cm only two (slow-deep and slow-shallow) of the three velocity-depth classes were available in Pool B, while only one (slow-shallow) remained at Pool D. The high variability in flow made it difficult to make any sensible conclusions of how the availability (or absence) of velocity-depth classes influenced species composition at these two sites.

Pool habitats

Three pool habitats were sampled, the large main pool, Pool A, a shallow bedrock pool, Pool C (min mean depth=17.1 cm; max mean depth=38.3 cm) and a deeper pool at the downstream end of the site, Pool E (min mean depth=31.2 cm; max mean depth=66.2 cm).

The main pool was the most productive habitat at EWR4 and was the only sampling point that persisted throughout the study period. Two sampling methods were applied on the main pool, namely gill-netting in the deeper parts of the pool about 500 m upstream of where the gauge plate is situated (Pool A1) and electrofishing at the shallower upstream end of the pool (Pool A). As expected, the gill-netting yielded mainly adult fish [the mean body length varied between 376.5 mm (min=180 mm; max=690 mm; std=94 mm) in March 2006 and 358.5 mm (min=165 mm; max=545 mm; std=80.8 mm) in September 2006]. Six species were present in the sample, including the exotic *M. salmoides*. The two large *Labeo* species dominated both the March and September samples, with *L. umbratus* being most abundant in March and *L. capensis* the most abundant in September. At the shallower end of the pool, all six of the above species were captured, as well as *B. anoplus,* which was frequently recorded. The riverine *Labeo capensis* was, again, numerically the most abundant indigenous species with the highest frequency of occurrence at the sampling point. In contrast to the deeper parts that were dominated by adult fish, the shallower parts yielded mostly juveniles. Between May and November 2006, the mean body length ranged between 34.9 mm (min=34 mm; max=38 mm; std=1.69 mm) in May and 37 mm (min=24 mm; max=46 mm; std=5.02 mm) in September 2006. However, in February 2007 the mean body length increased to 73.6 mm (min=24 mm; max 275 mm; std=32.5 mm), indicating larger differences in size. At the onset of the drying in February, Pool A was separated from the deeper parts of the main pool (Pool A1) due to the onset of the drying and the mean depth dropped by nearly 50%. As a result fish of various sizes were forced into the same habitat. By March the mean water depth in the pool had dropped to 12.2 cm and only juvenile fish (mean body length=37.14 mm; std=2.67 mm) were found; by June the pool was dry. When the surface water connectivity was restored in October 2007, the mean body length was 298.5 mm (std 186.5) indicating that the pool had been re-stocked.

During the dry period the main pool separated into a series of small isolated pools that varied in length and depth. Now fish were only present in pools deeper than 30 cm. Many of the shallower pools had a sandy bottom with virtually no fish cover. In one pool (with a mean depth of 39.4 cm) 68 fishes were sampled. Interestingly, only the large-bodied fish were represented (*L.*

aeneus, *L. capensis*, *L. umbratus*, *C. gariepinus* and *M. salmoides*) and no individuals smaller than 93 cm were recorded. Although cover could increase survival in shallow pools, it has been reported that the survival of fish approximately 100 mm long is much lower in shallow (±10 cm) than in deeper (±40 cm) pools, although cover could increase survival in shallow pools (Harvey and Stewart, 1991). According to them predation risk from wading or diving animals is much higher for larger fish in shallow pools than for these fishes in deeper water. However, piscivorous fishes, such as ≥ 50 mm long Micropterus salmoides, could again be important predators in deeper pools. It is unclear to what extent the adult *M. salmoides* en *C. gariepinus* could have impacted juveniles and *B. anoplus* numbers in the isolated pool.

The predominantly shallow Pool C appeared to be a nursery area for juvenile fish, especially for *L. capensis* and *L. umbratus* which comprised about 85% of the total number of fish sampled here. The juvenile fish were often associated with the bedrock crevices and overhanging rocks present in the pool.

Pool E comprised slow-deep and slow-shallow habitat. However, as the water level dropped at the site, the abundance of slow-deep habitat decreased while slow-shallow areas increased. It appears as if fish were more abundant at higher water levels when slow-deep habitat was dominant. This sampling point is, however, situated at the downstream end of the study site and was possibly influenced by a loss of connectivity due to Rapid B being dry or very shallow when the water level dropped below 85.5 cm. For example, when surface water connectivity was restored in October 2007, no fish were found in Pool E, despite it having a mean depth 42 cm and abundant substrate cover. Rapid B was, however, dry at this time, isolating Pool E from the rest of the sampling points.

5.3 Present ecological state of the fish community

The Fish Response Assessment Index (FRAI) of Kleynhans (2008) was applied on the fish data in order to determine the present ecological state (PES) of the Seekoei River fish community. For the purpose of presenting a FRAI score, the accumulated fish data are shown where fish were sampled at less than 3 sampling points (Table 5.26). The un-accumulated data for EWR Sites 3 and 4 are also shown in order to allow discussion of this point (see later).

5.3.1 Results

The PES of the fish community in the different sections of the Seekoei catchment varied between natural (Category A) and seriously modified (Category E):

EWR1 in the upper reaches was the most natural site (Category A/B). It was the only site where FRAI values remained constant over the study period. The available habitat, which comprised slow-deep (70%) and slow-shallow (30%) velocity-depth classes, remained stable over the 2-year period, sustaining a persistent *B. anoplus* population.

EWR2 showed the highest degree of change, with FRAI increasing from seriously modified (Category E) in March 2006 to largely modified (Category D) in October 2007. This increase was clearly a result of the improved data record and, most probably, not because of improved ecological integrity.

FRAI categories for EWR3 and 4 varied between C (moderately modified) and E (seriously modified). FRAI scores at both these sites showed a similar pattern of increase from March 2006 to March 2007, and thereafter dropped markedly in October 2007.

5.3.2 Discussion

The fact that accumulated data were used to calculate FROC scores potentially influenced the calculations of FRAI scores, leading to possible incorrect assumptions about the integrity of a river reach. Although it has been suggested that FRAI scores improve with the number of points sampled, it is not always possible to increase the number of sampling points at a site to 3 or more (e.g., when the river stopped flowing in December 2006 the diversity of habitats, and therefore the number of sampling points at EWR3 and 4, was reduced to 2 at each site). Habitat composition changed, which had a marked influence on fish species presence/absence and relative abundance (see e.g. differences between October 2007 datasets calculated on actual data vs. accumulated data for both sites EWR3 and 4 – Table 3). The use of accumulated data is, therefore, incorrect under such ephemeral conditions. One must also bear in mind that the catchability of fish in isolated pools differs from that in flowing streams in that fish density increase due to drying (Magoulick, 2000). Another reason for the change in FRAI scores is that some species (e.g. *L. kimberleyensis*) are removed from the reference list, as the available habitat (in an isolated pool) is deemed to be unsuitable. It is therefore suggested that FRAI scores in ephemeral rivers are not calculated using data accumulated under different flow conditions. In this study the differences in FRAI scores calculated with accumulated data vs. the data for that sampling only, were notable in: March 2007, at EWR3 the difference was almost one category (from B/C to C); in October 2007 at EWR4 the difference was one category (from E to D); and October 2007 at EWR3, the difference was almost 2 categories (from E to C/D).

Table 5.26: Fish species expected to be present at the 4 sampling sites, EWR1 to 4 on the Seekoei River, as well as the species recorded (in brackets) over a two-year period. FRAI scores calculated for the 4 sites are indicated. The recorded presence of species is expressed as frequency of occurrence ratings (FROC; as described by Kleynhans, 2008a). FROC values are interpreted according to the following categories: “0” = absent; “1” = present at < 10% of sites; “2” = present at > 10-25% of sites; “3” = present at >25-50% of sites; “4” = present at >50-75% of sites; and “5” = present at >75% of sites. The FRAI categories are interpreted as follows: A = 90-100%, natural; B= 80-89%, largely natural; C = 60-79%, moderately modified; D = 40-59%, largely modified; E = 20-39%, seriously modified; F = 0-19%, critically modified. Cum. data, cumulative data; NF, no-flow; IP, isolated pool; P, pool).

	EWR1 (Upper reach)				**EWR2 (Middle reach)**				**EWR3 (Lower reach)**						**EWR4 (Lower reach)**						
	Mar 06	**Sept 06**	**Mar 07**	**Oct 07**	**Mar 06**	**Sept 06**	**Mar 07**	**Oct 07**	**Mar 06**	**Sept 06**	**Mar 07**	**Mar 07**	**Oct 07**	**Oct 07**	**Mar 06**	**Sept 06**	**Sept 06**	**Mar 07**	**Mar 07**	**Oct 07**	**Oct 07**
Sampling information																					
No. of sampling points sampled	1	1	1	1	1	1	1	1	3	6	2	n/a	5	n/a	3	7	n/a	2	n/a	4	n/a
No. of sampling repetitions	1	5	9	11	1	5	9	11	1	1	n/a	9/29	n/a	11/42	1	1	5/26	n/a	9/35	n/a	11/40
Gauge plate reading (cm)	69	84	80	81	96	135	36	65	91	95.5	15.5	15.5	81	81	93	100	100	0	0	76	76
Flow description	NF (IP)	NF (IP)	NF (IP)	NF (IP)	NF (IP)	NF (IP)	NF (IP)	NF (IP)	Flow	Flow	NF (IP)	NF (IP)	NF	NF	Flow	Flow	Flow	NF (IP)	NF (IP)	NF (P)	NF (P)
Fish species information and FROC values						Cum. data*	Cum. data*	Cum. data*				Cum. data*		Cum. data*			Cum. data*		Cum. data*		Cum. data*
Indigenous																					
B. anoplus	5 (5)	5 (5)	5 (5)	5 (5)	5 (0)	5 (3)	5 (4)	5 (4)	5 (3)	4 (3)	5 (5)	4 (4)	5 (2)	4 (3)	3 (2)	4 (2)	4 (3)	5 (3)	4 (4)	3 (1)	5 (3)
L. kimberleyensis									2 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L. aeneus					3 (0)	3 (0)	3 (0)	3 (0)	5 (2)	3 (1)	5 (5)	3 (2)	2 (0)	3 (2)	2 (2)	3 (1)	3 (1)	3 (3)	4 (2)	1 (1)	4 (2)
L. capensis					5 (0)	5 (1)	5 (1)	3 (1)	5 (3)	4 (5)	5 (5)	4 (4)	2 (0)	4 (3)	5 (5)	5 (5)	5 (5)	3 (3)	5 (5)	2 (0)	5 (4)
L. umbratus					4 (4)	4 (3)	4 (3)	3 (3)	3 (0)	4 (3)	5 (5)	4 (3)	2 (0)	4 (3)	3 (3)	4 (5)	4 (5)	3 (3)	4 (4)	2 (0)	5 (3)
C. gariepinus					3 (3)	3 (1)	3 (1)	3 (1)	5 (3)	3 (1)	5 (5)	3 (1)	3 (0)	3 (1)	5 (3)	4 (5)	4 (2)	3 (3)	4 (2)	2 (0)	4 (2)
A. sclateri									2 (0)	1 (0)	3 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)
Exotic																					
C. carpio					3 (0)	3 (2)	3 (2)	3 (2)	3 (0)	3 (1)	5 (5)	3 (2)	2 (0)	3 (2)	3 (3)	4 (1)	4 (1)	3 (3)	4 (2)	2 (1)	4 (2)
M. salmoides																0 (1)	0 (1)	1 (0)	0 (1)	1 (0)	1 (1)
Indigenous species richness/total number	1/1	1/1	1/1	1/1	2/2	4/5	4/5	4/5	4/4	5/6	5/6	5/6	1/1	5/6	5/6	5/7	5/7	5/6	5/7	2/3	5/7
Index information																					
FRAI %	90.6	90.6	90.6	90.6	22.9	40.4	45.5	50.3	51.4	66.0	79.9	68.4	24.5	58.9 *	68.3	69.6	70.6	75.0	75.1	30.8	56.7
FRAI Class	A/B	A/B	A/B	A/B	E	D/E	D	D	D	C	B/C	C	E	C/D*	C	C	C	C	C	E	D

*Where sampled at <3 sampling points all the accumulated data up to that stage were used to calculate the FROC values and FRAI score (according to Kleynhans, 2008b).

5.4 General discussion and concluding thoughts

The Seekoei River hosts a depauperate fish community and only five indigenous species were recorded during the study. The river is a southern tributary of the upper Orange River – a naturally species-poor system compared to river systems situated to the north. It represents a harsh environment for fish, with large fluctuations in water temperature, variable and unpredictable surface flow, low levels of surface water connectivity, high levels of disturbance (floods and droughts) and confinement to isolated pools for varying periods of time. The high degree of environmental variability, and the continuous, but irregular, loss and gain of habitats, has possibly contributed to the low diversity of indigenous species. All of the species occurring in the Seekoei River are opportunists with generalised habitat, trophic and reproductive requirements.

The Seekoei River had an additive pattern of species richness with one species being present at EWR1 in the upper section of the river and seven species being recorded at EWR4 in the lower river section. The fish community was dominated by Cyprinidae with four of the five indigenous species belonging to this genus, namely *Barbus anoplus*, *Labeobarbus aeneus*, *Labeo capensis* and *L. umbratus*. With the exception of *L. aeneus*, these species were represented in relatively high numbers and the cyprinids, collectively, contributed nearly 80% to the total number of fish sampled in the Seekoei River. Two exotic species were also recorded: *Cyprinus carpio,* was found in the middle and lower reaches, and *Micropterus salmoides* was recently introduced into the lower Seekoei River.

Conditions in the upper and middle Seekoei River differed markedly from those in the lower reaches of the river. In the upper and middle reaches, surface water connectivity is naturally low (less than 10% of the time) and has been even further reduced by a large number of weirs and small dams erected on the river. The river, in these reaches, comprises a series of isolated pools with up to 94% of the channel being dry at times. In contrast, surface water in the lower reach is connected for nearly 50% of the time and the river comprises a combination of pools, riffles and rapids. Habitat diversity and complexity were, therefore, markedly higher in the lower Seekoei River, allowing more sampling points to be surveyed at EWR3 and 4 than at EWR1 and 2. Much of this heterogeneity was, however, lost when surface flow stopped. As the water level at the two downstream sites started to drop, surface flow slowed down and the mean water depths decreased until the larger pools became isolated. When dry conditions persisted, these pools separated into smaller isolated pools (varying in depth and volume and devoid of fish cover), that further decreased in volume and depth over time.

Results from this study also showed that fish density (CPUE) increased in the remaining habitats just after surface water connectivity was broken. The mean body length and standard deviation in body lengths increased, indicating that fish of various sizes were forced into the same habitat. This could increase the vulnerability of smaller fish to piscivorous predators.

Habitat conditions also differed between EWR1 and 2 situated in the upper and middle reaches, respectively. The pool at EWR1 persisted throughout the study period, presenting fish with a fairly stable habitat. In contrast, the shallower pool at EWR2 underwent large fluctuations in volume and water depth, presenting fish with a very variable and unstable habitat. As a result, species richness and composition, as well as total abundance, varied markedly between samples.

Barbus anoplus was both the most widespread and the most abundant species recorded in the Seekoei River. It was the only species to occur in the upper, middle and lower reaches and comprised about a third (34.2%) of all the fish sampled. This pioneer species is known to occur in a wide range of habitats (from mountain tributaries to isolated pools in the semi-arid central region, see Jubb 1967, 1972; Cambray et al. 1978; Skelton and Cambray 1981; Benade 1993; Skelton 2001). The results of this study again showed that *B. anoplus*' small size and life strategy are well-adapted to persist in harsh, unstable and unpredictable environments. Over the course of the study the minnow was recorded in both shallow and deep habitats, flowing and non-flowing habitats, over silt, boulders, cobbles, pebbles and bedrock substrate-types and associated with a variety of cover-types such as emergent aquatic vegetation (sedges and reeds), submerged aquatic vegetation (e.g. oxygen weed), filamentous algae, overhanging bedrock and substrate cover. It was numerically the most abundant species at three of the four sites (EWR1, 2 and 3) and the most frequently sampled species at all the sites. An interesting result was that a highly significant correlation ($p<0.001$) was found between the abundance of *B. anoplus* and total abundance at all the sites. The abundance of this species should, therefore, be further investigated as an indicator of total abundance in the system.

Barbus anoplus appeared to be breeding successfully at all the sites. The short-lived minnow, which reaches sexual maturity within one year, has a high productive rate and can produce multiple clutches per season (Cambray 1983). Multiple clutches decrease the chance of one or more generations being lost to unfavourable conditions, especially in rivers with variable and unpredictable flow-regimes (Cambray and Burton 1985). Cambray (1983) reported that in Vanderkloof Dam (where the Seekoei joins the Orange River) the first spawning occurred between November and January, while the second spawning occurred in February to March.

Intermittence of surface flow had an important impact on fish sampling in the sense that habitat characteristics (e.g. mean depth, maximum depth, flow, available cover, etc.) changed in response to fluctuations in the water level; and fish results should be interpreted against this variability. Also, the number of sampling points was reduced to two at sites EWR3 and 4 and influenced the application of the FRAI (Kleynhans 2008).

The weir situated between EWR3 and 4 had a marked impact on the flow regime at EWR4: it not only delayed the onset of flow at EWR4 (compared to EWR3), but also influenced the restocking of fish after the dry period (e.g. only three fishes were sampled in October 2007 after the site was isolated for six months).

Fish Response Assemblage Index

In South Africa the FRAI (Kleynhans 2008) is regarded as a useful tool to indicate biological integrity in most perennial rivers, as well as those non-perennial rivers with higher species richness in the northern parts of South Africa. This study, however, showed how difficult it will be to apply any scoring method on ephemeral rivers in the drier interior and western parts of South Africa where communities consist of relatively few, hardy, species. Here a high degree of environmental variability, and consequently the continuous, but irregular, loss and gain of habitats, has contributed to the low diversity of indigenous species (see also Grossman, 1982). The natural formation of isolated pools and man-made weirs add to the loss of system connectivity and prohibit the frequent and immediate re-colonisation of the upper, middle and lower stretches of the Seekoei from the important refugia (see also Sedell et al., 1990; Bramblett and Fausch, 1991 and Magoulick, 2000).

The relative absence of historical information on the fish species in these ephemeral rivers, further, complicates the use of an expected vs. observed species ratio. The low number of species adds to the problem as one species expected but not found, or *vice versa*, will change scores considerably and impact negatively on the conclusions drawn from the fish assessment. The current scoring methods are, therefore, inappropriate for these species-poor systems.

This study suggests that, for comparative purposes, it is best to sample when the river experiences similar conditions, e.g. when flow has connected pools and river reaches. However, it is nearly impossible to forecast flow connectivity, and difficult to predict how long re-colonisation will take after surface flow is resumed. This situation is further complicated by the fact that re-colonisation time is also influenced by biophysical variables during the specific time of the year when flow is resumed, and the reproductive phase and composition of the various species.

The low species richness and the generalised habitat, trophic and reproductive requirements of the fish species present in the Seekoei River ecosystem further makes it almost impossible to make use of the presence or absence of indicator species as a reference for biological integrity.

The current analysis of our data suggests that a more generalised approach to determine the integrity of fish communities should be considered for the Seekoei and similar rivers in the Orange River system. Community structure characteristics like age classes, species diversity and evenness, assessing the physical condition of individuals (external health; length/mass ratios, etc.) at local level, and the presence/absence of exotic species could provide useful insight into these depauperate fish communities. The next phase of the study will investigate these, as well as the challenges of including these variables under highly variable conditions.

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APPENDICES AND PLATES

Appendix A: Habitat assessment form used for the Seekoei River study.

Seekoei River – Information Sheet

Site classification and Locality

Table 11.1 Site information (adapted from Dallas 2005)

Assessor Name(s)								
Organisation					Date	/ /		
Site information - assessed at the site								
RHP Site Code			Project Site Number					
River			Tributary of					
Farm Name:				Farm Reg. Code:				
Latitude and longitude co-ordinates:								
Degrees-minutes-seconds		or Decimal degrees		or Degrees & decimal minutes				
S ° ' . "		S °		S ° ' . '		Cape datum Clarke		
E 0 ° ' . "		E 0 °		E 0 ° ' . '		WGS-84 datum HBH94		
Site Description								
Map Reference (1: 50 000)			Site Length (m)			Altitude (m)		
Longitudinal Zone	Source zone	Mountain headwater stream	Mountain stream	Transitional	Upper foothill	Lower foothill	Lowland river	
Rejuvenated cascades (gorge)	Rejuven-ated foothill	Upland floodplain	Other:					
Associated Systems:	Wetland	Estuary	Other:		Distance:			
Additional Comments:								

Desktop / spatial information – data used for classifying a site and subsequent querying of data								
Political Region				Water Management Area				
Ecoregion I				Ecoregion II				
Secondary Catchment				Quaternary Catchment				
Water Chemistry Management Region								
Vegetation Type				Geological Type				
Contour Range (m): From:			to:					
Source Distance (km)				Stream Order				
Rainfall Region	Summer		Winter	Aseasonal	Other:			
DWAF Gauging Station	Yes	No	Code :		Distance Upstream		Or Downstream	

Instream use and surrounding area land use

(Absent=0; rare=1; sparse=2; moderate=3; extensive=4)

Weirs:	Cultivated lands:	Grazing:	Plantations:
Imoundments:	Residential:	Mines:	Industries:
Roads:	Bridges:	Pumps:	Canals:
Exotic vegetation:	Aquaculture:	Fishing:	Recreation:
Remarks:			

Flow conditions and water quality at site

Approximate width:	General flow (none, low, moderate, strong, fresh, flood):	Water colour:	Turbidity (clear, moderate, turbid):
Water temperature:	Conductivity (mS/m):	pH:	Oxygen:
Remarks:			

Gauge plate reading

Physical habitat description

Local watershed NPS pollution:	No evidence		Pot. sources	Obvious sources
Canopy cover:	Partly open		Partly shaded	Shaded
Estimated stream depth	Riffle: m		Run: m	Pool: m
Canalized			Dam:	
Dominant riparian vegetation	Trees	Shrubs	Grasses	Herbacious
Aquatic vegetation	Rooted emer.	Rooted subm	Rooted float	Free floating
	Floating algae	Attached alg	Portion reach veg cover: %	
Sediment	Odours	Deposits	Oils	
Water	Odours	Oils		

Habitat type/biotope composition %

Habitat type/Biotope composition %						
Backwater	Pools	Glides	Rapids	Riffles	Runs	Other

Organic substrate components

Inorganic substrate components:			Organic substrate components:		
Type	Size	%	Type	Charact.	%
Bedrock			Detritus	Sticks, wood, plant material	
Boulder	>256 mm				
Cobble	64-256 mm		Muck-mud	Black, very fine organic	
Gravel	2-64 mm				
Sand	0.06-2 mm		Marl	Grey, shell fragments	
Silt	0.004-0.06 mm				
Clay	<0.004				

Fish velocity-depth classes and cover present at site

(Abundance: Absent=0; rare=1; sparse=2; moderate=3; extensive=4)

SLOW DEEP	SLOW SHALLOW	FAST DEEP	FAST SHALLOW
Overhanging vegetation	Overhanging vegetation	Overhanging vegetation	Overhanging vegetation
Undercut banks and root wads:	Undercut banks and root wads:	Undercut banks and root wads:	Undercut banks and root wads:
Substrate:	Substrate:	Substrate:	Substrate:
Aquatic macrophytes:	Aquatic macrophytes:	Aquatic macrophytes:	Aquatic macrophytes:
Remarks:	Remarks:	Remarks:	Remarks:

HCRs

HCRs	SD	SS	FD	FS	**Classification:** Pools/backwaters Slow <0.3 m/s Shallow <0.5m Riffles/Runs/Rapids Slow <0.3 m/s Shallow <0.3m **Rating:** 0=absent; 1=rare(<5%); 2=sparse(5-25%); 3=moderate(25-75%); 4=extensive(>75%)
Overhanging veg					
Bank undercut root wads					
Substrate					
Macrophyte					

Fish habitat integrity at site: estimated impact of modifications

(Severity of impact: None=0; small=1; moderate=3; large=5)

Water abstraction:	Flow modification:	Bed modification:	Channel modification:
Inundation:	Exotic macrophytes:	Solid waste disposal:	Exotic vegetation encroachment:
Remarks:			

Fish habitats sampled and effort

SAMPLING EFFORT	SLOW DEEP	SLOW SHALLOW	FAST DEEP	FAST SHALLOW
Electro shocker (Minutes)				
Seine net (Hauls)				

Remarks:

Appendix B: Microhabitat assessment form used for the Seekoei River study.

Fish Microhabitat Use

Site: ________________________________ Date: _______________

Sampling point/ Habitat type ____

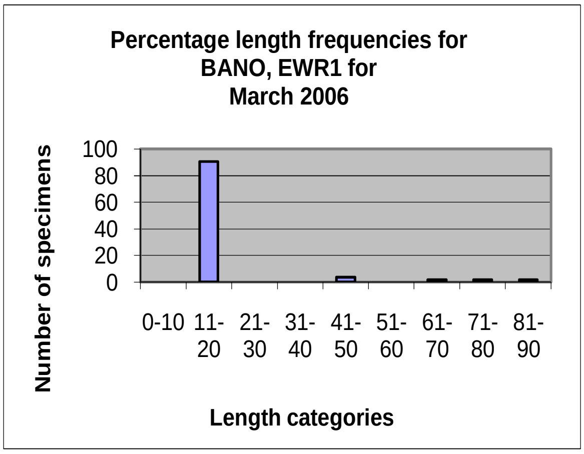
Velocity ______________________________

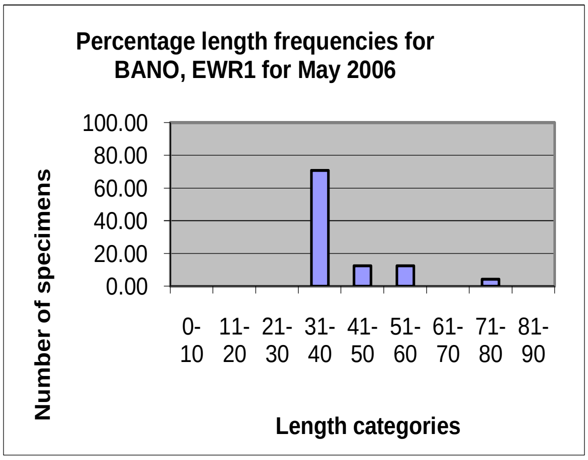
Random Points	Water depth	Substrate	Microhabitat structures
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

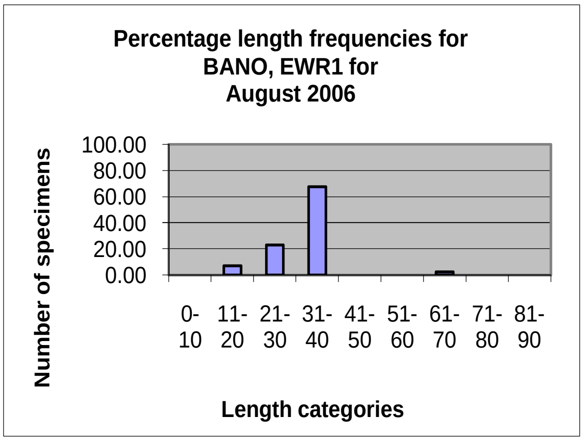
Substrate-types		
1	Mud	<0.063 mm
2	Sand	0.063-2 mm
3	Fine gravel	2-16 mm
4	Coarse gravel	16-64 mm
5	Small cobbles	64-128 mm
6	Large cobbles/boulders	< 128 mm
7	Bedrock	

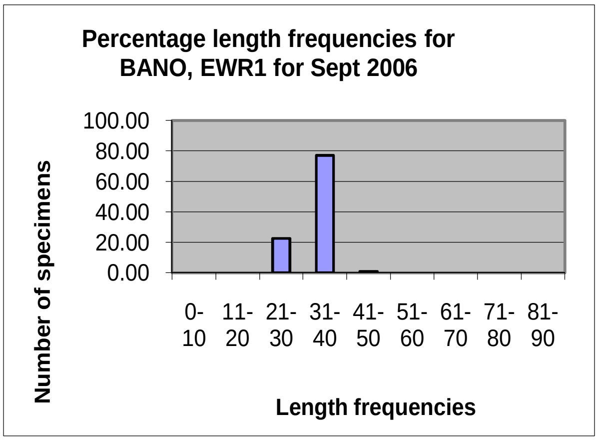
Microhabitat structures	
Aquatic macrophytes	
Filamentous algae	
Leaf litter	
Small wooden debris	
Large wooden debris	
Undercut banks	
Root masses	
Submerged vegetation	
Overhanging vegetation	

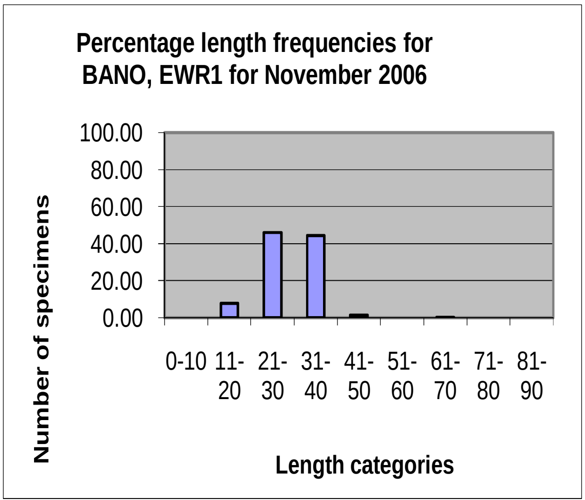
Appendix C: Length distributions for B. Anoplus, EWR1, March 2006 to March 2008.

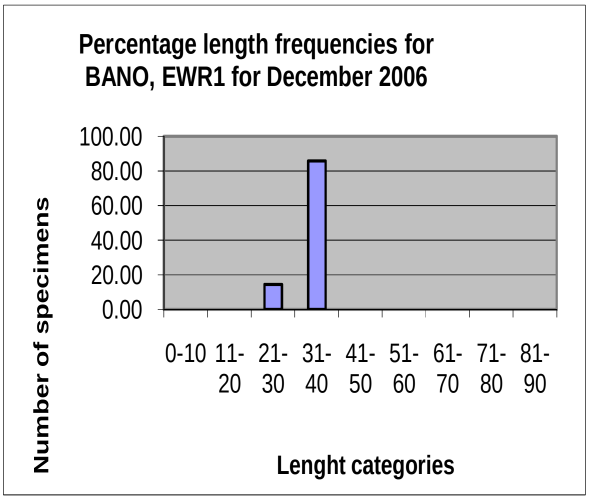


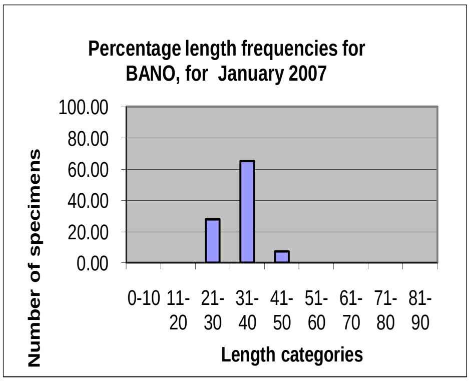


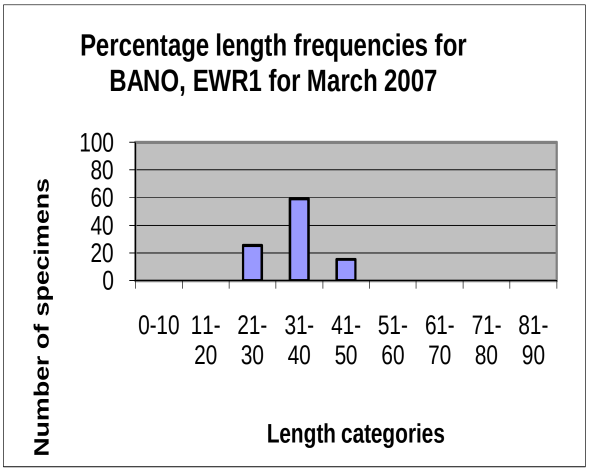


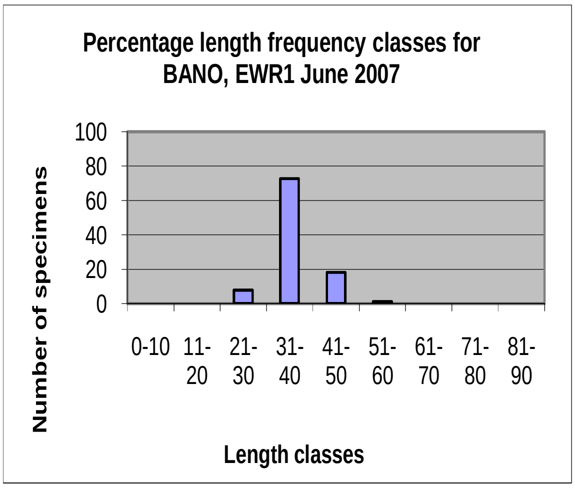


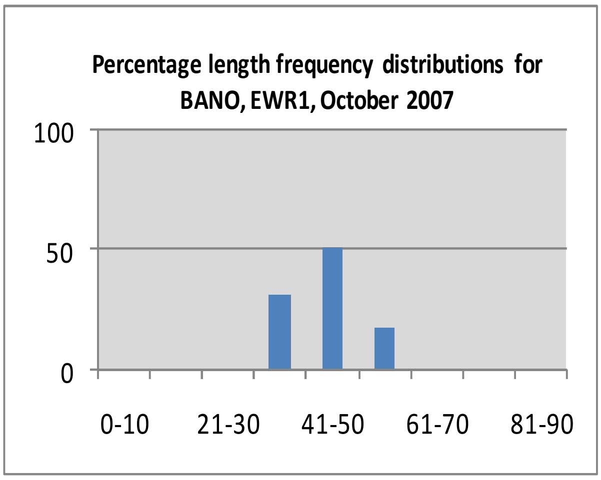





Percentage length frequencies for
BANO, for January 2007
100.00
80.00
60.00
40.00
20.00
0.00
Number of specimens
0-10 11-20 21-30 31-40 41-50 51-60 61-70 71-80 81-90
Length categories


Percentage length frequencies for
BANO, EWR1 for March 2007
100
80
60
40
20
0
Number of specimens
0-10 11-20 21-30 31-40 41-50 51-60 61-70 71-80 81-90
Length categories


Percentage length frequency classes for
BANO, EWR1 June 2007
100
80
60
40
20
0
Number of specimens
0-10 11-20 21-30 31-40 41-50 51-60 61-70 71-80 81-90
Length classes


Percentage length frequency distributions for
BANO, EWR1, October 2007
100
50
0
0-10
21-30
41-50
61-70
81-90

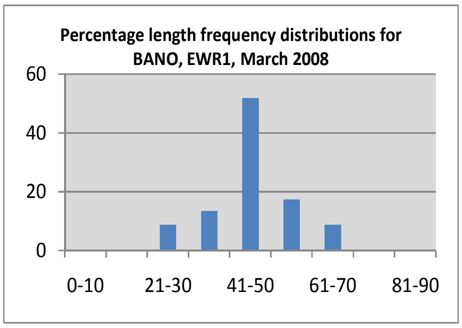

Percentage length frequency distributions for
BANO, EWR1, March 2008
60
40
20
0
0-10
21-30
41-50
61-70
81-90

Plate 1: Site EWR1

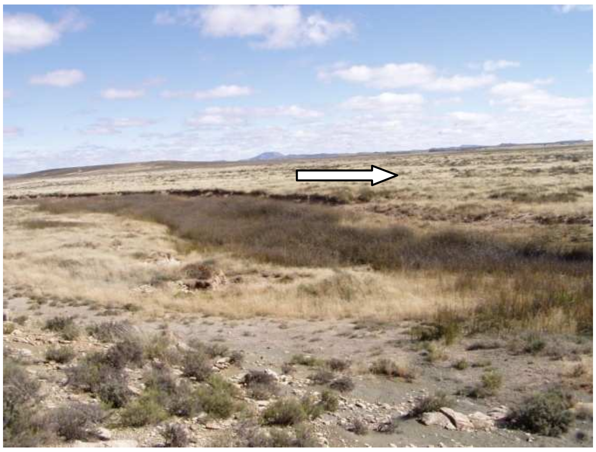


Photo 1: View of the landscape.
(Direction of flow indicated by arrow).


Photo 2: The pool is fringed by sedges.


Photo 3: Gauging plates (as seen from left bank).


Photo 4: View from the upstream end of the pool.


Photo 5: Upstream view of sampling pool as seen from from the gauge plates.


Photo 6: Downstream view of sampling pool as seen taken from the gauge plate.

Plate 2: Site EWR2

Photo 1: View of the landscape. (Direction of flow indicated by white arrow).

Photo 2: Upstream view of the river. The sampling pool is indicated by the red arrow.

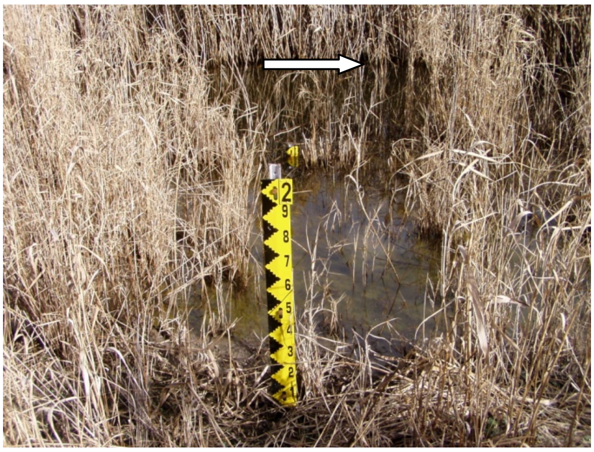


Photo 3: View of gauge plates (as seen from the right bank).

Photo 4: View of sampling pool taken from the right bank.

Photo 5: Upstream view as seen from the gauge plates.

Photo 6: Downstream view as seen from the gauge plates.

Plate 3a: Photos of the sampling points at EWR3.

Photo 1: Upstream view of the river showing the main pool. The point of outflow is indicated by the red arrow.

Photo 2: Downstream view of the river taken at the outflow from main pool. The direction of flow is indicated by the white arrow and the onset of the rapid/riffle by the red arrow.

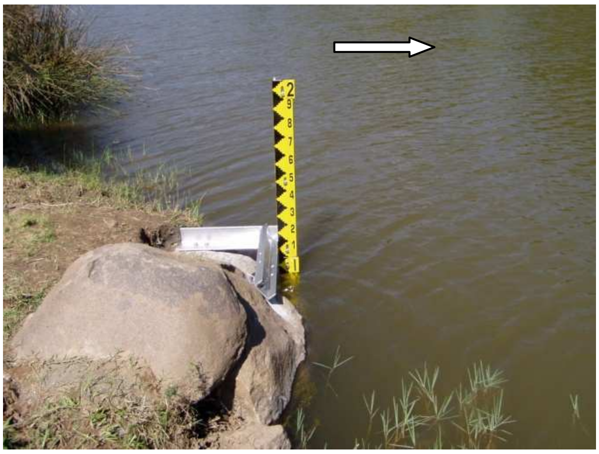


Photo 3: Gauging plate (right bank).

Photo 4: Upstream view of rapid/riffle.

Photo 5: Downstream view of sampling pool as seen from the gauge plate.

Photo 6: Upstream view of sampling pool as seen from the gauge plate.

Plate 3b: Photos of the sampling points at EWR3.

Photo 1: Main pool at a gauge plate reading of 84.5 cm

Photo 2: Pool A - the littoral areas on the right bank of the Main pool.

Photo 3: Pool B – a pool habitat in the left channel, downstream of the Main pool.

Photo 4: Outflow – glide situated in the right channel downstream of the Main pool.

Photo 5: Pool C – habitat downstream of Outflow and upstream of Rapid.

Photo 6: Rapid

Plate 4a: EWR4

Photo 1: Upstream view of the river showing the main pool. Note the state of the riparian vegetation in winter.

Photo 2: Upstream view of the site taken from the bottom-end pool. The middle pool is indicated by the red arrow and the outflow from the main pool by the blue arrow.

Photo 3: Gauging plate (left bank). The direction of flow is indicated by the white arrow.

Photo 4: Downstream view of the riffle leading to the bottom-end pool at the site.

Photo 5: Downstream view of the main sampling pool.

Photo 6: Upstream view of main sampling pool (taken from gauge plate).

Plate 4b: Sampling points at EWR4

Photo 1: Pool A1

Photo 2: Pool A

Photo 3: Pool B (a glide)

Photo 4: Pool C (shallow bedrock pool)

Photo 5: Rapid A

Photo 6: Pool D (glide)

Plate 4c: Sampling points at EWR4


Photo 7: Rapid B


Photo 8: Pool E (downstream-end pool)


Photo 9: Pool A, June 2007


Photo 4: Upstream view of channel, June 2007.


Photo 5: Upstream end of Pool A1, June 2007


Photo 6: Dry pool upstream of Pool A1, June 2007

Plate 5:

Photo 1: Weir situated between EWR3 and 4 (direction of flow indicated by arrow).

Photo 2: Overhanging rocks in Pool C (Gauge plate reading = 84 cm).