The behavioural ecology of the Orange-Vaal River yellowfish in lentic and lotic ecosystems, North-West Province, South Africa

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All men are equal before fish

Herbert Hoover
SUMMARY

Fishes are widely used by biologist as ecological indicators that measure key elements of complex systems, without having to capture the full complexity of a specific system. The Vaal River in South Africa is classified as Africa’s hardest working river and is home to, two yellowfish species that are socially and economically important. Both these yellowfish species are considered to be sensitive to changes in water quantity and quality, habitat destruction and utilisation pressure and are often used as ecological indicators to manage aquatic ecosystems. Very little however, is known about their movement, response to changing environmental variables and interspecies habitat preferences. This study therefore aims to use radio telemetry as a method to characterise and evaluate how yellowfish behaviour is influenced by changing environmental variables.

To characterise the behavioural ecology of the Vaal-Orange River yellowfish species in lentic and lotic ecosystems, *Labeobarbus aeneus* (n=18) and *L. kimberleyensis* (n=3) were fitted with externally attached radio transmitters in Boskop Dam (*L. aeneus*, n=4) and the Vaal River (*L. aeneus*, n=14) (*L. kimberleyensis*, n=3). Various methods were used to collect yellowfish species including: gill nets, to target mobile individuals, in deep habitats, electro-fishing (electro-narcosis) to collect yellowfish in shallow habitats and angling techniques in a wide variety of habitats. Thereafter yellowfish species were sedated and tagged with externally attached radio transmitters, before being released back into the system. Yellowfish were monitored for eleven months using a remote monitoring system together with manual monitoring surveys.

Analyses of data collected showed that *L. aeneus* follows distinct behavioural patterns, with some individual variations in behaviour. *Labeobarbus aeneus* exhibited higher movement that are associated with deeper water during daylight hours (04:00-16:00). During nocturnal periods (20:00-04:00) *L. aeneus* showed a decrease in movement activity and preferred shallower water compared to daytime. However, *L. aeneus* in the Vaal River seems to be less influenced by bright daylight and this might be due to the turbidity of the river water. *Labeobarbus aeneus* in Boskop Dam showed higher movement counts during full moon phases whereas *L. aeneus* in the Vaal River showed higher movement counts during new moon phases. All tagged fishes in Boskop Dam and in the Vaal River preferred deeper water during full moon
phases than during new moon phases. Movement were significantly higher (P<0.05) with increased temperatures and shallower water in summer whereas movement significantly decreased (P<0.05) with a decrease in temperature and increased depth in autumn and winter. Seasonal movement data were, however, limited.

This study confirms that radio telemetry methods can be used to characterise the behavioural ecology of yellowfish species. In addition, the study has improved the knowledge of how environmental variables may affect the behaviour of yellowfish species. However, due to limited data and our understanding of these species, it is still uncertain how behaviour of yellowfish species can be applied as an ecological indicator of aquatic ecosystems.

**Keywords:** ecological indicators; *Labeobarbus aeneus; Labeobarbus kimberleyensis*; radio telemetry; behaviour
Visse word tans algemeen deur bioloë as ekologiese indikators gebruik. Hierdie indikators meet die sleutelelemente van komplekse stelsels sonder om die volle omvang en kompleksiteit van ’n spesifieke stelsel te bepaal. Die Vaalrivier, in Suid Afrika, word geklassifiseer as een van Afrika se hardwerkendste riviere en akkommodeer, onder meer, twee geelvisspesies wat van beide sosiale en ekonomiese belang is. Albei geelvisspesies word beskou as sensitief ten opsigte van veranderinge in waterkwantiteit, waterkwaliteit sowel as habitatverlies en oorbenutting. Alhoewel hierdie spesies dikwels gebruik word as ekologiese indikators, is daar min bekend aangaand e hulle beweging, reaksie op omgewingsveranderlikes en interspesie habitatvoorkeure.

Om die gedragsekologie van die Vaal-Oranjerivier geelvisspesies in lentiese en lotiese ekostelsels te karakteriseer, is *Labeobarbus aeneus* (n=18) en *L. kimberleyensis* (n=3) in die Boskopdam (*L. aeneus*, n=4) en in die Vaalrivier (*L. aeneus*, n=14 en *L. kimberleyensis*, n=3) gevang en met eksterne radiosenders toegerus.

Verskeie metodes is gebruik om die geelvisspesies te versamel insluitend: nette om migrerende individue in diep water te teiken, elektriese-verdowing vir geelvisse in vlak-habitatte en hengeltegnieke vir ’n wye reeks habitatte. Gevolglik is die visse verdoof en die eksterne radiosenders is aangeheg voor die visse weer in die water vrygestel is. Die geelvis is vir elf maande beheer van ’n afstandbeheerde stelsel asook van fisiese moniteringsopnames, gebruik te maak.

Die ontlewing van data wat ingesamel is, het getoon dat *L. aeneus* duidelike gedragspatrone volg, met slegs enkele individuele variasies in gedrag. *Labeobarbus aeneus* het meer beweging wat met dieper water gedurende die dag (4:00-16:00) geassosieer word, getoon. Tydens die nagtelike ure (20:00-04:00) het *L. aeneus* ’n afname in bewegingsaktiwiteit asook ’n voorkeur vir vlakker water, in vergelyking met die dag, getoon. Alhoewel *L. aeneus* in die Vaalrivier getoon het dat dit minder deur helder daglig beïnvloed word, mag dit moontlik aan die troebelheid van die rivierwater toe te skryf wees. *Labeobarbus aeneus*, in Boskopdam, het meer beweging tydens die volmaanfases getoon, terwyl *L. aeneus* in die Vaalrivier, meer beweging in die nuwemaanfases getoon het.
Al die gemerkte visse in beide Boskop Dam en in die Vaalrivier het in vergelyking met die nuwemaanfases, ’n voorkeur vir dieper water getoon tydens die volmaanfases. Beweging was betekenisvol meer (P<0.05) met ’n toename in temperatuur en in vlakker water, tydens die somer, terwyl beweging betekenisvol verminder het met ’n afname in temperatuur en in dieper water, tydens herfs en winter. Data vir seisoenale beweging was egter beperk.

Hierdie studie bevestig dat radiotelemetriese metodes gebruik kan word om die gedragsekologie van geelvisspesies te karakteriseer. Die kennis aangaande die effek van omgewingsveranderlikes op die gedrag van geelvisspesies is ook aangevul. As gevolg van beperkte data en kennis van die spesies, is daar egter steeds onsekerheid oor hoe die gedrag van geelvisspesies as ekologiese indikators van akwatiese ekostelsels toegepas kan word.

**Sleutelwoorde:** ekologiese indikators; *Labeobarbus aeneus*; *Labeobarbus kimberleyensis*; radio senders; gedrag
Chapter One:

Literature Review, Hypotheses, Aim and Objectives
1 Literature review, hypotheses, aim and objectives

1.1 General introduction

By the end of World War II the world’s population totalled 2.3 billion people. Today this represents the total population of two countries: India and China. We are facing an unprecedented population growth in the 20th century with the world’s population reaching an incredible 6.4 billion, a record population of 3.5 billion having been added between 1950 and 2000 (Chamie, 2004). This inevitable growth has drastically impacted our way of life and demand on the environment (Chamie, 2004), with pressure on already stressed natural resources including freshwater ecosystems being amplified with the ever-increasing demand for ecosystem services (Postel, 2000). In addition, less than 1% of the earth’s total surface water is fresh and yet through ineffective water-protection policies and/or poor implementation policies, water scarcity is increasing in many regions (Johnson et al., 2001). Freshwater is among the natural resources that are vital to any country due to its associated economic implications such as population and industrial growth, development and infrastructure demands (Howarth and Farber, 2002; DEAT, 2005). Worldwide statistics show that as much as 70% of freshwater withdrawn from ecosystems is used in the agricultural industry for irrigation; of this, 35% is wasted through leakages and evaporation (Postel, 1995; Lanza, 1997). Freshwater ecosystems also serve as one of the most important food suppliers, with inland fisheries providing 15.3% of the total animal protein consumed (FAO, 2003). Development also contributes to an increase in water demand through mining, household supplies, food processing, cooling systems and power generation, with hydropower supplying 20% of the world’s energy (DEAT, 2005; Gleick, 2006). Of all living animals, 12% are freshwater ecosystem inhabitants that depend exclusively on this habitat for survival (Abramovitz, 1996). These statistics alone highlight the importance of freshwater ecosystems, and yet, increasing anthropogenic activities are degrading and modifying freshwater ecosystems around the world (Postel, 1995; Lanza, 1997; Howarth and Farber, 2002). About 2.3 billion people live in water-stressed river basins and abstract water from these basins as these are the only water sources available to them. These areas have annual per capita water availability of below the world average of 1 700 m³ (WRI, 2008).
Currently South Africa has an annual water availability of 1 100m³ per capita and is under serious water stress from a growing population, agricultural and industrial development (Johnson et al., 2001). In addition, construction of dams, weirs, bridges and excessive groundwater extraction, with improved technology, has further increased stress on freshwater ecosystems (Postel, 2000). At present only 30% of South Africa’s main rivers are still intact and sustainable, while 47% have been modified and 23% have been irreversibly transformed (Nel et al., 2007). A pilot study on global freshwater ecosystems showed that large dams in river basins have increased from 5 700 in 1950 to 41 000 at present (Vörösmarty et al., 1997; McCully, 1996). This means that 60% of the major river basins have been exposed to habitat destruction, causing freshwater ecosystems to lose their primary functions and services; these include nutrient recycling, waste purification and maintaining a large biodiversity (Revenga et al., 2000; Palmer et al., 2005). Activities such as these mentioned above can cause over-exploitation of freshwater ecosystems, which may lead to a shift in the ecological balance (WMO, 1997; Revenga et al., 2000). Today South Africa’s economic and social development greatly depends on key ecosystem services which are continuing to deteriorate (MEA, 2005; Ashton, 2007). What makes South Africa’s freshwater ecosystems so valuable is the fact that freshwater is a scarce commodity and unevenly distributed through a series of limited rivers and a few natural lakes (Davies and Day, 1998; Ashton, 2007). Conservation goals required to maintain aquatic ecosystems in the country are currently unattainable as a result of the excessive use of aquatic ecosystem services (O’Keeffe, 1989). The only way to reach our conservation goals is through integrated management plans where all stakeholders, including Department of Water Affairs and higher education institutions, become more closely involved in the social and institutional decision-making process (Ashton, 2007; DWAF, 2007). These integrated management plans must include a wide range of ecosystems and show how different stressors have an effect on the unique characteristics of a specific environment. Protection of aquatic and terrestrial biodiversity while allowing social and economic needs of society should be the outcome of integrated management plans (Ashton, 2007).

Aquatic ecosystems are usually very dynamic, and to a certain degree, difficult to study. Challenges usually relate to organisms living in hostile environments, especially when systems become turbid (Trefethen, 1956; Cooke and Schreer, 2003). The norm for addressing these challenges usually involves researchers removing organisms from hostile environments and conducting laboratory studies (Cooke and Schreer, 2003). This approach, however, separates the biotic and abiotic...
components of the ecosystem, and relationships are established with a level of uncertainty (Cooke and Schreer, 2003). To address this problem methods have been developed to monitor behaviour of organisms within their natural environments (Ramsey and Usner, 2003). These methods have made it possible to use biological organisms as indicators of ecological health. Therefore sustainable management plans for aquatic ecosystems have become ecologically, socially and economically viable (Trefethen, 1956; Skelton, 2001; Cooke and Schreer, 2003). Fishes are one of the most important groups of indicators of ecological health, locally and internationally. They are used in a wide range of research, conservation and environmental monitoring approaches (Karr and Dudley, 1981; Kleynhans, 1999; Harrison et al., 2000; Harrison and Whitfield, 2004; Kleynhans et al., 2005; Harrison and Whitfield, 2006; Elliott et al., 2007). These approaches are mainly dependent on a good understanding of the biology and ecology of the fishes that occur within different ecosystems (Karr and Dudley, 1981; Kleynhans, 1999; Elliott et al., 2007).

**Fishes as indicators of ecological health**

Ecological indicators measure key elements of complex systems without having to capture the full complexity of a specific system (Whitfield and Elliott, 2002). The primary function of ecological indicators is to monitor changes in ecosystems. Indicators that are used in aquatic environments include biological, chemical and physical measures (Harrison and Whitfield, 2004). Of these biological indicators macro-invertebrates and fishes are the most commonly used by biologists (Harrison and Whitfield, 2004). Using fishes as biological indicators include advantages such as:

- present in most aquatic ecosystems,
- usually easy identifiable in the field,
- life history and environmental responses are usually available,
- anatomical pathology from chemical pollutants can be present,
- distinguished behavioural, physiological and morphological responses to stressors,
- ability to avoid stressful environments, and can show aspects of large-scale habitats,
- provide long-term data,
- include all trophic levels,
- fishing is an important recreational, subsistence and commercial industry.
Using fishes as indicators of ecological health have some disadvantages, but statistics show that the public are more interested in fishes than any other form of aquatic biota, making them the preferred flagship species for aquatic ecosystems (Harrison and Whitfield, 2004). Disadvantages using fishes as indicators of ecological health include:

- sampling methods can be selective for specific habitats,
- fishes are seasonal, and sampling can be biased,
- characterising fish assemblies needs to be on large scale,
- species can be influenced by harvesting, stocking and angling,
- can be absent in pollutant areas,
- fishes can be more tolerant to pollution than some aquatic life forms, therefore some organisms may show earlier signs of poor water quality.

Overall, the advantages out-weigh the disadvantages of using fishes as indicators of ecological health (Harrison and Whitfield, 2004).

The use of tags to study freshwater fishes

Management and conservation of freshwater fish stocks is greatly dependent on the understanding of fish populations and community processes (Lucas and Baras, 2000; Cooke et al., 2004a). Tag or mark methods had to be developed for monitoring freshwater fishes in their natural environments. The first tagging experiment on record included attaching ribbon tags to the tails of juvenile Atlantic salmon (Salmo salar) to investigate their movement by Izaak Walton (Lucas and Baras, 2000). Izaak Walton describes his findings in the famous book entitled The Compleat Angler, published in 1653 (Walton and Cotton, 1921). Since then the range of techniques to monitor freshwater fishes as indicators of ecological health has improved immensely. Today these monitoring techniques can be divided into two categories, namely capture dependent and capture independent methods. Capture dependent techniques involve sampling of marked fish (mark-recapture) or unmarked fish over different time periods to obtain information about distribution and movement (Lucas and Baras, 2000). Captured fish may also be tagged with radio tags or transmitters, allowing them to be tracked throughout their natural environment. In addition, data on migration and ontogenetic changes can be obtained through destructive otolith microchemistry or non-destructive scale micro-chemistry (Lucas and Baras, 2000). Capture independent methods include video techniques, visual observation, hydro-acoustics, and automated fish counting (Lucas and Baras, 2000). Where long-term fish monitoring studies are in place, catch per unit effort or mark and recapture
studies, are usually preferred, as they have lower technical requirements and equipment costs. Telemetry methods are usually applied where there are serious ecological or management issues and provide high-resolution information of selected individuals (Lucas and Baras, 2000). Telemetry in freshwater ecosystems has been used as early as the 1950s and is the preferred method for behavioural ecology of freshwater fishes today (Trefethen, 1956; Stasko and Pincock, 1977; Mitson, 1978; Winter, 1996). A wide range of radio tags, methods and techniques are available for both tagging and marking fish (Koehn, 2000). The type of tagging or marking method used, however, depends on characteristics of different methods (Table 1). In addition, species of fish, habitat, size of fish and the ease of application should be considered when selecting a method (Koehn, 2000).

### Table 1: Different characteristics of various mark and tag types available to study fishes in their natural environments (compiled from Keenan and MacDonald, 1989; Kearney, 1989; Hancock, 1989; Ingram, 1989; Roche, 1999; Priede, 1980; Gunn and Young, 2000; Koehn, 2000)

<table>
<thead>
<tr>
<th>Mark/tag type</th>
<th>Individual/Batch mark</th>
<th>Cost per fish</th>
<th>Ease of use</th>
<th>Marine/freshwater</th>
<th>Need recapture?</th>
<th>Continues Monitoring</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tattoo, brand, fin clips, O-rings, dyes, polymer</td>
<td>Individual, Batch</td>
<td>$</td>
<td>Easy</td>
<td>Both</td>
<td>Yes</td>
<td>No</td>
<td>Not lasting</td>
</tr>
<tr>
<td>Antibiotic, radio isotope markings</td>
<td>Batch</td>
<td>$</td>
<td>Moderate</td>
<td>Both</td>
<td>Yes</td>
<td>No</td>
<td>Recapture and dissect to retrieve</td>
</tr>
<tr>
<td>Genetic tags</td>
<td>Individual</td>
<td>$</td>
<td>Difficult</td>
<td>Both</td>
<td>Yes</td>
<td>No</td>
<td>Expertise</td>
</tr>
<tr>
<td>Passive integrated transponder</td>
<td>Individual</td>
<td>$**</td>
<td>Easy</td>
<td>Both</td>
<td>Yes/No</td>
<td>No</td>
<td>Can monitor at close range</td>
</tr>
<tr>
<td>Dart, T-bar, streamer, disc</td>
<td>Individual</td>
<td>$</td>
<td>Easy</td>
<td>Both</td>
<td>Yes</td>
<td>No</td>
<td>Not available</td>
</tr>
<tr>
<td>Coded wire</td>
<td>Individual</td>
<td>$**</td>
<td>Moderate</td>
<td>Both</td>
<td>Yes/No</td>
<td>No</td>
<td>Equipment, kill fish to retrieve</td>
</tr>
<tr>
<td>Satellite Electro magnet</td>
<td>Individual</td>
<td>$$$$*</td>
<td>Difficult</td>
<td>Both</td>
<td>No</td>
<td>Yes</td>
<td>Cost</td>
</tr>
<tr>
<td>Archival</td>
<td>Individual</td>
<td>$$$$*</td>
<td>Difficult</td>
<td>Both</td>
<td>Yes</td>
<td>Yes</td>
<td>Size, recapture, cost</td>
</tr>
<tr>
<td>Radio</td>
<td>Individual</td>
<td>$$$$*</td>
<td>Difficult</td>
<td>Freshwater</td>
<td>No</td>
<td>Yes</td>
<td>Fish size, numbers, attachment, tracking time, limited battery life</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>Individual</td>
<td>$$$$*</td>
<td>Difficult</td>
<td>Both</td>
<td>No</td>
<td>Yes</td>
<td>Fish size, numbers, attachment, tracking time, limited battery life</td>
</tr>
</tbody>
</table>

Note: Cost normally plays an important part in the decision-making process of which method to be used. Each method involves different equipment, knowledge and time, thus certain methods like radio, satellite, electro magnet, archival and ultrasonic techniques can become very expensive. $=cheap ($5 per fish), $*=moderate ($5-$20 per fish), $$$$=expensive (>=$20 per fish). * Methods may have substantial set-up costs.
Freshwater fishes are difficult to observe in most situations. Thus recapture techniques to obtain data is widely used; however, the low percentage of tagged fish being recaptured poses a problem (Koehn, 2000). Addressing this difficulty, radio tags or sonic tags are used, which give researchers the advantage of tracking fishes on a regular basis. Both ultrasonic and radio tags consist of three essential components, namely a battery, transmitting aerial and circuitry that are enclosed in epoxy resin. Radio tags usually make use of radio frequencies between 30 MHz and 150 MHz whereas sonic tags make use of acoustic sound waves generally around the 50 KHz mark. Both these tags rely on battery power and have a limited life. New technology, however, can improve battery power and provide additional information such as activity, mortality, depth and temperature (Venditti and Rondorf, 1999; Koehn, 2000). Radio and ultrasonic tags have characteristics that make them usable in a variety of aquatic habitats (Table 2). Using these tags can provide users with benefits including, extensive data collecting and the possibility to collect a variety of data directly from fishes (Koehn, 2000).

Table 2: Ultrasonic and radio tags; performances compared to different characteristics that can be encountered in aquatic ecosystems (compiled from Koehn, 2000)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Tag type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ultrasonic</td>
</tr>
<tr>
<td>Salt water</td>
<td>Excellent</td>
</tr>
<tr>
<td>High conductivity</td>
<td>Excellent</td>
</tr>
<tr>
<td>Low conductivity</td>
<td>Excellent</td>
</tr>
<tr>
<td>Deep water</td>
<td>Excellent</td>
</tr>
<tr>
<td>Turbulent water</td>
<td>No</td>
</tr>
<tr>
<td>Fast animals</td>
<td>Poor</td>
</tr>
<tr>
<td>Long migrations</td>
<td>Poor</td>
</tr>
<tr>
<td>Dense aquatic vegetation</td>
<td>Poor</td>
</tr>
<tr>
<td>In water obstructions</td>
<td>Poor</td>
</tr>
<tr>
<td>Turbid water</td>
<td>Poor</td>
</tr>
<tr>
<td>Algae</td>
<td>Poor</td>
</tr>
<tr>
<td>Thermocline/temperature gradient</td>
<td>Fair</td>
</tr>
<tr>
<td>Ice</td>
<td>Poor</td>
</tr>
<tr>
<td>Number of animals</td>
<td>Same</td>
</tr>
<tr>
<td>Tracking options</td>
<td>Hydrophone in water</td>
</tr>
<tr>
<td>Power usage</td>
<td>Poor</td>
</tr>
</tbody>
</table>

Both ultrasonic and radio tags offer the advantage of allowing tagged individuals to be tracked in their natural environment and collecting data on a continuous basis, without having to recapture the fish. However, tagging methods involving both these
tags have some disadvantages (Table 1), including high cost, high level of expertise, limitation on fish size and limitations on the number of fish that can be tagged. Fishes can be fitted with these tags, either internally or externally, depending on the species, expertise of person tagging, cost, type of tag and characteristics of environment in which study is being done (Koehn, 2000) (Table 3).

**Table 3:** Characteristics of different tagging methods, including external, stomach and implant methods, which can be attached to fishes in various aquatic ecosystems (compiled from Koehn, 2000; Bridger and Booth, 2003)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Tagging method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>External</td>
</tr>
<tr>
<td><strong>Installation time</strong></td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>Difficulty</strong></td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>Recovery time</strong></td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>Balance problems</strong></td>
<td>Greatest</td>
</tr>
<tr>
<td><strong>Transmitter size</strong></td>
<td>Smallest</td>
</tr>
<tr>
<td><strong>Entanglement</strong></td>
<td>Greatest</td>
</tr>
<tr>
<td><strong>Mortality</strong></td>
<td>Low</td>
</tr>
<tr>
<td><strong>Species diversity</strong></td>
<td>Highest</td>
</tr>
<tr>
<td><strong>Biological limitations</strong></td>
<td>Low</td>
</tr>
<tr>
<td><strong>Risk of tag loss</strong></td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>Infection</strong></td>
<td>Low</td>
</tr>
<tr>
<td><strong>Irritation</strong></td>
<td>Highest</td>
</tr>
</tbody>
</table>

The attachment method is the most important aspect of any biotelemetry study, as it should not cause mortalities or affect the normal physiology or behaviour of experimental fishes (Barlow, 1993; Bridger and Booth, 2003). For intensive short-term freshwater fish studies, in areas without thick vegetation, and deep water, externally attached radio tags have an overall advantage over ultrasonic stomach or implant tags (Table 1, Table 2, and Table 3). In addition externally attached tags have the lowest mortality rate, and can be applied to more fish species, because of fewer biological limitations, such as attachment possible to fishes without true stomachs, and have no interference with gonad development that may alter spawning behaviour in fishes (Koehn, 2000; Bridger and Booth, 2003). Furthermore a study on *Cyprinus carpio* from a reservoir in Namibia have experienced a 100% mortality or tag loss from surgically implanting tags, and concluded that externally attached radio tags are more successful for certain cyprinid species in Southern African waters (Økland *et al.*, 2003).
Biotelemetry as a method to monitor ecological health

Biotelemetry methods involve the remote measurement of the physiology, behaviour and energy status of free living animals (Cooke et al., 2004a). These methods make use of a variety of tools, including transmitters, receivers, antennas, Internet, and remote stations that can send and receive signals from far away, or satellite receiving stations able to receive remote sensing data. Signals can be real-time behavioural data and can give the researcher an opportunity to document long uninterrupted periods of how organisms interact with their environment (Cooke et al., 2004a).

Biotelemetry studies usually start with a sedated specimen that is fitted with a radio tag and released back into its natural environment. After the specimen is released, the scientist can monitor or track certain specimens at different intervals as the radio signal is available continually throughout the study (Dunn and Gipson, 1977; Lucas and Baras, 2000; Cooke et al., 2004a). The scientist aims to get as many fixes of each specimen as possible throughout a study, to increase confidence of data (Dunn and Gipson, 1977; Lucas and Baras, 2000). Biotelemetry methods have already been valuable in our characterisation of our understanding of the physiological and behavioural patterns of organisms, in their natural environments. Although biotelemetry has its limitations, it is becoming the most widely used method of studying ecology and can be applied to all major animal groups, including invertebrates, fish, amphibians, reptiles, birds, aquatic and terrestrial mammals (Cooke et al., 2004b).

Biotelemetry studies on fishes have already provided substantial information on their behaviour and physiology in their natural environment. Although these studies usually provide information on the activity and movement of individuals, home range, habitat selection, territoriality, foraging and reproductive behaviour, this approach has the ability to identify and evaluate environmental stressors that can contribute towards the conservation and management of freshwater ecosystems (Godin, 1997; Cooke et al., 2004b; Rogers and White, 2007). Very little is known about any behavioural ecology of Southern African freshwater fishes, and the majority of information is based on visual observations (Paxton, 2004; Roux, 2006; Venter et al., 2009). Despite the known value of biotelemetry techniques, to date only a few dedicated freshwater fish behavioural ecology studies have been carried out in Southern Africa. Of these, the majority have been restricted to the upper Zambezi system in Namibia and estuaries of the Eastern Cape (Thorstad et al., 2001; Thorstad et al., 2003; Økland et al., 2005).
**Yellowfish as indicators of ecological health**

Yellowfish species are primarily freshwater fishes and belong to the family Cyprinidae (Skelton, 2001). Cyprinids can be found in a wide variety of sizes and shapes, life history styles and habitats. The family is without teeth on jaws, but has pharyngeal (throat) bones with teeth. They are all without a true stomach and in some detritus and plant feeders such as labeos; the gut may be extended and convoluted (Skelton, 2001). Although males and females from specific species may have characteristic pigment patterns, they can differ by having brighter breeding colours, longer fins, tubercles on head, body and fins, it is therefore always necessary to consider the full range of variation when identifying a species (Skelton, 2001). Cyprinids are a family of about 275 genera and more than 1 600 species, from Africa, North America, Asia and Europe. Twenty four genera can be located in Africa, consisting of about 475 species of which eight genera and about 80 species can be found in southern Africa (Skelton, 2001). Yellowfish are common in African rivers and lakes with a lineage of about 80 species, all members of the genus *Labeobarbus* Rüppel, 1836 (Cyprinidae). Unlike most other cyprinids that are normal diploid organisms with 50 chromosomes, these large cyprinids are hexaploid and have about 150 chromosomes. They have a spiny primary dorsal fin ray and their scales are in longitudinal or parallel striae. Intra-population differences are common within this genus, especially in the mouth and lip structures. These differences include: the normal U-shaped mouth with moderate lips; straight-edged mouth with horny lower lips; and thick ‘fleshy’ lips, that they seem to change in order to adapt in different environments. These large barbine cyprinids are mostly migratory species that accumulate at certain areas over spawning periods, and since humans have first fished African rivers they have exploited this mass gathering of fishes (Skelton and Bills, 2007). Yellowfish species always have been valued as an important social and economic source, evident in historically significant rock art, shell middens and hieroglyphics and in modern time as a targeted angling species (Skelton and Bills, 2007; Brandt, 2009).

In Southern Africa there are seven ‘true’ yellowfish species (*Labeobarbus* spp.) These species can be divided into a small-scaled group including, *Labeobarbus aeneus* (Burchell, 1822), *Labeobarbus capensis* (Smith, 1841), *Labeobarbus kimberleyensis* (Gilchrist and Thompson, 1913), *Labeobarbus natalensis* (Castelnau, 1861) *Labeobarbus polylepis* (Boulenger, 1907) and a large-scaled group represented by *Labeobarbus marequensis* (Smith, 1841) and *Labeobarbus codringtonii* (Boulenger, 1908) (Table 4) (Skelton, 2001; Skelton and Bills, 2007). The current IUCN criteria for yellowfish species in South Africa, according to a revision
(2006) of the South African yellowfish conservation status, listed the Clanwilliam yellowfish *L. capensis* as vulnerable and the Orange-Vaal largemouth yellowfish *L. Kimberleyensis* as near threatened (Skelton and Bills, 2007).

**Table 4:** General information on Southern African yellowfish species, including scientific names, common names and current conservation status (Skelton and Bills, 2007)

<table>
<thead>
<tr>
<th><em>Labeobarbus</em> species</th>
<th>Common name</th>
<th>Conservation status</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>L. aeneus</em></td>
<td>Vaal-Orange smallmouth yellowfish</td>
<td>Least concern</td>
</tr>
<tr>
<td><em>L. capensis</em></td>
<td>Clanwilliam yellowfish</td>
<td>Vulnerable</td>
</tr>
<tr>
<td><em>L. Kimberleyensis</em></td>
<td>Vaal-Orange largemouth yellowfish</td>
<td>Near threatened</td>
</tr>
<tr>
<td><em>L. polylepis</em></td>
<td>Bushveld small-scale yellowfish</td>
<td>Least concern</td>
</tr>
<tr>
<td><em>L. natalensis</em></td>
<td>KwaZulu-Natal yellowfish</td>
<td>Least concern</td>
</tr>
<tr>
<td><em>L. marequensis</em></td>
<td>Lowveld large-scale yellowfish</td>
<td>Least concern</td>
</tr>
<tr>
<td><em>L. codringtonii</em></td>
<td>Upper Zambezi yellowfish</td>
<td>Least concern</td>
</tr>
</tbody>
</table>

The distribution of these seven species is varied, with some restricted to a single river system while others are distributed in many systems (Skelton and Bills, 2007). *Labeobarbus capensis* are the most restricted of the yellowfish species, occurring in only the Olifants-Doring River system and the species is under threat from alien invasive species. *Labeobarbus aeneus* and *L. Kimberleyensis* were also restricted to the Orange-Vaal River system, but are found across the entire catchment which extends over half of South Africa. These two species have also been translocated to various areas through inter-basin water-transfer schemes and stocking programmes decades ago (Skelton and Bills, 2007). *Labeobarbus marequensis* is distributed in the Limpopo and middle Zambezi River systems, and is widely found in the east-flowing rivers as far south as the Phongolo system. Although they are still widely distributed their abundance is declining due to water abstractions throughout the systems (Skelton and Bills, 2007). *Labeobarbus codringtonii* are restricted to the Okavango and upper Zambezi River systems. *Labeobarbus polylepis* can be found in the southern tributaries of the Limpopo, Inkomati and Phongolo River systems. These species are used as important indicator species for in-stream flow requirements (Skelton and Bills, 2007). *Labeobarbus natalensis* can be found in KwaZulu-Natal in the east of South Africa. They occur in a wide variety of habitats and extend from coastal lowlands to the foothills of the Drakensberg (Skelton and Bills, 2007).
Yellowfish species of the Vaal River system

The Vaal River supplies water to South Africa’s economic heartland, Gauteng and is classified as Africa’s hardest working river (Braune and Rodgers, 1987). The river rises on the western slopes of the Drakensberg escarpment near the lake Chrissie area and flows roughly 900 km west-south-west to its confluence with the Orange River near Douglas (Braune and Rodgers, 1987; Bertasso, 2004). The catchment area of the Vaal River extends over 192 000 km² and has the highest concentration of industrial, urban, mining and power generation development throughout South Africa (Braune and Rodgers, 1987). The Vaal River system is currently divided into three water management areas (WMAs), namely the Upper Vaal (WMA 8), Middle Vaal (WMA 9) and Lower Vaal (WMA 10) (DWAF, 2010). These three water management areas have all been affected by water quantity and quality problems. The Upper Vaal catchment is mostly impacted by discharges from gold mines, from industry directly into the river and a large number of sewage-treatment plants in urban areas. Secondly, tailings dam seepage has also caused major water-quality and health problems in the Vaal River. In addition, discharges have resulted in abnormally high flows throughout the year. Coal mines, with concomitant polluting components, are also located in the upper reaches of the Vaal River in the Waterval and Grootdraai Dam catchments (ORASECOM, 2007; DWAF, 2010). The Middle Vaal is impacted most heavily by mining activities and sewage-treatment facilities, although it is less urbanised than the Barrage area in the Upper Vaal. Decreased flows from water extractions are the biggest threat in the Lower Vaal, as this area is dominated by agricultural land uses (ORASECOM, 2007; DWAF, 2010). In 1975 the Vaal River already contributed to the production of 55% of South Africa’s gross domestic product and provided water to 42% of the urban population. All the major coal industries for power generation were situated in the catchment, and a total of 155 000 ha of land was irrigated from the Vaal River (Raubenheimer et al., 1985; Braune and Rogers, 1987). In the year 2000 the Vaal River provided 915 x 10⁶ m³ of water for urban and rural development, 264 x 10⁶ m³ of water for mining and industrial uses and 798 x 10⁶ m³ of water for irrigation (Department Environmental Affairs and Tourism (DEAT), 2007). In addition to these direct uses there is a high demand for recreational use throughout the system (Braune and Rodgers, 1987). Some ecosystem services have been altered due to the excessive use and abuse of the Vaal River. Its poor water-quality status is reflected in the following:

- High levels of salinity – water becomes unsuitable for some domestic, industrial and agricultural uses.
- Eutrophication from high nutrient levels resulting in algal blooms.
- Algal blooms result in odour and colour problems that most water-treatment plants cannot deal with.
- Increased microbial pollution making the water unusable.
- Elevated total dissolved solids (TDS) levels and increased levels of dissolved organic carbon (DOC) have become problematic for users downstream (ORASECOM, 2007).

In addition, several of South Africa’s largest in-stream impoundments, including Grootdraai Dam, Vaal Dam, Vaal Barrage, Bloemhof Dam, Vaalharts, and Douglas Weir, can be found along its length. Construction of these weirs and dams, together with numerous smaller manmade lakes throughout the system, has altered the natural flow of this system (Koch and Schoonbee, 1975). These obstructions can have negative effects on riverine fish species, while other fish species adapted to the changed environment may show a population increase. In worst-case scenarios, dam constructions in rivers have cut off spawning grounds for migrating fishes and caused a decline in the total fish populations (Koch and Schoonbee, 1975). This highly utilised Vaal River system is home to South Africa’s best freshwater game fishes namely the Vaal-Orange largemouth yellowfish *Labeobarbus kimberleyensis* and the Vaal-Orange smallmouth yellowfish *Labeobarbus aeneus*. As mentioned earlier, *L. kimberleyensis* is currently listed as a near threatened species (Table 4) in the IUCN data list, and thus used as flagship species for the Vaal-Orange River System. Accordingly, conservation for this species has become a high priority in South Africa (De Villiers and Ellender, 2007). Limited studies on these species, in their natural environment, have been carried out in South Africa, and information on biology, life history and ecology are based on only a few studies (Mulder, 1973; Hamman, 1981; Tômasson *et al.*, 1984; Ellender *et al.*, 2012) while a number of biological studies have been carried out that involved mark and recapture techniques, destructive otolith, microchemistry or non-destructive scale micro-chemistry (Lucas and Baras, 2000; Skelton, 2001; De Villiers and Ellender, 2007; Skelton and Bills, 2007; Ellender *et al.*, 2012).

Both these yellowfish species are considered to be sensitive to changes in water quantity and quality, habitat destruction and utilisation pressure and are often used as sensitive ecological indicators by local ecosystem regulators and conservationists (De Villiers and Ellender, 2007). These species are also considered to be the flagship species for aquatic ecosystems in South Africa (De Villiers and Ellender, 2007).
Furthermore, these species play an important role in the success of management programmes and are an essential economic injection into South Africa’s economy (De Villiers and Ellender, 2007). Today the yellowfish industry alone is valued at R133 million per annum (De Villiers and Ellender, 2007). This contributes to the total economic value of fisheries of R15 billion in South Africa. This industry is bigger than rugby and cricket combined in South Africa, with an estimated 2.48 million anglers in 2007 (Leibold, 2008). These numbers alone highlight the importance of managing our fish stocks throughout the country.

Biology and ecology of *Labeobarbus aeneus*

*Labeobarbus aeneus* (Figure 1), or Vaal-Orange smallmouth yellowfish as it is known locally, is one of the most common fish species, and listed as least concern (IUCN, 2007) in South Africa (De Villiers and Ellender, 2007; De Villiers and Ellender, 2008a). They are endemic to the Orange-Vaal River System, but their distribution is restricted by water temperatures and natural barriers (De Villiers and Ellender, 2007). Although this species is endemic to the Orange-Vaal River system they have been translocated by inter-basin transfer schemes and introduced for angling purposes outside their natural ranges (Skelton, 2001; De Villiers and Ellender, 2007; Skelton and Bills, 2007). These systems include the larger Cape coastal rivers, namely the Gourits, Great Fish and Kei, Mtata, Olifants, Sabi, Limpopo Rivers, and the Mutirikwe Dam in Zimbabwe (Skelton, 2001; De Villiers and Ellender, 2007). This species is tolerant to anthropogenic changes and is found in abundance throughout South Africa (Skelton, 2001; De Villiers and Ellender, 2007).

They are omnivorous feeders and prefer clear flowing waters with rocky or sandy substrates. This species can be found in almost all manmade lakes throughout South Africa (Skelton, 2001). The species in its early stages of development feed on plankton, insects and insect larvae. Their diet later changes and mainly consists of algae, molluscs, detritus and aquatic vegetation (Mulder, 1973; Skelton, 2001). Initial growth to reach maturity for *L. aeneus* is relatively fast in the first six years where males can reach (350 mm fork length) and females (400 mm fork length). After maturity is reached males are expected to grow only another 160 mm to 200 mm in length where females are expected to grow another 200 mm to 250 mm in length (Gerber *et al.*, 2011).
This species does not reach the same weight as *L. kimberleyensis* and the current SA record stands at 7.837 kg. Males become sexually mature after four years (300 mm fork length) and females after five years (350 mm fork length) (Mulder, 1973; Gerber et al., 2011). Although ripe and running males can be found late in August (winter) the main spawning event is in October (spring) with a possible second spawning event in January (summer) (Mulder, 1973; Skelton, 2001, De Villiers and Ellender, 2007; Skelton and Bills, 2007). The breeding behaviour of *L. aeneus* has been well documented and spawning occurs when water temperatures reach 18.5°C in the Vaal River together with flow cues and availability of spawning habitat (cobbles, gravel) (Mulder, 1973; Tómasson et al., 1984; Ellender et al., 2012).

**Biology and ecology of *Labeobarbus kimberleyensis***

*Labeobarbus kimberleyensis* (Figure 2) or Vaal-Orange largemouth yellowfish, as it is locally known, has become one of the most sought after freshwater fish species for fisherman in South Africa (Skelton, 2001; De Villiers and Ellender, 2007; Ellender et al., 2012). It is endemic to the Vaal-Orange River system, but is restricted to larger tributaries and dams below 1 500 m (Skelton, 2001; De Villiers and Ellender, 2007;
De Villiers and Ellender, 2008b). They are absent in the higher reaches of Lesotho and southern tributaries of the Northern Cape, but have established in manmade lakes including, Gariep, Van Der Kloof, Bloemhof, Vaal Dam and various other small dams throughout the Vaal-Orange River system.

Figure 2: Adult Vaal-Orange largemouth yellowfish (Labeobarbus kimberleyensis) from the Vaal River

This apex predator can attain weights of over 20 kg, with the current South African angling record standing at 22.2 kg (Mulder, 1973; Skelton, 2001; De Villiers and Ellender, 2007; Ellender et al., 2012). Habitat requirements are more specific for L. kimberleyensis than for L. aeneus, evident by their absence in certain areas. In general, L. kimberleyensis prefer fast-flowing waters with sandy or rocky substrates (Mulder, 1973; Skelton, 2001). This predator’s main diet is small crustaceans and insects in its juvenile stage, and they become piscivorous above 300 mm fork length (Mulder, 1973). Growth is relatively slow, with males reaching sexual maturity at six years (392 mm fork length) and females mature at the age of nine years (518 mm fork length) (Mulder, 1973; Ellender et al., 2012). Although there are currently no accurate data on maximum ages that can be reached by L. kimberleyensis, studies have shown that this species can grow to ages 11 years (Hamman, 1981), 12 years
(Mulder, 1973), 14 years (Tòmasson, 1983), and 17 years (Ellender et al., 2012). However, research on *L. aeneus* has shown that these species can reach ages of up to 19 years (Gerber, 2010) and it can therefore be assumed that the largest scale-bearing indigenous fish species in Southern Africa will reach the same ages (Mulder, 1973; Skelton, 2001; De Villiers and Ellender, 2007; Gerber, 2010; Ellender et al., 2012). No spawning event of this species has been recorded in the wild, but it is assumed that spawning occurs in late summer. Mulder (1973) found well-developed gonads in males from late October and in females from November (Mulder, 1973; Skelton, 2001; De Villiers and Ellender, 2007).

**Behavioural response of yellowfish species to changing environmental variables**

Movement of fishes as a behavioural variable to evaluate the changes in ecosystem conditions has been widely documented as fishes are known to change their behaviour to regulate body temperatures, and for feeding, respiration, reproduction, avoiding predators, avoiding parasites and during changing physical and chemical conditions (Godin, 1997; Cooke et al., 2004a; Økland et al., 2005). Of these different fishes large cyprinids has also been known to change their feeding and breeding behaviour during certain changes in ecosystem variables (Bruton, 1985). Studies on other cyprinid species have concluded that certain species can stop feeding completely and decrease movement activities when environmental variables become unfavourable and energetically costly (Eccles, 1985; Akhtar, 2002). Lunar cycles have always been a more prominent factor in marine ecosystems than in freshwater ecosystems, with at least four orders of marine/estuarine fish species synchronising spawning activity with lunar activity (Taylor, 1984). These spawning mechanisms may be essential for survival of the species that occupy marshes where dissolved oxygen in the water column can be near zero or where fishes synchronise reproduction with moonlight or current conditions that enhance parental care or predator avoidance (Taylor, 1984). As rivers and reservoirs are not influenced by tides from different moon phases, light intensity is investigated to play an important role in predator-prey interactions in aquatic ecosystems (Cerri, 1983).

The movement behaviour of yellowfish species from the effect of various environmental variables including temperature, time of day (light intensity), barometric pressure, lunar cycles and flows has not been well documented for the species. Only recently a study has been carried out to characterise the behaviour of
yellowfish to changing environmental variables (O’Brien et al., 2013). This study, being the first on yellowfish species, showed that there is a significant difference in movement behaviour during different seasons, with increase in movement during spring and summer (O’Brien et al., 2013). Daily behavioural patterns were identified during this study; however, it was suggested that further studies be carried out to further characterise the movement behaviour of yellowfish species (O’Brien et al., 2010).

1.2 Hypotheses, aim and objectives

Based on the aforementioned limited understanding of the biology, ecology, conservation and management of the Vaal River yellowfish species, the following hypotheses have been set up and may provide authorities with valuable information that can be used to assist in the planning and implementation of conservation strategies.

The hypotheses for this study are:

1. Biotelemetry methods can be used in lentic and lotic environments of the Vaal River catchment to characterise the habitat use, movement and activity of yellowfish species.

2. Behaviour of Orange-Vaal River yellowfish species is influenced by changes in environmental variables.

3. Behaviour of Orange-Vaal River yellowfish species can be used as an ecological indicator of changing environmental conditions.

To test these hypotheses, the aim of this study was to successfully use biotelemetry methods to characterise the behavioural ecology of Vaal-Orange River yellowfish species in lentic (Boskop Dam) and lotic (Vaal River) systems. In order to reach this aim the following objectives were established:

1. Establish biotelemetry methods that will be used to monitor the behavioural ecology of yellowfish in one lentic and one lotic system in the North West Province, South Africa.
2. Assess the availability of yellowfish in Boskop Dam to carry out the behavioural study.

3. Capture, tag, release and monitor yellowfish individuals in Boskop Dam and the Vaal River to characterise their behaviour.

4. Monitor changes in selected environmental variables (water quantity, habitat and selected atmospheric variables) in Boskop Dam and the Vaal River.

5. Statistically characterise the habitat use, movement and activity of yellowfish species in these systems.

6. Evaluate possible links between yellowfish behaviour and changing environmental variables.

1.3 Layout of dissertation

The study is divided into six separate chapters:

- Chapter 1 is the general introduction that provides an outline of the various aquatic issues that we are faced with today, as well as how biotelemetry methods can be used to monitor ecological health. Furthermore, this chapter describes the various yellowfish species in Southern Africa, and refers to the biology, ecology and behavioural response to changing environmental variables of yellowfish species in the Vaal River system.

- Chapter 2 describes the materials and methods that were used for assessing, collecting, tagging, monitoring and evaluating data during the entire study.

- Chapter 3 presents all the results obtained from applying the materials and methods described in Chapter 2, including various behavioural aspects associated with different environmental variables monitored.

- Chapter 4 discusses the findings obtained in the study, and includes a discussion of the results obtained in Chapter 3, while comparing the different behavioural patterns identified in yellowfish species in the two systems with those identified in various other behavioural studies that have been carried out.

- Chapter 5 gives a brief summary of the results obtained and the conclusions drawn as well as additional recommendations for future studies.

- Chapter 6 provides a complete list of all the references cited in the various chapters of this dissertation.
Chapter Two: Study Areas with General Materials and Methods
2 Study areas with general materials and methods

2.1 Introduction to study areas

To reach the aims and objectives for this study, one lentic and one lotic system within the Vaal catchment had to be selected. The lentic component of the study involved a manmade lake or reservoir, suitable for this radio telemetry study. Boskop Dam, with GPS coordinates 26°33′31.17″ (S), 27°07′09.29″ (E), was selected as the most representative (various habitats, size, location, fish species, accessibility) site for this radio telemetry study. For the lotic component of the study a representative reach of the Vaal River flowing adjacent to Wag ‘n Bietjie Eco Farm, with GPS coordinates 26°09′06.69″ (S), 27°25′41.54″ (E), was selected (Figure 3).

![Figure 3: Map of the two study areas within the Vaal River catchment, South Africa](image)

**Boskop Dam**

Boskop manmade lake also known as Boskop Dam is situated 15 km north of Potchefstroom (Figure 4) in the Dr. Kenneth Kaunda District Municipality in the North West Province (Van Aardt and Erdmann, 2004). The dam is part of the Mooi River water scheme and is currently the largest reservoir built on the Mooi River (Koch,
Apart from Boskop Dam, two other manmade lakes can be found on the Mooi River including Kerkskraal and Lakeside Dam (also known as Potchefstroom Dam). The Mooi River rises in the north near Koster and then flows south into Kerkskraal Dam which feeds Boskop Dam. Boskop Dam stabilises the flow of the Mooi River and two concrete canals convey water from the Boskop Dam to a large irrigation area. The Mooi River then flows about 20 km in a southerly direction and reaches Potchefstroom Dam. From there the Mooi River enters the Vaal River at GPS 26°52'27.31" (S), 26°57'06.33" (E) to form an important tributary (Koch, 1975). Boskop Dam was completed in 1959 with a total dam-wall length of 1 320 m (DWAF, 2009). This reservoir can hold a maximum capacity of 21x10⁶ m³ with an annual outlet capacity of 5.6x10⁶ m³ (DWAF, 2010). The littoral zone around the lake is mostly covered with an aquatic weed *Potamogeton pectinatus* (Koch and Schoonbee, 1975). This weed invaded 50% of the total surface area of the lake in 1975, and this percentage has remained more or less constant (Koch and Schoonbee, 1975).

**Figure 4:** Map of study area 1: Boskop Dam situated 15 km north of Potchefstroom within Boskop Dam Nature Reserve in the North West Province, South Africa
Due to the clarity of the water in Boskop Dam, sufficient sunlight penetrates the water and allows plants to grow in depths of up to 6 m (Brand, 1975). In addition to weeds and plants, Boskop Dam has a large diversity of habitats available. These habitats include aquatic vegetation that can be 200 m wide in some areas (Figure 5A-C), boulders (Figure 5D), shallow gravel beds (Figure 5E-F) and deep habitats with reeds (Figure 5G-H) surrounding the entire edge of the reservoir (Skelton, 2001).

Boskop Dam is situated in a summer rainfall region and receives an average annual rainfall of 649 mm and has an average summer temperature range of 22°C to 34°C with a winter temperature range of 2°C to 20°C. Average water temperatures usually range between 11°C in winter and 26°C in summer (Koch and Schoonbee, 1975).

This lentic system is situated inside Boskop Dam Nature Reserve, a sanctuary extending over an area of 3 000 ha (Van As and Combrinck, 1979). Access to Boskop Dam is mainly controlled by personnel of the North West Parks Board, but private land owners on its eastern bank and the Department of Water Affairs on its southern bank have permanent access to the system.
Figure 5: Habitats in Boskop Dam include aquatic vegetation (A-C); boulders (D); shallow gravel beds (E-F); and deep water with reeds surrounding entire study area (G-H).

Vaal River

The lotic component of the study is a reach of the Vaal River situated downstream of the Orkney weir and about 125 km upstream of Bloemhof Dam, in the Middle Vaal Water Management Area (WMA) (Figure 6). The reach is 10 km in length and situated in a wilderness area controlled by Orange-Vaal River Yellowfish Conservation and Management Association (OVRYCMA) members. As a result, the
entire area was closed to other water-related recreational activity users throughout the experiment, thereby minimising disturbance to yellowfish monitored in the study.

Figure 6: Map of study area 2, a reach of the Vaal River flowing through Wag ‘n Bietjie Eco Farm, on the border between North West Province and Free State Province, South Africa

The area contained a large diversity of habitat types, including deep pools (Figure 7A), undercut banks with submerged roots and trees (Figure 7B), fast rapids, riffles with reeds and vegetation (Figure 7C), sand, gravel beds with boulders (Figure 7D-E) and aquatic vegetation (Figure 7F). This lotic system is situated in a summer rainfall region and receives an annual rainfall of 500 mm to 600 mm (Støwer, 2013). In addition, large parts of the Vaal River upstream have been transformed in many ways; these include quality of the water, quantity alterations, timing and duration of flows, habitat modifications and impacts associated with alien invasive species (Davies and Day, 1998). No barriers or point-source pollution impacts that might influence the natural movement of yellowfish were present in the study area (Davies and Day, 1998; Van Wyk, 2001; Nel et al., 2007).
Figure 7: The Vaal River study area has a large diversity of habitat types, including deep pools (A); undercut banks with submerged roots and trees (B); fast rapids, riffles with reeds and vegetation (C); sand, gravel beds with boulders (D-E); and aquatic vegetation (F)

2.2 Suitability of the study areas

Boskop Dam

Boskop Dam was selected as the most representative site for this radio telemetry study; however, very little information on fish species occurring in this reservoir
exists. Information collected on fish species in Boskop Dam included the following case study: A Fish Mark-Recapture Study, Boskop Dam, Western Transvaal by Koch and Schoonbee (1975). Their study resulted in 35 253 fishes being collected. Of these 35 253 fishes: 85.71% were *Labeo capensis* (A. Smith, 1841), 9.28% *Labeo umbratus* (A. Smith, 1841), 0.31% *Cyprinus carpio* Linnaeus, 1758, 0.15% *Clarias gariepinus* (Burchell, 1822), 0.05% *Micropterus dolomieu* (Lacepède, 1802), 3.63% *Tilapia sparmanii* (A. Smith, 1840), and 0.87% were *L. aeneus* (Koch and Schoonbee, 1975). This study concluded that there was a healthy yellowfish population in Boskop Dam, but it was carried out 37 years ago. It was therefore necessary to carry out fish suitability assessment of Boskop Dam to ensure that there is a healthy yellowfish population available, that can be used for this radio telemetry study. Although the suitability assessment was aimed at identifying healthy yellowfish populations, information on all species occurring in Boskop Dam would be collected (Table 5).

**Table 5**: Various fish species that could occur in Boskop Dam, including order, family, taxon and common names, alien fish species are identified with an * in the table (Skelton, 2001)

<table>
<thead>
<tr>
<th>Order</th>
<th>Family</th>
<th>Taxon</th>
<th>Common name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cypriniformes</td>
<td>Cyprinidae</td>
<td><em>Barbus anoplus</em></td>
<td>Chubby-head barb</td>
</tr>
<tr>
<td>Cypriniformes</td>
<td>Cyprinidae</td>
<td><em>Barbus pallidus</em></td>
<td>Goldie barb</td>
</tr>
<tr>
<td>Cypriniformes</td>
<td>Cyprinidae</td>
<td><em>Barbus paludinosus</em></td>
<td>Straight-fin barb</td>
</tr>
<tr>
<td>Cypriniformes</td>
<td>Cyprinidae</td>
<td><em>Barbus trimaculatus</em></td>
<td>Three spot barb</td>
</tr>
<tr>
<td>Cypriniformes</td>
<td>Cyprinidae</td>
<td><em>Ctenopharyngodon idella</em></td>
<td>Grass carp*</td>
</tr>
<tr>
<td>Cypriniformes</td>
<td>Cyprinidae</td>
<td><em>Cyprinus carpio</em></td>
<td>Common carp*</td>
</tr>
<tr>
<td>Cypriniformes</td>
<td>Cyprinidae</td>
<td><em>Labeo capensis</em></td>
<td>Mudfish</td>
</tr>
<tr>
<td>Cypriniformes</td>
<td>Cyprinidae</td>
<td><em>Labeo umbratus</em></td>
<td>Moggel</td>
</tr>
<tr>
<td>Cypriniformes</td>
<td>Cyprinidae</td>
<td><em>Labeobarbus aeneus</em></td>
<td>Smallmouth yellowfish</td>
</tr>
<tr>
<td>Perciformes</td>
<td>Centrarchidae</td>
<td><em>Micropterus salmoides</em></td>
<td>Largemouth yellowfish</td>
</tr>
<tr>
<td>Perciformes</td>
<td>Centrarchidae</td>
<td><em>Micropterus dolomieu</em></td>
<td>Largemouth bass*</td>
</tr>
<tr>
<td>Perciformes</td>
<td>Cichlidae</td>
<td><em>Pseudocrenilabrus philander</em></td>
<td>Southern mouthbrooder</td>
</tr>
<tr>
<td>Perciformes</td>
<td>Cichlidae</td>
<td><em>Tilapia sparmanii</em></td>
<td>Banded tilapia</td>
</tr>
<tr>
<td>Siluriformes</td>
<td>Austroglanididae</td>
<td><em>Austroglanis scolati</em></td>
<td>Rock catfish</td>
</tr>
<tr>
<td>Siluriformes</td>
<td>Clariidae</td>
<td><em>Clarias gariepinus</em></td>
<td>Barbel</td>
</tr>
</tbody>
</table>
To assess the availability of yellowfish species in Boskop Dam, different methods were used, including gill nets (Figure 8A), fyke net traps (Figure 8B), seine nets (Figure 8C), electro-fishing (Figure 8D), angling (Figure 8E) and visual observations (Figure 8F).

**Figure 8**: Methods used to assess the suitability of Boskop Dam included gill nets (A); fyke net traps (B); seine nets (C); electro-fishing (D); angling (E); and visual observations (F-H)
Vaal River
The Vaal River study area has been used to carry out numerous research studies throughout the past seven years. In addition, this area is a well-known angling destination in South Africa. It was therefore not necessary to carry out a suitability assessment of the area as numerous suitable yellowfish individuals are caught on a regular basis.

2.3 Establishing radio telemetry methods

2.3.1 Radio tags
In this study, adult yellowfish were fitted with externally attached radio tags obtained from Wireless Wildlife International (WW) in Potchefstroom, North West Province, South Africa. These tags have been part of a developmental project and were therefore tested by personnel from Wireless Wildlife in a controlled environment. The tags were then again tested in the field before being attached to individual fish. Three types of tags were used, including:

**WW-tag Series III** – External fish mount tag with activity and temperature (Figure 9A) monitoring components. Total mass: 20 g (+/-1.5g).

**WW-tag Series V** - External fish mount tag with activity, temperature and depth (Figure 9B) monitoring components. Total mass: 20 g (+/-1.5g).

**WW-tag Series VI** - External fish mount transceiver with activity, temperature, depth and memory monitoring components (Figure 9C) to save data obtained while the WW-tag is not within transmission range. The stored data are then transmitted when connection to a receiver is established. Total mass: 20 g (+/-1.5g).

The lifespan of the WW-tags currently exceeds 365 days (based on a battery life expectancy with an 80% safety factor) by combining default and tracking modes. Tags transmitting in default mode transmit every 10 min, whereas tags in tracking mode transmit every second. Monitoring scenarios available to all tags include:

- **Scenario 1**: Default mode (transmission every 10 min) without any tracking modes results in a WW-tag lifespan of 20 months.
- **Scenario 2**: Default mode (transmission every 10 min) with 40 h total manual tracking mode (transmission every second) results in a WW-tag lifespan of 12 months.
Therefore the tags were suitable to use and to monitor yellowfish individuals for one year. To obtain best results, three types of tags were allocated for this study; these included: five (WW-tag Series III), fifteen (WW-tag Series V), and one (WW-tag Series VI).

![Different tags that were used in this study, including WW-tag Series III (A), WW-tag Series V (B) and WW-tag Series VI (C). A scale has been added for size.](image)

**Figure 9:** Different tags that were used in this study, including WW-tag Series III (A), WW-tag Series V (B) and WW-tag Series VI (C). A scale has been added for size.

### 2.3.2 Remote monitoring systems

Each study area had a remote monitoring system that consisted of one base station and a number of repeater stations (HAWK UHF-DL). They can be erected far apart to increase coverage area, with the only requirement being line of sight. Stations were all protected with activity and global positioning system (GPS) sensors. Activity sensors acted as an early warning if someone tampered or damaged the stations whereas GPS tracking sensors were used to recover stolen stations.

Remote monitoring stations consisted of five separate parts. These parts were assembled with a range of tools before stations were raised. It consisted of an Omni antenna (Figure 11A), a solar panel with the remote station (Figure 11B-C), and a cable that connect the antennae to the remote station (Figure 11D). For maximum
height the antenna was connected to a length of angle iron that was connected to a wooden pole (Figure 11E-F). Remote monitoring stations were then attached to an existing structure such as a tree or building, or anchored in the ground and supported with concrete. Stations erected in trees and structures (Figure 11G) had an average height of 14 m while stations erected on the ground had an average height of 7 m (Figure 11H). The communication radius of tags to remote stations was approximately 1 km. Each station was identifiable, which assisted with theft, damage and malfunction issues. Station identification also contributed to identify the locality of fishes when a tag was in range of a remote monitoring station. Stations were allocated with code numbers starting from the base station as number one and then followed sequentially in a clockwise direction or in a downstream direction. The remote monitoring stations transmit data via GSM (cell phone) or radio networks to a server at Wireless Wildlife making use of a data-management system (Figure 10). Data can be downloaded or viewed from the data-management system using a password-protected Internet-based interface. Communication from tag to data-management system operates bi-directional, allowing users to change frequency of transmissions via a short message service (SMS) using a mobile telephone to the remote monitoring stations. By changing the transmission frequency of the tag (default transmits every 10 min) to tracking mode (transmits every second) it was easier to carry out manual tracking exercises. To change tag settings on fishes they had to be within range of a remote monitoring station for an extended time period.

**Figure 10:** Diagram of the remote monitoring system, including signals from tags on individuals transmitted to remote monitoring stations around the study area; these data are then transmitted via a GSM network and can be accessed on a computer via the Internet.
Figure 11: Assembly materials used for the remote monitoring stations: Omni antenna (A); solar panel with remote station (B-C); and a cable (D) that connects antennae and remote station (E-F). For extra height remote monitoring station was raised on any available structures such as trees (G-H).
Erecting remote monitoring stations at Boskop Dam

Possible locations for remote monitoring stations were identified using Google Earth and contour maps. Thereafter arrangements were made with all landowners for site inspections and to obtain permission to erect remote monitoring stations on their land if necessary. During site inspections a Garmin GPS (E-trex®) was used to obtain accurate locations for the stations. Binoculars were used to select the positions of other stations from the base station which required line of sight. This process was repeated until six locations were selected (Table 6). Remote monitoring stations in Boskop Dam were allocated with numbers starting with the base station as number one, and then numbering followed in a clockwise direction around the study area (Figure 12). Thereafter assembly materials were transported to each location, and stations were erected (Figure 13).

Table 6: Remote monitoring stations around Boskop Dam, including GPS position, allocated number, station code and land use

<table>
<thead>
<tr>
<th>GPS position</th>
<th>Allocated number</th>
<th>Station code</th>
<th>Land use</th>
</tr>
</thead>
<tbody>
<tr>
<td>26°32'16.57&quot;S 27° 7'35.49&quot;E</td>
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<td>244</td>
<td>Private</td>
</tr>
<tr>
<td>26°33'38.15&quot;S 27° 7'19.72&quot;E</td>
<td>2</td>
<td>245</td>
<td>Private</td>
</tr>
<tr>
<td>26°34'5.30&quot;S 27°6'51.74&quot;E</td>
<td>3</td>
<td>251</td>
<td>Department of Water Affairs</td>
</tr>
<tr>
<td>26°33'43.78&quot;S 27° 6'44.21&quot;E</td>
<td>4</td>
<td>241</td>
<td></td>
</tr>
<tr>
<td>26°31'53.53&quot;S 27° 7'21.89&quot;E</td>
<td>5</td>
<td>253</td>
<td>Boskop Dam Nature Reserve</td>
</tr>
<tr>
<td>26°32'44.80&quot;S 27° 6'51.85&quot;E</td>
<td>6</td>
<td>247</td>
<td></td>
</tr>
</tbody>
</table>
Figure 12: Map of remote monitoring stations around Boskop Dam: orange circle is the base station (1) and green circles are repeater stations (2-6)

Figure 13: Boskop Dam remote monitoring system, including one base station (1) and five repeater stations (2-6)
Erecting remote monitoring stations on the Vaal River

In this study area all remote monitoring stations were erected on one property (Wag ‘n Bietjie Eco Farm) along the Vaal River (Table 7). In order to have coverage of the entire study area, the first remote monitoring station was set up on an elevated water tank. From this position line of site access to the entire study area allowed for stations to be positioned, up to 5 km from the base station. Stations were mostly set up in trees to gain extra height for better coverage. Allocation of remote monitoring station numbers started from the base station as number one, and then the numbering followed from upstream of the study area downstream (Figure 14). Initially only four stations were set up on the Vaal River, but its effectiveness resulted in the addition of four more stations (Figure 15).

Table 7: Remote monitoring stations at the Vaal River, including GPS position, allocated number, station code and land use

<table>
<thead>
<tr>
<th>GPS position</th>
<th>Allocated number</th>
<th>Station code</th>
<th>Land use</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Wag ‘n Bietjie Eco Farm</td>
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<tr>
<td>27°7'53.23&quot;S, 26°29'4.83&quot;E</td>
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</tr>
<tr>
<td>27°9'18.02&quot;S, 26°27'5.09&quot;E</td>
<td>3</td>
<td>253</td>
<td></td>
</tr>
<tr>
<td>27°9'1.42&quot;S, 26°26'25.50&quot;E</td>
<td>4</td>
<td>255</td>
<td></td>
</tr>
<tr>
<td>27°9'1.85&quot;S, 26°26'3.57&quot;E</td>
<td>5</td>
<td>245</td>
<td></td>
</tr>
<tr>
<td>27°9'8.27&quot;S, 26°25'39.51&quot;E</td>
<td>6</td>
<td>251</td>
<td></td>
</tr>
<tr>
<td>27°9'16.65&quot;S, 26°25'33.89&quot;E</td>
<td>7</td>
<td>243</td>
<td></td>
</tr>
<tr>
<td>27°9'47.55&quot;S, 26°25'25.46&quot;E</td>
<td>8</td>
<td>247</td>
<td></td>
</tr>
</tbody>
</table>
Figure 14: Map of remote monitoring stations on the Vaal River: orange circle is the base station (1) and green circles represent repeater stations (2-8)

Figure 15: The Vaal River remote monitoring system, including one base station (1) and 7 repeater stations (2-8)
2.3.3 Manual monitoring system

The manual tracking equipment consists of a programmable receiver, headphones and a directional Yagi antenna (Figure 18). The laptop receiver (Gigabyte model Q2005 incorporating Microsoft® Windows 7 operating system) or programmable mobile receivers connected to the directional Yagi antenna are used to monitor the location of tagged fish and associated behavioural information such as movement. It had the ability to show which tag was transmitting to which remote monitoring station. Numerous tags can be tracked simultaneously if in range with the laptop receiver. The mobile receiver can only be programmed to track a specific tag. Signal strength would then be displayed on the receiver, which gave an indication of the locality of the tagged yellowfish individuals in a specific coverage area. The programmable directional mobile receiver connected to the Yagi antenna could then be programmed to track a specific tag. Once the tag was in range the programmable mobile receiver would be used to send a setting to change the tag into tracking mode. Through triangulation signal and sound strength on the receiver the tagged individual could be pin-pointed accurately (Figure 17).

Figure 16: The receiver (GIGABYTE laptop) connected to the programmable mobile receiver attached to the directional Yagi antenna with headphones and data sheets
Figure 17: Diagram of the manual monitoring system. The receiver connected to the mobile programmable receiver attached to the directional Yagi antenna is used to monitor the location of tagged fish and associated behavioural information such as movement.

2.4 Environmental variables monitored

For this study, a number of environmental variables, including water flow, lunar cycles and different weather variables, were identified and monitored in order to assess whether they could possibly influence the behaviour of yellowfish. These variables were monitored at both study areas and assessed using a range of different techniques. Monthly environmental variables were recorded and divided into four seasons. Seasons were selected according to the normal South African seasonal calendar where September marks the beginning of spring; seasons were therefore divided as follows: spring (September, August, and November), summer (December, January, February), autumn (March, April, May) and winter (June, July, August).

Atmospheric variables including barometric pressure, rainfall and air temperatures were collected throughout the study using the closest possible weather station (Boskop Dam: C2R001Q01 UWQ) and (Vaal River: 04362041: Klerksdorp, South African Weather Service).
The influence of lunar cycles on yellowfish species has not been documented. Therefore this study used a normal lunar calendar and monitoring surveys were established according to the different lunar stages. Lunar stages were divided into full moon and new moon phases, where information from tagged individuals was recorded two days before, on the full or new moon, and two days thereafter. Therefore the information was gathered over five days for every full moon or new moon cycle.

Water flows were also monitored as an environmental variable as it changes habitat types, and behaviour of yellowfish species could be affected by volumes, timing and duration of flows. The South African Department of Water Affairs gauging station number (C2H007Q01 Vaal River at Pilgrims estate, Orkney) was used to estimate the water-quantity variables for the Vaal River study area. These changing habitat types were classified using Hirschowitz et al. (2007) and DWA (2010). These habitats included the use and/or availability of backwater areas, pools, glides, riffles, runs and rapids. In addition to consideration of these habitats, a few cover features included the use of and/or availability of undercut banks or root wads, dead and/or submerged trees, complex substrate types such as boulder beds, rocky outcrops and underwater ridges, marginal, aquatic and emergent vegetation, islands, water column and the top of or tail out of pools. The recording and scoring of habitat availability were aided by the use of three-dimensional digital terrain models of important reaches of the study area. These models were generated using ARC GIS®, from data that were either collected from a Hummingbird® 789CI side-scan fish finder or from manual observations identifying different depths, substrates and flows, and thereafter data were transferred to a computer for further analysis and to generate maps.

2.5 Capture, tag, release and monitor suitable yellowfish across four seasons

2.5.1 Fish collection
All methods used to capture yellowfish for this study were carefully evaluated to prevent unrepresentative sampling and biased statistics (Rogers and White, 2007). Suitable yellowfish included specimens that were large enough to carry a radio tag according to the 2% biotelemetry rule (Winter, 1996). Collection included the use of
gill nets to target mobile individuals, in deep habitats, electro-fishing (electro-narcosis) to collect yellowfish in shallow habitats and angling techniques in a wide variety of habitats.

Netting techniques included large mesh gill nets (Figure 18A-C) that ranged between 93 mm and 120 mm. Large mesh sizes were selected to target only large individuals and minimize by catch. Gill nets were deployed in deep slow-flowing areas adjacent to suitable cover features and monitored until visible movement indicated that fishes had been caught. As soon as movement was observed fishes were immediately removed. Large fyke net traps (Figure 18D-E) were also used in areas with shallow, slow-flowing water to trap suitable individuals that could be used in the study. This involved deploying the traps in areas frequented by yellowfish and leaving them overnight. Two inflatable boats were used to transport nets and researchers around study areas (Figure 7F-G) and to access deeper water. Cast nets (Figure 18H-I) were also used in possible holding areas.

Electro-fishing or electro-narcoses were used as sampling methods for collecting yellowfish. The electro-fisher used in this study was a backpack electro-fisher (SAMUS725M) (Figure 18J-K). The anode carried by the person electro-fishing is inserted into the water which connects to a cathode trailing behind the individual. This connection creates an electrical stream with a 2 m radius approximately, depending on the conductivity of the water. Any fish within that radius will go into a state of narcosis (stunned). Stunned fish are then collected by means of a landing net.

Three types of angling disciplines were used in this study:

- Fly-fishing techniques (Figure 18L-N) where anglers use artificial flies made from synthetic material to represent natural food of yellowfish.
- Bait fishing (Figure 18O) with two or more hooks baited with worms, bread, sweet-corn or crabs. Suitable areas were selected, usually close to a current where rods would be rested on a tripod until a fish picked up the bait and jerked the line.
- The third angling discipline included the use of artificial lures (Figure 18P). This involved using lures made from balsa wood, iron or hard plastic (Rapalas®, Blue Fox spinners®, Action Lures®) to represent live swimming baitfish.
Figure 18: Methods used to capture yellowfish included: gill nets (A-C); fyke net traps (D-E); boats used (F-G); cast nets (H-I); electro-fishing (J-K); fly-fishing (L-N); bait fishing (O); and artificial lure fishing (P)
2.5.2 Radio tagging

The radio tags used in this study were mounted externally. Although this method is known to have the potential to imbalance the tagged fish and has a high fouling potential, this method has been proven to be successful on yellowfish (O’Brien et al., 2013). In addition, the two percentage rule of tag mass to fish mass was maintained which has proven successful for use on fish in freshwater ecosystems (Knights and Lasee, 1996; Winter, 1996; Koehn, 2000). For this study a collapsible tagging station was developed. Advantages of having a collapsible tagging station included:

- Fish could be tagged where captured (Figure 19A).
- No out-of-water transport from one point to another required.
- Water from the same area is circulated through container.
- Fully submerged fish usually kept calm (Figure 19B).
- Correct amount of anaesthetic was added every time (Figure 19C).
- Holding time of fish was kept to a minimum.
- Fish was never taken out of water and tagged while fully submerged (Figure 19D).
- Close-up inspection and treating of fish diseases was possible (Figure 19E).
- System consists of only a few parts (battery, bilge pump and tagging kit) (Figure 19F-H).
- Fish could easily be measured.
- Tagging could be done quickly and effectively.
- Very little physical handling of fish was necessary.
- Fish could be fully revived in the container before being released back into its environment (Figure 19I).

When a suitable yellowfish was captured it was immediately transferred to the collapsible tagging container. Care was taken to keep fish in water at all times and as a rule, little or no touching was practised. To begin the tagging process (approved by the North West Ethics Committee NWU-00095-12-A4) the out flowing tap on the container was closed and the bilge pump supplying fresh water was disconnected. Thereafter 10 ml of a pre-mixed bottle containing 2-phenoxy ethanol (0.4 ml/l) was added to the still standing water, until signs of narcosis became evident.
Figure 19: Collapsible tagging station included advantages such as: fish tagged were captured (A); preparations made while fish totally submerged and calm (B); correct amount of anaesthetic always added (C); fish tagged in water (D); close-up inspection and treatment of fish diseases (E); station consists of only a tagging kit, battery and bilge pump (F-H); and fish can be fully revived before being released (I)
Signs of narcosis included: operculum movement slowed down, fish became sluggish and if left any longer, fish turned over (Figure 20A). As soon as any signs of narcosis became evident, the tap on the container was immediately opened, releasing the water containing the anaesthetic while the bilge pump supplying fresh water was reconnected.

Tagging equipment was cleaned in ethanol before use. In the anaesthetised state, two surgical needles were pushed through the musculature of the individual yellowfish at the base of the dorsal fin (Figure 20B-C). Nylon lines with plastic stoppers at one end were then threaded through the surgical needles (Figure 20D). Thereafter needles were slowly removed (Figure 20E). The tag was attached by inserting the nylon through the holes of the tags and seated firmly against the fish (Figure 20F). Crimping pliers were then used to crimp the copper sleeves on the nylon, and to cut off the excess nylon to make it neat (Figure 20G-H). An antibiotic (Terramycin® containing oxy-tetracycline) was then injected in the muscle at a concentration of 1 ml/kg (Figure 20I), Betadine was used on areas where fish had been touched (Figure 20J), and wound-care gel (Aqua Vet) was applied to wounds (Figure 20K) to treat and minimise risk of infections. After tagging measurements (TL, FL, SL and girth) and mass (g) had been recorded, the tagged yellowfish was left in the circulating water in the container until it had fully recovered (Figure 20L). Thereafter photographs of the fish were taken (Figure 20M) in a semi-narcotic state and after full recovery the fish was safely released back into the system (Figure 20N-O).
Figure 20: Tagging process following sedation (A). Two surgical needles were pushed through the muscle at the base of the dorsal fin (B-C), thereafter nylon line with plastic stoppers was threaded through the needles (D). Needles were then slowly removed (E); nylon line was then put through holes on tag until tag sat firmly (F); crimping pliers were used to crimp the copper sleeves (G); and side-cutters cut excess nylon (H); Terramycin, Betadine and wound-care gel are used to treat and prevent infections (I-K); yellowfish fully revived (L); quick picture was taken (M); and fish released back into system (N-O).
2.5.3 Tracking and monitoring

Yellowfish individuals were monitored directly after tagging, to establish behavioural response to tagging and to ensure the survival of the tagged fish. In this study 24 h were allocated to the recovery process of the tagged fish following anaesthesia and attachment procedures (Bridger and Booth, 2003). Thereafter tracking and monitoring of the tagged yellowfish individuals were carried out at scheduled and random intervals. Scheduled surveys were established according to the lunar cycle, where surveys would take place on full moon and new moon phases predominantly (Table 8). The random surveys were carried out throughout the study period and were used to tag fishes, repair equipment and document behaviour in events such as cold fronts, rainfall and sudden changes in water flows.

Table 8: Surveys carried out throughout the study, including study area, specific or random intervals, season, month, survey dates, moon phases and aim of surveys

<table>
<thead>
<tr>
<th>Study area</th>
<th>Specific/ random</th>
<th>Season</th>
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<th>Survey dates</th>
<th>Moon phase</th>
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<td>Erect remote monitoring stations</td>
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<td>Oct-11</td>
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<td>Tagging</td>
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<td>Tagging</td>
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<td>Tagging</td>
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<td>Summer</td>
<td>Feb-12</td>
<td>20-21</td>
<td>New moon</td>
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<td>Summer</td>
<td>Feb-12</td>
<td>25-27</td>
<td>New moon</td>
<td>Document behaviour in rainfall/flow changes</td>
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<td>Summer</td>
<td>Feb-12</td>
<td>27-29</td>
<td>First quarter</td>
<td>Tracking and monitoring/tagging</td>
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<tr>
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<td>Summer</td>
<td>March</td>
<td>14-16</td>
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<td>May-12</td>
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<td>Jul-12</td>
<td>3-5</td>
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<td>13-15</td>
<td>New moon</td>
<td>Tracking and monitoring/tagging</td>
</tr>
<tr>
<td>Vaal River</td>
<td>Random</td>
<td>Spring</td>
<td>Sep-12</td>
<td>7-9</td>
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<td>Sep-12</td>
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<td>Full moon</td>
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</tr>
</tbody>
</table>

Tracking and monitoring surveys were initiated by setting up manual monitoring equipment (Figure 21) at the study area, in range of any remote monitoring station. The receiver would then display which tags were transmitting to which remote...
monitoring station. If a tag transmits frequently (transmits every 10 min) to a specific remote monitoring station, transmitting frequency could be changed to tracking (transmitting every second) using the SMS system. Alternatively the programmable mobile receiver was programmed to change the transmitting frequencies of a tag, if in range of the tag.

Once the transmitting frequency of the tag has been changed (tag number displayed in green block) (Figure 22) the exact position (1 m accuracy) of the tagged fish could be determined. To identify exact position of the tagged fishes, the person tracking began searching from the remote monitoring station, to which the tag transmitted. From there the receiver connected to the programmable directional Yagi will be in range of the transmitting tag; signal strength is then displayed on the receiver and audio sounds through headphones.

The receiver picked up tagged fishes from a distance of about 500 m depending on the depth of the tagged fish. From there the position of tagged fishes could be accurately identified by walking (Figure 22A) or drifting in a boat (Figure 22B), following signal strength and sound. When a tagged fish was located monitoring

Figure 21: Manual monitoring equipment set up in range of remote monitoring station
(Figure 23A-B) with 10 min intervals for 40 min were initiated. To accurately locate tagged individuals signal strength was used. Signal strength became stronger (red to orange and then yellow) (Figure 24A-C) and sound pitch becomes higher as a tagged fish was approached. When signal strength is at its strongest (green) (Figure 24D) and sound pitch is maximised, a positive location of a tagged fish was identified. At each fix the following data were recorded on data sheets: date and time; tag number; location (obtained from geo-referenced maps on a Trimble (Geo-explore or hand-held GPS eTrex); movement (maximum displacement per minute (MDPM)); habitat types associated with location; weather variables; noted sketches of yellowfish movement; any other fish activity; disturbance; predators; insect hatches; and any other information that would be available at a specific area.

Figure 22: Researcher identifying position of tagged fish, either by walking on the bank (A) or drifting in a boat (B)

Figure 23: Behaviour of tagged fishes being monitored and documented
Figure 24: Signal strength displayed on receiver approaching a tagged fish, including weak red signal (A); orange (B); yellow (C); and finally green (D) indicating that signal strength is strongest, and exact position can be identified.
2.6 Statistical evaluation of yellowfish behavioural data collected throughout the study

In this study the movement of the yellowfish was selected as the behavioural variable used to evaluate the effect of changing environmental variables on the test organisms. Movement data included MDPM obtained during manual tracking events and movement counts per minute (MC/min) of individuals using remote systems. Variables considered included seasons, time, tag number, activity of the fish, associated substrate, habitat, weather, and moon phases. In addition, the depth and temperature recordings from the tags were used; these data were downloaded from the data-management system in a *.csv file format. The water quality and flow (measured as discharge) variables, lunar cycles and different atmospheric weather variables presented above were also considered.

Spatial and temporal trends were analysed using ARC GIS®. Using this approach each individual's spatial area use could be evaluated, including high area use, preferred areas and the relationships between location and environmental variables (Hodder et al., 2007). Movement and depth were calculated using box-and-whisker plots where estimates are based on 25th and 75th percentiles while whisker extremes are based on 5th and 95th percentiles. Relationships between the movement of yellowfish species in MDPM and changes in the environmental conditions were statistically analysed using the approach adopted by O’Brien et al. (2013). This approach used a mixed-model analysis of variance (ANOVA) together with a coefficients model (Littell et al., 1996) and Akaike’s Information Criteria (AIC) (Burnham and Anderson, 1998) and data were statistically analysed and significant values (P<0.05) were calculated by the Statistical Consultation Services of the North West University in Potchefstroom using SAS Version 9.3 (SAS Institute, Cary, NC).
Chapter Three: Suitability Assessment, Environmental variables and Radio Telemetry Results
3  Suitability assessment, environmental variables and radio telemetry results

3.1  Suitability assessment of Boskop Dam

The fish availability survey to Boskop Dam resulted in 507 fishes being collected using various methods. Seventeen fish species were expected to occur in Boskop Dam; the survey identified at least ten different fish species. All fish collected were measured and photographed (Figure 25) throughout the survey. These 507 fishes included: 5 Barbus paludinosus size range (FL 40 mm to 60 mm), 4 Cyprinus carpio size range (FL 200 mm to 780 mm), 16 Labeo capensis size range (FL 470 mm to 500 mm), 13 Labeo umbratus size range (FL 200 mm to 550 mm), 26 Labeobarbus aeneus size range (FL 200 mm to 550 mm), 38 Gambusia affinis size range (TL 13 mm to 20 mm), 8 Micropterus salmoides size range (TL 350 mm to 400 mm), 14 Pseudocrenilabrus philander size range (TL 20 mm to 60 mm), 380 Tilapia sparmanii size range (TL 10 mm to 60 mm) and 3 Clarias gariepinus size range (TL 300 mm to 1 500 mm). The survey concluded that Boskop Dam has a suitable L. aeneus population that can be used for this radio telemetry study.
Figure 25: Different fish species collected throughout the survey, including: (A) Micropterus salmoides; (B) Labeo umbratus; (C) Labeo capensis; (D) Clarias gariepinus; (E) Cyprinus carpio; (F) Pseudocrenilabrus philander; (G) Tilapia sparmani; (H-I) Labeobarbus aeneus; (J) Barbus paludinosus; and (K-L) Gambusia affinis
3.2 Environmental variables monitored

Temperatures for the Boskop Dam study area were obtained from South African Department of Water Affairs, Boskop Dam, Weather Station (C2R001Q01 UWQ). Dry bulb temperatures (in °C) were recorded at 08:00, 14:00 or 20:00. Data were continually recorded throughout the study and average monthly temperatures were obtained (Figure 26). Monthly temperatures ranged from 21°C in January to 8.1°C in winter.

![Temperature Graph](image)

**Figure 26**: Average dry bulb monthly temperatures of Boskop Dam obtained from the Weather Station at Boskop Dam (C2R001Q01)

For the Vaal River study area the dry bulb temperatures (in °C) were reported at 08:00, 14:00 or 20:00 by the weather station [0436204 1] in Klerksdorp, North West Province, South Africa. The weather station had an elevation of 1 322 m above mean sea level and data were obtained from the South African Weather Service on 2012/10/17 at 15:04. For the purpose of this study average monthly temperatures were used to identify movement activity of species during various seasons (Figure 27).

Atmospheric pressure (in hPa) was reported at 08:00, 14:00 or 20:00. Data were recorded by weather station [0436204 1] in Klerksdorp, North West Province, South
Africa. The data were supplied by the South African Weather Service and were received on the 2012/10/17. The monthly averages for atmospheric pressure were calculated (Figure 28).

Figure 27: The average monthly temperatures of the Vaal River study area as obtained from the South African Weather Service

Figure 28: The average monthly atmospheric pressure (in hPa) was obtained from the South African Weather Service
When air temperatures decreases during autumn and winter, the study areas experienced an increase in atmospheric pressure. Autumn (March, April, and May) marks the start of increased atmospheric pressures and a decrease in temperatures. Winter (June, July, August) had the highest atmospheric averages and represented the lowest temperatures (July) throughout the study. Spring (September, October, and November) usually marks the end of winter. The graphs show that atmospheric pressure started decreasing in August and average monthly temperatures started to increase.

Discharge (in m$^3$/s) in the Vaal River was measured at Pilgrims Estate at site C2H007. This site was located closest to the Vaal River study area and was considered most accurate for the study area. Monthly averages were used to establish whether any relationships existed between the behaviour of yellowfish species and increase and decrease in flows.

![Graph of average discharge in m$^3$/s for Vaal River study area](image)

**Figure 29:** The average discharge (in m$^3$/s) of the Vaal River study area as obtained from the Department of Water Affairs

Monthly rainfall (in mm) figures were obtained from the South African Department of Water Affairs. Rainfall during 2011/2012 was lower than the normal monthly rainfall for both the study areas (Figure 30)(Figure 31). The highest monthly rainfall for Boskop Dam was recorded in December and for the Vaal River the highest monthly rainfall was recorded in February. Higher rainfall was recorded in spring and summer than during autumn and winter. One specific rainfall event in the middle of winter was
identified to possibly have an effect on the behavioural activity of yellowfish species. This event took place in June 2012 where the average temperature for that month was recorded to be 4.8°C; this month also had the highest average atmospheric pressures throughout the study. The study areas received 18 mm and 10 mm of rainfall, respectively, from the 21-23 June 2012. The barometric pressure decreased by 8.7 hPa and the temperature increased by 6°C during this time period, which is a considerable drop in atmospheric pressure and increase in temperature.

Figure 30: Monthly rainfall (in mm) for Boskop Dam study area. Highest rainfall was recorded during December, with an important rainfall event in the middle of winter (June) 18 mm, which is associated with an increase in temperatures and a drop in atmospheric pressure.
Figure 31: Monthly rainfall (in mm) for Vaal River study area. Highest rainfall was recorded during February with an important rainfall event in the middle of winter (June) of 10 mm, which is associated with an increase in temperature of 6°C and a drop of 8.7 hPa in the atmospheric pressure.

3.3 Radio telemetry results for *Labeobarbus aeneus* in Boskop Dam

The behavioural ecology findings of *L. aeneus* in Boskop Dam are based on information obtained by monitoring four suitable yellowfish individuals that were captured at various locations in Boskop Dam, using a range of different techniques (Figure 18), after which they were sedated, measured, tagged, photographed (Figure 32) and released. Information on yellowfish was recorded on a data sheet (Table 9). Three of the four tags contained activity, temperature and depth peripheral components with the fourth tag containing activity and temperature peripheral components. Radio tags were able to transmit to remote monitoring stations at a maximum depth of about 2 500 mm over 500 m. From the study a total of 9 153 data strings containing movement counts and temperatures for all tags and depth for three tags were recorded by the six remote monitoring stations set up around the study area. Data strings were collected by all six remote monitoring stations, confirming that the entire study area had optimum coverage. These data were used to evaluate the behavioural response, using movement as a behavioural variable, of the yellowfish to changes in environmental variables.
### Table 9: General information on yellowfish individuals captured, tagged, released and monitored in Boskop Dam

<table>
<thead>
<tr>
<th>Species</th>
<th>Capture date</th>
<th>Capture method</th>
<th>Tag</th>
<th>Sensor on tag</th>
<th>Mass</th>
<th>Total length</th>
<th>Fork length</th>
<th>Standard length</th>
<th>Girth</th>
<th>Season</th>
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</thead>
<tbody>
<tr>
<td>L. aeneus 1</td>
<td>16/11/2011</td>
<td>Gill net</td>
<td>39</td>
<td>Act,Temp,Depth</td>
<td>3500</td>
<td>660</td>
<td>610</td>
<td>550</td>
<td>330</td>
<td>Summer</td>
</tr>
<tr>
<td>L. aeneus 2</td>
<td>26/01/2012</td>
<td>Gill net</td>
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<td>Act,Temp,Depth</td>
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<td>525</td>
<td>482</td>
<td>324</td>
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<tr>
<td>L. aeneus 3</td>
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<td>Gill net</td>
<td>43</td>
<td>Act,Temp,Depth</td>
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<td>560</td>
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<tr>
<td>L. aeneus 4</td>
<td>27/01/2012</td>
<td>Gill net</td>
<td>36</td>
<td>Act,Temp</td>
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<td>510</td>
<td>460</td>
<td>441</td>
<td>281</td>
<td>Summer</td>
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</tbody>
</table>
Figure 32: The four *Labeobarbus aeneus* that were captured, tagged, photographed, released and monitored in Boskop Dam
*Labeobarbus aeneus* (1)

*Labeobarbus aeneus* (1) with radio tag number 39 was monitored from 16/11/2011 until 30/09/2012 during which time 1 810 data strings were remotely obtained. These strings contained activity, temperature and depth peripheral information. Data showed that *L. aeneus* (1) had movement counts per minute that ranged between 155.5 MC/min and 160.3 MC/min during nocturnal (dark) periods (00:00-04:00 and 20:00-24:00) of the day whereas daytime movement counts increased and ranged between 1 548.3 and 2 349.4 MC/min. *Labeobarbus aeneus* (1) was most active during time periods from 04:00-08:00 whereas least movement counts were between 00:00-04:00 (Figure 33A). Movement count was lower during full moon phases 2 062.2 MC/min than during new moon phases 2 224.3 MC/min (Figure 33B). The seasonal movement count was highest during spring 2 930 MC/min and thereafter summer 1 655.2 MC/min (Figure 33C). The tag on this individual transmitted its last information on the 26/12/2011 to remote monitoring station five. After this recording the tag did not transmit again throughout the duration of the study. It is therefore possible that the individual may have lost the tag, or that the individual had died. Therefore movement behaviour data are limited to spring and summer.

The depth range of *Labeobarbus aeneus* (1) was between 876 mm and 1 673 mm during nocturnal periods (00:00-04:00 and 20:00-24:00) whereas depth in daylight ranged from 439 mm to 582 mm (Figure 33A). During full moon phases the depth of *L. aeneus* (1) was 543 mm and during new moon phases the depth was 345 mm (Figure 33B). Seasonal variations in depth ranged from 390 mm in spring to 533 mm in summer (Figure 33C).
Figure 33: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. Higher activity movement was observed during daytime, new moon phases, spring and summer, whereas this individual with tag number 39 also preferred shallower habitats.
**Labeobarbus aeneus (2)**

*Labeobarbus aeneus* (2) with radio tag number 40 was monitored from 26/01/2012 to 30/09/2012 during which time 6 920 data strings were remotely obtained. These strings contained activity, temperature and depth peripheral information. *Labeobarbus aeneus* (2) had a movement count range of 19.1 MC/min to 19.2 MC/min during nocturnal periods (00:00-04:00 and 20:00-24:00) of the day whereas daytime movement counts increased and ranged between 27.0 MC/min and 43.2 MC/min. Peak movement counts were recorded during time periods from 12:00-16:00, whereas lowest movement counts were recorded between 20:00 and 24:00 (Figure 34A). Movement counts were lower during new moon phases with 21.4 MC/min than during full moon phases 33 MC/min (Figure 34B). The seasonal movement count was highest during summer 1 298.5 MC/min, while during autumn the movement count was 27.4 MC/min and during winter the movement count was 23.3 MC/min (Figure 34C). The last information from the radio tag on this individual was recorded on 12/06/2012 to station five. After this no further information from the tag was received; either the radio tag got damaged or the individual died.

The depth range of *Labeobarbus aeneus* (2) was between 267 mm and 460 mm during nocturnal periods (00:00-04:00 and 20:00-24:00) whereas depth in daylight ranged from 514 mm to 1 570 mm (Figure 34A). During new moon phases the depth of *L. aeneus* (2) was 548 mm and during full moon phases the depth increased to 891.1 mm (Figure 34B). In summer the depth of *Labeobarbus aeneus* (2) was 1 359 mm; however, this is calculated from (n=4) and it is possible that this individual used these depths for recovery as information was recorded directly after tagging. Depth for this individual was 899 mm in autumn and 1 360 mm during winter. During autumn considerably more data were recorded (n=4 795) than during winter (n=258); it is therefore possible that this individual spent time in deeper water during winter at depths greater than the maximum depth where tags could transmit from (Figure 34C).
Figure 34: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. Higher activity movement was observed during daytime and full moon phases where deeper habitat was used. Limited data was collected for seasons; however this individual with tag number 40 seemed to prefer deeper habitats towards winter.
**Labeobarbus aeneus (3)**

*Labeobarbus aeneus* (3) with radio tag number 43 was monitored from 26/01/2012 during which time 9,152 data strings were remotely obtained. These strings contained activity, temperature and depth peripheral information. Data showed that *Labeobarbus aeneus* (3) had movement count ranges of between 10.5 MC/min and 12.8 MC/min during nocturnal periods (00:00-04:00 and 20:00-24:00) of the day whereas daytime movement counts increased and ranged between 12.9 MC/min and 30.7 MC/min. *Labeobarbus aeneus* (3) had peak movement counts during time periods from 12:00-16:00 with a count of 30.7 MC/min, whereas the lowest movement activity was recorded between 00:00-04:00 with a count of 10.5 MC/min (Figure 35A). Movements were lower during new moon phases 15.2 MC/min than during full moon phases 18.5 MC/min (Figure 35B). The seasonal movement was highest during summer 876.7 MC/min (n=24). Thereafter the movement activity decreased notably to 17.9 MC/min in autumn (n=1133) (Figure 35C). The last information transmitted by the radio tag was on the 23/04/2012 through remote monitoring station five. Thereafter no information was transmitted by the tag and thus seasonal movement data are limited to summer and autumn.

The depth range of *Labeobarbus aeneus* (3) was between 407 mm and 548 mm during nocturnal periods (00:00-04:00 and 20:00-24:00) whereas depth in daylight ranged from 559 mm to 848 mm (Figure 35A). During full moon phases the depth of *L. aeneus* (3) was 548 mm and during new moon phases the depth was 529 mm (Figure 35B). Seasonal variations in depth ranged from 62 mm in summer to 662 mm in autumn (Figure 35C). It is possible that the tag got damaged in autumn when the individual moved to deeper water or the individual may have died.
Figure 35: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. Higher movement activity was observed during daytime and full moon phases where deeper habitat was used. Limited data was collected for seasons; however this individual with tag number 43 seemed to prefer deeper habitats towards winter.
*Labeobarbus aeneus* (4)

*Labeobarbus aeneus* (4) with radio tag number 36 was monitored from 27/01/2012 during which time 486 data strings were remotely obtained. These strings contained activity and temperature peripheral information. Data showed that *Labeobarbus aeneus* (4) had movement counts ranging between 15.4 MC/min and 20.3 MC/min during nocturnal periods (00:00-04:00 and 20:00-24:00) of the day whereas daytime movement increased and ranged from 29.2 MC/min to 80.1 MC/min. *Labeobarbus aeneus* (4) had peak movement counts during time periods from 12:00-16:00 with an count of 80.1 MC/min whereas lowest movement counts were recorded between 20:00-24:00 with an of 15.4 MC/min (Figure 36A). The movement count during new moon phases was 32.1 MC/min but data are limited to new moon phases (Figure 36B). The seasonal movement was highest during summer 231.2 MC/min and thereafter autumn 32.1 MC/min (Figure 36C). The last data were recorded on the 24/03/2012 by remote monitoring station five and thus seasonal movement data were limited to summer and autumn. It is possible that the tag may have been damaged if this individual followed the same trend as the other tagged individuals and moved to deeper water, or the individual may have died.
Figure 36: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. Higher movement activity was observed during daytime as opposed to nocturnal periods. This individual with tag number 36 showed higher movement activity during summer opposed to winter.
General behaviour pattern of *Labeobarbus aeneus* in Boskop Dam

The following section presents data from all four tagged individuals incorporated into a single group, to identify the general movement behaviour pattern of *L. aeneus* in Boskop Dam. The following table presents the highest and lowest movement counts during periods throughout a day, moon phases, seasons and shows where data were not available (N/A) (Table 10).

**Table 10:** Highest and lowest movement counts plotted (x) against time periods, moon phases and seasons; it also shows which data were not available (N/A) from *Labeobarbus aeneus* remotely monitored in Boskop Dam

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<tr>
<th>Time period of day</th>
<th>Moon phase</th>
<th>Season</th>
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</thead>
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<td>04:00-08:00</td>
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<td>08:00-12:00</td>
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<td>12:00-16:00</td>
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<td>16:00-20:00</td>
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<td>20:00-24:00</td>
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<table>
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<tr>
<th>Tag nmr</th>
<th>00:00-04:00</th>
<th>04:00-08:00</th>
<th>08:00-12:00</th>
<th>12:00-16:00</th>
<th>16:00-20:00</th>
<th>20:00-24:00</th>
<th>Full</th>
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<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
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<td>x</td>
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<tr>
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<td>N/A</td>
<td>N/A</td>
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<td>N/A</td>
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<td></td>
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</table>

This data together with box-and-whisker graphs were used to illustrate the movement counts (activity), depth and number of data strings collected (n=) during time of day, moon phases and seasons of all four tagged individuals (Figure 37). ANOVA together with a coefficients model (Littell *et al*., 1996) and Akaike’s Information Criteria (AIC) (Burnham and Anderson, 1998) were used to statistically analyse data and significant values (P< 0.05) were calculated using SAS.

*Labeobarbus aeneus* in Boskop Dam follows distinct behavioural patterns, with some individual variations in behaviour. *Labeobarbus aeneus* exhibited significantly (P<0.05) higher movement counts that are associated with deeper water during daylight hours (04:00-16:00). During nocturnal periods *L. aeneus* significantly
(P<0.05) decreased movement activity and preferred shallower water as opposed to daytime (Figure 37A). During new moon phases the box-and-whisker graph shows higher movement counts, but displays incorrect as *Labeobarbus aeneus* (4) showed no data during full moon phases, but showed data during new moon phases and therefore it seems that they have higher movement counts during new moon phases than during full moon phases, when in fact three of the four *L. aeneus* individuals showed higher movement counts during full moon phases. Individuals preferred deeper water during full moon phases than during new moon phases (Figure 37B).

Movement counts were significantly higher (P<0.05) with increased temperatures and shallower water in summer whereas movement significantly decreased (P<0.05) with decreased temperatures and increased depth in autumn and winter. Seasonal movement data were, however, limited (Figure 37C).

The influence of rainfall events that were identified in winter (June) and may have had an effect on the behaviour of *L. aeneus* was not confirmed as no data from any individual in Boskop Dam were recorded in that specified period. Atmospheric pressure did not have a significant effect on *L. aeneus* in Boskop Dam; however, as atmospheric pressure is closely related to changes in temperature, it might be necessary for future studies to combine atmospheric pressure and temperature and not separate them as two different environmental variables.
Figure 37: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. Movement activity increased during daytime periods, whereas depth also increased. Shallower habitats were occupied during full moon phases as well as spring and summer. Individuals gradually increased using deeper habitats during autumn and winter when movement activity decreased as temperatures decreased and atmospheric pressure increased.
**Preferred areas of tagged *Labeobarbus aeneus* in Boskop Dam**

Data obtained from the remote monitoring stations set up around Boskop Dam were used to identify which areas *L. aeneus* preferred during which seasons (Table 11). *Labeobarbus aeneus* (1) with radio tag number 39 used the entire study area during spring, but spent most of its time during summer in the vicinity of remote monitoring station five (n=786). *Labeobarbus aeneus* (2) with radio tag 40 made use of most of the study area, but avoided the area near remote monitoring station two which consisted of deep water with very little substrate. In summer this individual preferred the area near remote monitoring station one from where *L. aeneus* used the area around remote monitoring station three (n=2 560) which consisted of rocky substrates, gravel and aquatic vegetation. This station recorded more than 35% of the total data. Remote monitoring station five (n=1 543) was preferred during autumn and winter. *Labeobarbus aeneus* (3) with radio tag 43 and *L. aeneus* (4) with radio tag 36 both preferred two areas of the study area. In summer these individuals were located near remote monitoring station one, an area which consisted of rocky substrates, gravel and aquatic vegetation. During autumn both individuals preferred the area around remote monitoring station five.

All four tagged individuals seemed to use the area around remote monitoring station five; more than 50% of the total data were recorded by this monitoring station, although none were caught and tagged in this area (Figure 38). It seems that individuals avoided areas where they were caught and tagged. *Labeobarbus aeneus* preferred the area around remote monitoring station five during various periods throughout the study, but seemed to spend prolonged periods of time there during autumn and winter. The area near remote monitoring station five was selected as the most preferred area for *L. aeneus* monitored in Boskop Dam, therefore a three-dimensional digital terrain model was built for this specific area (Figure 39). This area is covered with aquatic vegetation, has a depth of up to 8 000 mm, and is characterised by rocky outcrops and reeds surrounding the entire area. The area was also situated in a protected area within Boskop Dam Nature Reserve and was closed to water-related activities. Furthermore, this area was sampled in the winter during the suitability assessment and the results showed that the area held high numbers of *L. aeneus*. 

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Table 11: The preferred areas marked with an (x) of *Labeobarbus aeneus* in Boskop Dam throughout the study, including tag numbers, seasons and station numbers

<table>
<thead>
<tr>
<th>Tag nmr</th>
<th>Season</th>
<th>STATION 1</th>
<th>STATION 2</th>
<th>STATION 3</th>
<th>STATION 4</th>
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</table>

Figure 38: Percentage (%) data recorded by each remote monitoring station around Boskop Dam. Remote monitoring station five recorded more than 50% of the total data followed by station three with more than 35% of the total data.
Figure 39: Three-dimensional digital terrain model of the area near remote monitoring station five. This map includes: positions of remote monitoring stations around Boskop Dam, tagging areas, depth and habitat of preferred area and area where *Labeobarbus aeneus* were successfully sampled during fish suitability assessment in Boskop Dam.
3.4 Radio telemetry results for *Labeobarbus aeneus* in the Vaal River

The behavioural ecology findings of *L. aeneus* in the Vaal River are based on information obtained by monitoring 14 suitable *Labeobarbus aeneus* individuals that were captured at various locations using a range of different techniques (Figure 18), after which they were sedated, measured, tagged, photographed and released (Figure 40, Figure 41, Figure 42, Figure 43). Information on tagged *L. aeneus* was recorded on a data sheet (Table 12). Nine of the 14 radio tags contained activity, temperature and depth peripheral components, one tag contained activity, temperature, depth and memory components, and four tags contained activity and temperature components (Table 13). Radio tags were able to transmit to remote monitoring stations at a maximum depth of about 2500 mm over a range of about 500 m. From the study a total of 94 757 data strings were recorded by the eight remote monitoring stations set up around the study area. The furthest two remote monitoring stations were set up at a distance of about 9 km from each other.

**Table 12:** General information on *Labeobarbus aeneus*, including species capture dates, capture method, tag number, measurements, and season of capture

<table>
<thead>
<tr>
<th>Species</th>
<th>Capture date</th>
<th>Capture method</th>
<th>Tag</th>
<th>Mass (g)</th>
<th>Total length (mm)</th>
<th>Fork length (mm)</th>
<th>Standard length (mm)</th>
<th>Girth (mm)</th>
<th>Season</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>L. aeneus</em> 1</td>
<td>15/02/2012</td>
<td>Fly-fishing</td>
<td>50</td>
<td>2350</td>
<td>580</td>
<td>520</td>
<td>500</td>
<td>310</td>
<td>Summer</td>
</tr>
<tr>
<td><em>L. aeneus</em> 2</td>
<td>20/02/2012</td>
<td>Electro fishing</td>
<td>44</td>
<td>1800</td>
<td>520</td>
<td>470</td>
<td>450</td>
<td>240</td>
<td>Summer</td>
</tr>
<tr>
<td><em>L. aeneus</em> 3</td>
<td>20/02/2012</td>
<td>Electro fishing</td>
<td>46</td>
<td>2300</td>
<td>570</td>
<td>540</td>
<td>470</td>
<td>300</td>
<td>Summer</td>
</tr>
<tr>
<td><em>L. aeneus</em> 4</td>
<td>20/02/2012</td>
<td>Electro fishing</td>
<td>47</td>
<td>2100</td>
<td>490</td>
<td>445</td>
<td>405</td>
<td>270</td>
<td>Summer</td>
</tr>
<tr>
<td><em>L. aeneus</em> 5</td>
<td>20/02/2012</td>
<td>Electro fishing</td>
<td>49</td>
<td>2500</td>
<td>568</td>
<td>525</td>
<td>490</td>
<td>330</td>
<td>Summer</td>
</tr>
<tr>
<td><em>L. aeneus</em> 6</td>
<td>20/02/2012</td>
<td>Electro fishing</td>
<td>51</td>
<td>1400</td>
<td>520</td>
<td>450</td>
<td>420</td>
<td>220</td>
<td>Summer</td>
</tr>
<tr>
<td><em>L. aeneus</em> 7</td>
<td>20/02/2012</td>
<td>Electro fishing</td>
<td>53</td>
<td>4000</td>
<td>680</td>
<td>625</td>
<td>580</td>
<td>390</td>
<td>Summer</td>
</tr>
<tr>
<td><em>L. aeneus</em> 8</td>
<td>20/02/2012</td>
<td>Electro fishing</td>
<td>37</td>
<td>2100</td>
<td>560</td>
<td>490</td>
<td>420</td>
<td>305</td>
<td>Summer</td>
</tr>
<tr>
<td><em>L. aeneus</em> 9</td>
<td>20/02/2012</td>
<td>Electro fishing</td>
<td>38</td>
<td>2500</td>
<td>580</td>
<td>535</td>
<td>500</td>
<td>380</td>
<td>Summer</td>
</tr>
<tr>
<td><em>L. aeneus</em> 10</td>
<td>21/02/2012</td>
<td>Electro fishing</td>
<td>45</td>
<td>1900</td>
<td>540</td>
<td>480</td>
<td>455</td>
<td>290</td>
<td>Summer</td>
</tr>
<tr>
<td><em>L. aeneus</em> 11</td>
<td>21/02/2012</td>
<td>Electro fishing</td>
<td>52</td>
<td>2500</td>
<td>570</td>
<td>525</td>
<td>500</td>
<td>330</td>
<td>Summer</td>
</tr>
<tr>
<td><em>L. aeneus</em> 12</td>
<td>01/08/2012</td>
<td>Lure fishing</td>
<td>20</td>
<td>2400</td>
<td>568</td>
<td>511</td>
<td>487</td>
<td>370</td>
<td>Winter</td>
</tr>
<tr>
<td><em>L. aeneus</em> 13</td>
<td>01/08/2012</td>
<td>Lure fishing</td>
<td>33</td>
<td>2800</td>
<td>570</td>
<td>520</td>
<td>480</td>
<td>380</td>
<td>Winter</td>
</tr>
<tr>
<td><em>L. aeneus</em> 14</td>
<td>07/09/2012</td>
<td>Bait fishing</td>
<td>109</td>
<td>4550</td>
<td>670</td>
<td>610</td>
<td>560</td>
<td>380</td>
<td>Autumn</td>
</tr>
</tbody>
</table>
Table 13: Information on radio tags used, including species, capture dates, tag number, tag functions, manual, remote fixes and comments on the performance of the radio tags used

<table>
<thead>
<tr>
<th>Species</th>
<th>Capture date</th>
<th>Radio tag number</th>
<th>Tag functions</th>
<th>Manual fixes</th>
<th>Remote fixes</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>L. aeneus 1</td>
<td>15/02/2012</td>
<td>50</td>
<td>Act, Temp, Depth</td>
<td>0</td>
<td>0</td>
<td>Tag failed</td>
</tr>
<tr>
<td>L. aeneus 2</td>
<td>20/02/2012</td>
<td>44</td>
<td>Act, Temp, Depth</td>
<td>0</td>
<td>0</td>
<td>Tag failed</td>
</tr>
<tr>
<td>L. aeneus 3</td>
<td>20/02/2012</td>
<td>46</td>
<td>Act, Temp, Depth</td>
<td>0</td>
<td>29661</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>L. aeneus 4</td>
<td>20/02/2012</td>
<td>47</td>
<td>Act, Temp, Depth</td>
<td>0</td>
<td>3246</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>L. aeneus 5</td>
<td>20/02/2012</td>
<td>49</td>
<td>Act, Temp, Depth</td>
<td>0</td>
<td>666</td>
<td>Limited data</td>
</tr>
<tr>
<td>L. aeneus 6</td>
<td>20/02/2012</td>
<td>51</td>
<td>Act, Temp, Depth</td>
<td>328</td>
<td>25586</td>
<td>Limited data</td>
</tr>
<tr>
<td>L. aeneus 7</td>
<td>20/02/2012</td>
<td>53</td>
<td>Act, Temp, Depth</td>
<td>151</td>
<td>26399</td>
<td>Limited data</td>
</tr>
<tr>
<td>L. aeneus 8</td>
<td>20/02/2012</td>
<td>37</td>
<td>Act, Temp</td>
<td>0</td>
<td>0</td>
<td>Tag failed</td>
</tr>
<tr>
<td>L. aeneus 9</td>
<td>20/02/2012</td>
<td>38</td>
<td>Act, Temp</td>
<td>0</td>
<td>0</td>
<td>Tag failed</td>
</tr>
<tr>
<td>L. aeneus 10</td>
<td>21/02/2012</td>
<td>45</td>
<td>Act, Temp, Depth</td>
<td>0</td>
<td>56</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>L. aeneus 11</td>
<td>21/02/2012</td>
<td>52</td>
<td>Act, Temp, Depth</td>
<td>0</td>
<td>2478</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>L. aeneus 12</td>
<td>01/08/2012</td>
<td>20</td>
<td>Act, Temp</td>
<td>0</td>
<td>3974</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>L. aeneus 13</td>
<td>01/08/2012</td>
<td>33</td>
<td>Act, Temp</td>
<td>0</td>
<td>3356</td>
<td>Limited data</td>
</tr>
<tr>
<td>L. aeneus 14</td>
<td>07/09/2012</td>
<td>109</td>
<td>Act, Temp, Depth, Memory</td>
<td>0</td>
<td>0</td>
<td>Tag failed</td>
</tr>
</tbody>
</table>

Radio tags were tested at WW facilities before they were brought into the field. Before any tag was externally attached to an individual it was again tested to ensure that they worked properly. All 14 radio tags worked before they were attached to individuals; however, radio tag numbers 50, 44, 37, 38 and 109 failed as soon they were attached to individuals and did not transmit any data to remote monitoring stations. Tag numbers 49, 51 and 52 resulted in limited data when depth sensors on tags failed. Tag number 33 was a production error as temperature peripheral components were not included in the tag and five tags, i.e. numbers 46, 47, 20, 45 and 52, performed satisfactorily.
Figure 40: *Labeobarbus aeneus* number 1-4 captured, tagged and monitored in the Vaal River. Note the scar on *L. aeneus* 3.
Figure 41: *Labeobarbus aeneus* number 5-8 captured, tagged and monitored in the Vaal River.
Figure 42: *Labeobarbus aeneus* number 9-12 captured, tagged and monitored in the Vaal River
Figure 43: *Labeobarbus aeneus* number 13-14 captured, tagged and monitored in the Vaal River
**Labeobarbus aeneus (3)**

*Labeobarbus aeneus* (3) with radio tag number 46 was monitored from 20/02/2012 during which time 29 661 data strings were remotely obtained. These strings contained activity, temperature and depth peripheral information. Data showed that *Labeobarbus aeneus* (3) had movement counts in the range of 64 MC/min to 67.4 MC/min during nocturnal periods (00:00-04:00 and 20:00-24:00) of the day whereas daytime movement counts increased and ranged from 106.5 MC/min to 193.5 MC/min. *Labeobarbus aeneus* (3) had peak movement counts during time periods from 08:00-12:00 with an count of 193.5 MC/min whereas lowest movement counts were observed between 00:00-04:00 with an count of 64 MC/min (Figure 44A). Movement counts were lower during new moon phases 117.4 MC/min (n=1 485) than during full moon phases 121.3 MC/min (n=955) (Figure 44B). The seasonal movement was highest during summer 117.5 MC/min (n=192), thereafter autumn 117.5 MC/min (n=6 735), winter 0.5 MC/min (n=518) and very limited data were collected in spring 0.1 MC/min (n=3) (Figure 44C).

*Labeobarbus aeneus* (3) maintained a depth range of 577 mm to 643mm during nocturnal periods (00:00-04:00 and 20:00-24:00) whereas depth in daylight hours ranged from 558 mm to 641 mm (Figure 44 A). These depths overlapped during night and day time and may be as a result of the limited water column in the Vaal River.

During full moon phases depth of *L. aeneus* (3) was 667 mm (n=644) and during new moon phases depth was 611 mm (n=826) (Figure 44B). Seasonal variations in depth d from 558 mm (n=1 973) in summer to 618 mm (n=5 232) in winter. Limited seasonal depth data were recorded and seasonal depth is based on summer and winter data (Figure 44C).
Figure 44: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. Movement activity was higher during daytime periods, full moon phases and summer. This individual with tag number 46 preferred shallower habitats during full moon phases and summer.
*Labeobarbus aeneus* (4)

*Labeobarbus aeneus* (4) with radio tag number 47 was monitored from 20/02/2012 during which time 3 246 data strings were remotely obtained. These strings contained activity, temperature and depth peripheral information. Data showed that *Labeobarbus aeneus* (4) had movement counts ranging between 123.5 MC/min and 137.1 MC/min during nocturnal periods (00:00-04:00 and 20:00-24:00) of the day whereas daytime movement counts increased and ranged from 142.8 MC/min to 226.6 MC/min. *Labeobarbus aeneus* (4) had peak movement counts during time periods from 08:00-12:00 with a count of 226.6 MC/min whereas lowest movement counts were observed between 00:00-04:00 with a count of 123.5 MC/min (Figure 45A). Movement counts were higher during new moon phases 186.4 MC/min (n=182) than during full moon phases 83 MC/min (n=182) (Figure 45B). The seasonal movement was highest during autumn (181.1 MC/min) (n=687), and then summer 142 MC/min (n=151). This trend may be as a result of the limited data obtained during summer (Figure 45C). The radio tag on this individual transmitted data until 12/03/2012 and therefore seasonal data are limited. The radio tag might have been damaged against the rocks in the Vaal River or the fish may have died.

*Labeobarbus aeneus* (4) maintained a depth range of 563 mm to 608 mm during nocturnal periods (00:00-04:00 and 20:00-24:00) whereas depth in daylight ranged from 589 mm to 648 mm. Depth ranges overlapped, which means that *L. aeneus* used the entire water column available (Figure 45A). During full moon phases depth of *L. aeneus* (4) was 664 mm (n=668) and during new moon phases depth was 498 mm (n=556) (Figure 45B). Seasonal variations in depth d from 619 mm (n=175) in summer to 577 mm (n=1 491) in autumn. It seems that *L aeneus* (4) still used the entire water column available, although water temperatures decreased during autumn (Figure 45C).
Figure 45: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. Higher movement activity was observed during daytime periods, new moon phases and autumn. Individual with tag number 47, habitats during diurnal periods seemed to be uniform; however shallower habitats were preferred during new moon phases.
**Labeobarbus aeneus** (5)

*Labeobarbus aeneus* (5) with radio tag number 49 was monitored from 20/02/2012 during which time 666 data strings were remotely obtained. These strings contained activity, temperature and depth peripheral information. Data showed that *Labeobarbus aeneus* (5) had movement counts ranging between 48.8 MC/min and 49.1 MC/min during nocturnal periods (00:00-04:00 and 20:00-24:00) of the day whereas daytime movement counts increased to between 72.4 MC/min and 128.9 MC/min. *Labeobarbus aeneus* (5) had peak movement counts during time periods from 08:00-12:00 with an count of 128.9 MC/min whereas lowest movement counts were observed between 20:00-24:00 with an count of 48.8 MC/min (Figure 46A). Moon phase data were limited and a movement count during new moon phases of 72.3 MC/min (n=472) (Figure 46B). The seasonal movement during summer was 70.5 MC/min (n=568). Data from this tag were limited and movement counts were restricted to summer (Figure 46C).
Figure 46: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. Highest movement activity of individual with tag number 49 was observed during daytime periods as opposed to nocturnal periods.
Labeobarbus aeneus (6)

Labeobarbus aeneus (6) with radio tag number 51 was monitored from 20/02/2012 during which time 25 586 data strings were remotely obtained. These strings contained activity, temperature and depth peripheral information. Data showed that Labeobarbus aeneus (6) had movement counts ranging between 15.3 MC/min and 15.6 MC/min during nocturnal periods (00:00-04:00 and 20:00-24:00) of the day whereas daytime movement increased and ranged from 27.3 MC/min to 45.3 MC/min. Labeobarbus aeneus (6) had peak movement counts during time periods from 12:00-16:00 with an count of 45.3 MC/min whereas lowest movement counts were observed between 00:00-04:00 with an of 15.3 MC/min (Figure 47). Movement counts were higher during new moon phases 31.6 MC/min (n=2 298) than during full moon phases 23.7 MC/min (n=2 262) (Figure 47A). The seasonal movement count was highest during summer 334.5 MC/min (n=1437), then autumn 29.3 MC/min (n=8 104), spring 16.3 MC/min (n=1 247) and then winter 12 MC/min (n=2 363) (Figure 47B). Depth for this individual ranged from 150 mm to 180 mm throughout the entire monitoring period (Figure 47C). Depth data were limited although the tag transmitted data throughout the entire study period up until the 30/09/2012, which resulted in continuous data being recorded.
Figure 47: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. Movement activity and depth of tag number 51 increased in daytime and new moon phases. Highest movement activity was observed during summer and lowest movement activity during autumn and winter.
*Labeobarbus aeneus* (7)

*Labeobarbus aeneus* (7) with radio tag number 53 was monitored from 20/02/2012 during which time 26,399 data strings were remotely obtained. These strings contained activity, temperature and depth peripheral information. Data showed that *Labeobarbus aeneus* (7) had movement counts ranging between 19.2 MC/min and 19.3 MC/min during nocturnal periods (00:00-04:00 and 20:00-24:00) of the day whereas daytime movement counts increased to 25.5 MC/min to 41.3 MC/min. *Labeobarbus aeneus* (7) had peak movement counts during time periods from 12:00-16:00 with a count of 41.3 MC/min whereas lowest movement counts were between 00:00-04:00 with a count of 19.2 MC/min (Figure 48A). Movement counts were higher during new moon phases 33.6 MC/min (n=2,508) than during full moon phases 26.3 MC/min (n=2,536) (Figure 48B). The seasonal movement was highest during summer 34.7 MC/min (n=853), autumn 34.7 MC/min (n=1,220), spring 10.5 MC/min (n=225) and then winter 9.5 MC/min (n=3,335) (Figure 48C). The radio tag on this individual transmitted data until 30/09/2012 and provided satisfactory data.

*Labeobarbus aeneus* (7) maintained a depth range of 796 mm to 840 mm during nocturnal periods (00:00-04:00 and 20:00-24:00) whereas depth in daylight ranged from 630 mm to 810 mm (Figure 48A). Depth seems to overlap during night and daytime, suggesting that *L. aeneus* (7) uses the entire water column throughout a 24 h day cycle (Figure 48B). During full moon phases the depth of *L. aeneus* (7) was 750 mm (n=4,281) and during new moon phases depth was 780 mm (n=3,700) (Figure 48). Seasonal variations in depth ranged from 780 mm (n=1,013) in summer, 411 mm (n=733) in spring, 630 mm (n=1,442) in autumn and 796 mm (n=4,560) in winter (Figure 48C).
Figure 48: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. Movement activity increased during daytime, new moon phases and summer. Deeper habitats where preferred by tag number 53 during new moon phases and winter.
Labeobarbus aeneus (10)

Labeobarbus aeneus (10) with radio tag number 45 was monitored from 21/02/2012 during which time 56 data strings were remotely obtained. These strings contained activity, temperature and depth peripheral information. Data showed that Labeobarbus aeneus (10) had movement counts ranging between 48.2 MC/min and 57.9 MC/min during nocturnal periods (00:00-04:00 and 20:00-24:00) of the day whereas daytime movement increased and ranged from 188.8 MC/min to 464.6 MC/min. Labeobarbus aeneus (10) had peak movement counts during daytime periods from 08:00-12:00 with an of 464.6 MC/min whereas lowest movement counts were between 20:00-24:00 with an of 48.2 MC/min (Figure 49A). Movement during new moon phases was 81.1 MC/min (n=52) (Figure 49B). The seasonal movement counts were limited to summer with a movement count of 81.1 MC/min (n=52) (Figure 49C). The tag on the individual transmitted data until the 22/02/2012, after which the tag got damaged or the fish died.

Labeobarbus aeneus (10) maintained a depth range of 177 mm to 437 mm during nocturnal periods (00:00-04:00 and 20:00-24:00) whereas depth in daylight ranged from 177 mm to 437 mm (Figure 49A). Data were limited during moon phases and only new moon phases were recorded with an depth of 332 mm (n=52) (Figure 49B). Summer depth for this individual were 332 mm (n=56) in summer (Figure 49C).
Figure 49: Box-and-whisker plot of the movement counts for tag number 45 and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles.
**Labeobarbus aeneus (11)**

*Labeobarbus aeneus* (11) with radio tag number 52 was monitored from 21/02/2012 during which time 2,478 data strings were remotely obtained. These strings contained activity, temperature and depth peripheral information. Data showed that *Labeobarbus aeneus* (11) had movement counts ranging between 15 MC/min and 24.7 MC/min during nocturnal periods (00:00-04:00 and 20:00-24:00) of the day whereas daytime movement count ranges increased to between 55 MC/min and 105.8 MC/min. *Labeobarbus aeneus* (11) had peak movement counts during daytime periods from 12:00-16:00 with an count of 105.8 MC/min whereas lowest movement counts were observed between 00:00-04:00 with an count of 15 MC/min (Figure 50A). Movement counts were higher during new moon phases 64 MC/min (n=598) than during full moon phases 55.2 MC/min (n=141) (Figure 50B). The seasonal movement was highest during autumn 88.7 MC/min (n=1421), summer 78.5 MC/min (n=170), spring 29.7 MC/min (n=14) and then winter 9.3 MC/min (n=536) (Figure 50C). The tag on this individual transmitted data until 24/09/2012 and provided continuous data.

*Labeobarbus aeneus* (11) maintained a depth range of between 291 mm and 300 mm during nocturnal periods (00:00-04:00 and 20:00-24:00) whereas depth in daylight ranged from 270 mm to 390 mm (Figure 50A). During full moon phases depth of *L. aeneus* (11) was 240 mm (n=40) and during new moon phases depth was 360 mm (n=560) (Figure 50B). Seasonal variations in depth ranged from 435 mm (n=220) in summer to 287 mm (n=1,272) in autumn. Limited data were obtained and depths during different seasons are based on data recorded during summer and autumn (Figure 50C).
Figure 50: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. Movement activity of tag number 52 increased during daytime, full moon phases and summer. There is a slight increase in habitat depth during daytime and during new moon phases.
**Labeobarbus aeneus (12)**

*Labeobarbus aeneus* (12) with radio tag number 20 was monitored from 01/08/2012 during which time 3 974 data strings were remotely obtained. These strings contained activity and temperature peripheral information. Data showed that *Labeobarbus aeneus* (12) had movement counts ranging between 14.5 MC/min and 18.4 MC/min during nocturnal periods (00h00-04h00 and 20h00-24h00) of the day whereas daytime movement counts increased to between 23.7 MC/min and 51.2 MC/min. *Labeobarbus aeneus* (12) had peak movement counts during time periods from 12:00-16:00 with a count of 151.2 MC/min whereas lowest movement counts were observed between 00:00-04:00 with a count of 14.5 MC/min (Figure 51A). Movement counts were higher during new moon phases 30.3 MC/min (n=203) than during full moon phases 24.1 MC/min (n=422) (Figure 51B). Seasonal data were limited and movement count during winter was 25.8 MC/min (n=1 375) (Figure 51C).
Figure 51: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. Movement activity of tag number 20 increased during daytime, new moon phases and spring.
Labeobarbus aeneus (13)

Labeobarbus aeneus (13) with radio tag number 33 was monitored from 01/08/2012 during which time 3 356 data strings were remotely obtained. These strings contained activity and temperature peripheral information. Data showed that Labeobarbus aeneus (13) had movement counts ranging between 15.4 MC/min and 16.9 MC/min during nocturnal periods (00:00-04:00 and 20:00-24:00) of the day whereas the daytime movement count range increased to between 41.4 MC/min and 72.6 MC/min. Labeobarbus aeneus (13) had peak movement counts during time periods from 12:00-16:00 with an of 72.6 MC/min whereas lowest movements were observed between 00:00-04:00 with an of 15.4 MC/min (Figure 52A). Movement counts were higher during new moon phases 46.4 MC/min (n=321) than during full moon phases 20 MC/min (n=241) (Figure 52B). Limited seasonal data were obtained and the movement count during spring was 46.9 MC/min (n=97) and during winter it was 36.9 MC/min (n=1 978) (Figure 52C).
Figure 52: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. Higher movement activity of tag number 33 was observed during daytime and new moon phases.
General behavioural pattern of *Labeobarbus aeneus* in the Vaal River

The following section presents data from all tagged individuals incorporated into a single group, to identify the general movement behaviour pattern of *L. aeneus* in the Vaal River. The same procedure as used with Boskop Dam data was followed for the Vaal River study area (Table 14).

*Labeobarbus aeneus* in the Vaal River follows distinct behavioural patterns, with some individual variations in behaviour. *Labeobarbus aeneus* in the Vaal River showed a significant decrease (P<0.05) in movement activity with increasing flows, and significantly increased (P<0.05) movement activity during stable flows. *Labeobarbus aeneus* exhibited significantly (P<0.05) higher movement counts during daylight hours (08:00-20:00). During the nocturnal time of day *L. aeneus showed a decrease in movement activity* (Figure 53A). *Labeobarbus aeneus* showed significantly (P<0.05) higher movement counts during new moon phases. Individuals preferred deeper water during full moon phases than during new moon phases (Figure 53B).

Movement counts were higher and individuals preferred shallower habitats with increased temperatures in summer and spring whereas movement activity significantly (P<0.05) decreased with decreased temperatures and increased depth in autumn and winter (Figure 53C).

The rainfall event that occurred in winter (21-23 June) may have had an effect on the behaviour of *L. aeneus* but this was not confirmed as data obtained during that period were insufficient to draw an accurate conclusion. Atmospheric pressure alone did not have a significant effect on *L. aeneus* in the Vaal River.
Table 14: Highest and lowest movement counts plotted (x) against time periods, moon phases and seasons. It also shows which data were not available (N/A) for *Labeobarbus aeneus* remotely monitored in the Vaal River.

<table>
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<tr>
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<td>N/A</td>
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</table>
Figure 53: Box-and-whisker plot of the movement counts and depth against time of day (A) moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. Overall highest movement activity where observed during daytime, new moon phases and summer. Lowest movement activity was during winter where individuals also preferred deepest habitats.
Preferred areas of *Labeobarbus aeneus* in the Vaal River

Data obtained from the remote monitoring stations set up along the Vaal River were used to identify which areas *L. aeneus* preferred in the study area (Table 15). *Labeobarbus aeneus* seemed to use the entire study area during the year, especially the areas around remote monitoring station two, four, five, six, seven and eight. These areas contained a large diversity of habitat types including deep pools, undercut banks with submerged roots and trees, fast rapids, riffles with reeds and vegetation, sand, gravel beds with boulders and aquatic vegetation. It seemed that *L. aeneus* used a large area in the Vaal River as information was collected by every station in the study area.

The area usage of *L. aeneus* could, however, not be accurately identified as tags were sometimes recorded by more than one station, therefore implicating the statistical evaluations of position. The minimum distances were not significantly evaluated because of the aforementioned problem; therefore distances were calculated using the furthest two remote monitoring stations that recorded data from a specific individual. The largest area usages for individuals ranged from remote monitoring station two all the way downstream to remote monitoring station eight, that is approximately 9 km in length. Tagged individuals that were recorded throughout the specific focus area had an movement range of approximately 2 km in length. However, these data are influenced by depth and position of individuals and is the reason why continuous data were not obtained for individuals moving from one area to another.

**Table 15:** The preferred areas marked with an (x) of *Labeobarbus aeneus* in the Vaal River throughout the study: including tag numbers and station numbers.

<table>
<thead>
<tr>
<th>Tag nmr</th>
<th>STATION1</th>
<th>STATION2</th>
<th>STATION3</th>
<th>STATION4</th>
<th>STATION5</th>
<th>STATION6</th>
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</table>
Manual monitoring results for *Labeobarbus aeneus* in the Vaal River

Due to the nature of the manual monitoring equipment development process, manual monitoring surveys was started during winter. Two (tagged at same location) of the 14 tagged fish were tracked during June, July, August and September 2012 in the Vaal River. During time of manual tracking these two yellowfish mostly occupied the same areas. The limited time available for manual monitoring surveys resulted in adapting the original monitoring plan of locating an individual every 10 min for 40 min. Instead surveys aimed at maximizing data. Once a tagged individual was located, a GPS fix together with all relevant information was recorded every 10 min for as long as possible. *Labeobarbus aeneus* (6) with radio tag number 51 was monitored for a total of nine separate days during which time 328 GPS fixes were manually obtained. *Labeobarbus aeneus* (7) with radio tag number 53 was monitored for six separate days during which time 151 GPS fixes were manually obtained (Figure 54). During manual monitoring surveys these two individuals had an average habitat preference of less than 1 km$^2$, with only one downward movement of more than 1 km$^2$, after which both yellowfish returned to the same area.

**Figure 54:** A total of 479 GPS fixes was obtained from manually monitoring (Tag 51=328, Tag 53=151). These two individuals had an average habitat preference of less than 1 km$^2$ in range of remote monitoring station 4, 5, 6 and 7, and showed only one movement event outside this area.
**Habitat utilization**

Both yellowfish were located mostly in the middle of the river during tracking surveys. They seemed to prefer this area and consisted of scattered boulders, cobbles and gravel with relatively deep pools > 1 000 mm during daytime. Movement activity was high during these periods and yellowfish moved over short distances < 2 m regularly. The two individuals mostly moved away from this area during low light periods. *Labeobarbus aeneus* (6) had habitat preferences for undercut bank/roots with submerged roots and trees during low light periods often moving over longer distances > 10 m after which yellowfish returned to area in the middle of the river. *Labeobarbus aeneus* (7) different to *L. aeneus* (6) was found to have habitat preferences for fast rapids, riffles with reeds and vegetation during which time yellowfish would continue moving over short distances < 2 m regularly (Figure 55).

![Figure 55](image.png)

**Figure 55**: Yellowfish seemed to prefer an area in the middle of the river that consisted of scattered boulders, cobbles and gravel with relatively deep pools > 1 000 mm during daytime after which *Labeobarbus aeneus* (6) had habitat preferences for undercut bank/roots with submerged roots, trees and *Labeobarbus aeneus* (7) preferred fast rapids, riffles with reeds and vegetation during low light periods.
3.5 Radio telemetry results for *Labeobarbus kimberleyensis* in the Vaal River

The findings on the behavioural ecology of *L. kimberleyensis* in the Vaal River are based on information monitored from three suitable largemouth yellowfish that were captured at various locations using a range of different techniques (Figure 18), after which they were sedated, measured, tagged, photographed and released (Figure 56). Information of tagged *L. kimberleyensis* was recorded on a data sheet (Table 16) for future reference. All the radio tags contained activity, temperature and depth peripheral components. Of these four radio tags, two tags had malfunctions which resulted in lost data (Table 17). Radio tags were able to transmit to remote monitoring stations at a maximum depth of about 2 500 mm over a range of about 500 m. A total of 5 701 data strings were recorded by the eight remote monitoring stations set up around the study area.

**Table 16**: General information on *Labeobarbus kimberleyensis* including: species capture dates, capture method, tag number, measurements, and season of capture

<table>
<thead>
<tr>
<th>Species</th>
<th>Capture date</th>
<th>Capture method</th>
<th>Tag</th>
<th>Mass (g)</th>
<th>Total length (mm)</th>
<th>Fork length (mm)</th>
<th>Standard length (mm)</th>
<th>Girth (mm)</th>
<th>Season</th>
</tr>
</thead>
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<tr>
<td><em>L. kimberleyensis</em> 1</td>
<td>20/02/2012</td>
<td>Electro fishing</td>
<td>48</td>
<td>1150</td>
<td>485</td>
<td>430</td>
<td>400</td>
<td>240</td>
<td>Summer</td>
</tr>
<tr>
<td><em>L. kimberleyensis</em> 2</td>
<td>18/07/2012</td>
<td>Gill nets</td>
<td>54</td>
<td>2300</td>
<td>530</td>
<td>510</td>
<td>500</td>
<td>300</td>
<td>Winter</td>
</tr>
<tr>
<td><em>L. kimberleyensis</em> 3</td>
<td>02/08/2012</td>
<td>Gill nets</td>
<td>47</td>
<td>3800</td>
<td>560</td>
<td>520</td>
<td>510</td>
<td>320</td>
<td>Winter</td>
</tr>
</tbody>
</table>

**Table 17**: Information on radio tags used, including species, capture dates, tag number, tag functions, manual, remote fixes and comments on the performance of the radio tags used

<table>
<thead>
<tr>
<th>Species</th>
<th>Capture date</th>
<th>Radio tag number</th>
<th>Tag functions</th>
<th>Manual fixes</th>
<th>Remote fixes</th>
<th>Comments</th>
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</thead>
<tbody>
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<td>20/02/2012</td>
<td>48</td>
<td>Act, Temp, Depth</td>
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<td>5512</td>
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<td>18/07/2012</td>
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<td>Act, Temp, Depth</td>
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<td>46</td>
<td>Limited data</td>
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<tr>
<td><em>L. kimberleyensis</em> 3</td>
<td>02/08/2012</td>
<td>47</td>
<td>Act, Temp, Depth</td>
<td>0</td>
<td>143</td>
<td>Limited data</td>
</tr>
</tbody>
</table>
Figure 56: *Labeobarbus kimberleyensis* number 1-3 caught, tagged, photographed and monitored in the Vaal River study area. Note *L. kimberleyensis* 2-3 have sores covering large parts of their bodies.

*Labeobarbus kimberleyensis* (1)

*Labeobarbus kimberleyensis* (1) with radio tag number 48 was monitored from 20/02/2012 during which time 5 512 data strings were remotely obtained. These strings contained activity, temperature and depth peripheral information. Data showed that *Labeobarbus kimberleyensis* (1) had movement counts ranging between 85.5 MC/min and 86.6 MC/min during nocturnal periods (00:00-04:00 and
20:00-24:00) of the day whereas daytime movement counts increased to between 111.9 MC/min and 220.4 MC/min. *Labeobarbus kimberleyensis* (1) had peak movement counts during time periods from 12:00-16:00 with an count of 220.4 MC/min whereas lowest movement counts were observed between 00:00-04:00 with an count of 85.5 MC/min (Figure 57A). Movement counts were higher during full moon phases 112.4 MC/min (n=644) than during new moon phases 99.8 MC/min (n=889) (Figure 57B). Limited data were obtained during seasons and the movement count was highest during summer 396.6 MC/min (n=1 119), and then autumn 90.6 MC/min (n=4 035) (Figure 57C). The radio tag on *L. kimberleyensis* (1) transmitted information up until 05/08/2012. The individual seemed to spend a lot of time around station five where it was captured and tagged; from there *L. kimberleyensis* (1) used habitats around station six and seven, which contained rocky substrates, riffles and rapids, aquatic vegetation, undercut banks with deeper pools.

*Labeobarbus kimberleyensis* (1) maintained a depth range of 516 mm to 586 mm during nocturnal periods (00:00-04:00 and 20:00-24:00) whereas depth in daylight periods ranged from 546 mm to 1 043 mm. Depth ranges overlapped, but *L. kimberleyensis* (1) seemed to prefer the deepest water during time periods of highest light intensity (Figure 57A). During full moon phases the depth of *L. kimberleyensis* (1) was 676 mm (n=697) and during new moon phases depth was 536 mm (n=944) (Figure 57B). Limited seasonal variations in depth were obtained and ranged from 548 mm (n=1 142) in summer to 635 mm (n=4 370) in autumn (Figure 57C).
Figure 57: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles. High movement activity of tag 48 was observed during daylight periods, full moon phases and summer. Deeper habitats where preferred with higher movement activity during daylight periods, full moon phases and autumn.
*Labeobarbus kimberleyensis* (2)

*Labeobarbus kimberleyensis* (2) with radio tag number 54 was monitored from 18/07/2012 in which time 46 data strings were remotely obtained. These strings contained activity, temperature and depth peripheral information. Data showed that *Labeobarbus kimberleyensis* (2) maintained an depth range of 338.3 mm to 379 mm during nocturnal periods (00:00-04:00 and 20:00-24:00) whereas depth in daylight periods ranged from 317 mm to 1269 mm (Figure 58). Limited data were collected during moon phases and depth was 539 mm (n=38) during new moon phases. Seasonal data were limited to winter and recorded depth down to 748 mm (n=46) (Figure 58).

![Box-and-whisker plot of tag 54](image)

**Figure 58:** Box-and-whisker plot of tag 54 shows the movement counts and depth against time of day (A) and seasons (B). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles.

*Labeobarbus kimberleyensis* (3)

*Labeobarbus kimberleyensis* (3) with radio tag number 47 was monitored from 02/08/2012 months during which time 143 data strings were remotely obtained. These strings contained activity, temperature and depth peripheral information. Data
showed that *Labeobarbus kimberleyensis* (3) had movement counts of 12.1 MC/min during nocturnal periods (00:00-04:00 and 20:00-24:00) of the day whereas daytime movement counts increased to 171.1 MC/min. *Labeobarbus kimberleyensis* (3) had peak movement counts during time periods from 04:00-08:00 with an average of 171.1 MC/min whereas lowest movement counts were observed between 20:00-24:00 with an average count of 12.1 MC/min. Limited data were obtained and the movement count during full moon phases was 13.9 MC/min (n=34) (Figure 59). Limited seasonal movement during winter was 12.1 MC/min (n=43) (Figure 59).

**Figure 59:** Box-and-whisker plot of tag 47 shows the movement counts and depth against time of day (A) and seasons (B). The box estimates are based on the 25th and 75th percentiles while the whisker extremes are based on 5th and 95th percentiles.
General behavioural pattern of *Labeobarbus kimberleyensis* in the Vaal River

The following section presents data from all three tagged individuals incorporated into a single group, in order to identify the general movement behavioural pattern of *L. kimberleyensis* in the Vaal River. The same procedure as used with Boskop Dam data was followed for the Vaal River study area.

The amount of data collected is insufficient; however, a general behavioural pattern can be identified, as it can be accepted that there will be individual variations in behaviour. *Labeobarbus kimberleyensis* in the Vaal River showed higher movement counts during daylight hours (08:00-20:00) than during nocturnal hours of the day (Figure 60A). *Labeobarbus kimberleyensis* showed higher movement counts during full moon phases than during new moon phases, whereas individuals preferred deeper water during full moon phases than during new moon phases (Figure 60B). Movement counts were higher during summer and individuals preferred shallower habitats with increased temperatures whereas movement decreased with decreasing temperatures and individuals used deeper habitats during autumn and winter (Figure 60C).
Figure 60: Box-and-whisker plot of the movement counts and depth against time of day (A), moon phases (B) and seasons (C). The box estimates are based on the 25\textsuperscript{th} and 75\textsuperscript{th} percentiles while the whisker extremes are based on 5\textsuperscript{th} and 95\textsuperscript{th} percentiles.
Chapter Four:
Discussion of the behavioural ecology of Vaal-Orange River yellowfish species in Boskop Dam and the Vaal River
4 Discussion of the behavioural ecology of Vaal-Orange River yellowfish species in Boskop Dam and the Vaal River

4.1 Behavioural ecology of *Labeobarbus aeneus* in Boskop Dam

From the results of the radio telemetry methods applied in the lentic system (Boskop Dam) for one year, it is possible to successfully identify movement, habitat use and activity of *L. aeneus* in Boskop Dam.

*Labeobarbus aeneus* in Boskop Dam shows higher movement activity during daylight hours (04:00-08:00, 12:00-16:00) with lower movement activity during nocturnal periods of the day (20:00-24:00, 00:00-04:00). This trait can be expected in *L. aeneus* as it is well documented that when a predator’s prey is relatively smaller than itself, searching for prey items forms the greater part of the foraging time occupied (Godin, 1997). Furthermore one of the most important food sources for *L. aeneus* is benthic prey which requires a more mobile foraging tactic in lentic systems (Gaigher and Fourie, 1984; Godin, 1997; Skelton, 2001). Higher light intensity during daytime may be the trigger for *L. aeneus* to actively start searching for prey, as movement activity increases with higher light intensity. When light intensity decreases during night time, movement activity also decreases, suggesting that *L. aeneus* change the foraging tactic that they use during daytime. Studies on the blacksmith (*Chromis punctipinnis*) on a reef off Santa Barbara in California have shown the same behaviour. This species spends the night time in crevices and start actively foraging and searching for prey during daylight hours (Bray, 1981; Godin, 1997). These findings are further supported by notes from Joubert (1970) who commented on the best methods of targeting *L. aeneus*. He suggested that the best time to fish for them was during midday (12:00-16:00), because they ‘seem to be more actively feeding during these times than any other time of the day’.

This behaviour by tagged individuals is correlated with the use of deeper water during periods of high light intensity periods during the day (04:00-08:00, 12:00-16:00) whereas they moved to shallow areas during periods of low light intensity during the night (20:00-24:00, 00:00-04:00). Fish preferring deeper habitats when light intensity is highest (04:00-08:00, 12:00-16:00) could be a defensive reaction to avoid predators (Cerri, 1983). The risk of becoming prey while foraging can influence diet selection to such an extent that individuals may prefer less profitable prey in
safer areas (Godin, 1990; Sih, 1993). Studies on coho and Atlantic salmon (*Salmo salar*) show that when individuals are simulated with a threat of predation, they become reluctant to move away from their refuge areas (Dill and Fraser, 1984). This, however, implies that prey items which were more profitable far away are traded for prey items that are closer but less profitable (Godin, 1990). Hugie and Dill (1994) further suggest that when predators (*L. aeneus*) become prey (*L. aeneus*) individuals are sometimes forced to avoid habitats (shallow water) at certain times of the day, therefore avoiding humans, otters and avian predators that were observed in the area (Cerri, 1983; Godin, 1990; Sih, 1993). *Labeobarbus aeneus* moving to deeper (safer) water during these periods may incur certain costs (Werner *et al*., 1983). The increased movement activity during these periods might be a cost that is needed to make foraging in deeper water profitable (Schlosser, 1988; Harvey and Stewart, 1991; Godin, 1997). Studies on other cyprinid species have found that forager show higher movement activity due to higher light intensity, as prey items are more difficult to catch because of higher light intensity and therefore better visibility (Cerri, 1983). Another possibility for *L. aeneus* moving to deeper water during high light intensity might be that better light penetration and increased visibility allow individuals to forage more effectively in deeper water (Gaigher and Fourie, 1984; Skelton, 2001).

This reaction to light intensity is also prominent during full and new moon phases. During the full moon (higher light intensity) *L. aeneus* in Boskop Dam showed higher movement counts than during new moon phases. This is the same reaction they exhibited during daylight and night periods of a day. Individuals preferred deeper water during full moon phases than they did during new moon phases, possibly for the same reasons as higher light intensity during day time.

Results from movement counts during seasonal variations are inconclusive as seasonal data from each individual were not recorded through all four seasons. Limitations of the radio tags may have caused these gaps in data through some of the seasons. Movement activities during spring and summer are significantly (P<0.05) higher than during autumn and winter. Movement counts were significantly higher (P<0.05) with increased temperatures and shallower water in summer whereas movement significantly decreased (P<0.05) with decreased temperatures and increased depth in autumn and winter. This decrease in movement from spring and summer to autumn and winter has also been documented for *L. aeneus* in the Vaal River (O'Brien *et al*., 2013). Lower movement suggest that *L. aeneus* spend less energy moving around. It may be that movement during these seasons becomes
metabolically costly when water temperatures reach a certain point (Brett and Groves, 1979). Studies on another large cyprinid the mahseer (*Tor putitora*) a relative of the *L. aeneus* species, showed that they do not feed below 16°C and show very little movement during these temperatures (Akhtar, 2002). This has also been documented in other Cyprinidae species including *Cyprinus carpio* where feeding stops completely at temperatures of 10°C and movement activity decreases notably (Eccles, 1985; Akhtar, 2002). This might be the case for *L. aeneus*, that when water temperatures reach a certain point they stop feeding or change foraging tactics (Godin, 1997).

The low movement activity during autumn and winter is correlated with *L. aeneus* moving to deeper water. This reaction to changing seasons is associated with higher atmospheric pressure and lower temperatures; however, no significant (P>0.05) relationship between movement and atmospheric pressure could be identified. *Labeobarbus aeneus* in Boskop Dam may avoid high movement activity during these seasons as the specific oxygen consumption will be lower in colder temperatures as a result of a reduction in metabolism (Eccles, 1985). *Labeobarbus aeneus* can therefore survive certain periods within these seasons being relatively stationary and immobile. Cold water can carry more oxygen than hot water; therefore the oxygen percentage in colder water is sufficient to allow *L. aeneus* to exert minimum movement activity during certain periods (Eccles, 1985).

The movement of *Labeobarbus aeneus* is significantly (P<0.05) higher during spring and summer than during autumn and winter. *Labeobarbus aeneus* is an omnivorous feeder which relies mainly on plankton, algae, insects and insect larvae, which greatly increase during spring and summer (Mulder, 1973; Skelton, 2001). Therefore *L. aeneus* has higher movement during this ‘fertile’ period of the year and show increased movement activities possibly due to increased foraging. The depth parameters during these two seasons also suggest that *L. aeneus* spend generally more time in shallower water even sometimes feeding on the surface than they do during autumn and winter. Another possibility of the increased movement during spring in summer is spawning activities. Ripe and running males can already be found late in August (winter), but the main spawning event is in October (spring) with a possible second spawning event in January (summer) (Mulder, 1973; Skelton, 2001, De Villiers and Ellender, 2007; Skelton and Bills, 2007). Males and females were found ripe and running in Boskop Dam during various monitoring surveys, suggesting that they also spawn during this time period. Some of the data collected
during spring and summer (spawning period) by remote monitoring station one were
definitely not spawning activity, as individuals never stayed in that specific area, and
had to swim past this station to reach the inlet of the dam (Mooi River). This area
around remote monitoring station one also lacks the spawning habitat for *L. aeneus.*
*Labeobarbus aeneus* in reservoirs are known to spawn in inflowing rivers and
shallow rocky bays were wind-driven currents are created (Tomasson *et al.*, 1984;
Impson, 2007). This study has identified two possible spawning areas. One spawning
area is on gravel beds within the Mooi River at the inlet of Boskop Dam and the other
is in a manmade rocky bay near the Department of Water Affairs (DWA) Regional
Office on the southern bank. The manmade rocky bay at Water Affairs is built at an
angle were wind creates the necessary current that yellowfish prefer for spawning
(De Villiers and Ellender, 2007). None of the tagged individuals were recorded using
these spawning areas, but *L. aeneus* was seen on numerous occasions spawning in
these areas.

*Labeobarbus aeneus* in Boskop Dam move around in shoals that can be seen
around the entire study area. This behaviour was also observed in the suitability
assessment where shoals of *L. aeneus* were always captured as opposed to single
individuals. From the amount of data obtained by remote monitoring station five (n=4
895) which formed the bulk of the data, it is possible that *L. aeneus* chose this as a
refuge area during autumn and winter. This area had a depth of up to 8 000 mm and
consisted of various habitat types including rocky substrates, weeds, grass beds and
reeds. *Labeobarbus aeneus* were also sampled in this area during the suitability
assessment of Boskop Dam in winter, which further supports the notion that this area
may possibly be an important refuge area during autumn and winter. Furthermore,
this area is situated inside a small protected area within the nature reserve, and is
closed to the public for fishing and other water-related activities. This area is already
classified as a management area in the Boskop Dam Nature Reserve and it is thus
further emphasised to be a very important refuge area for *L. aeneus* in Boskop Dam.
It is suggested that stricter rules and regulations be applied to this specific area, to
increase conservation and protection of this highly utilised species in Boskop Dam.
Observation notes on possible predatory behaviour of *Labeobarbus aeneus* in Boskop Dam

Species within the Cyprinidae family are known to change their feeding habits to adapt to changing environmental conditions. Individuals of the same species have often been described as a herbi-omnivore and carnivorous feeders that feed mainly on algae, molluscs, micro vegetation and insects, but also hunt small fishes if conditions permit (McDonald, 1948; Kaushal *et al.*, 1980; Dubey, 1985; Shrestha, 1997). Individuals within the same species may also have different morphological variations in their jaws. Variation in jaw morphology is usually associated with different feeding behaviours, which may change in different environments (Jubb, 1967; Bloomer *et al.*, 2007). *Labeobarbus aeneus* in Boskop Dam is possibly using different foraging tactics where fish could forage on invertebrates and then change to hunting small fishes (Gaigher and Fourie, 1984; Wootton, 1984; Hart, 1996). The clarity of Boskop Dam should allow for predatory behaviour of *L. aeneus* on smaller fish species. This phenomenon has been witnessed on numerous occasions where *L. aeneus* would actively hunt small fishes on the water surface. The jaw morphology of *L. aeneus* in Boskop Dam (Figure 61A-B) furthermore resembles that of more predatory fish like *L. kimberleyensis* (Figure 61C-D) whose jaw morphology differs from fishes only foraging on invertebrates (Figure 61E-G). *Labeobarbus aeneus* in Boskop Dam may possibly be more predatory compared to *L. aeneus* in rivers. This is furthered supported by numerous *L. aeneus* specimens caught on artificial lures by anglers targeting *M. salmoides* around the dam.
Figure 61: Different jaw morphologies developing with various feeding habits, including (A-B) *L. aeneus* from Boskop Dam with very distinct hard bony jaws situated in a similar position as jaws of *L. kimberleyensis* (C-D). Common jaw morphology (rubber lips) of *L. aeneus* in the Vaal River (E-G), resembling those of fish that feed on invertebrates between rocks.
4.2 Behavioural ecology of *Labeobarbus aeneus* in the Vaal River

*Labeobarbus aeneus* tagged in the Vaal River show that there is a high variation in individual movement behaviour and habitat selection. The majority of fishes, however, seemed to adopt a general movement pattern. *Labeobarbus aeneus* in the Vaal River exhibit the same movement behaviour patterns, during day and night periods as in Boskop Dam. *Labeobarbus aeneus* in the Vaal River showed the same trend for deeper habitats during high movement activity; however, this trend is not distinct. The reason for this might be the topographic layout of the study area where the water column is fairly similar in most habitats or that turbidity might influence this behaviour. The Vaal River being a naturally turbid river may be the reason for an individual’s behaviour being different from that of an individual in the clear water in Boskop Dam. Studies have shown that turbidity affects the feeding and movement behaviour of certain Cyprinids (Bruton, 1985; Clough *et al*., 1998). Turbidity may act as a cover feature in this case where individuals are sometimes forced to avoid habitats (shallow water) in clear water during certain periods of the day, therefore avoiding humans, otters and avian predators might be regarded as being less of a threat in the turbid Vaal River water (Godin, 1990; Sih, 1993). *Labeobarbus aeneus* show higher movement activity during new moon phases than full moon phases. This higher activity during new moon phases is associated with shallower habitats, which implies that predator avoidance is a possible reason for selecting deeper habitats during full moon phases (Godin, 1990; Sih, 1993). Fishes, including omnivores that have to extensively search for prey, need to explore their habitats more than, for example, ambush predators, to find the most productive food sources (Godin, 1990). This might possibly be why *L. aeneus* uses the entire water column to find prey items throughout a day.

Movement counts of *L. aeneus* varied during the different seasons monitored. Seasons are one of the driving forces that influence the distribution and habitat preference of certain cyprinids (Penne and Pierce, 2008). *Labeobarbus aeneus* in the Vaal River displayed similar movement behaviour as in Boskop Dam; however, reasons for the same behaviour might be different. This decrease in movement activity during winter and increased movement during summer has been documented for *L. aeneus* in the Vaal River (O’Brien *et al*., 2013). The decrease in movement is usually associated with changes in environmental variables such as flow, pressure and temperatures (O’Brien *et al*., 2013). Autumn and winter are generally associated
with low flows were *L. aeneus* prefer deeper water >1 000 mm as a result of tradeoffs between swimming costs, and the supply rate of capturing food items (Hughes and Dill, 1990). Rapids and riffles which are generally shallower habitats might be avoided during low-flow periods because of the increased effort to catch prey successfully in shallower habitats (Hughes and Dill, 1990). During spring and summer *L. aeneus* used shallower habitats that might suggest that individuals preferred habitats such as glides, runs and riffles whereas in autumn and winter *L. aeneus* preferred deeper water suggesting pool habitats (O’Brien et al., 2013). *Labeobarbus aeneus* are known summer riffle dwellers and have therefore adapted specific foraging strategies that further support *L. aeneus* moving from shallower <1 000 mm water in summer to deeper >1 000 mm water in winters (Wootton, 1984; Hart, 1996). The preferred habitats were relatively shallow (<1 000 mm) with only a few pools deeper than >1 000 mm. These habitat preferences are further supported by O’Brien et al. (2013) where *L. aeneus* preferred fast-flowing to moderately shallow (<1 000 mm) habitats throughout the year. Being an omnivorous feeder *Labeobarbus aeneus* seems to prefer these fast-flowing habitats where the majority of their diet can be found (Dörgeloh, 1994; 1996; Stadtlander et al., 2011). Feeding behaviour of *L. aeneus* that was identified in this study showed that *L. aeneus* will occupy an area behind a suitable rock, while facing upstream. Drifting food is then brought in the current like a conveyer belt, where *L. aeneus* would then dart up and down or from side to side to capture prey. *Labeobarbus aeneus*, like other Cyprinidae species, also have the ability to change their foraging tactics to suit environmental changes (Wootton, 1984; Hart, 1996). It is a well-known fact that *L. aeneus* can change from feeding in riffles and rapids in summer to avoiding riffles and rapids in winter, and then change to feeding on other prey found in deeper habitats. Further studies are needed to identify the movement activity signatures from radio tags to identify different foraging tactics.

Cyprinids are highly mobile and are therefore capable of using areas ranging from a few metres to hundreds of kilometres (Crook, 2004; Stuart and Jones, 2006; Penne and Pierce, 2008). Individuals monitored in this study exhibited area usage of up to 9 km² (n=3) whereas some individuals preferred to remain in focus areas of up to 2 km². This contradicts findings in a previously published report stating that *L. aeneus* is believed to use home ranges of maximum 2 km (O’Brien et al., 2013). *Labeobarbus aeneus* in the Vaal River are known to migrate during spawning periods in summer and spring (Tomasson, 1983). These spawning events are triggered in late September and October when water temperatures reach 18.5°C in conjunction
with the rainy season that create suitable flows over spawning habitats which are dominated by gravel, cobbles and boulders (Tómasson et al., 1984; Bruton, 1985; De Moor and Bruton, 1998; O’Brien et al., 2013). Five of the tagged individuals possibly partook in a spawning migration. These individuals all migrated upstream to the vicinity of remote monitoring station two in spring and summer.

4.3 Behavioural ecology of *Labeobarbus kimberleyensis* in the Vaal River

*Labeobarbus kimberleyensis* in the Vaal River exhibited the same daily movement as *L. aeneus* in the Vaal River. The high movement activity of *L. kimberleyensis* is associated with deeper water during daytime periods and vice versa. These movement patterns are identical to the movement patterns of *L. aeneus* during daytime periods in Boskop Dam. It is possible that the predatory behaviour of *L. aeneus* in Boskop Dam is similar to that of *L. kimberleyensis* in the Vaal River which are known predators that hunt in shallow habitats during low light conditions of the day (Skelton, 2000). Movement activity of *L. kimberleyensis* during full moon phases was observed to be higher than during new moon phases; individuals also generally kept to shallower water (<500 mm) during new moon phases possibly avoiding predators the same way *L. aeneus* does (Godin, 1990; Sih, 1993). *Labeobarbus kimberleyensis* may also use the increased light intensity during full moon to ambush fodder fish species that tend to stay in shallower water during nocturnal periods. Like other piscivorous fish species like perch *Perca fluviatilis* (Scott and Crossman, 1973) and pike *Esox lucius* studied in North America, it is possible that *L. kimberleyensis* may use some of the same foraging strategies (Webb and Skadsen, 1980; Hart and Hamrin, 1988; Eklöv and Diehl, 1994). These strategies include *L. kimberleyensis* using a sit-and-wait search tactic. This tactic implies that *L. kimberleyensis*, especially the dominant (large) individuals, will select the best structure from where it can ambush fodder fish (Webb and Skadsen, 1980; Hart and Hamrin, 1988; Eklöv and Diehl, 1994). This tactic can and will, however, change during certain times of the year when individuals will leave their advantage points and actively hunt smaller fishes. This tactic has been witnessed by numerous anglers where shoaling *L. kimberleyensis* have been seen rounding up fodder fishes and attacking them from all sides. It is possible that younger (smaller) individual *L. kimberleyensis* prefer to
move around in shoals therefore increasing their chances of survival and finding food (Webb and Skadsen, 1980; Hart and Hamrin, 1988; Eklöv and Diehl, 1994). *Esox lucius* are known to cover large distances and may end up using different habitats than where they started from (Eklöv and Diehl, 1994). When they reach a suitable new habitat they again employ the sit-and-wait tactic which is identified by short bursts of movement around the same area (Eklöv and Diehl, 1994). It is possible that *L. kimberleyensis* uses the same tactic as it is known for long-distance movements of up to 12 km, after which they will occupy that specific area for a specific period (O’Brien et al., 2013). During this period *L. kimberleyensis* uses a small area, until it makes another long-distance movement.
5 Conclusions and recommendations

5.1 Conclusion

The original aims proposed to test the established hypothesis for this study (Chapter 1) were to: (Chapter 2) establish biotelemetry methods that will be used to monitor the behavioural ecology of yellowfish in one lentic and one lotic system in the North West Province, South Africa: assess the availability of yellowfish in Boskop Dam to carry out the behavioural study: capture, tag, release and monitor yellowfish species in Boskop Dam and the Vaal River to characterise their behaviour: monitor changes in selected environmental variables (water quantity, habitat and selected atmospheric variables) in Boskop Dam and the Vaal River: (Chapter 3) statistically characterise the habitat use, movement and activity of the yellowfish species in these systems: and (Chapter 4) evaluate possible links between yellowfish behaviour and changing environmental variables. By achieving all these aims we can revisit the hypotheses in order to reject or accept them.

Hypothesis 1:

Biotelemetry methods can be used in lentic and lotic environments of the Vaal River catchment to characterise the habitat use, movement and activity of yellowfish species.

Biotelemetry methods have successfully been used in Boskop Dam and the Vaal River to characterise habitat use, movement and activity of yellowfish species. The remote monitoring aspect of the study worked very well, although some investigation needs to be done on the radio tags that resulted in limited data being recorded. This hypothesis is therefore accepted.

Hypothesis 2:

Behaviour of Orange-Vaal River yellowfish species is influenced by changes in environmental variables.

The behaviour of Orange-Vaal River yellowfish species is influenced by specific environmental variables such as temperature, flow, time of day, seasons and moon phases. This hypothesis is therefore accepted.
Hypothesis 3:

1. Behaviour of Orange-Vaal River yellowfish species can be used as an ecological indicator of changing environmental conditions.

It has been shown that environmental conditions do influence the behaviour of yellowfish species; however, the use of behaviour as an ecological indicator of changing environmental conditions has not been achieved in this study. The outcome has been that more and new behavioural information that was previously unknown is now available. This hypothesis is therefore rejected.

5.2 Concluding remarks

The behaviour of *L. aeneus* has been shown to be influenced by changing environmental variables. By using biotelemetry methods these changes have been characterised and some previously unknown behaviour is described. *Labebarbus aeneus* follows distinct behavioural patterns, with some individual variations in behaviour. *Labebarbus aeneus* exhibited higher movement counts that are associated with deeper water during daylight hours (04:00-16:00). During nocturnal periods *L. aeneus* showed a decrease in movement activity and preferred shallower water compared to daytime. However, *Labebarbus aeneus* in the Vaal River seems to be influenced less by bright daylight and this might be due to the turbidity of the river water. *Labebarbus aeneus* in Boskop Dam showed higher movement counts during full moon phases whereas *L. aeneus* in the Vaal River showed higher movement counts during new moon phases. All tagged fishes in Boskop Dam and in the Vaal River preferred deeper water during full moon phases than during new moon phases.

Movement counts were significantly higher (P<0.05) with increased temperatures and shallower water in summer whereas movement significantly decreased (P<0.05) with decreased temperatures and increased depth in autumn and winter. Seasonal movement data were, however, limited.

*Labebarbus aeneus* in the Vaal River showed a significant decrease (P<0.05) in movement with increasing flows, and significantly increased (P<0.05) movement during stable flows. Movement counts of all individuals were higher when
temperatures increased in spring and summer whereas individuals’ movement counts significantly (P<0.05) decreased with decreased temperatures and increased depth in autumn and winter.

### 5.3 Limitations and recommendations

There are variations in behaviour of the same species and continual studies need to be carried out to gain a better understanding of the yellowfish species. This study being part of a developmental project gave us the opportunity to identify many shortcomings that can be eliminated in the future. One of the greatest limitations for the Boskop Dam study area was the radio telemetry tags. These tags can transmit data down to a depth of 2 500 mm over a distance of approximately 500 m. The depth and size of the study area may have been too large for this type of radio telemetry study and this could possibly have resulted in limited data being recorded. In addition, no manual monitoring could be successfully carried out on Boskop Dam as tagged fishes could not be located. Furthermore, the high number of defective tags in the Vaal River study area may be as a result of the rougher water and submerged obstacles such as rocks or sandbars in the river environment compared to Boskop Dam. Radio tags might have been damaged by chafing and abrasion, and constant friction between the fish and the substrate while fishes were feeding, or by rubbing themselves (‘flashing’) against rocks or substrate due to irritation.

It is therefore recommended that these radio tags be tested for rigidity before applying to other projects. The amount of data collected from fishes tagged in the Vaal River by remote monitoring stations was sufficient for the purpose of this study. Our understanding of the behaviour of *Labeobarbus species* has been improved, this being only the second radio telemetry study on the species; however, it is strongly suggested that further more focused studies be carried out on these highly important indigenous species.

Possible further studies may include:

1. testing yellowfish behaviour to light intensity in a controlled environment
2. determine swim performance of yellowfish in a controlled environment and calibrate movement with activity readings on radio tags
3. apply the biotelemetry approach at a source point pollution area to test if yellowfish behaviour can be used as an ecological indicator

One of the most valuable projects that can be carried out to classify yellowfish behaviour is to observe yellowfish in an aquarium like manner as they have done on pike and bass in the Americas to visually learn about their behaviour in induced environmental changes.
Chapter Six: References
6 All references cited in each chapter


DEPARTMENT OF WATER AFFAIRS (DWA) 2010. River Health Assessment on the Vaal River: Downstream of the Rietspruit and Vaal River confluence to the Erina Spa Bridge and Vaal River Crossing. DWA Project WP9672. Carried out by Jeffares and Green (Pty) Ltd. and the University of Johannesburg on behalf of the Department of Water Affairs, Sasol and Rand Water.


O'BRIEN, G. & SMIT, N. & WEPENER, V. 2011. Regional Scale Risk Assessment of threats to the yellowfish (*Labeobarbus spp.*) and the ecosystem services they provide in the Vaal River, South Africa’s hardest working river.


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