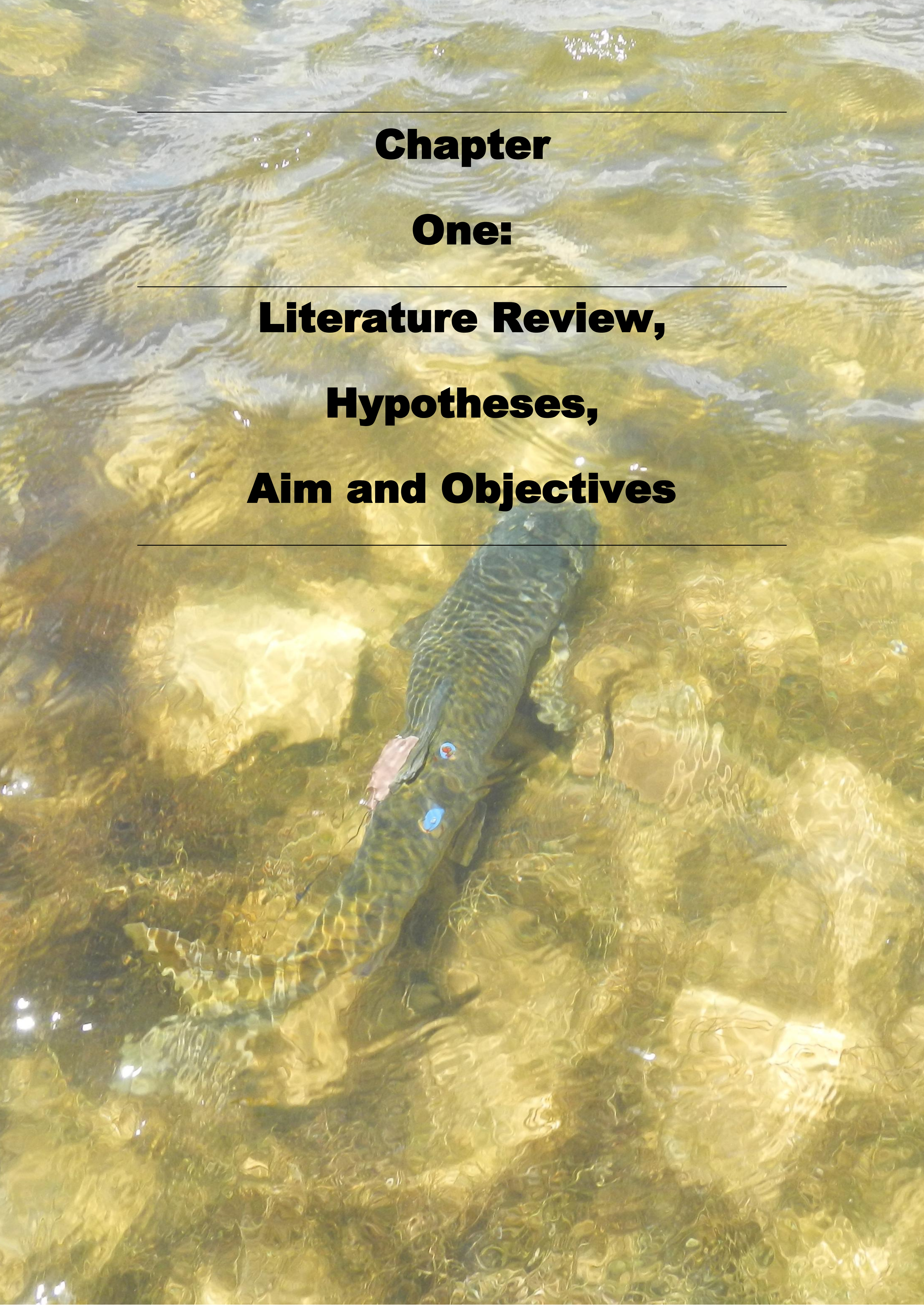
Chapter One:

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 20^{th} 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 Worldwide statistics show that as much as 70% of freshwater withdrawn from ecosystems is used in the agricultural industry for irrigation; of this, 35% is wasted through leakages and evaporation (Postel, 1995; Lanza, 1997).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 m^3 (WRI, 2008).

Currently South Africa has an annual water availability of 1 100m^3 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)

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

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)

Characteristics	Tag type	
	Ultrasonic	Radio
Salt water	Excellent	No
High conductivity	Excellent	Poor
Low conductivity	Excellent	Excellent
Deep water	Excellent	Limited
Turbulent water	No	Excellent
Fast animals	Poor	Excellent
Long migrations	Poor	Excellent
Dense aquatic vegetation	Poor	Very good
In water obstructions	Poor	Very good
Turbid water	Poor	Very good
Algae	Poor	Excellent
Thermocline/temperature gradient	Fair	Good
Ice	Poor	Good
Number of animals	Same	Same
Tracking options	Hydrophone in water	Land, boat, air, remote
Power usage	Poor	Good

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)

Characteristics	Tagging method		
	External	Stomach	Implant
Installation time	Moderate	Quick	Slow
Difficulty	Moderate	Low	Highest
Recovery time	Moderate	Quick	Longest
Balance problems	Greatest	Least	Least
Transmitter size	Smallest	Moderate	Largest
Entanglement	Greatest	Low	Low
Mortality	Low	Moderate	Highest
Species diversity	Highest	Moderate	Moderate
Biological limitations	Low	Highest	Moderate
Risk of tag loss	Moderate	Moderate	Low
Infection	Low	Low	Highest
Irritation	Highest	Moderate	Low

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)

Labeobarbus Species	Common name	Conservation status
L. aeneus	Vaal-Orange smallmouth yellowfish	Least concern
L. capensis	Clanwilliam yellowfish	Vulnerable
L. kimberleyensis	Vaal-Orange largemouth yellowfish	Near threatened
L. polylepis	Bushveld small-scale yellowfish	Least concern
L. natalensis	KwaZulu-Natal yellowfish	Least concern
L. marequensis	Lowveld large-scale yellowfish	Least concern
L. codringtonii	Upper Zambezi yellowfish	Least concern

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 km^2 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 10^6 m^3 of water for urban and rural development, 264 x 10^6 m^3 of water for mining and industrial uses and 798 x 10^6 m^3 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; Tòmasson *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).

Figure 1: Adult Vaal-Orange smallmouth yellowfish (*Labeobarbus aeneus*) from Boskop Dam bearing a radio tag

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.