REMOTE AND MANUAL RADIO TELEMETRY METHODS TO MONITOR AND USE FISH BEHAVIOUR IN SOUTH AFRICA'S INLAND WATERS

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

In South Africa the excessive use of aquatic ecosystem services is resulting in the depletion of fish stocks and as a result, threatening the social and economic wellbeing of South Africans. Currently, as much as 80% of South Africa's inland ecosystems (rivers, lakes and estuaries) may be threatened and the populations of fishes within these ecosystems are being exposed to ever increasing levels of stress which ultimately affects the survivability of populations. In addition to increasing the use of aquatic ecosystem services, technology developments are empowering scientists, who have an ever increasing ability to evaluate the biological requirements of fishes and characterise the effects of altered ecosystem states to populations of fishes. Only recently, primarily due to the development of radio telemetry monitoring techniques, have scientists had the ability to characterise the behaviour of fishes in inland aquatic ecosystems. Radio telemetry techniques allow researchers to document, for long uninterrupted periods, how undisturbed fish interact with each other and their environment in real time. Remote and manual monitoring techniques are internationally recognised as an effective way of acquiring a wide range of behavioural information of freshwater fishes and other aquatic animals over extended periods within their natural environments.

Wireless Wildlife (WW) is a commercial radio tracking and monitoring system provider located in Potchefstroom, North West Province, South Africa. Although the WW radio tracking and monitoring system have been designed for use on terrestrial animals, the systems have had the potential to be adapted for use on aquatic animals including fish. This study has been established to develop remote and manual radio telemetry methods to monitor and use fish behaviour in South Africa's inland waters. As such the aims of the study include:

1. Design and produce WW radio telemetry tracking system requirements for fish in inland surface aquatic ecosystems in South Africa.
2. Test the functionality of the WW radio telemetry tracking systems for fish in suitable case studies.
3. Compare the WW radio telemetry tracking systems to internationally available systems.

This report presents the approach adopted and the findings of the study in the form of eight chapters.

In Chapter 1, available international radio telemetry systems to monitor the behaviour of fish in inland surface aquatic ecosystems are presented. This chapter provides the introduction to the study including the rationale for the study and a review of the use and value of radio telemetry methods. Internationally there are a wide range telemetry systems available including satellite ultrasonic (acoustic) and radio systems. Each system has a range of tags, attachment techniques and monitoring techniques that have been designed to address a range of fish biology and ecology questions. For freshwater fishes, the size that species attain does not allow for satellite options and in river ecosystems where a lot of acoustic noise occurs naturally, the ultrasonic option is not suitable. There are numerous radio telemetry systems available for use on fish in inland ecosystems. The types of tagging and tracking methods of these systems depend on the behavioural questions being asked or hypotheses that need to be tested; the nature of the ecosystem in which the study is being undertaken; the species of fish being used including the size the species attains, and the ease of application.

In Chapter 2, an overview of the WW digital radio telemetry systems that were developed to monitor the behaviour of fish in South Africa's inland waters is provided. Wireless Wildlife has developed a somewhat unique “smart” system incorporating remote and radio receivers that receive data from and send data to transceivers (as opposed to transmitters that can only transmit data). The WW radio telemetry system is based on a digital format which makes use of single frequency. The system also incorporates a data management system that allows for real time remote monitoring; facilitates communications between receivers and transmitters which allows the operator to switch from remote to manual modes for example; provides a system to store; manage, iterate and use the data.

In summary, the locally-produced biotelemetry system makes use of remote and manual tracking or monitoring systems as well as smart tags or transceivers. The latter is attached to the organism being monitored. Once tagged, the animals (in the case of the study fish and crocodiles) are released to re-establish their normal behavioural patterns. With remote and manual monitoring systems researchers now monitor the continuous behaviour of the animal for at least a year. The remote monitoring systems include the use of ‘listening stations’ or receivers that are deployed into the study area. These record and transmit information from the tags at a ten-minute interval to an Internet-based data management system. The researchers can log onto the data management system at any time from any computer with Internet access and download real-time behavioural data from the tagged animal. In turn, manual monitoring systems involve the use of directional antennae and hand-held receivers which are used to locate and download behavioural data from any tagged animal in the field.

The benefits of combining remote and manual monitoring methods are that scientists can manually monitor the behaviour of the tagged animals and important environmental variables whenever they choose, as well as get additional information from the remote systems when they are not in the field. Although the WW radio telemetry approach is unique, biotelemetry methods are not, so ecologists have access to a wide range of very useful data analyses methods that allow for the graphical and statistically analyses of the behavioural data collected. The system has been designed to allow for the monitoring of the location of fish, the movement and activity as well as some environmental variables, including the depth of the fish in the water, as well as the temperature in the water. In addition, by monitoring the location, movement and activity of the fish over extended periods of time, scientists are able to evaluate the response of the animal to changing habitat variables, flows, water quality components and weather variables, such as atmospheric pressure. A limitation of the use of the approach includes the size of the tag which is largely limited by the battery needed to power the tags. This means that the smallest tags that last one year are currently the size of an AA battery and weigh about 8 g. Due to the size of the tags the approach is largely directed towards adult fish that grow larger than 500 g. In the near future this approach will allow ecosystem managers to make real-time management decisions based on the immediate response of organisms to changing environmental variables. This will be achieved by identifying and using unique coordinated behavioural responses of a sub-population of tagged fish in a study area as indicators of the state of a system variable that the managers are interested in monitoring. For example, in a case study where the pre-determined coordinated behavioural responses of a tagged sub-population of a species responds to reduced flows or a water quality pollution event into a river occurs, managers will be able to respond immediately to that event. This approach could be useful to manage flow releases in real time for example when a tagged sup-population of a species initiates a migration event for example.

Chapter 3 presents the first of four case studies that used the WW radio telemetry system to evaluate the habitat preferences of adult lowveld largescale yellowfish (*Labeobarbus* marequensis) and tigerfish (*Hydrocynus vittatus*) in the Crocodile River, Kruger National Park. This case study includes a spatial area use assessment of a reach of the Crocodile River by a population of adult *L.* marequensis and *H. vittatus* using manual radio telemetry methodologies incorporating the WW digital radio telemetry system. The case study includes considerations of the availability of habitat and cover feature types within the Crocodile River. Some biotelemetry components of the remote WW digital radio telemetry system were used to contribute to the habitat preference assessment. This chapter also includes the use of Advanced Telemetry System equipment which allows for direct comparison of the functionality of the two systems. This case study was carried over a three year period during which time 479 manual fixes were obtained from 15 individuals and 39505 fixes/data strings containing transmission signal strength, movement counts and temperature, and or depth were obtained from an additional 17 individuals. This case study also incorporated the use of statistical evaluation techniques to evaluate the radio telemetry data.

In Chapter 4, the WW radio telemetry tracking system has been used to evaluate the behavioural response of adult Lowveld largescale yellowfish (*L. marequensis*) to flow and other ecosystem variable changes in the Crocodile River, Kruger National Park. This case study involves evaluating changes in the behaviour (measured as movement) of an adult population of *L. marequensis* in the Crocodile River to flow variations (measured as discharge). The case study incorporates the application of the remote WW digital radio telemetry system to generate behavioural data of the *L. marequensis* population and the statistical comparison of changes in this behavioural data with discharge data observed from a local DWA gauging weir. This case study characterises the ability of the WW digital radio telemetry system to evaluate the behavioural response of a population of tracked fish to an important environmental variable namely flows.   Similarly this case study was carried over a three year period during which time 479 manual fixes were obtained from 15 individuals and 39505 remote fixes/data strings containing transmission signal strength, movement counts, temperature and depth (some tags) from 17 individuals. This case study also incorporated the use of statistical evaluation techniques to evaluate the radio telemetry data

In Chapter 5, the habitat use and the effect of diurnal, lunar and seasonal cycles on the movement of adult Vaal-Orange smallmouth yellowfish (*L. aeneus*) in Boskop manmade lake, North West using WW radio telemetry methodologies is presented. In this case study four *L. aeneus* were tagged and tracked for over a year in the Boskop manmade lake, North West. During the tracking period, numerous manual and remote monitoring surveys were undertaken to evaluate the spatial area use of the tagged yellowfish using manual triangulation tracking techniques and remote techniques which is based on the coverage ranges of the remote receivers stationed in the study area. In addition, the effects of diurnal, lunar and seasonal cycles on the movement of adult Vaal-Orange smallmouth yellowfish were undertaken by monitoring the movement of the yellowfish and evaluating a differences in the movement during different times of day, lunar cycles and seasonal cycles. During this experiment that was carried out for more than a year, a total of 9153 fixes/data strings containing movement counts and temperatures for all tags and depth were recorded.

Chapter 6 consists of the final case study which evaluated the effect of diurnal, lunar and seasonal cycles on the movement of adult Orange-Vaal yellowfishes (*L. aeneus* and *L. kimberleyensis*) in the Vaal River, Free State. In this chapter the effects of time of day, moon cycles and temperature on the movement of adult yellowfish were undertaken. From this case study which was undertaken over a 10 month period 38655 and 5198 fixes or data strings with movement, temperatures and on occasion depth peripheral sensory components were obtained from 14 and 3 *L. aeneus* and *L. kimberleyensis* individuals respectively. The case study provides valuable information pertaining to the biology of yellowfish in the Vaal River and contributes the suitability evaluation of the WW radio telemetry system approach.

In Chapter 7, the functionality of WW radio telemetry systems are compared to available international systems. In this study comparisons were made between ATS radio telemetry systems applied by O'Brien et al. (2011) using yellowfish in the Vaal River, O'Brien et al. (2012) using tigerfish in the Schroda and Letsibogo manmade lakes and in Chapters 3 and 4 with WW radio telemetry systems. In this chapter a table that addresses the technical support options, radio telemetry systems (general), receivers and transmitters/transceivers of both ATS and WW systems are compared. The findings indicate that the unique WW radio telemetry systems that have been developed in South Africa, by South Africans, for South Africa out performs the Advanced Telemetry System approach which has been more widely utilised in inland ecosystems in South Africa to date than any other radio telemetry technique.

In the final chapter (Chapter 8) an overview of the conclusions and recommendations of the study are provided. Through the implementation of the objectives of the study the three aims were achieved. The outcomes include the successfully used of the WW radio telemetry system to tag, track and or monitor (manually and remotely) >40 individual fishes in both lentic (Boskop manmade lake) and lotic (Vaal and Crocodile Rivers) ecosystems from a few days to more than one year. All of the WW radio telemetry system components were tested including the tags (with various peripheral components), manual and remote tacking techniques and the data management system. Some noticeable outcomes of the study include:

- The areas used and depth profiles occupied the fishes were accurately monitored and successfully used to characterise the home ranges, habitat preferences and behavioural response of fishes to changing ecosystem variables (water quality, quantity, atmospheric and habitat variables) in lentic and lotic ecosystems. In this study the locations of tagged fish were primarily monitored with manual tracking techniques. Towards the end of this study the developments made in remote triangulation techniques by WW allowed for the general locations of tagged fishes to be monitored remotely as well. Wireless Wildlife now offer accurate triangulation options for the WW radio telemetry system. Communication ranges between tags and receivers are limited by depth (>2 m) and distance from tags to receivers. In this study, WW developed various peripheral components for tags including data storage (memory) facilities. With the inclusion of data storage capabilities the location of the tagged fish cannot be obtained but other features such as depth profiles can be stored and downloaded when the tagged fish returns to the coverage area. Techniques to characterise the habitat preferences and or requirements of fishes in lentic and lotic ecosystems were demonstrated in the study by comparing the area use and depth profiles of tracked fishes with habitat availability. The study also demonstrated how changes in the behaviour of tagged fishes, including area use and depth profiles can be used to evaluate the consequences of changes ecosystem variable (such as flows) states.

- The movement of tagged fish, measured as MC/m from an accelerometer incorporated into tags as a peripheral component, and maximum displacement (m/min) that was manual recorded were successfully documented and used to characterise the behaviour of fishes in the study. This variable was established as the main behavioural variable/indicator for this fish behavioural monitoring tool to evaluate the behavioural response of fishes to changes in diurnal, lunar and seasonal cycles, habitat availability/states, flows and temperatures on the movement of adult yellowfish and or tigerfish were achieved. The approach demonstrated in the study included the use of statistical procedures to evaluate the significance of the behavioural responses to variable changes. This approach can be used to evaluate the environmental consequences of water quality, quantity and habitat alterations associated with excessive use of aquatic ecosystem service use.
- Aspects of the behavioural ecology of the fishes considered in the study were characterised. This includes information on the timing and location of spawning events, aspects of the feeding biology and general activity of tagged individuals. In addition, the study demonstrated the ability of the technique to evaluate inter- and intra-species interactions including individual behavioural variability in both lentic and lotic ecosystems (yellowfish), differences between species (yellowfish and tigerfish) and shoaling behaviour of yellowfish in the Boskop Manmade lake.

The WW radio telemetry system developed in the study has been shown to be robust, easy to implement, informative and suitable to answer a host of fish behavioural ecology and associated ecosystem conservation and management questions. In addition the approach has been shown to not only compare with international fish behavioural monitoring systems but has many advantages that make the approach more suitable for application in South Africa. In particular, the advances made in the remote behavioural monitoring systems, which include the use of a range of peripheral sensory components and the availability of local technical support makes the use of the WW radio telemetry system ideal for application in South Africa. With this technology South Africans now have access to a relatively cost affective fish behavioural monitoring tool locally with local technical and scientific support that can contribute to the conservation and management of fishes and the ecosystems they occur in.

For the continued development of telemetry tracking techniques in South Africa the following recommendations have been made:

1. Wireless wildlife should still be enabled to continue with the development of the WW radio telemetry system through more case studies in different inland ecosystems.
2. The WW radio telemetry system and the associated scientific methodology developed in this study to monitor the behavioural ecology of fish should be promoted.
3. The effects of the tagging process, the long term effects of the attached tags and alternative tagging methods (external vs. internal) should be evaluated.
4. In South Africa a large portion of the biological requirement information of many fishes, which is used as ecological indicator information to manage and conserve ecosystems is not based on data but inferred by specialists. The WW radio telemetry behavioural monitoring technique should be used to collect data to validate the known biological requirement information of large (> 250 g) fishes in South Africa thereby improving the use of this information to manage and conserve aquatic ecosystem.
5. The statistical techniques used in the study should be developed into a suite of well-presented, easily applied methodologies. This will allow future operators to analyse the findings of the study immediately which will optimise the usefulness of the approach and contribute to the validity of the technique.
6. A centralised archive of South African inland fish behavioural data should be developed where remote and manual behavioural data can accessed by stakeholders, analysed and stored to continually improve on our understanding of fish biology and ecology in South Africa.
7. The suitability of the WW radio telemetry system to contribute to the monitoring of water quality, flow, habitat (including barriers) and atmospheric variable states has

been demonstrated in this study. This tool should be implemented to contribute to the development of a sustainable balance between the use and protection of ecosystems and monitor the effects of altered variable states.

8. The real time data management system with alert development capabilities of the WW radio telemetry system allows for real time behavioural monitoring of tagged fish with build in behavioural change indicators. This technique allows for the real time monitoring a range of environmental conditions with alert notifications being sent to managers when a previously characterised coordinated (many individuals) behavioural response of the tagged fish occurs in real time. This will allow managers to respond to changes in environmental conditions immediately.

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ACRONYMS/ABBREVIATIONS

ADC	– Analogue to Digital Converter
A-veg	– Habitat type: aquatic vegetation
CPU	– Central processing unit of a computer
E-boulders	– Habitat type: emergent boulders
FRU	– Freshwater Research Unit
GSM	– Global System for Mobile Communications
MC/m	– Units of movement or maximum counts per minute
MPB	– Mpumalanga Parks Board
M-veg	– Habitat type: marginal vegetation
RF	– Radio frequency
SAIAB	– South African Institute of Aquatic Biodiversity
S-boulders	– Habitat type: submerged boulders
SMS	– Short Message Service (mobile phones)
Tags	– Radio transmitters/transceivers
UBRRW	– Habitat type: submerged boulders
WRC	– Water Research Commission
WW	– Wildlife International (Pty) Ltd

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CHAPTER 1: RADIO TELEMETRY METHODS TO MONITOR THE BEHAVIOUR OF FISH IN INLAND SURFACE AQUATIC ECOSYSTEMS

1.1 Telemetry techniques to track and monitor fish

The ecological, social and economic value of fishes extend to the use of these animals as ecological indicators, keystone, flagship and umbrella species which has been widely used to manage and conserve species and the ecosystems in which they occur (Trefethen, 1956; Skelton, 2000; Cooke and Schreer, 2003). Currently fish can be considered to be one of the most important groups of indicators of ecological health in aquatic ecosystems locally and internationally and are being extensively used in a range of environmental monitoring, conservation and research techniques (Karr, 1981; Kleynhans, 1999; Harrison et al., 2000; Kotze, 2002; Harrison and Whitfield, 2004; Kleynhans, 2005; Harrison and Whitfield, 2006a; Harrison and Whitfield, 2006b; Elliott et al., 2007; O'Brien et al., 2009 for example). These techniques are heavily dependent on the understanding of the biology and ecology of the fish that occur within ecosystems where these tools are being applied (Karr, 1981; Kleynhans, 1999; Elliott et al., 2007; O'Brien et al., 2009 for example). In particular, as indicators species for application in management techniques, the known or inferred responses or requirements of fishes to a wide range of environmental variables states, including anthropogenic impacts that alter variable states, is required (e.g. Kleynhans, 2005). In many instances very little real data on the effects of fishes to a wide range of environmental variable states exist. As such, the use of fish as indicators of ecological health will be associated with a degree of uncertainty until sufficient biological and ecological information of fishes can be obtained.

Telemetry techniques have been used to characterise the biology and ecology of fishes from as early as the 1950s, and is now a preferred method for the behavioural monitoring of freshwater fishes today (Trefethen, 1956; Stasko and Pincock, 1977; Winter, 1996; Cooke and Schreer, 2003). This approach has transformed the understanding of fish behaviour and distribution where aquatic ecosystems conventional do not allow for visual observation techniques (Cooke et al., 2005). A wide range of ultrasonic (acoustic), radio and more rarely satellite telemetry systems are available for fish tracking and biotelemetry studies (Koehn, 2000; Cooke and Schreer, 2003). Type of telemetry system used however, depends on the biology and or ecology question being answered, functionality of techniques, the species being used for the study, habitat that the target fish occurs in and the ease of application

(Koehn, 2000). None the less, behavioural studies using telemetry techniques have contributed to gaining an understanding of how fish adapt to; optimise the utilisation of the ecosystem resources, successfully recruit and survive natural and anthropogenic changes in ecosystem conditions (Godin, 1997). This includes characterisations of migration behaviour, habitat selection and requirements, territoriality behaviour, foraging tactics and diet, anti-predator tactics, reproductive strategies and the response of species to changing environmental variables states for example (Godin, 1997). Telemetry techniques are recognised as the most effective way of acquiring information of wild adult fish over extended periods and areas to meet specified management questions (Winter, 1996; Lucas and Baras, 2000; Rogers and White, 2002; Paxton, 2004a). In addition to telemetry tracking techniques, that are concerned with the use of the positions of a tagged fish and the use of changing positions primarily to evaluate the biology and ecology of fishes, biotelemetry methods involve the remote direct measurement of the physiology, behaviour and or energetic status of free living animals for example (Rogers and White, 2002; Cooke et al., 2004). In combination radio tracking and biotelemetry techniques have been contributed to the characterisation of our understanding of the physiological and behavioural patterns of organisms, in their natural environments (Winter, 1996; Lucas and Baras, 2000; Rogers and White, 2002; Cooke et al., 2004). These techniques are becoming the most widely used method of studying behavioural ecology of invertebrates, amphibians, reptiles, birds, aquatic and terrestrial mammals (Cooke et al., 2004). In addition, these techniques are gaining popularity amongst ecotoxicologists as they have the ability to identify and allow for the evaluation environmental stressors (Gerhardt, 2007).

1.2 Use of telemetry techniques in southern Africa

Very little is known about any behavioural ecology of southern African freshwater fishes, and the information that is available is largely based on visual observations (Paxton, 2004; Roux, 2006; Venter et al., 2009). Despite the known value of radio telemetry techniques, to date only a few dedicated inland 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 with a few case studies on the Vaal River, Komati River and in a few manmade lakes (Thorstad et al., 2001; Økland et al., 2003; Paxton, 2004b; Thorstad et al., 2004; Økland et al., 2005; Kerwathet al., 2005; James et al., 2007; Næsje et al., 2007; Cowley et al., 2008; Childs et al., 2008; Kerwath et al., 2009; Becker et al., 2011; Bennett et al., 2011; O'Brien and De Villiers, 2011; O'Brien et al., 2012; Pers. Comm: Roux, 2012).

Initially biotelemetry methods were introduced to southern Africa through the Nina Norwegian Institute for Nature Research (NINA) who initially collaborated with the Ministry of Fisheries and Marine Resources, Namibia (Pers. Comm.: Hay, 2003) and three other research groups namely;

- the South African Institute of Aquatic Biodiversity (SAIAB) (Dr. Paul Cowley, Pers. Comm.: Cowley, 2010),
- Mpumalanga Tourism and Parks Agency (Mr. Francois Roux, Pers. Comm.: Roux, 2012) and,
- the Freshwater Research Unit (FRU) in Cape Town (Paxton, 2004).

As a result preliminary research on the behaviour of fish in the Zambezi River system (Thorstad et al. 2001, Økland et al. 2003, Thorstad et al. 2004, Økland et al. 2005) were evaluated using radio telemetry systems. Radio and later acoustic telemetry research was established by SAIAB on many estuaries in the Eastern and lately the Western Cape estuaries predominantly and radio telemetry research was initiated on tigerfish (*Hydrocynus vittatus*) by MPA. Although research was proposed by Freshwater Research Unit no studies were initiated due to financial and technical constraints. In 2007 a radio telemetry programme was initiated by the University of Johannesburg and the Water Research Commission (O'Brien and De Villiers, 2011) to monitor the behaviour of the yellowfishes in the Vaal River in relation to changing environmental conditions (O'Brien et al., in press). The same group thereafter used radio telemetry techniques to evaluate the suitability of two lentic ecosystems for tigerfish (*H. vittatus*) in the Limpopo Catchment (O'Brien et al., 2012). To date all endeavours carried out in lentic (lake) and lotic (river) ecosystems in South Africa have involved the use of radio telemetry systems obtained from Advanced Telemetry Systems (ATS), United States of America. Although some remote monitoring systems are available from ATS and other international biotelemetry equipment manufacturers, due to the high costs of the equipment and the technical support requirements for the studies no remote radio telemetry monitoring endeavours have been attempted locally. In addition, frequency transmitting transmitters (tags) that allow for positioning and tags with peripheral sensory components that allow for biotelemetry studies including variable monitoring such as activity, temperatures and depth are becoming exceedingly costly. Unfortunately although the need to address a host of local environmental management problems that could be solved using biotelemetry studies are increasing, the cost associated with the methods are making the use of biotelemetry methods unaffordable.

Radio telemetry techniques are not unique to aquatic ecologists, in fact terrestrial ecologists who do not have to deal with telemetry communications from aquatic to terrestrial ecosystems have widely developed the techniques (consider for e.g. www.awt.co.za). This local demand for biotelemetry equipment has resulted in the establishment of a local manufacturer and service provider of products named Wireless Wildlife International (Pty) Ltd. (WW) (Personal Communication: Botha 2010; WW, 2013). Wireless Wildlife was established in 2002 and offers specialist services in electronic product design and manufacturing (WW, 2013). This company has been producing biotelemetry products for at least eight years and offers remote and manual monitoring systems design and data support to local and international clients. To date WW have provided terrestrial biotelemetry products to researchers throughout Africa, Malaysia and North America. They have designed at least ten wildlife tracking product lines that have been used to monitor the behaviour of animals as small as birds to as large as elephants. At the moment they have at least 2000 active Global Positioning System transmitters actively tracking animals from southern and central Africa (Personal Communication: Botha, 2010). What makes WW a leader in the field is the technologically advanced remote monitoring systems established to allow for the real time remote monitoring of tagged organisms via the internet through network systems developed by WW using existing GPRS (cell phone) or radio network systems.

For the management and conservation of inland fisheries the understanding of fish population dynamics and community processes and structures is paramount (Lucas and Baras, 2000; Cooke et al., 2004). Tag or marking methods which include radio telemetry systems have been developed for monitor fishes in their natural environments (Cooke et al., 2004). Currently there are two recognised types of monitoring techniques using tags including capture dependant and capture independent methods. Capture dependant techniques involve sampling of marked fish (mark-recapture) or unmark fish over different time periods to get 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 within their natural environment. Capture independent methods include video, visual observation, hydro acoustic and automated fish counting (Lucas and Baras, 2000). Where long term fish monitor 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 were there are serious ecological or management issues and provide high resolution information of selected individuals (Lucas and Baras, 2000).

Telemetry techniques consist of various components including; transmitters (tags), receivers, antennas, internet and remote stations that can send and receive signals from transmitters to receivers. Signals can consist of real time behavioural data and can give the researcher a chance to document long uninterrupted periods of how organisms interact with their environment (Cooke et al., 2004). Telemetry studies usually start with a sedated specimen that is fitted with a 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 signal is available continually throughout the study (Dunn and Gipson, 1977; Lucas and Baras, 2000; Cooke et al., 2004). 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). Telemetry in freshwater ecosystems has been used as early as the 1950s and is now considered to be a preferred method for behavioural ecology monitoring of freshwater fishes (Trefethen 1956; Stasko and Pincock, 1977; Winter, 1996). A wide range of radio tags, methods and techniques are available for both tagging and marking fish (Koehn, 2000). 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 choosing a method (Koehn, 2000).

Due to the difficulty of visually monitoring freshwater fishes and recapture techniques often result in low percentage of recaptures telemetry techniques have gained in popularity (Koehn, 2000). Inland (freshwater) telemetry techniques involve the use of radio or acoustic (also known as ultrasonic) techniques. Radio tags usually make use of radio frequencies between 30-150 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 limited life spans. New technology however has included better more powerful batteries and more energy saving electronic components which also allow for peripheral sensory components to be incorporated into tags (Venditti and Rondorf, 1999; Koehn, 2000). Advantages and disadvantages exist for both acoustic and radio telemetry techniques (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 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, 1998; Ingram, 1989; Roche, 1999; Priede, 1980; Jernakoff, 1989; Gum 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 will 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. $ = low cost (≤$10 per fish), $$ = moderate cost ($10-$100 per fish), $$$ = expensive (>$100 per fish). (*) denotes methods that may have substantial set up costs.

Acoustic and radio techniques both offer the advantage of collecting continues data from tagged individuals in its natural environment, without having to recapture the fish. However tagging methods involved with 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 done (Koehn, 2000) (Table 3).

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

Characteristics	Telemetry techniques	
	Acoustic	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
Tracking options	Hydrophone in water	Land, boat, air, remote
Power Usage	Poor	Good

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 normal physiology or behaviour of experimental fishes (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 acoustic stomach or implant tags (Table 1, Table 2, 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).

1.3 Aims and objectives

The following aims have been established for the study:

1. Design and produce WW radio telemetry tracking system requirements for fish in inland surface aquatic ecosystems in South Africa.
2. Test the functionality of the WW radio telemetry tracking systems for fish in suitable case studies.
3. Compare the WW radio telemetry tracking systems to internationally available systems.

To achieve the aims the following objectives were established and achieved:

- Provide WW with specifications of suitable radio telemetry systems for use in inland surface aquatic ecosystems in South Africa.
- In accordance with the requirements of the study WW will develop a WW radio telemetry tracking system to track and monitor behavioural aspects of fish for lotic and lentic ecosystems.
- The functionality of the WW radio telemetry tracking system will be tested by implementing the system in a range of case studies.
- The functionality of WW digital radio telemetry, fish tracking systems will be compared with an international system.

This report consists of eight chapters that have been designed and implemented to address the aims and objectives of the study as follows.

- Chapter 1: In this chapter radio telemetry methods that have been developed locally to monitor the behaviour of fish in inland surface aquatic ecosystems are presented. This chapter provides the introduction to the study including the rationale for the study and a review of the use and value of radio telemetry methods. This chapter also presents the aims, objectives and structure of the study.
- Chapter 2: Includes an overview of the WW digital radio telemetry systems that has been developed locally to monitor the behaviour of fish in South Africa's inland waters. This chapter presents the WW digital radio telemetry system components and utilisation methodologies.

- Chapter 3: In this chapter the WW radio telemetry tracking system has been used to evaluate the habitat preferences of adult lowveld largescale yellowfish (*Labeobarbus* marequensis) and tigerfish (*Hydrocynus vittatus*) in the Crocodile River, Kruger National Park. This case study includes a spatial area use assessment of a reach of the Crocodile River by a population of adult *L.* marequensis and *H. vittatus* using manual radio telemetry methodologies incorporating the WW digital radio telemetry system. The case study includes considerations of the availability of habitat and cover feature types within the Crocodile River. Some biotelemetry components of the remote WW digital radio telemetry system were used to contribute to the habitat preference assessment. This section also includes the use of Advanced Telemetry System equipment which allows for direct comparison of the functionality of the two systems. This case study was carried over a three year period during which time 479 manual fixes were obtained from 15 individuals and 39505 fixes/data strings containing transmission signal strength, movement counts and temperature, and or depth were obtained from an additional 17 individuals. This case study also incorporated the use of statistical evaluation techniques to evaluate the radio telemetry data.
- Chapter 4: Here the WW radio telemetry tracking system has been used to evaluate the behavioural response of adult Lowveld largescale yellowfish (*L. marequensis*) to flow and other ecosystem variable changes in the Crocodile River, Kruger National Park. This case study involves evaluating changes in the behaviour (measured as movement) of an adult population of *L. marequensis* in the Crocodile River to flow variations (measured as discharge). The case study incorporates the application of the remote WW digital radio telemetry system to generate behavioural data of the *L. marequensis* population and the statistical comparison of changes in this behavioural data with discharge data observed from a local DWA gauging weir. This case study characterises the ability of the WW digital radio telemetry system to evaluate the behavioural response of a population of tracked fish to an important environmental variable namely flows. Similarly this case study was carried over a three year period during which time 479 manual fixes were obtained from 15 individuals and 39505 fixes/data strings containing transmission signal strength, movement counts and temperature, and or depth were obtained from an additional 17 individuals. This case study also incorporated the use of statistical evaluation techniques to evaluate the radio telemetry data.
- Chapter 5: The habitat use and the effect of diurnal, lunar and seasonal cycles on the movement of adult Vaal-Orange smallmouth yellowfish (*L. aeneus*) in Boskop

manmade lake, North West is evaluated in this study using WW radio telemetry methodologies. In this case study four *L. aeneus* were tagged and tracked for over a year in the Boskop manmade lake, North West. During this year numerous manual and remote monitoring surveys were undertaken to evaluate the spatial area use of the tagged yellowfish using manual triangulation tracking techniques and remote techniques which is based on the coverage ranges of the remote receivers stationed in the study area. In addition the effects of diurnal, lunar and seasonal cycles on the movement of adult Vaal-Orange smallmouth yellowfish were undertaken by monitoring the movement of the yellowfish and evaluating any differences in the movement during different times of day, lunar cycles and seasonal cycles. During this experiment that was carried out for more than a year, a total of 9153 fixes/data strings containing movement counts and temperatures for all tags and depth were recorded.

- Chapter 6: In this last case study the effect of diurnal, lunar and seasonal cycles on the movement of adult vaal-orange yellowfishes (*L. aeneus* and *L. kimberleyensis*) in the Vaal River, Free State is assessed using WW radio telemetry systems. In this chapter the effects of time of day, moon cycles and temperature on the movement of adult yellowfish were undertaken. From this case study which was undertaken over a 10 month period 38655 and 5198 fixes or data strings with movement, temperatures and on occasion depth peripheral sensory components were obtained from 14 and 3 *L. aeneus* and *L. kimberleyensis* individuals respectively.
- Chapter 7: Following the completion of the case studies, the functionality of WW radio telemetry, fish tracking systems is compares with available international systems. In this study comparisons were made between ATS radio telemetry systems applied by O'Brien et al. (2011) using yellowfish in the Vaal River, O'Brien et al. (2012) using tigerfish in the Schroda and Letsibogo manmade lakes and in Chapters 3 and 4 with WW radio telemetry systems. In this chapter a table that addresses the technical support options, radio telemetry systems (general), receivers and transmitters/transceivers of both ATS and WW systems are compared.
- Chapter 8: In this final chapter an overview of the conclusions and recommendations of the study are provided. In this chapter the successful development and testing of the of the WW radio telemetry system is revisited. This includes the consideration of the aims of the study and future recommendations for the continued development and or validation of the approach and the successful utilisation of the tracking system.

CHAPTER 2: WIRELESS WILDLIFE DIGITAL RADIO TELEMETRY SYSTEMS TO MONITOR THE BEHAVIOUR OF FISH IN SOUTH AFRICA'S INLAND WATERS

2.1 Introduction

Considering everyday FM radio receivers and cellular mobile phones, the revolution in radio technology during the past decades is easily noticed. Radio and communication devices in the 1980s where made from bulky discrete components and where mostly designed for a very specific purpose with little flexibility. On the other hand, modern radio systems, such as cellular phones, are made up of only a few small integrated circuits (ICs), each one consisting of thousands of components. This exponential growth in integration at an exponentially decrease in cost per component over time is generally called Moore's law (Moore, 1965) The results is that modern system, such as mobile phones, are becoming more and more flexible, in which the same system can be used for diverse applications. Different functionality can be achieved by running different programs on the same hardware.

Although considered to be out dated, most radio telemetry systems still use old technology to monitor the behaviour of fishes (O'Brien et al., 2012). This can be seen by the large discrepancy between currently available telemetry systems and modern cellular phones. Radio telemetry tags weight and cost almost the same as the world's lightest mobile phones (i.e. LOGO (RPC, 2013)) phone weighing 38g and costs $35 and similarly the Modu phone (Modu, 2013), but with the mobile phones being far superior in functionality. One reason for this discrepancy is that the size and complexity of software also follow's Moore's law, resulting in increasing product development costs (Van Ommering et al., 2000). For mass market products, such as mobile phones, these costs are distributed over millions of devices. However, for systems with a much lower demand for quantities (such as radio systems for fish telemetry), these high costs has been a barrier for these new system to enter the market. The current telemetry system are in general well established and have been validated over many years of application, making it further difficult for new products to enter the market.

However, it is believed that technology has improved to such an extent that the advantages in performance outweighs these difficulties. This has led to the development of a new telemetry system that is described in this chapter. Note that this system does not used bleeding edge technology, but mature technology which is generally only a few years behind and which is generally much cheaper and more reliable than new technology (OECD, 2003).

In this chapter a modern digital radio telemetry system that makes use of existing commercially available systems for application in fish telemetry is presented. To achieve this an existing digital radio telemetry system developed by Wireless Wildlife (Pty) Ltd. (WW) was adapted to allow for application in the aquatic environment. This chapter presents the development of the existing digital radio telemetry system and the adaptions made to the system for application in surface aquatic ecosystems. The advantages of the digital radio telemetry system for the manual and remote tracking of fish in South Africa's inland aquatic ecosystems are described.

2.2 Development of radio telemetry monitoring systems for South Africa

2.2.1 Wireless Wildlife radio tracking and monitoring system

Wireless Wildlife developed a commercial radio tracking and monitoring system for large domesticated terrestrial livestock primarily (WW, 2013).These systems have been used extensively in South Africa (>4100 animals tracked over five years) monitor the collective behaviour of livestock, and some mammalian wildlife species for security reasons (WW, 2013). Within this WW radio telemetry tracking system a portion of the population of animals monitored are fitted with small radio transceivers (tags) that monitor the location and behaviour (movement) of the tagged animal. These tags are enabled to transmit the location and behaviour information periodically, according to an established scenario (usually hourly), or when a defined violation of "normal" behaviour is observed, to a receiver or base station located within range (<10 km) of the tagged animals (Figure 1). In addition to the base stations, additional receivers or "repeater stations" can be positioned within the study area to extend the coverage area of the base station by relaying transmissions from the tags to the base station if required (Figure 1). The base station re-transmits data to a remote server through a global system for mobile communications (GSM) network. The data is stored and is protected on the remote server through a series of on and off site backup systems. The location and behaviour of all the tagged animal as well as telemetry systems operational status data can be accessed by a user in real time through an internet based web browser on a password protected website. The communication channels (from the tags to the end user) are bidirectional, which allows the user to change any parameters on the tags or radio tracking and monitoring system via a web-browser or a mobile phone Short Message Service (SMS). The different components of the system will now be discussed in more detail.

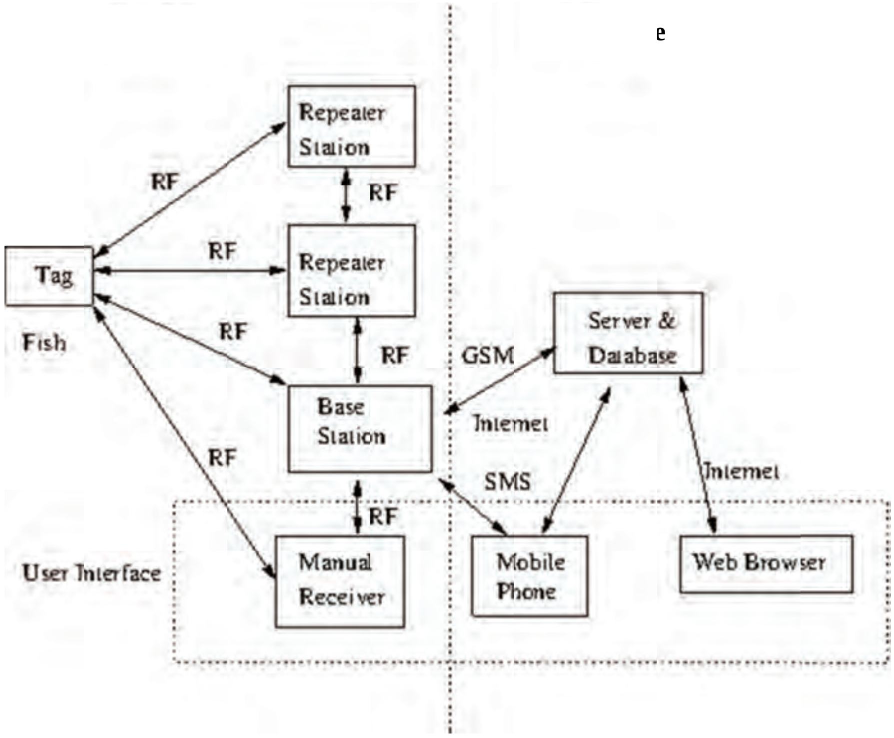


Figure 1: Schematic representation of the Wireless Wildlife commercial radio tracking and monitoring system for terrestrial animals.

2.2.2 Radio transmitters (tags)

Hardware

The tags consist of a main electronic circuit, to which a number of additional peripheral sensory components can be added to extend the functionality of the tag. The electronic circuit consists of a high speed central processing unit (CPU) which executes the firmware (i.e. the program) that is stored in its internal memory. It also has a build-in analogue to digital converter (ADC). The ADCs make it possible to connect the circuit directly to additional sensors. It also has extreme low power consumption (<1uA) in sleep or standby mode. When active, the power consumption depends on which build-in components are used, making it possible to manage the active power by only using the required components. The electronic circuit also has a radio frequency (RF) transmitter (>10 dBm output power) and a sensitive receiver (<120 dBm) to send and receive the radio signals. The circuits are light (0.1 g) and cheap (a few US$) when compared with the remaining components of the tags. The CPU of tags can be connected to various peripheral components such as motion or movement, temperature and pressure sensors (for depth), data storage component (memory) and light-emitting diodes (LED’s) which were considered in this study:

- Motion sensor: An omnidirectional tilt and vibration sensor is used to monitor the movement of the tags (or animal). The sensor acts as a switch which chatters open and closed as it is tilted or vibrated. It is connected to one of the CPU's internal counters, so that motion results in a higher count rate over a specified period of time (usually every 10 minutes). The values of the counter therefore give the integrated motion of the animal over a defined period of time.
- Temperature: a temperature sensor with an accuracy of 0.5^{o}C after calibration was connected to the CPU to measure the ambient temperature.
- Pressure sensor (depth): By adding a pressure sensor, it is possible to monitor and record the depth of a tag at certain time intervals. The output of these sensors, which are proportional to the absolute pressure, where connected to the CPU and calibrated (proportionality constant of 33 ADC counts per meter water depth). The sensors have a linearity of 0.2% over the full scale and connected to the ADC a resolution of 3 cm.
- Data storage capabilities (memory): During application in aquatic ecosystems the tags will not always be within radio reception of the base/relay stations. In an attempt to preserve data generated by tags which would otherwise have been lost by the transmission from the tags not being received, the data will be stored in data storage component on the tag and only transmitted to the base/relay stations when the tag is in range and the data is requested. Based on a 30 minute transmission scenario, the storage capacity of the memory components will allow for in excess of one years’ remote monitoring data to be stored and downloaded. This generally exceeds the lifespan of the transmitter suggesting that storage capacity on the tags will not be reached. An example of the data storage capabilities are demonstrated in Figure 2 which depicts two graphs of remote monitoring data from six Vaal-Orange smallmouth yellowfish (*Labeobarbus aeneus*) individual tracked over a 15 day period (1 December 2012 to 15 December 2012). In this example all of the yellowfish only entered transmission range during the night (Figure 2B) which is highlighted by arrows on the graph. Without data storage capabilities the movement and associated peripheral data such as temperature in this case (not displayed on the graph) would only have been available while the tagged yellowfish are in range of the receivers (during the night). With the data storage capabilities of the tags, as shown in the graph (Figure 2 A), the daily movement data that is observed while the tag is out of range (during the day), stored and downloaded at night. With this capability the tag

can store continuous data according to an established schedule for up to a year and download the entire data set.

- Light-emitting Diodes (LEDs): A single LED can be incorporated into tags making it possible to visually locate the fish in low light, low turbidity water during manual tracking modes. The LED can then be switch on (for a certain time period) and off via the base station (Figure 3).

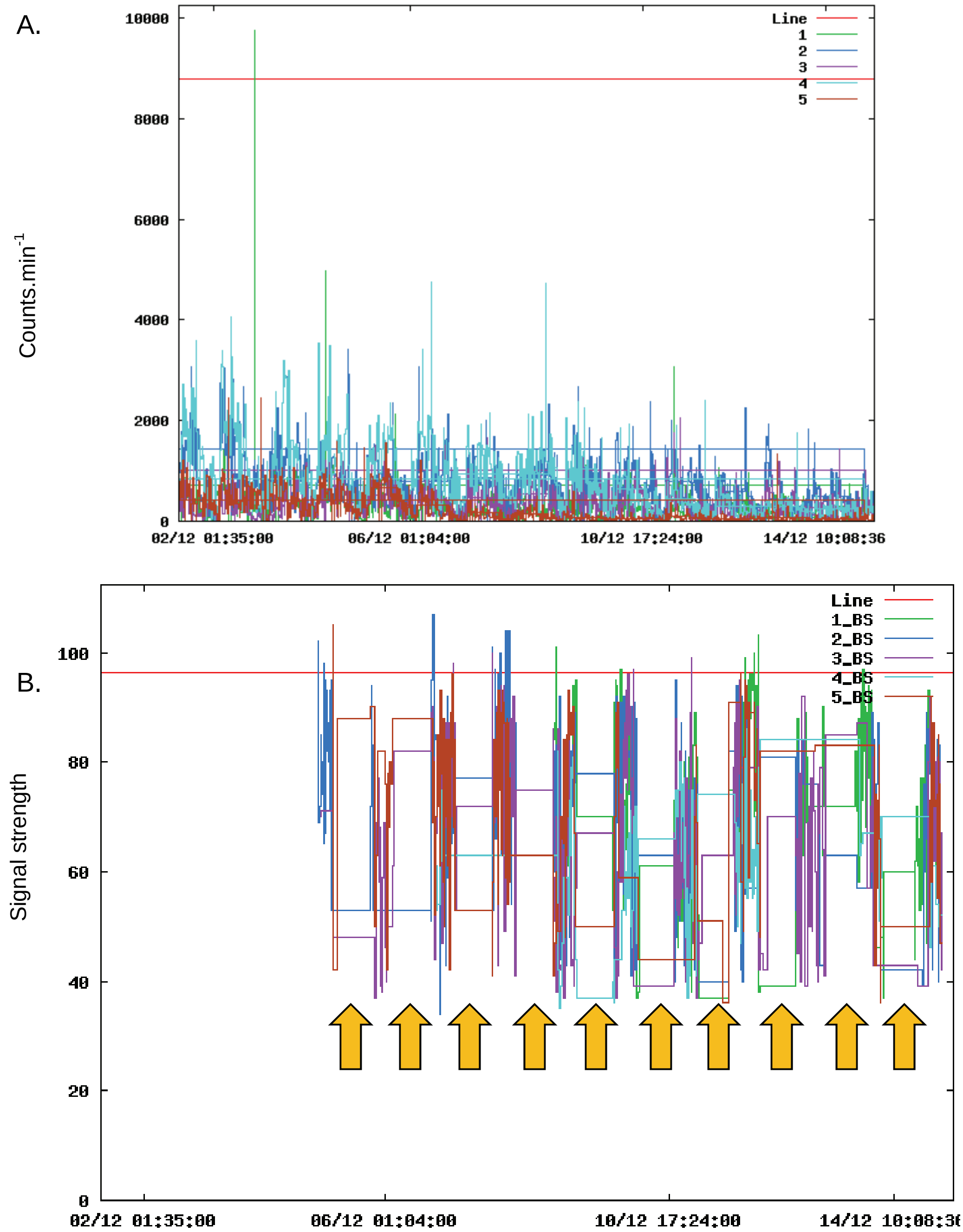


Figure 2: Typical remote fish behavioural monitoring data including the movement (A) and corresponding signal strength (B) readings from six radio tracked yellowfish (*Labeobarbus aeneus*) from 1 December 2012 to 15 December 2012. Arrows highlight daily periods from 5 December to 15 December when all of the tagged yellowfish only moved into coverage range during the night.

Figure 3: Photograph of a flickering Wireless Wildlife transceiver with a Light-emitting Diode (LED) peripheral sensory component revealing the exact location of an adult largemouth bass (*Micropterus salmoides*) which was tagged and tracked during the developmental phase of the radio telemetry systems.

Tag frequency

The RF circuitry used in the WW radio telemetry tracking systems does not support the typical low radio frequency of approximately 140-150 MHz range (Koehn, 2000), a frequency of 433 MHz was chosen for the WW telemetry systems. This higher frequency results in a lower penetration of RF in water. The average total loss across all incidence angles from 0 to 89 degrees at 0.5 m (2 m) depths are about 6 (12) dB at 141 MHz and about 12dB (25dB) at 433 MHz (Jiang et al., 2011) for parallel polarization and fresh water conditions as in Hasted (1973) with a conductivity of 17.4 Sm^{-1}.) However, as pointed out by Sisak et al., (1998), higher frequencies result in improved system variables, such as larger antenna gain, which tend to compensate for the loss in penetration. Due to the improved system variables the WW radio telemetry system results in similar performance of low frequency systems at low depths (<1 m), but comparatively poorer performance at deeper depths (>2 m). To mitigate the reduced performance of the WW radio telemetry system at depth (>2 m) mitigation measures including storage potential of tags have been established to improve on functionality of the system.

Tag mass

The mass of the range of tags available in the WW radio telemetry system for fish depends on the barriers used, which affects the life spans of tags and the components of the tags. The mass (8-20 g) and life span (10 days to >1 year) of the WW radio telemetry system for fish is similar to the range of fish tags available from Advanced Telemetry Systems (ATS) “F” series ranging between 14 and 30 g and 110 and 1200 days (Table 4).

Table 4: Summary of the physical and operational options of radio transmitter (tag) range developed by Wireless Wildlife available for use on fish in inland aquatic ecosystems in South Africa.

WW- tags	Type	Weight	Mass range of tagged organism^ø	Life span (with remote monitoring)*	Attachment options			Functionality/peripheral components								
					External harness	Internal implant	Substrate attachment	Location (manual tracking)	Activity	Temperature	LED lights	Depth	Memory	GPS	Conductivity	pH
Series I	Small fish tag#	8g	>500g	>30 days (10 days)				●	●							
Series II	Small fish tag#	12g (± 1g)	>1000g	>90 days (30 days)				●	●	●						
Series III	Large fish tag	20g (± 1.5g)	>1800g	>3 years (>1 year)	●	●		●	●	●						
Series IV	Large fish tag	20g (± 1.5g)	>1800g	>3 years (>1 year)	●	●		●	●	●	●					
Series V	Large fish tag	20g (± 1.5g)	>1800g	>3 years (>1 year)	●	●		●	●	●		●				
Series VI	Large fish tag	20g (± 1.5g)	>1800g	>3 years (>1 year)	●	●		●	●	●		●	●			
Series VII	Mammal tag#	65g (± 1.5g)	>5kg	>3 years (>1 year)	●	●		●	●	●			●	●		
Series VIII	Reptile tags	120g (± 10g)	>10kg	>3 years (>1 year)	●	●		●	●	●			●	●		
Series IX	Abiotic tag	120g (± 10g)	NA	>3 years (>1 year)			●	●		●		●			●	●

Note: (*) Normal routine life span includes remote monitoring with data transmissions every 10 minutes. Manual tracking scenarios can be determined (usually reduce life span to 1/3 of standard).

(#) Trancievers that were not tested in this study.

(ø) Based on the 2% rule for tag mass according to Knights and Lasee (1996).

Firmware

Based on the flexibility of the WW radio telemetry system hardware, the performance of the tags are mostly determined by its firmware, i.e. the program that determine its operation (WW, 2013). A feature of the WW radio telemetry system is the ability to update the configuration of the firmware remotely after the tags have been deployed into the field. To optimise available battery power the firmware incorporated into WW tags has been designed to use the available power optimally. The tags are mostly kept in a programmed low power standby condition between transmissions. The tags then activate or 'wake up' periodically according to a scenario (usually hourly) which is programmed into its firmware, or when the normal behaviour is disrupted and a violation occurs. All the tags operate on the same frequency, with the unique identification numbers (IDs) of each tag digitally coded onto transmissions. The unique ability of the configuration of the WW fish tags to be changed during deployment offers several advantages:

- The ability to receive data allows the tags to save power. In this situation tags only transmit data when they are in range of the base/relay station which transits “authorisation” transmissions, allowing power to be saved.
- Data can be stored when the tag is out of range and transmitted later.
- The configuration of the tag can be changed as will be shown in more detail during application of the WW radio telemetry tracking system in the following chapters.
- The firmware software can be updated allowing for improved operating systems to be incorporated onto existing tags.

The configuration of the tags can also make use of the sensory capabilities of the peripheral components (such as the motion sensor) to establish operational scenarios. For example, this makes it possible for a tag to remain in standby mode while its host is in a resting phase, when movement signature of the host is minimal. When the hosts’ activity increases, the motion sensor “alerts” the IC and more data will be collected compared to than the inactive condition. Therefore, to achieve low power consumption scenario for tags data can only be recorded when the host is active and data is only transmitted when there the tag is in range of a receiver.

2.2.3 Data management system

The WW system makes it possible for behavioural studies of several animals to be undertaken remotely over a large period of time (WW, 2013). The large amount of data collected (a year's data from one tag transmitting hourly amounts to 8760 data points) requires management. To do this, a data management system was developed consisting of a database where all the information is stored on a server that collects the data from the tags and make it available to the user. When combined with the remove receiver station network, any tag's data can be access in real from anywhere in the world immediately when the tag is in coverage.

Database

The database not only stores the data collected by each tag, but also keeps track of the type of tag (i.e. peripherals, battery, firmware), the current status of the tag (e.g. if it is in coverage, battery power available) and the history of the tag (when it was configured in different configuration).The database also has a security feature where user information is stored including the data accessed and the settings changes of which tag for example. In addition, some users can have full access to their tags, the settings of the tags and the ability to download raw data, other users may be provided with limited access to query graphs of the tag's data etc., without being able to change the configuration of the tags. Primary users can also be provided with notifications pertaining to the use of the database by other users.

Server

The server has several capabilities:

- It receives and sends data to tags via internet or GSM network as will be discussed in next section.
- It has an SMS interface which can send alert messages to users if certain conditions occur and receive SMS's from user to change the settings of a tag.
- It has a web interface through which the user can login to see the status of his tags, access its data and change its setting.

2.2.4 Remote monitoring systems and techniques

Description

For remote monitoring of fish in a study area (such as a river), a base stations, with a number of repeater stations, can be installed to establish a coverage network of the study area (Figure 4). The base and relay stations are solar powered and have a RF link to the tags and between themselves. Only the base station transmits data to the data management system via a GSM link to the server of the data management system. In unique situations, other communication methods such as short wave radio incorporating very high frequency (VHF) systems can be established in remote areas where GSM is unavailable.

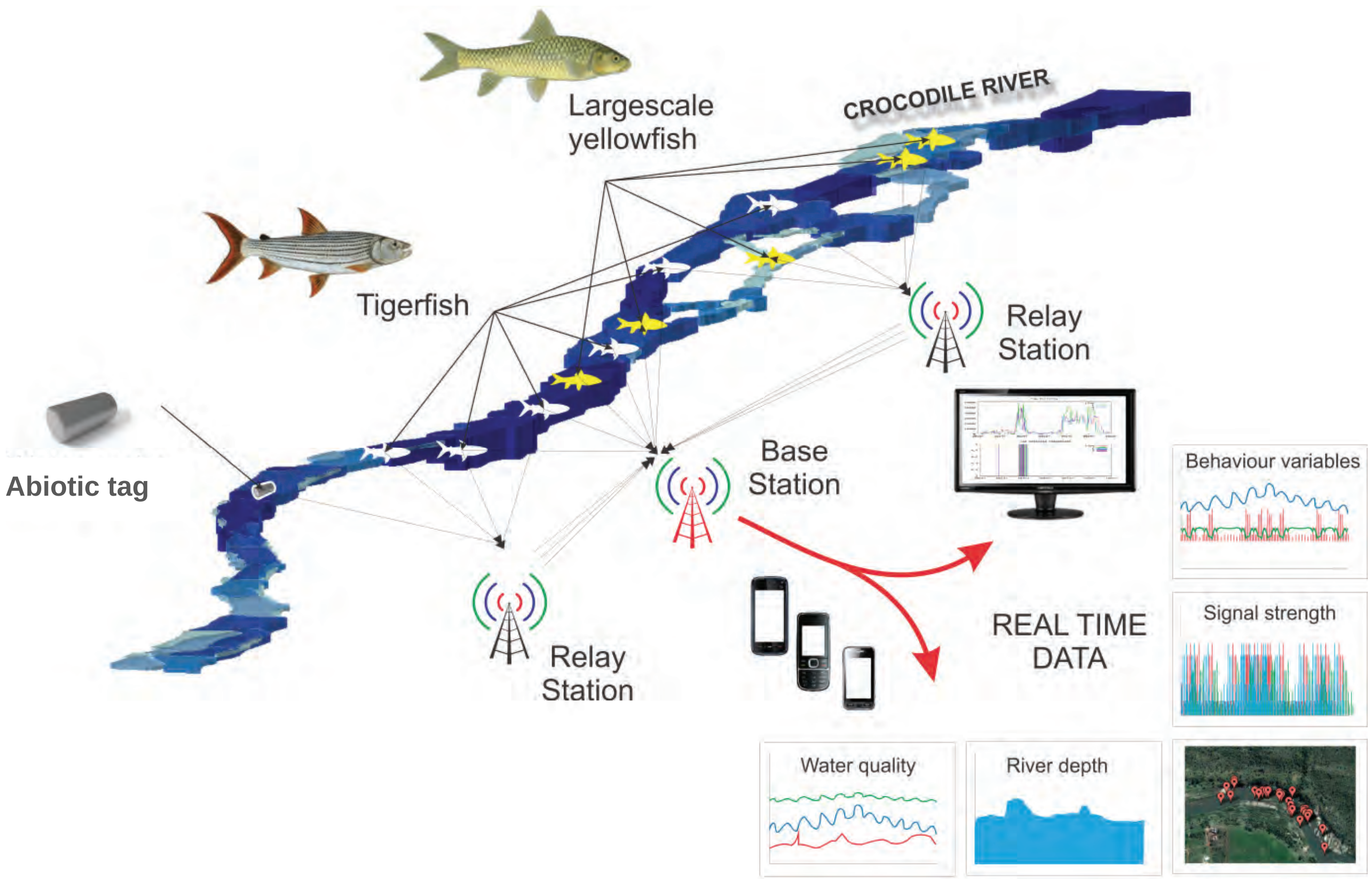


Figure 4: Schematic representation of a Wireless Wildlife remote monitoring system. The system incorporates tagged fish and an abiotic tag within a river that has base and relay stations positioned on the banks to generate a coverage area for the study area. The transmission data direction shown from tag to data management system is bi-directional.

The remote monitoring system with numerous relay stations allows for a large area with numerous fish being monitored continuously. This makes it possible to automatically collect a large amount of data over an extended period of time (many years). In addition, when an animal moves out of range of the network area, notification can be sent to users when it leaves and when it moves back into range.

Triangulation techniques

When more than one base/relay station is used to monitor tagged fish, the differences in the strength of the RF signal from the tag to each station can be used to determine the location of the tag (referred to as triangulation). For this to be achieved the variations in signal strength due to; tag depth, orientation of the tag's antenna and the immediate environment around the fish has to be compensated for. In this study the general location of a fish was determined using triangulation by taking the average signal strength over a few data points (Figure 5). This allowed for the variations in signal strength due to be addressed. The more data points used in the average, the more the effect of antenna orientation, depth and environment is averaged out. When the signal of two stations is available, the position can be estimated using the relative strength of the two signals.

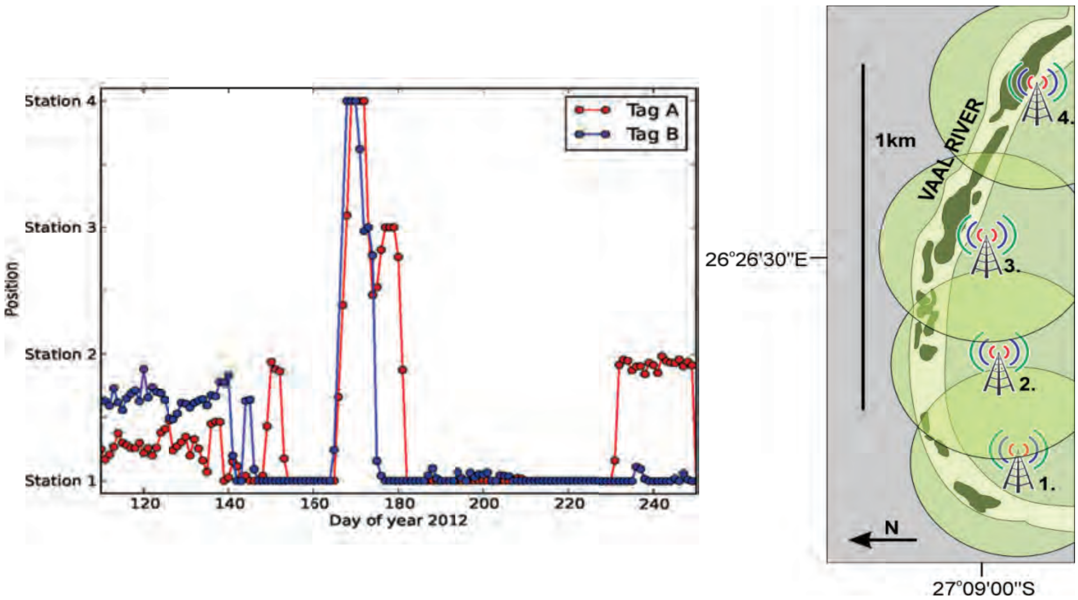


Figure 5: Position of two yellowfish tagged with Wireless Wildlife radio telemetry tags (left) in the Vaal River relative to the position of remote monitoring stations (right), obtained remotely using signal strength from the remote monitoring stations.

2.2.5 Manual monitoring systems and techniques

Description

A manual receiver was developed for the WW radio telemetry tracking system which can be used in the field to communicate directly to the tags, without requiring a base station. The manual tracking equipment consists of a programmable receiver, headphones and a directional Yagi antenna. The laptop receiver (Gigabyte model Q2005 incorporating a Linux 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. Other data collected by peripheral components on the tags, such as depth, temperature and movement can also be monitored, in addition to the signal strength, with the manual receiver. If a tag with memory capabilities is located outside of the coverage area the stored data can also be transferred onto the manual receiver.

Conventional manual tracking

The manual receiver can be used to track individual tags base on receiver strength, as has been commonly used in analog systems (Figure 6) (Lotek, 2013). Tags that are in range of base/relay stations are usually used for manual tracking which makes it easy to locate the tagged fish with a manual receiver. Each tag can be set to *tracking mode* by either the base station (via SMS or the internet) or directly with the manual receiver. The tag will then transmit its ID number periodically (usually every second). The period of these transmissions and the time the tag should be in tracking mode can both be set. The tag can then be tracked in the conventional way by considering the change in signal strength as the orientation and position of the antenna are varied. Peripheral components of the tags including the incorporation of LEDs assist in the verification of the accuracy of the manual tracking techniques. This manual tracking approach makes more efficient use of available power as the tag remains in standby mode until a receiver (manual or remote) activates the manual tracking transmission scenarios. The standby mode is reactivated after a prolonged period where no tracking takes place via the manual receiver such as in a situation when the tag moves out of range of the receiver. This make is possible to use the available battery power optimally if collecting and transmitting data as required.

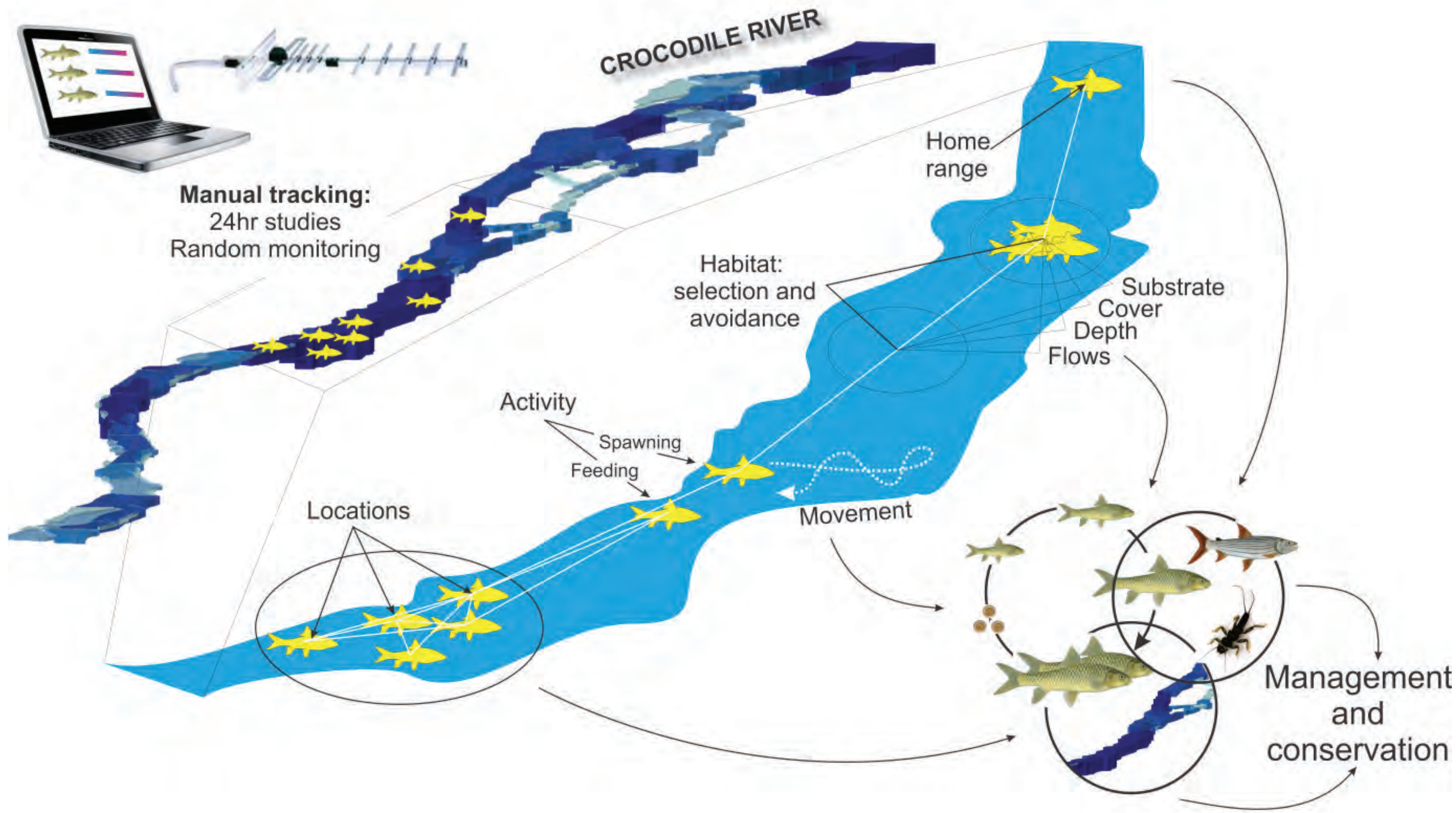


Figure 6: Schematic representation of a Wireless Wildlife manual monitoring system. The system incorporates the use of a manual receiver and directional Yagi antennae and tagged fish. For manual monitoring the location and associated movement of the tagged fish is monitored to address various biological and ecological questions of the species.

2.2.6 Application of Wireless Wildlife fish radio telemetry systems

The WW radio telemetry system has been developed in South Africa to offer local inland aquatic animal (specifically fish) behavioural ecologists, with radio telemetry equipment and technical support to undertake radio telemetry behaviour studies. These may include but are not limited to addressing the spatial area use of aquatic animals over extended periods (>1 yr) to evaluate home range, habitat use and the behavioural response of animals to changing environmental variable states for example. In addition, radio telemetry studies using WW radio telemetry systems may be carried out to evaluate numerous biological components of the life cycle of species such as; reproductive strategies, territoriality, feeding biology, anti-predation defence strategies and inter- and intra-species interactions. This technology will also allow scientists to evaluate the behavioural response of aquatic animals, which is considered to be between 10 and 100 times more sensitive than mortality endpoints for example (Gerhardt, 2007), to water quality alterations and other ecotoxicology factors, flow alterations and habitat alterations for example (Cooke and Schreer, 2003; Cooke et al., 2004; WW, 2013). Not only do researchers have the radio telemetry equipment to carry out these studies, but application methods including attachment techniques, manual and remote tracking and biotelemetry monitoring techniques and the procedures to manage the behavioural data, iterate the data and statistically analyse the data (Rogers and White, 2002; WW, 2013). This approach has already been used in southern African rivers to characterise aspects of the biology and ecology of the tigerfish (*Hydrocynus vitattus*), yellowfish (*Labeobarbus spp.*) and cichlids (*Oreochromis* spp.; *Serranochromis* spp.) for example and to evaluate the ecological consequences of altered depths, flows, weather variables, barriers and various water quality variable states (Thorstad et al., 2001; Økland et al., 2003; Paxton, 2004b; Thorstad et al., 2004; Økland et al., 2005; O'Brien and De Villiers, 2011; O'Brien et al., 2012; Pers. Comm: Roux, 2012). Wireless Wildlife is continually developing the available WW radio telemetry systems specifically to:

- allow for the inclusion of more peripheral sensory components to tags for biotelemetry application (such as orientation, conductivity and pH sensory components) and,
- improve on available technologies to reduce tag size and increase longevity of tags,
- improve communication range of tags to increase coverage area of remote and manual monitoring techniques,

- allow for various tag attachment techniques (external, internal and oesophageal attachment options for example) and,
- continue developing tags and systems for use on other aquatic animals such as crocodiles, aquatic mammals and birds (WW, 2013) and finally,
- improving data storage and online management systems to optimise real time data evaluation with an alert system for real time, remote environmental monitoring of aquatic ecosystems.

CHAPTER 3: HABITAT PREFERENCES OF ADULT LOWVELD LARGESCALE YELLOWFISH (*LABEOBARBUS MAREQUENSIS*) AND TIGERFISH (*HYDROCYNUS VITTATUS*) IN THE CROCODILE RIVER, KRUGER NATIONAL PARK

3.1 Introduction

Knowledge of the habitat requirements of fishes with conservation status or populations that are diminishing is important to the stock management and conservation of the species or populations (Huber and Krichhofer, 1998). This includes the cyprinids of which many species and or populations are economically important (Lucas and Frear, 1997; Huber and Krichhofer, 1998). Habitat preferences of fishes are dynamic and vary over spatial and temporal scales as well as over life cycles of species (Baras, 1992; Arnekleiv and Karbol, 1996; Bourke et al., 1996; Scholtem, 1995). Radio telemetry methods have been extensively used to characterise the habitat use and preferences of a wide range of fishes, many of which are rare species with conservation status (Huber and Krichhofer, 1998 for example). These techniques are well suited for use on large fishes that attain more than 250 g (Huber and Krichhofer, 1998). The technique can be used effectively to gain important habitat requirement data from a species using a relatively small number of individuals (<10) (Priede, 1991; Stormer and Maceina, 2009; Baras et al., 2002a).

The Kruger National Park (KNP) is recognised as a world leading conservation area for savannah ecosystems and boasts over 100 years of successful conservation (Mabunda et al., 2003). The mandate of the KNP is to conserve all ecosystems within its boundaries including riverine ecosystems, which is particularly difficult as the sources of all seven major rivers are outside the park. As a result these rivers transport a wide range of stressors into the KNP (Rogers and O’ Keeffe, 2003). These stressors include water quality, water quantity and habitat alterations that hinder the conservation efforts of rivers the KNP. From as early as the late 1980s concerns were raised about the poor state of KNP Rivers due to development had increased over two decades with the quality and quantity of water being affected by the developments west of the KNP (Du Preez and Steyn, 1992). The Olifants and Crocodile Rivers are two of the most highly polluted KNP Rivers (Heath and Claasen, 1999). The Crocodile River forms the southern boundary of the KNP and continually receives stressors along its length from agricultural and industrial activities (O' Keeffe and Rogers, 2003). The Crocodile River catchment drains an area of 10 400 km^2 (Hills et al., 2001). Twenty percent of the river flows through the KNP (Hills et al., 2001). This is concerning as the Crocodile River is one of the most productive and biologically diverse catchments in South Africa (DWAF, 2004).

The poor state of the Lowveld largescale yellowfish (*Labeobarbus marequensis* (Smith, 1841)) population in the Crocodile River in KNP has recently received attention (Leslie, 2007). There has been a noticeable decline in the abundance of adult *L. marequensis* individuals in the system without any cause agents being identified during the past ten years (Leslie, 2007). Surprisingly the *L. marequensis* populations in the other impacted rivers in the KNP, such as the Olifants River, are in a better state of health (Kleynhans, 1991; Rogers and O' Keeffe, 2003; Fouché, 2009). The decline in abundances of adult yellowfish in the Crocodile River suggests that the species may be intolerant to an unknown stressor or the synergistic effect of multiple stressors associated with the change in environmental variable states in the river. The aim of this chapter is to implement the WW radio telemetry tracking system and an ATS system to characterise the habitat preferences of the adult *L. marequensis* and compare this to the habitat preferences of a local population of tigerfish (*Hydrocynus vittatus*) in the Crocodile River in the KNP.

3.2 Materials and methods

The study was carried out on the Crocodile River within the KNP (Figure 9). The site selected is situated along the lower sections of the Crocodile River, upstream from its confluence with the Inkomati River. The site is located close to the Mjejane Game Reserve's Lodge which is located on the southern bank of the Crocodile River. The area's access is controlled by KNP (Mabunda et al., 2003). The Crocodile Site is well known for large specimens of *L. marequensis* despite the notable decline in abundances of this species. *Labeobarbus marequensis* have been found to utilise cobble, gravel and deep rocky pools or rapids (Figure 7) (Pienaar, 1978; Russel, 1997; Fouché, 2009). The site is also known to contain a large abundance of *H. vittatus* that are known to use a wide range of habitat types including pools, deep fast flowing glides and also frequent shallow areas with suitable cover features (Figure 8). The Crocodile Site is the only stretch of river where these habitats occurs extensively. The rest of the Crocodile River forms long sandy runs and pools (Hill et al., 2001). The river is clear during the low flow period from late April to October and turbid during spring and summer flows usually from November to March. Radio telemetry tracking techniques suitable to monitor the behaviour of fishes in the Crocodile River particularly when water clarity is poor and the “noise” generated from the shallow fast flowing habitats (riffles and rapids) makes acoustic telemetry unsuitable in the area.

Figure 7: A typical adult *Labeobarbus marequensis* adult that was tagged and tracked in the study.

Figure 8: A typical adult *Hydrocynus vittatus* adult that was tagged and tracked in the study.

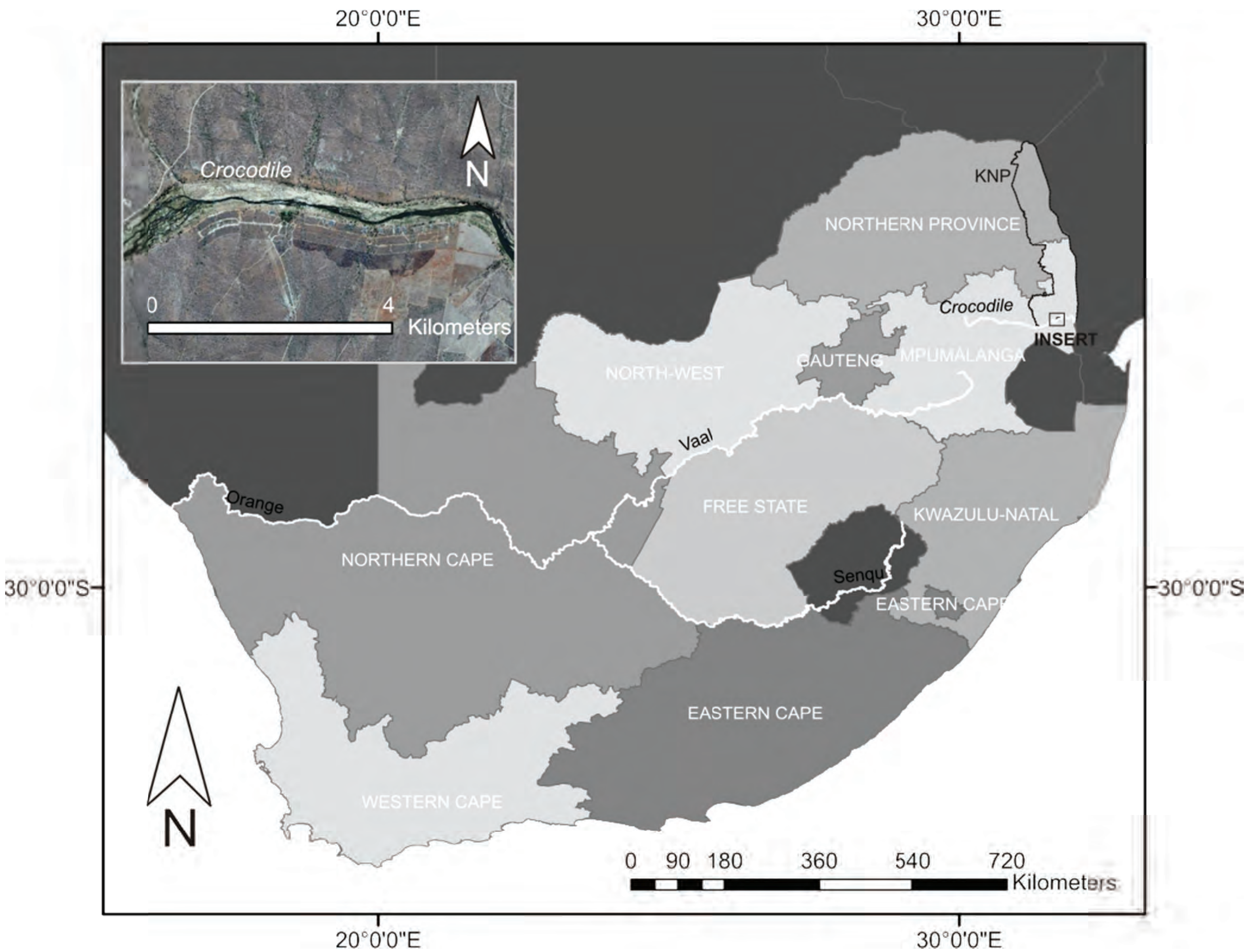


Figure 9: The reach of the Crocodile River chosen for the radio telemetry evaluation of the Lowveld largescale yellowfish (*Labeobarbus marequensis*) and tigerfish (*Hydrocynus vittatus*), on the southern boundary of the Kruger National Park, South Africa

3.2.1 Biotelemetry systems

In this study two radio telemetry systems including Advance Telemetry Systems Inc. (ATS) and Wireless Wildlife (WW) radio telemetry systems were used. As the effect of the tags on the yellowfish were not evaluated, the tag mass in relation to the body weight of the fish used in the study ranged between 0.6% and 1.1% of body mass, consistent with the recommended carrying capacity of fishes (<2%) (Gallepp and Magnuson, 1972).

Advanced Telemetry Systems

The ATS telemetry systems were implemented from August 2009 to March 2011. Three types of externally attached analog transmitters with a 40 ppm transmission scenario were used (Table 5). Tags were attached externally through the musculature on the mid-dorsal region of the back at the base of the dorsal fin (O'Brien and De Villiers, 2011). Tagged fish were tracked by foot using a portable ATS-R2100 receiver connected to a directional 4 element Yagi antennae (Figure 10). The guaranteed lifespan of the tags used ranged between 94 to 366 days but usually lasted for up to 4% longer with the signal transmission frequency set to approximately every second. In addition, an ATS receiver, model R4500S (Receiver/ Datalogger), was deployed on site to act as a remote receiver. The ATS remote station contained two directional Yagi antennae positioned perpendicularly, one facing upstream and the other downstream (Figure 10). The station was positioned along the bank of the Crocodile River at a GPS location of 25.37880 (S) and 31.714350 (E).

Table 5: The types of tags used by Advanced Telemetry Systems and Wireless Wildlife Systems in the study. Wireless Wildlife tags series IV included a LED light and series V included a depth sensor.

Models	Weight (g)	length (mm)	diameter/width (mm)	height (mm)	Time span (days)	pulse per minute (ppm)	Activity (counts)	Temperature (°C)	Depth (mm)
ATS-2030	10.1	50	12	-	264	40	40	40	40
ATS-2060b	22	53	17	-	366	35	35	35	35
ATS-1930	2.4	25	9	6	94	30	30	30	30
WW-Series *III*	20 (+/_ 1.5g)	53	17	-	365 +	10 default*	Y	Y	N
WW-Series *IV*	20 (+/_ 1.5g)	53	17	-	365 +	10 default*	Y	Y	N
WW-Series *V*	20 (+/_ 1.5g)	53	17	-	365 +	10 default*	Y	Y	Y

Note: (*) Refers to tags with remote/manual monitoring pulse frequencies which can be changed.

Wireless Wildlife radio telemetry systems

From September 2011 to June 2012 WW radio telemetry systems were used. The WW tags were also externally attached. Three types of WW tags with different peripheral sensory components were used in the study (Table 5). Tagged fish were tracked by foot using a portable Laptop receiver and a programmable mobile receiver connected to a directional 4 element Yagi antenna (Figure 10). The lifespan of all the WW-tags exceeded 365 days (based on battery life expectancy with an 80% safety factor). Different transmission scenarios, namely; remote and manual modes, were set to 10 minute and 1 second transmission intervals respectively. Peripheral sensory components that were used in the study includes: motion sensors measurements in maximum counts per minute (MC/m), temperature (^{o}C) sensors and depth (mm) sensors. Five remote monitoring stations were erected in the study area to cover approximately 5 km of the Crocodile River. This included a WW base station and four WW repeater stations (Figure 11).

A range of fish sampling techniques were used to collect a diverse sub-population of individuals to be representative of the whole population as recommended by Rogers and White (2002) for radio telemetry studies. Suitable adult *L. marequensis* were captured using *L. aeneus* or *H. vittatus* targeted angling techniques, an electro-shocker (220 V) in wadable areas and monitored cotton gill nets (93 mm diamond mesh) in deep habitats. Captured fish were immediately placed in an aerated container with clove oil (0.1 ml/l) until signs of narcosis became evident (O'Brien et al., 2012). Sixteen of the *L. marequensis* and 12 *H. vittatus* used in the study were captured, tagged and released in close proximity to the capture location (<10 m) within the focus area of the Crocodile River (Table 6). One *L. marequensis* individual (LMAR 8) was however captured, tagged and released approximately 5 km upstream from the focus area in the Crocodile River. Two weeks was given to each individual before perceived natural behavioural activities were documented (Rogers and White, 2002; O' Brien and De Villiers, 2010, O Brien et al. 2012).

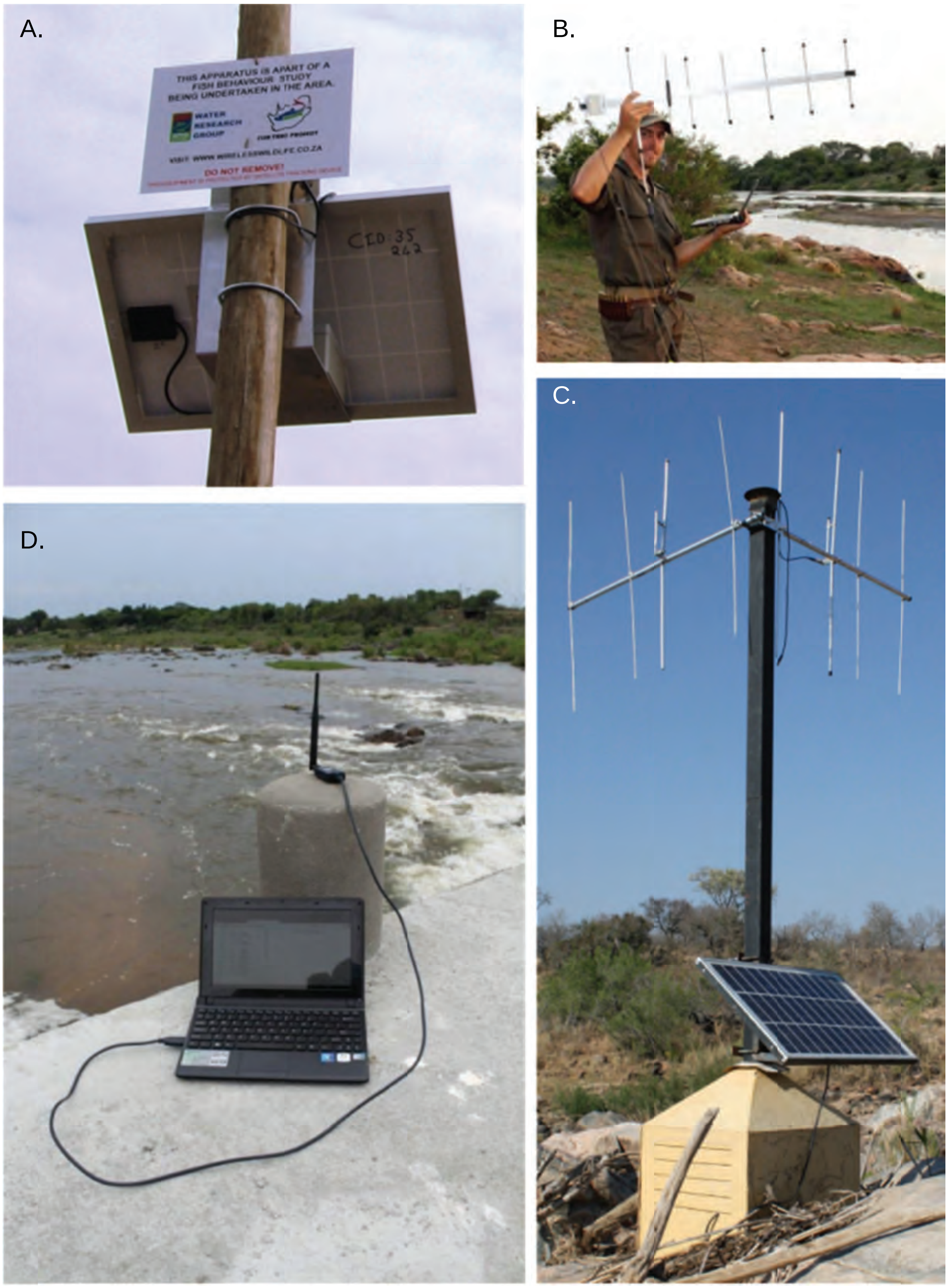


Figure 10: Radio telemetry tracking equipment used in the study including; Wireless Wildlife (WW) remote monitoring receiver mounted on a wooden pole with a warning sign (A), and the WW manual tacking receiver with directional antenna (B) and onmi directional antenna (D) and the Advanced Telemetry System remote data logging base station which included a R4500 receiver positioned in an armour plated, ventilated steel box with two directional yagi 4 element antennae mounted perpendicular to each other (C).

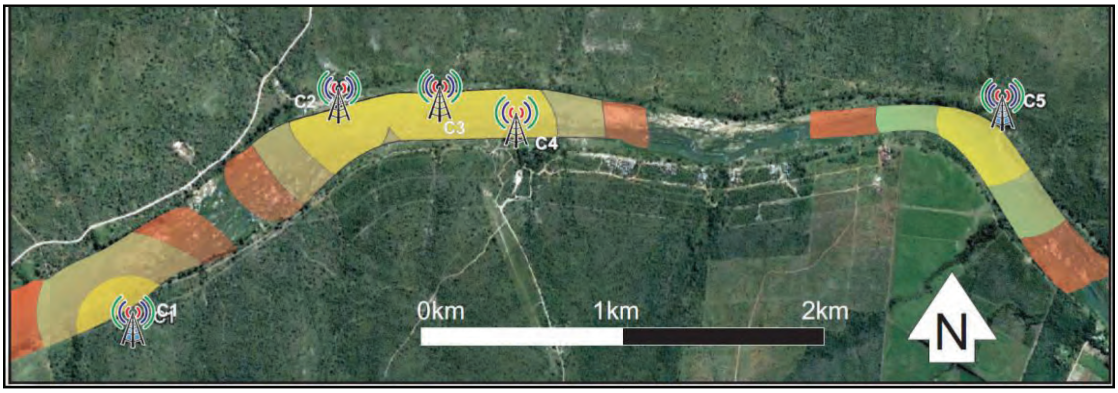


Figure 11: Location of the remote station used for the Wireless Wildlife system covering the Crocodile River site. Yellow, green and orange shaded areas depict confirmed coverage areas.

Table 6: Summary of the *Labeobarbus marequensis* and *Hydrocynus vittatus* individuals used in the study with the associated capture location, capture date, last day tracked (end date), days tracked and manual and or remote monitoring fixed where applicable.

Name	Tag type	Tag no.	Mass (g)	Capture location (GPS location)		Capture Date	End Date	Days tracked	Manual monitoring fixes	Remote monitoring fixes
LMAR1	ATS-2030	142.214	2500	-25.37942	31.71041	15/08/2009	19/09/2009	35	15	-
LMAR2	ATS-1930	142.232	1800	-25.37872	31.71271	15/08/2009	15/05/2010	273	30	-
LMAR3	ATS-1930	142.113	2200	-25.37804	31.70758	15/08/2009	1/12/2009	108	16	-
LMAR4	ATS-1930	142.092	2100	-25.37804	31.70758	16/08/2009	15/05/2010	272	42	-
LMAR5	ATS-2030	142.153	2500	-25.37872	31.71271	16/08/2009	17/02/2011	550	109	-
LMAR6	ATS-1930	142.051	2100	-25.37872	31.71271	16/08/2009	15/05/2010	272	42	-
LMAR7	ATS-1930	142.032	3000	-25.22722	31.71271	19/09/2009	15/05/2010	238	65	-
LMAR8	ATS-1930	142.072	2500	-25.39905	31.6784	19/06/2010	16/02/2011	242	46	-
LMAR9	ATS-2030	142.014	2600	-25.37884	31.71291	17/09/2010	14/11/2010	58	19	-
LMAR10	WW-*Series II*	6	2550	-25.3784	31.7197	19/09/2011	01/06/2012	232	8	6602
LMAR11	WW- *Series I*	25	2875	-25.3784	31.7197	19/09/2011	01/06/2012	232	7	2229
LMAR12	WW-*Series II*	7	2550 est	-25.3784	31.7197	19/09/2011	01/06/2012	232	2	6116
LMAR13	WW- *Series I*	17	2300 est	-25.3784	31.7197	19/09/2011	01/06/2012	232	4	316
LMAR14	WW- *Series I*	12	2250 est	-25.37885	31.71478	19/09/2011	01/06/2012	232	-	3324
LMAR15	WW- *Series I*	14	2300	-25.3784	31.7197	15/10/2011	01/06/2012	206	-	479
LMAR16	WW-*Series IV*	42	3900	-25.3784	31.7197	29/11/2011	01/06/2012	161	-	1262
HVIT1	ATS-2060b	142.322	1300	-25.37884	31.71469	19/08/2009	19/09/2009	31	1	-
HVIT2	ATS-1930	142.132	500	-25.37884	31.71469	19/08/2009	-	-	-	-
HVIT3	WW- *Series I*	21	2200	-25.37864	31.71333	16/09/2011	01/06/2012	235	-	1552
HVIT4	WW- *Series I*	23	1380	-25.22438	31.42529	19/09/2011	01/06/2012	232	-	58
HVIT5	WW- *Series I*	19	2580	-25.37871	31.71586	19/09/2011	01/06/2012	232	-	1626
HVIT6	WW- *Series I*	9	1750	-22.22422	31.43179	19/09/2011	01/06/2012	232	-	3702
HVIT7	WW- *Series I*	13	2100	-22.22422	31.43179	22/09/2011	01/06/2012	229	74	6774
HVIT8	WW- *Series I*	15	4000	-22.22422	31.43179	20/10/2011	01/06/2012	201	-	1834
HVIT9	WW- *Series I*	16	2000	-25.37885	31.71478	04/11/2011	01/06/2012	186	-	2272
HVIT10	WW-*Series IV*	41	3000	-25.22394	31.44291	23/11/2011	01/06/2012	167	-	899
HVIT11	WW- *Series I*	31	2100	-22.22422	31.43179	26/11/2011	01/06/2012	164	-	236
HVIT12	WW- *Series I*	35	2000	-25.2249	31.42282	28/11/2011	01/06/2012	162	-	224

Note: LMAR = *Labeobarbus marequnesis*; HVIT = *Hydrocynus vittatus*

3.2.2 Monitoring techniques

Manual monitoring methods used in this study were adapted from O'Brien and De Villiers (2011) (Figure 12). Tagged individuals were monitored from the banks of the Crocodile River. The narrow width of the river allowed for easy access to accurately track (<5 m) tagged fish which allowed for the spatial habitats associated with the location of the tagged fish to be observed. Manual monitoring surveys that usually lasted for one week were scheduled on a monthly basis throughout the study. This allowed for a seasonal evaluation of spatial movement of the tagged fish to be carried out and compared with habitat availability and diversity. To facilitate this process a flow dependent habitat digital terrain model of the study area was generated (Figure 13 and Figure 14).

3.2.3 Behavioural variables

The behavioural variable used in this portion of the study was movement, measured either by an accelerometer which has been incorporated as a peripheral component of tags for the remote monitoring system, measured as maximum counts per minute (MC/m), or during manual tracking exercises as maximum displacement per minute (MDPM) (Rogers and White, 2012). The MDPM is the recorded displacement (m) of the fish during a five minute manual monitoring period spaced over ten minute intervals. In addition, some activity variables include;

- feeding, identified as foraging movements within suitable habitats,
- holding, indicated when the fish was stationary in slow flowing, refuge habitats,
- spawning which occurred when yellowfish congregated in unique spawning habitat types, during spawning periods (Fouché, 2009), and displayed vigorous movements that were dissimilar to other activities such as feeding activity.
- Migration, included distinct co-ordinated movement patterns by a population of fish (Godin, 1997),
- flight involved the tagged fish moving rapidly in response to a disturbance from the presence of the observer, other included any activity that did not fit into these categories (Table 3).

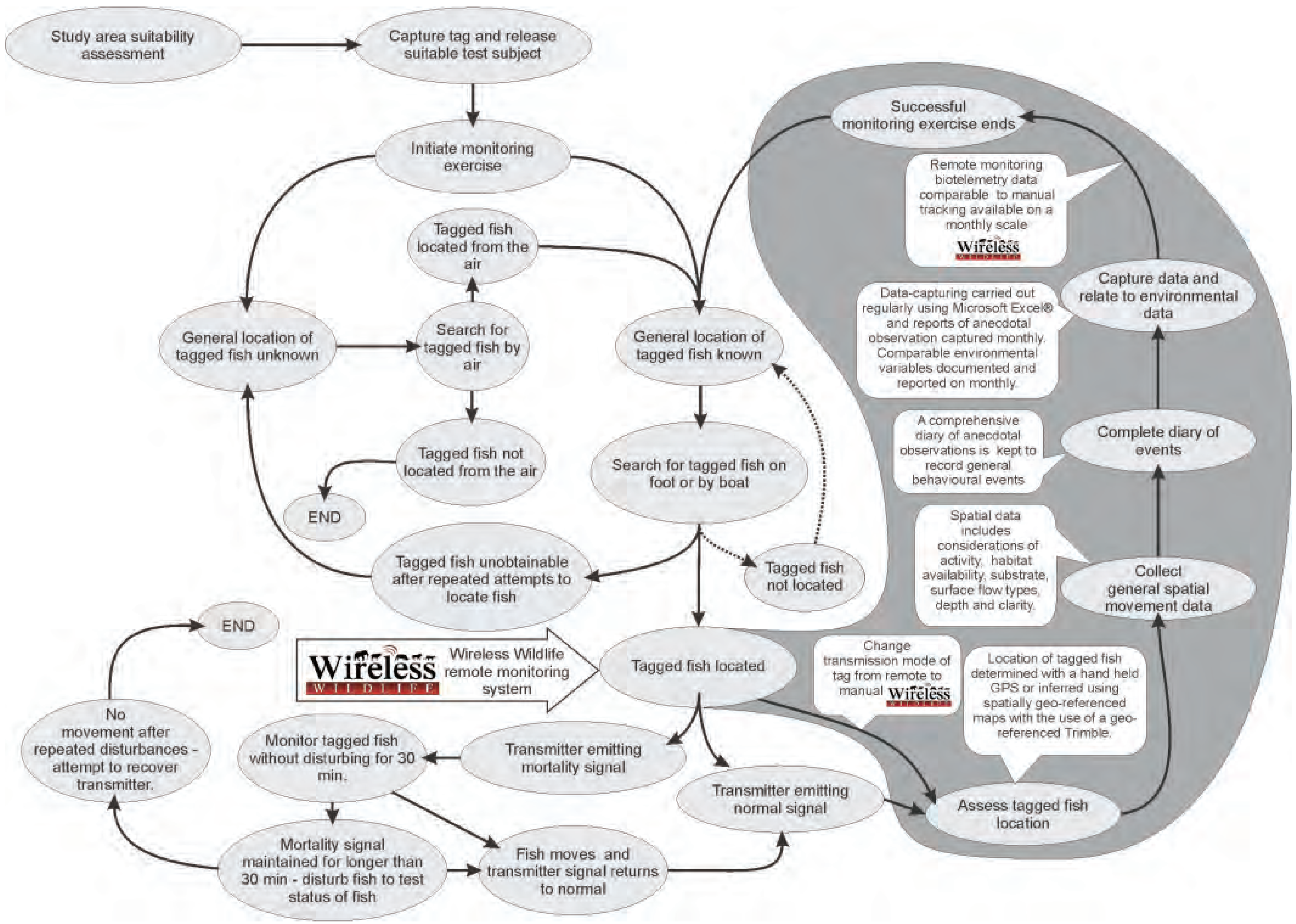


Figure 12: Schematic diagram presenting an adapted manual monitoring method established by O'Brien and De Villiers (2011), including the manual tracking component of the Wireless wildlife system developed in this study (shaded area).

3.2.4 Habitat preferences

The location and movement data of tracked fish were analysed using spatial analyses software namely ARC GIS ®. This approach allows for the assessment of; the spatial behaviour of individuals, high use areas, preferred areas and some relationships between the locations of the tagged fish and the state of general environmental variables as demonstrated by Hodder et al. (2007). Habitat characteristics of the Crocodile River were correlated to the locations (manual fixes) of the tagged fish (accuracy <2 m^2) that were manually tracked using ATS and WW radio telemetry systems. Habitat characteristics associated with the locations of the tagged fish were either documented manually at each fix so that accurate correlations between habitat use could be made and or related to available habitats that were modelled from a flow dependent habitat digital terrain model. The diversity and abundance of flow-dependent habitat types or units of a reach of the Crocodile River were characterised by spatially modelling the “preferred” reach to generate a series of digital terrain models using ArcPAD® (8.0) on a hand held Trimble. Each habitat unit was selected and mapped according to the unique velocity-depth class (Kleynhans et al., 2005), surface flow type, actual velocities measured in m/s and substrate types. Depth was measured using a measurement stick in centimetres (accurate to 0.5 cm). Velocities were measured using a calibrated OTT flow meter using triplicate readings. The mean velocities were used in the analyses. Habitat classifications and evaluations were based on the hierarchal classification system developed Frissel et al. (1986). Substrate type considerations included; silt, sand, gravel, cobble, boulder and bedrock types. Surface flow types monitored included barely perceptible flow, smooth and turbulent flows and undular or breaking standing waves. Fish cover features associated with each habitat type including undercut banks and root wads, cover where water depth allowed for sufficient cover for the species, overhanging vegetation and substrate types including the occurrence of substrates such as cobble and boulder beds that are preferred by some species, associated with each segment were assessed. This information was used to classify broad integrated habitat types including backwaters, pools, riffles, glides, rapids and chutes (Frissel et al., 1986). The data collected was used to generate digital terrain models of the study area.

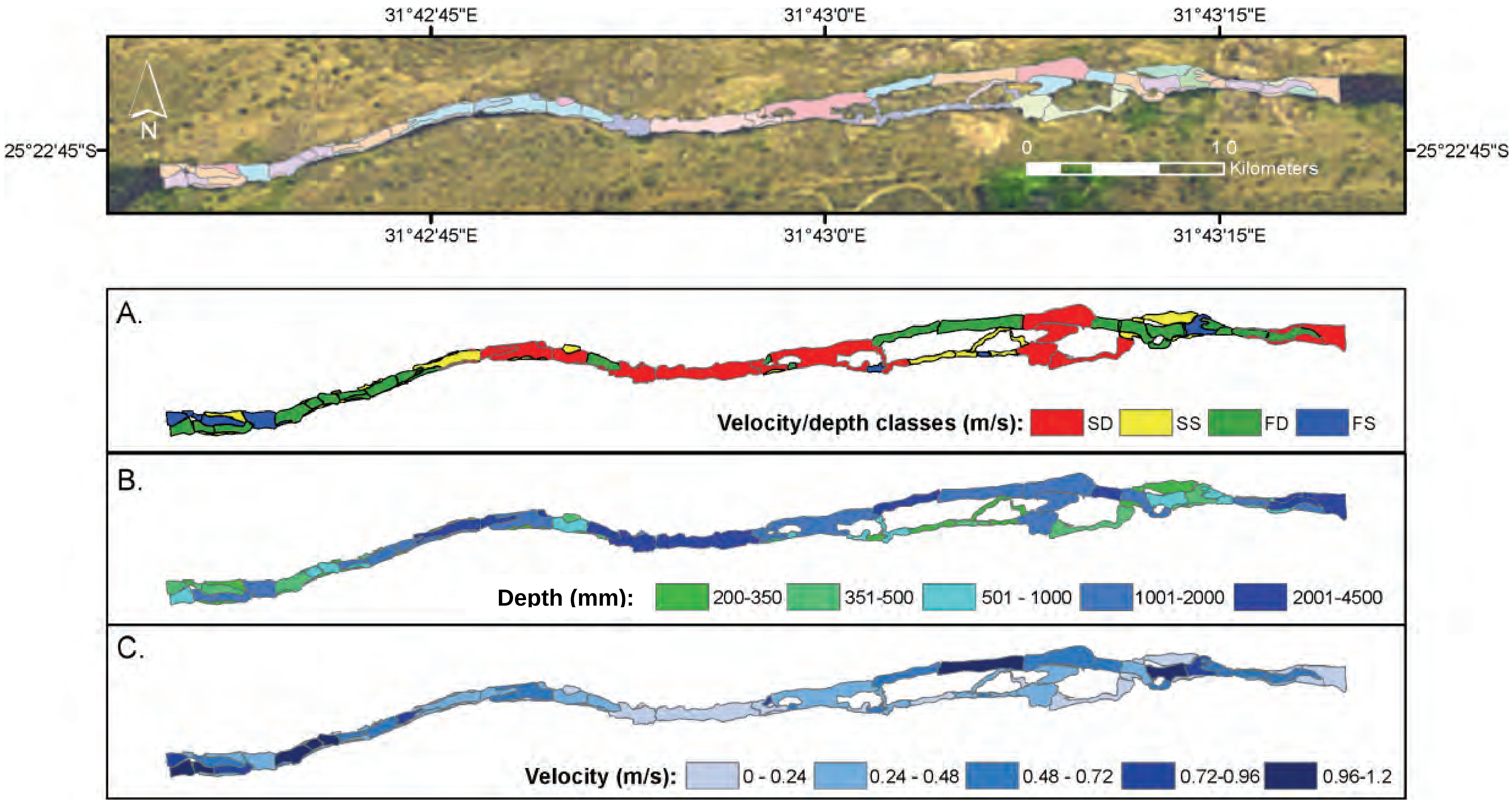


Figure 13: Digital terrain model projections of flow dependent habitat units (top) characterised in the study , and overlays including velocity depth classes (A), depth alone (B) and velocity alone (C) in the Crocodile River.

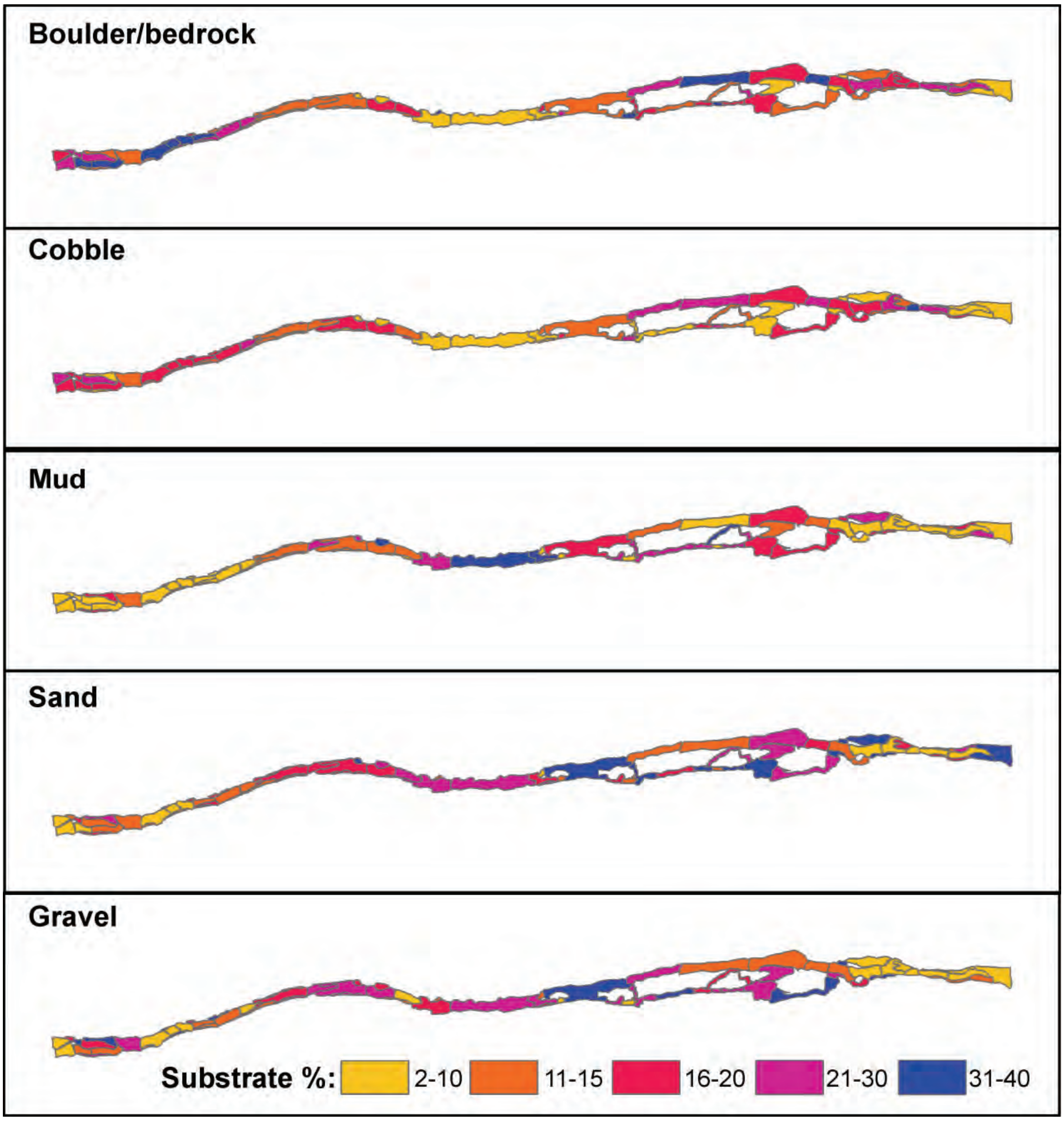


Figure 14: Digital terrain model projections with substrate types used as overlays in the Crocodile River.

3.3 Results

The data collected from 16 *L. marequensis* and 12 *H. vittatus* used in this evaluation, nine L. marequensis and two H. vittatus were attached with ATS tags and seven *L. marequensis* and 10 *H. vittatus* were attached with WW tags. *Labeobarbus marequensis* mean mass was 2464.1kg (SD=476.6 kg) with the mean standard length 453 mm (SD=33.8 mm). *Hydrocynus vittatus* mean mass was 1874.8kg (SD=879.7 kg) with the mean standard length 45 mm (SD=81. mm) (Table 6).

In the study, 479 manual fixes were obtained from 15 individuals (Table 6). Remote monitoring fixes totalled 39505 data strings (transmission signal strength, movement counts and temperature readings) from 17 individuals, two of which also contained depth sensory components on tags (16 September 2011 to 01 June 2012) (Table 6). Remote monitoring from the ATS system recorded 22171 hourly transmissions from tagged fish where signal strength was stored remotely (21 September 2010 to 12 November 2010). Wireless Wildlife tags obtained 20327 *L. marequensis* and 19130 *H. vittatus* strings of which 1262 data strings included depth for *L. marequensis* and 899 for *H. vittatus*. Activity data from the WW tags was only available for spring (September to November), summer (December to February) and autumn (March to May) and depth data was available from spring and summer.

Spatial distributions of the tagged fish were generally confined to the focus area of the study area, locations of each individual varied (Figure 15, Figure 16 and Figure 17). Both LMAR5 and LMAR9 frequented the area (± 2 km) associated with the ATS remote monitoring system. The remote data from the ATS remote station showed that LMAR5 and LMAR9 were found constantly in the study area for a period of two months before the station was destroyed during floods. Key areas were identified within the Crocodile Site which was used frequently by tagged individuals (Figure 18).

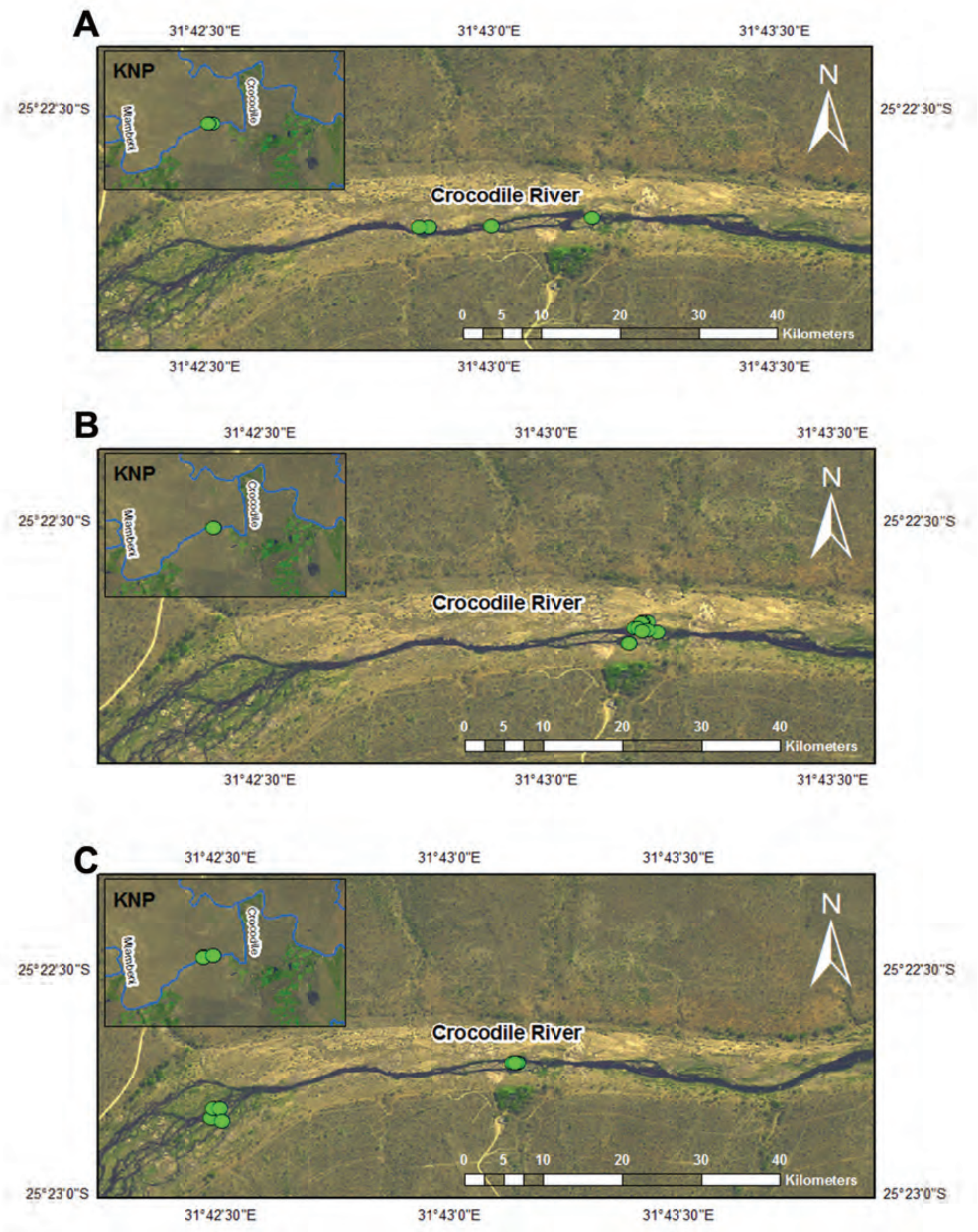


Figure 15: The locations where *Labeobarbus marequensis* individuals LMAR 1 (A), LMAR 2 (B) and LMAR 3 (C) were tracked in the study.

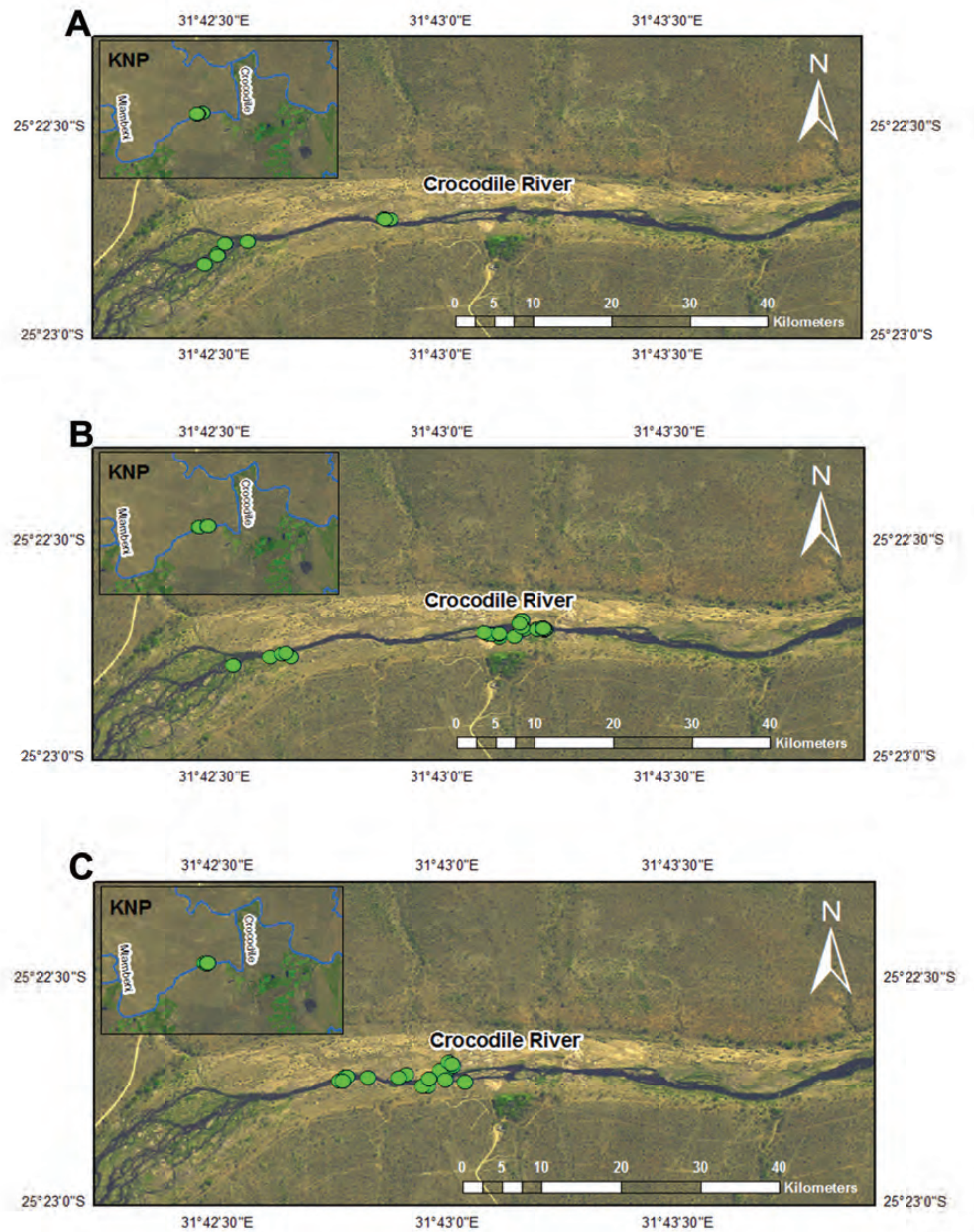


Figure 16: The locations where *Labeobarbus marequensis* individuals LMAR 4 (A), LMAR 5 (B) and LMAR 6 (C) were tracked in the study.

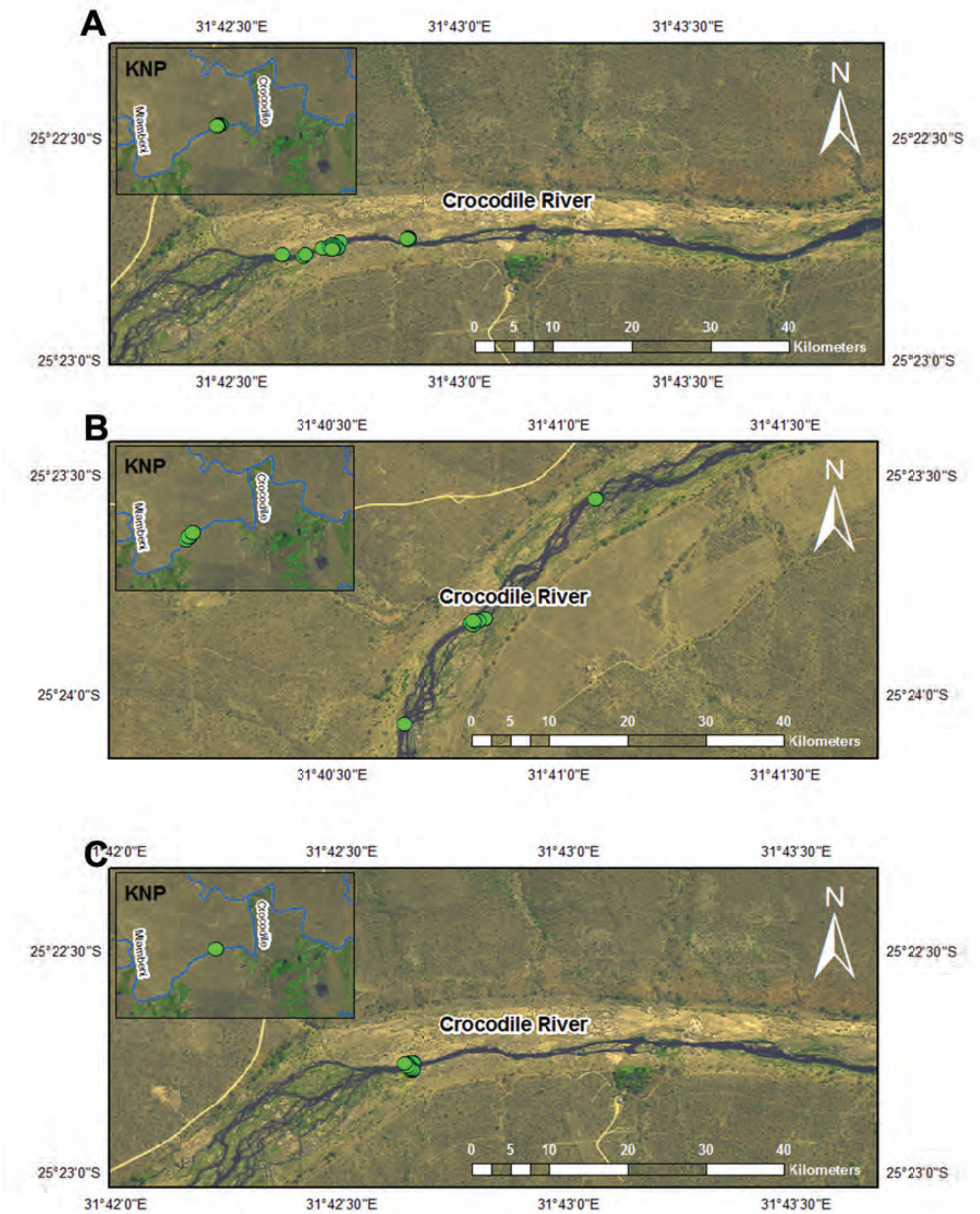


Figure 17: The locations where *Labeobarbus marequensis* individuals LMAR 7 (A), LMAR 8 (B) and LMAR 9 (C) were tracked in the study.

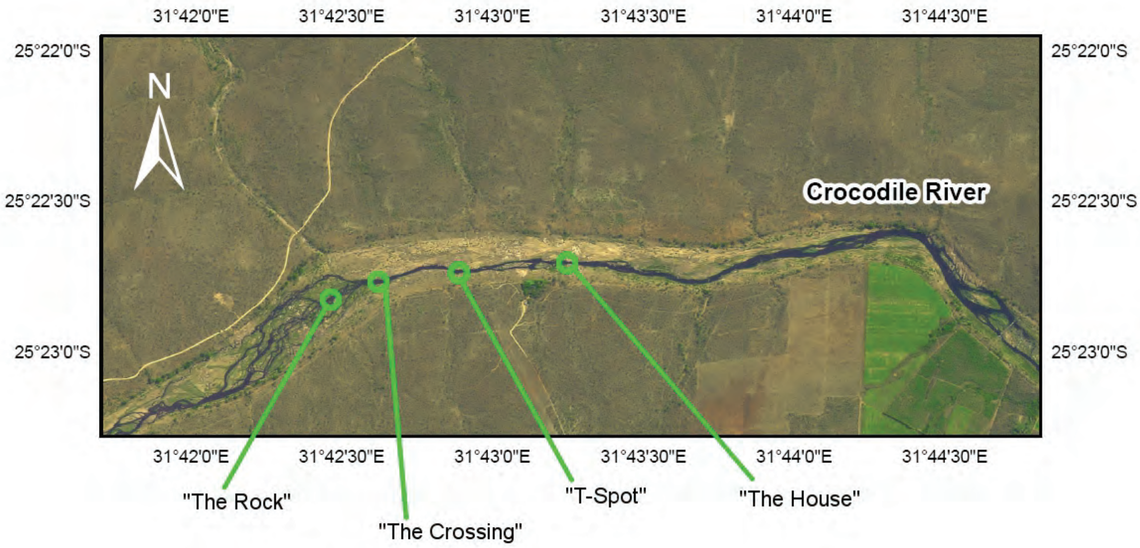


Figure 18: Selected physical features associated with high use by tagged *Labeobarbus marequensis* in the study.

The tagged fish showed a tendency to return to and were frequently found within close proximity (<5 m) to the release location. This was evident with LMAR3 and LMAR4. All individuals established home ranges that included high use or key areas containing distinct cover features and habitats. Individuals LMAR3 and LMAR 4 were frequently associated with a high use area that contained bedrock dominated deep (>1.2 m) fast flowing (>0.5 m/s) run just upstream of a deep pool. Six other *L. marequensis* individuals including LMAR 1, LMAR 6, LMAR 7 and LMAR 4 and LMAR2 and LMAR5 that were frequently found together frequented a pool area habitat that contained marginal vegetation dominated south bank and bedrock dominated northern bank. Five of the *L. marequensis* used for the WW component of the study where collected in this location emphasizing the importance of the high use areas of tagged individuals (Table 2).

Differences in habitats including substrate type, cover feature and integrated habitat type use of *L. marequensis* and *H. vittatus* were observed. *Hydrocynus vittatus* were more closely associated with and as such preferred vegetated habitat types compared to *L. marequensis*. Submerged boulders were commonly used by both species, but a significant difference in the movement of *L. marequensis* associated with S-boulder cover ($p < 0.05$) compared to *H. vittatus*. Apart from these two habitat types which were predominantly preferred by *H. vitattus*, *L. marequensis* showed a high affinity for UBRW (22.92%), E-boulders (13.37%) and M-veg (12.76%) all having some permanent structure with the exception of M-veg. A-veg (1.39%) along with substrate ridge (1.39%) was the least presented cover feature (Figure 19).

Habitat types preferred by the *L. marequensis* varied seasonally (Figure 20). During autumn and winter only three habitat types were frequented. In spring and summer a greater diversity of habitat types were used. Submerged boulders were utilised the greatest through all seasons, summer (26.3%), autumn (39.3%), winter (51.0%) and spring (33.55 %). Marginal vegetation featured in three of the four seasons namely: summer (12.5%), winter (17.7%) and spring (14.6%). Aquatic vegetation and substrate (rocky ridge) only featured in summer (both at 3.19 %). Cover features used in different flow discharges showed that despite different discharges submerged boulders was used more frequently than any other cover feature (low flow, 35.8%, and moderate flow, 44.9% and high flow, 22%) (Figure 20). High flow cover features used were UBRW (25.2%) and S-boulders (22%). Undercut bank and root wad cover features with submerged boulders in moderate flows were utilised 28.4% of the time. Marginal vegetation with submerged boulder were utilised as cover in low flows (19.7%) while it did not feature in moderate flows. Note that aquatic vegetation was only associated with fish positions 3.49% of the time in high flows and not associated with fish positions in low and moderate flows. High and low flow showed high use for various cover features where moderate flow had high use of submerged boulders (Figure 20).

Habitat types used by *L. marequensis* included glides that were associated with locations 55% of the time. Run and pools were also utilised 21.2% and 11.9% respectively. *Hydrocynus vittatus* were associated with different habitats than *L. marequensis* frequenting the riffles. This showed *L. marequensis* used deeper habitat types than that of *H. vittatus*. Habitats used in different season varied in a manner similar to that of cover features (Figure 20). Autumn and winter had only three frequented habitat types whilst summer and spring had a high diversity of types. Riffles were frequented in autumn, more than in the other seasons. Glides were preferred by *L. marequensis* throughout the seasons. In winter pools, glides and runs were highly utilised. Habitats during moderate and high flows showed similar uses for glide, pool and run. Low flows had the most diverse habitat type use (Figure 20).

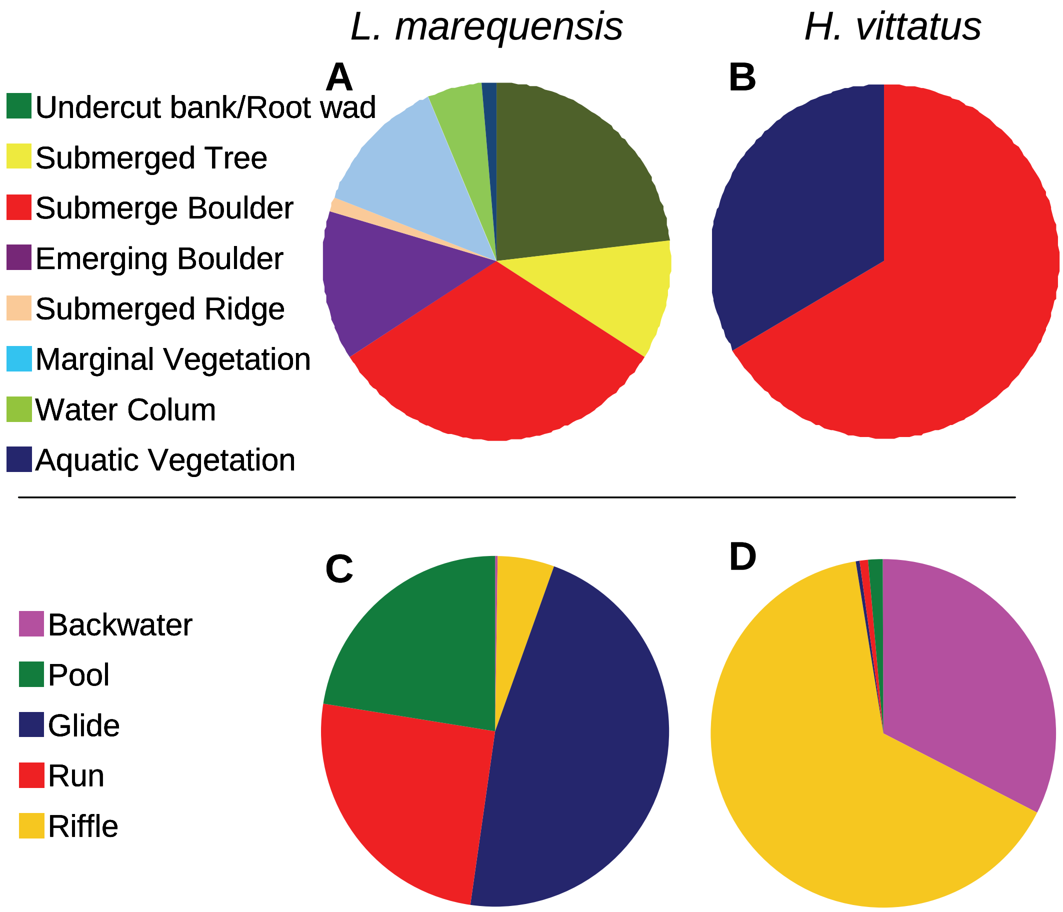


Figure 19: Interspecies (*Labeobarbus marequensis* and *Hydrocynus vittatus*) preferences for cover features (A and B) and integrated habitat types (C and D) based on classification system by Frissel et al. (1986).

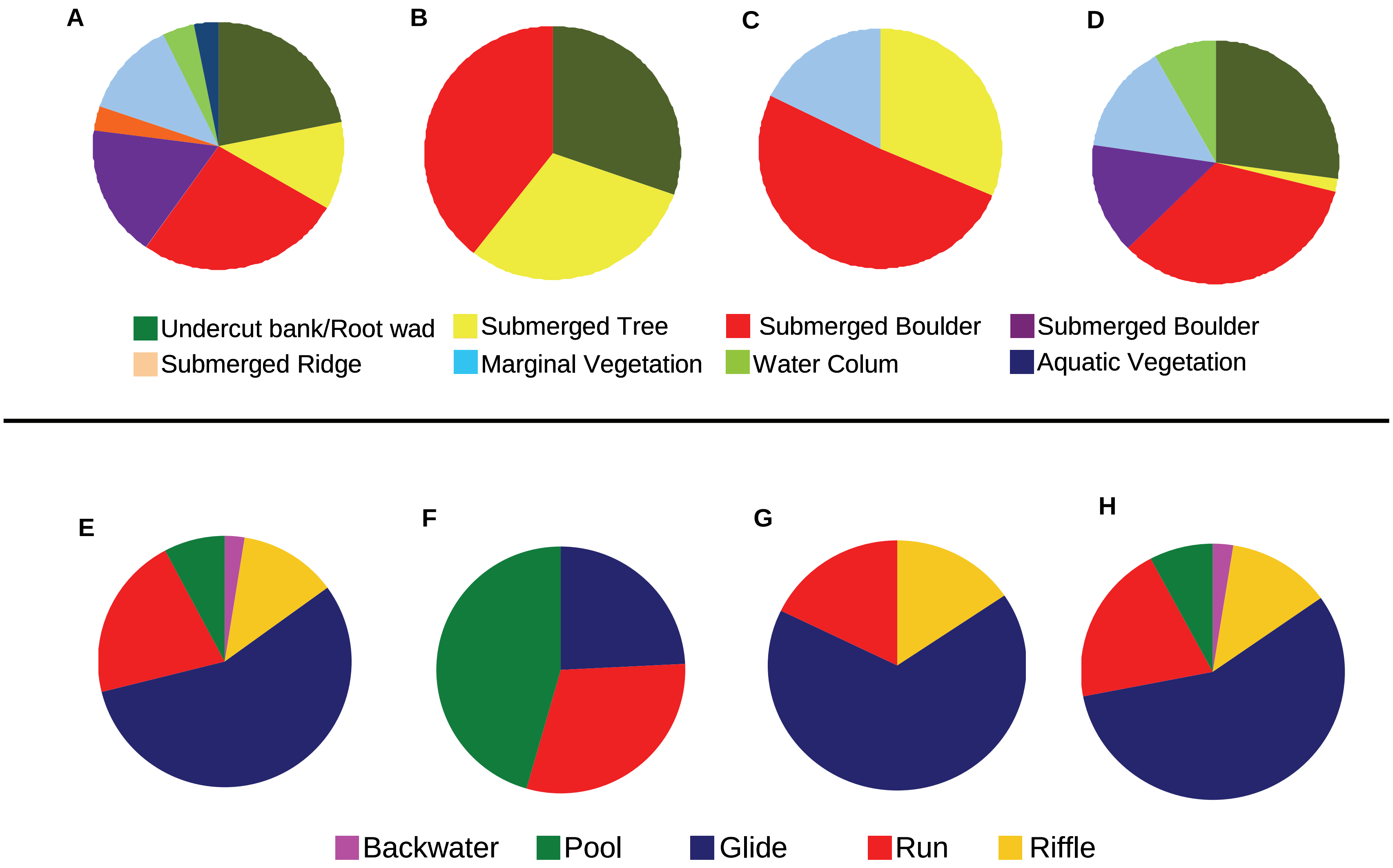


Figure 20: Cover features (A-D) and integrated habitat types (E-H) of *Labeobarbus marequensis* for different seasons, summer (A and E), autumn (B and F), winter (C and G) and spring (D and H) based on classification system by Frissel et al. (1986).

3.4 Discussion

Within the study area the adult *L. marequensis* established relatively small (<2 km) home ranges with some individuals establishing small (<500 m) focal areas. No observations of fish migrating out of the study area were observed. Within these home ranges specific area where frequented. The establishment of small home ranges in the study areas suggests that adult *L. marequensis* are relatively sessile and that this unique reach of the Crocodile River and its associated unique habitat types are important. Fouché (2009) showed that *L. marequensis* undertake reach scale migrations (<50 km). These migrations may only be undertaken by juvenile and sub-adult individuals and or other populations of *L. marequensis* which were considered by Fouché (2009). Home ranges and migrations may also be influenced by the abundance and diversity of habitats and are possibly affected by population pressure which is suspected to be low in the Crocodile River in the KNP.

Preferred habitats of the local *L. marequensis* population were found to be similar to that described by Pienaar (1978), apart from the sandy reaches which appeared to be avoided by the tagged individuals. Contrary to what Fouché (2009) described this study showed that large *L. marequensis* made extensive use of slow deep habitats as opposed to fast deep and fast shallow habitats. Furthermore this study showed that *L. marequensis* habitat preferences changed seasonally. Day length and water temperatures are considered to be the drivers of differences in habitat use. In this study adult *L. marequensis* showed to frequent various habitats and cover features during summer and spring rather than in winter and autumn. This appears to be linked to the biology of the adult yellowfish which includes spring and summer spawning with the associated seasonal changes the feeding biology and condition of the population (sensu Fouché, 2009). According to Kramer et al. (1997), under changing conditions habitat use varies, with fish changing location in response to changes in season and flows seeking out preferred habitat types. The diverse cover features in high flows and summer and spring periods could be due to the availability of different habitat types that come with changes in flows for example.

Labeobarbus marequensis were shown to use habitats that differed to *H. vittatus*. *Labeobarbubs marequensis* preferred glides and runs while *H. vittatus* showed a preference for riffles and backwater habitats. This was also observed by Thorstad et al. (2003). In this study aquatic vegetation was an important habitat type for *H. vittatus*. The species is known to predate on small fish within and adjacent to aquatic vegetation (O'Brien et al., 2012). The adult *L. marequensis* showed very little preference for aquatic vegetation and did not appear to forage within or close to vegetated areas. These findings demonstrate the differences in the feeding behaviour of the species to the predatory nature of *H. vittatus*.

This study shows that the behaviour and associated biology of the *L. marequensis* and *H. vittatus* populations in the Crocodile River differ significantly. These results also show that a wide diversity with suitable abundances of habitat types are required in the Crocodile River for the biological requirements of these fishes to be optimised.

CHAPTER 4: BEHAVIOURAL RESPONSE OF ADULT LOWVELD LARGESCALE YELLOWFISH (*LABEOBARBUS MAREQUENSIS*) TO FLOW AND OTHER VARIABLE CHANGES IN THE CROCODILE RIVER, KRUGER NATIONAL PARK

4.1 Introduction

Behavioural studies, using radio telemetry methods have widely been used to evaluate the ecological consequences of changes in ecosystems conditions, including those that are of anthropogenic origin such as water quality, flow and habitat changes (Cooke et al., 2004; Økland et al., 2005; Gerhardt, 2007). Radio telemetry methods are now widely considered to be a preferred fish behavioural ecology monitoring methods (Rogers and White, 2007). Although these methods are well established internationally, the approach has only recently received attention in developing countries, including southern Africa (Thorstad et al., 2001; Baras et al., 2002b; Økland, 2005; Næsje et al., 2007; Childs et al., 2008; Cowley et al., 2008).

Flow regulation and associated impacts of rivers has increased noticeably from the mid-1900s and continued to escalate (Vörösmarty et al., 2004). Flow alterations are considered to be one of the most extensive forms of human disturbances known to man (Stanford et al., 1996). Flow alterations are known to affect fish through physical displacement, loss or alterations of flow-dependent habitat types and behavioural changes (e.g. Bain et al., 1988; Bunn and Arthington, 2002; Hauer and Lorang, 2004). Although many different techniques are available to evaluate the effects of changing flows on fish behaviour, radio telemetry techniques have been extensively used in the evaluate the effects of flows on fishes (Scruton el al., 2002; Arnekleiv and Ronning, 2004; Murchie et al., 2008). Excessive water abstraction from the Crocodile River system in Mpumalanga affects the structure and function of the lower Crocodile River in the KNP (Hill, 2005). There has been a noticeable decline in the abundance of adult *L. marequensis* individuals in the system without any cause agents being identified during the past ten years (Leslie, 2007). This yellowfish is known to have specific flow requirements for certain life cycle events such as ecological cues for reproductive biology (Fouché, 2009). Knowledge of the behavioural response by *L. marequensis* to different flows could contribute greatly to the conservation of the species and the Crocodile River. In addition, flow alterations may possibly be a variable that is negatively affecting the population in the Crocodile River. The aim of this chapter is to report on the application of the remote WW radio telemetry tracking system to evaluate the behavioural response of adult *L. marequensis* to changing flows and other variables associated with changing flow regimes in the Crocodile River in the KNP.

4.2 Materials and methods

The study was carried out on the Crocodile River within the KNP (Figure 9). Similarly in this portion of the study both ATS and WW radio telemetry systems were used which incorporated the capture, tagging and monitoring of *L. marequensis* as presented in Chapter 3. Some data obtained from tracked tigerfish (*Hydrocynus vittatus*) was considered in this chapter for explanatory purposes.

In this study WW remote radio telemetry systems were used to evaluate changes in behaviour (movement (MC/m)) of *L. marequensis* during different flows (discharge in m^3/s). Additional variables that were considered included daily and seasonal movement patterns and relationships between flows and depths. For the daily movement assessment six periods divided into 4 hr natural breaks were selected for the study. These periods included 24h00-04h00, 04h00-08h00, 08h00-12h00, 12h00-16h00, 16h00-20h00, 20h00-24h00. The seasonality assessment made use of the summer season patterns for the Southern Hemisphere's subtropical zone, specifically for South Africa which is located between the 22^{nd} and 34^{th} horizontal degrees south of the equator (Gertenbach, 1980). As such for this study spring was considered to occur from September to November, summer occurs between December and February, autumn occurs between March and May and winter occurs between June and August. Discharges were obtained from the Department of Water Affairs (DWA) gauging station on the Crocodile River at Riverside/Kruger National Park (Station number: X2H046Q01). Based on historical data flows were divided in to three natural break classes namely: low flows (0 m^3/s to 10 m^3/s), moderate flow (10 m^3/s to 60 m m^3/s) and high flows (>60 m^3/s). Descriptive analyses were carried out using Windows Excel© (Microsoft Corporation, 2011). Statistical evaluations of movement changes related to changes in the states of variables were undertaken using a mixed-model analysis of variance (ANOVA) approach, with a random coefficients model (Littell et al., 1996) and Akaike’s information Criteria (AIC) model selection (Burnham and Anderson, 1998). Analyses were conducted using SAS version 9.3 (SAS Institute, Cary, NC).

4.3 Results

The movement (MC/m) of the yellowfish demonstrated diurnal behaviour with increased movements between 08h00 and 16h00. *Hydrocynus vittatus* displayed more crepuscular behaviour with high early morning movements between 04h00 and 08h00 (Figure 21). Increased movement of *L. marequensis* during the day was closely associated with increased depth use and the associated change in habitat use. In comparison the tagged *H. vittatus* individuals also exhibited increased in depth use during the day which may not have been associated with feeding which was highest early in the morning. Results also indicated that the yellowfish generally spend significantly ($p < 0.05$) more time roaming (movement in MC/m) in comparison with the *H. vitattus* (Figure 21). This also included a broader range of depths ($p < 0.05$). This seems to have associated with the benthic nature of *L. marequensis* where increases in depth of the Crocodile River, due to increases in discharge, resulted in deeper depth uses (Figure 22 for example). In comparison *H. vitattus* exhibited consistent daily depth use profiles which generally included decreases in depth use during mid-day that was not influenced by increased depth of the river and not associated with substrates (Figure 22 for example).

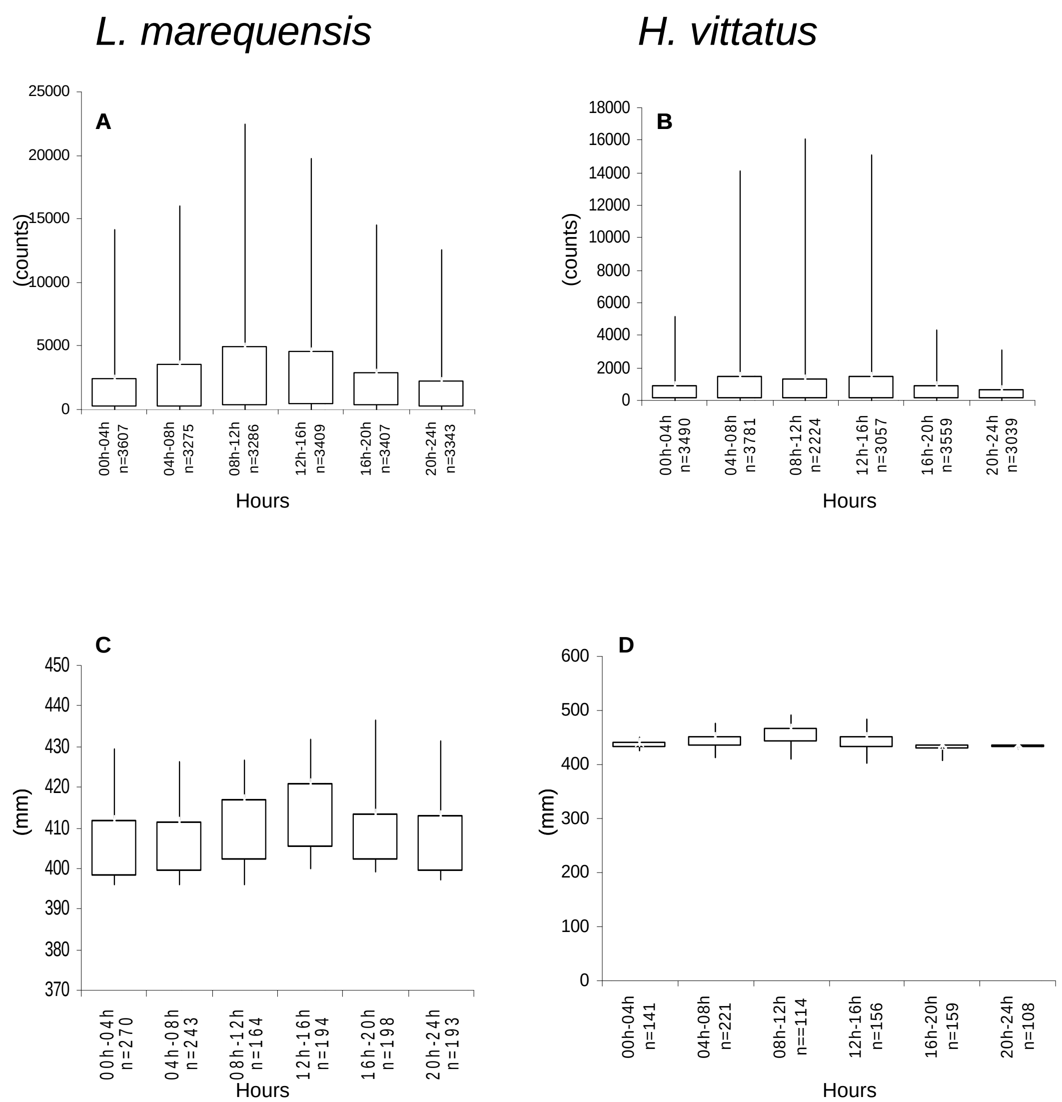


Figure 21: The comparative movement (MC/m) and depth (mm) relationship between time of day for *Labeobarbus marequensis* and *Hydrocynus vittatus*. Box limits of box and whisker plots represent the 25th and 75th percentiles while whiskers represent 5th and 95th percentiles.

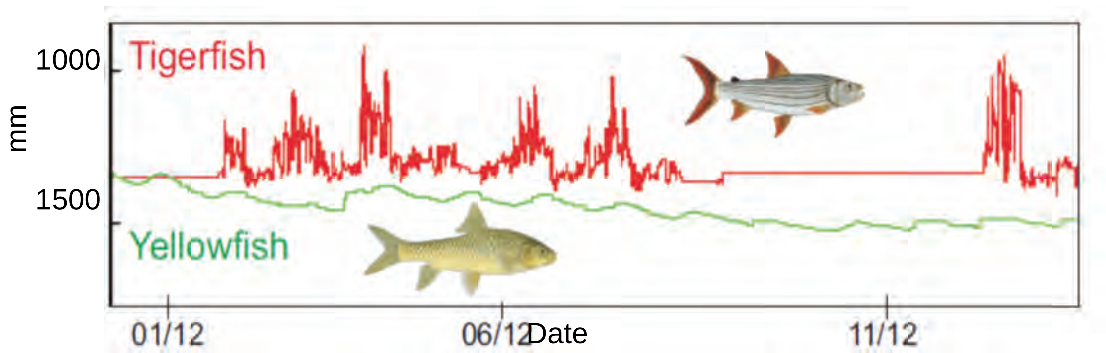


Figure 22: Comparative use of depth of an individual *Labeobarbus marequensis* and a *Hydrocynus vittatus* tracked in the same area (< 50 m) in the study between the 01 December 2010 and 13 December 2010 when the discharge of the river increased from 62 m^3/s to 66 m^3/s.

Labeobarbus marequensis movement decreased from spring to autumn (Figure 23). Depth profile use also varies where significantly shallower ($p<0.05$) areas were frequented by the tagged *L. marequensis* individuals in summer. Flows showed to have an effect on the movement of *L. marequensis* in that during low and moderate flows movement was significantly higher ($p<0.05$) than in high flows where almost no movement was found (Figure 24). Depth preferences were more variable during low flows than moderate flows.

The results obtained from seasons and flow discharges differed. Seasonal results reflect the effect of day length and temperature fluxes while flow discharges show changes in different flow discharges despite the seasons. Flow discharges varied in different seasons with spring having a mix of high fluxes and extreme low fluxes. Average flow discharges per season were as follows: Summer 86.53 m^3/s, Autumn 35.22 m^3/s, Winter 8 m^3/s and Spring 14.54 m^3/s (Figure 24).

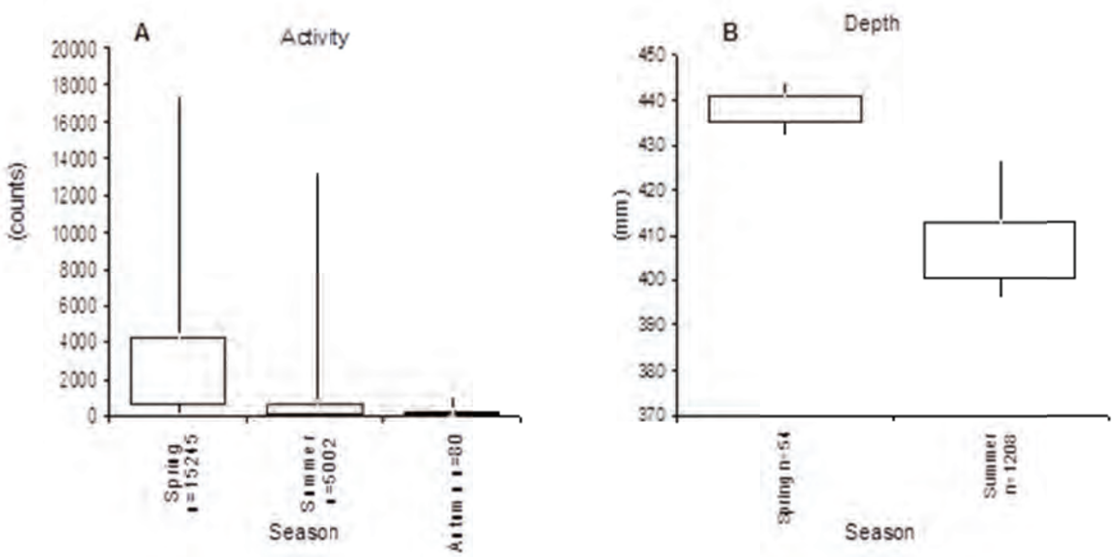


Figure 23: Seasonal movement counts (MC/m) and depth (mm) exhibited by the adult *Labeobarbus marequensis* tracked remotely in the study. Box limits represent the 25th and 75th percentiles while whiskers represent 5th and 95th percentiles.

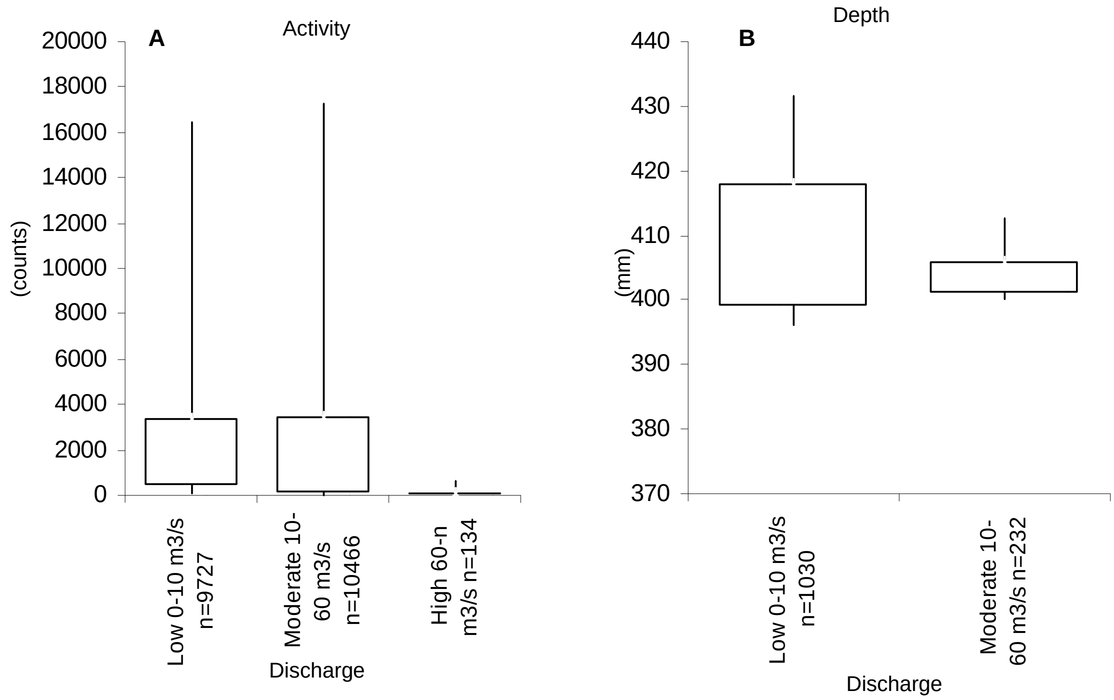


Figure 24: The movement MC/m and depth (mm) relationship between flows (discharges) for *Labeobarbus marequensis*. Box limits represent the 25th and 75th percentiles while whiskers represent 5th and 95th percentiles.

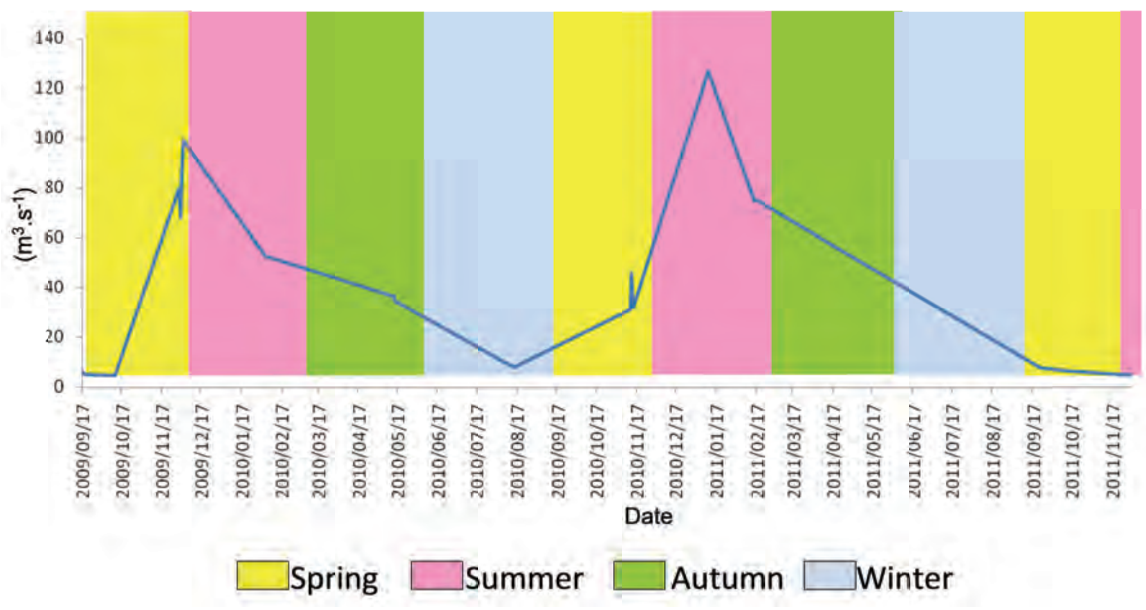


Figure 25: Discharges (m^3/s) for the Crocodile River and season correlation for the duration of the study.

4.4 Discussion

Movement during the day show *L. marequensis* to be more active during mid-day periods. Low movements during the night indicate *L. marequensis* resting during these periods. These shows that L. marequensis can be regarded as diurnal fish. Depth showed L. marequensis to move into deeper waters during the mid-day periods this could be due to visibility increasing within the water allowing them to feed deeper also evasion from predators such as the African fish eagle (*Haliaeetus vocifer*). The increase in movement with the increase in depth over the same part of day indicates that the yellowfish feed in deeper habitats during the day. *Hydrocynus vittatus* showed very different movement patterns during the course of the day. Their movement increased early mornings suggesting crepuscular behaviour which decreased towards mid-day. These results reflect the differences in the time and areas preferred by the yellowfish and tigerfish during the course of the day in the same reach of the Crocodile River.

The movement of *L. marequensis* decreases during summer. These summer periods have variable flows and extreme high flows which cause fish to move into cover features and wait out unfavourable conditions. This was shown in that *L. marequensis* moved into deeper waters during summer periods. This co-related with the habitat preferences over the different seasons. High movements during spring correlate to spawning periods of *L. marequensis* (Fouché, 2009), therefore indicating the change in day length in spring to be a cue (Fouché, 2009).

Flow changes can be regarded as an important influence on a river system; habitats are subject to strong temporal variation during flow discharges, with the rise and fall of water levels causing a change in habitat conditions within segments of rivers (Rogers and O'keeffe, 2003). The movement of the tracked *L. marequensis* individuals monitored decreased significantly ($p<0.05$) in response to increases in flow to a point where no movement occurred in high flows. This disruption in behaviour demonstrates the negative effect that large increases in flow have on movement of the yellowfish population which prefers low to moderate flows. High flows were also associated with increases in turbidity that may have affected the yellowfish behaviour (Stephens and Krebs, 1986). These findings reveal that excessive increases in flows (>60 m^3/s) cause significant disruptions to the behaviour of yellowfish in the Crocodile River. Whether the causes of increases are natural and or unnatural, due to the excessive use of ecosystem services and or as a result of climate change the increase in frequency of these events may threaten the wellbeing of the yellowfish population in the Crocodile River.

Movement differed noticeably between species *H. vittatus* and *L. marequensis*. *Hydrocynus vittatus* were found to have an average of 4.08 MC/m while *L. marequensis* average was 1.17 MC/m. Differences in the feeding biology of *L. marequensis* and *H. vittatus* can be a possible cause for the differences in the amount of movement (Skelton, 2001; Fouché, 2009). Results showed that adult *H. vittatus* adopt holding patterns at night predominantly in backwater areas that have floating aquatic vegetation. Both species were active during daylight period but made use of significantly ($p < 0.005$) different habitats. In the study *H. vittatus* individuals made extensive use of the water column during the day while the *L. marequensis* individuals were more benthic in nature and remained in close proximity to the bottom of the river (Figure 22). This behaviour also suggests that during foraging periods (04h00 to 08h00) the species make use of different habitats and move differently indicating that these species have noticeably different feeding behaviours.

The findings of this assessment showed that the flows significantly affected the movement of adult *L. marequensis*. Flows have been known to affect fish movements; Brenden et al. (2006) also found that discharge significantly affected both habitat use and selection of cyprinids in the New River, Virginia, USA. In this study sudden increases in flows caused disruptions to the behaviour of the adult *L. marequensis*, and that at a discharge above 60 m^3/s the movement of the yellowfish ceased. Although there were only two noticeable increases in flows (> 60 m^3/s) during the study period there were many more freshet events. Should the frequency of freshet and high flow events increase excessively in the study area the behaviour of the yellowfish may be disrupted.

CHAPTER 5: HABITAT USE AND THE EFFECT OF DIURNAL, LUNAR AND SEASONAL CYCLES ON THE MOVEMENT OF ADULT VAAL-ORANGE SMALLMOUTH YELLOWFISH (*LARBEOBARBUS AENEUS*) IN BOSKOP MANMADE LAKE, NORTH WEST.

5.1 Introduction

Aquatic ecosystems are dynamic environments that are difficult to monitor, especially when ecosystems become turbid (Trefethen, 1956; Cooke and Schreer, 2003). Research on aquatic animals usually involves removing organisms from these environments to conduct controlled 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, 2000; Cooke and Schreer, 2003). One of the most important groups of indicators of ecological health, locally and internationally are fishes. They are used in a wide range of research, conservation and environmental monitoring approaches (Karr, 1981; Kleynhans, 1999; Harrison et al., 2000; Harrison and Whitfield, 2004; Kleynhans, 2005; Harrison and Whitfield, 2006; Elliott et al., 2007). These approaches are mainly dependant on the understanding of the biology and ecology of the fishes that occur within different ecosystems (Karr, 1981; Kleynhans, 1999; Elliott et al., 2007).

The aim of this chapter is to apply WW radio telemetry systems to evaluate the spatial area use of Boskop Manmade Lake and the effect of diurnal, lunar and seasonal cycles on the movement of adult Vaal-Orange smallmouth yellowfish (*L. aeneus*) in the lake.

5.2 Materials and methods

5.2.1 Study area

Boskop manmade lake (Boskop Dam) is situated 15 km north of Potchefstroom in the Dr. Kenneth Kaunda district municipality in the North-West Province (Figure 26) (van Aardt and Erdmann, 2004). The 21 million m^3 lake is the largest manmade lake built in the Mooi River catchment (Koch, 1975). Boskop Lake is a part of the Mooi River irrigation scheme which provides irrigation water via a canal system below the dam for approximately 40 km. From Boskop Lake the Mooi River flows past Potchefstroom and into the Vaal at (26°52'27.31" (S), 26°57'06.33" (E)) (Koch, 1975).

The littoral zone around the lake is dominated by an aquatic vegetation *Potamogeton pectinatus* (Koch and Schoonbee, 1975). This vegetation has invaded 50% of the total surface area of the lake (Koch and Schoonbee, 1975). High water clarity allows plants to grow in water up to six meters deep. In addition to aquatic vegetation the lake has a large diversity of habitats and cover features (Figure 27). These habitats include extensive banks of aquatic vegetation up to 200 m across boulder dominated areas, shallow sand and gravel beds and deep water with reeds, 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 range of 2°C to 20°C (NW DACE, 2002). 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 3000 ha (Van As and Combrinck, 1979). Access to Boskop Dam is mainly controlled by personnel of the North West Department of Agriculture Conservation and the Environment, but private land owners on its eastern bank and Department of Water Affairs on its southern bank have permanent access to the system.

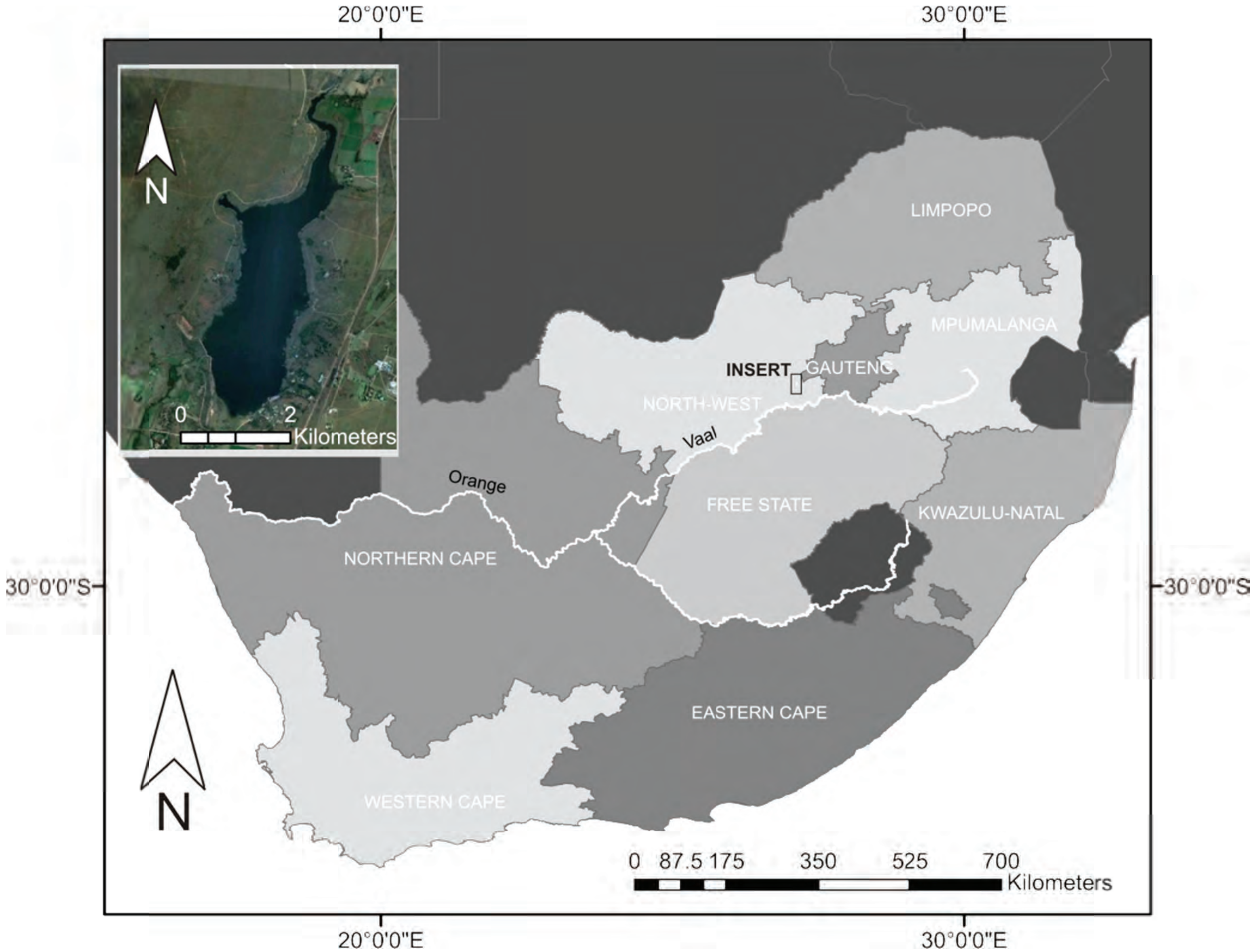


Figure 26: The Boskop manmade Lake chosen for the radio telemetry evaluation of the Orange Vaal smallmouth yellowfish (*Labeobarbus aeneus*), on the located on the Mooi River, North-West, South Africa.

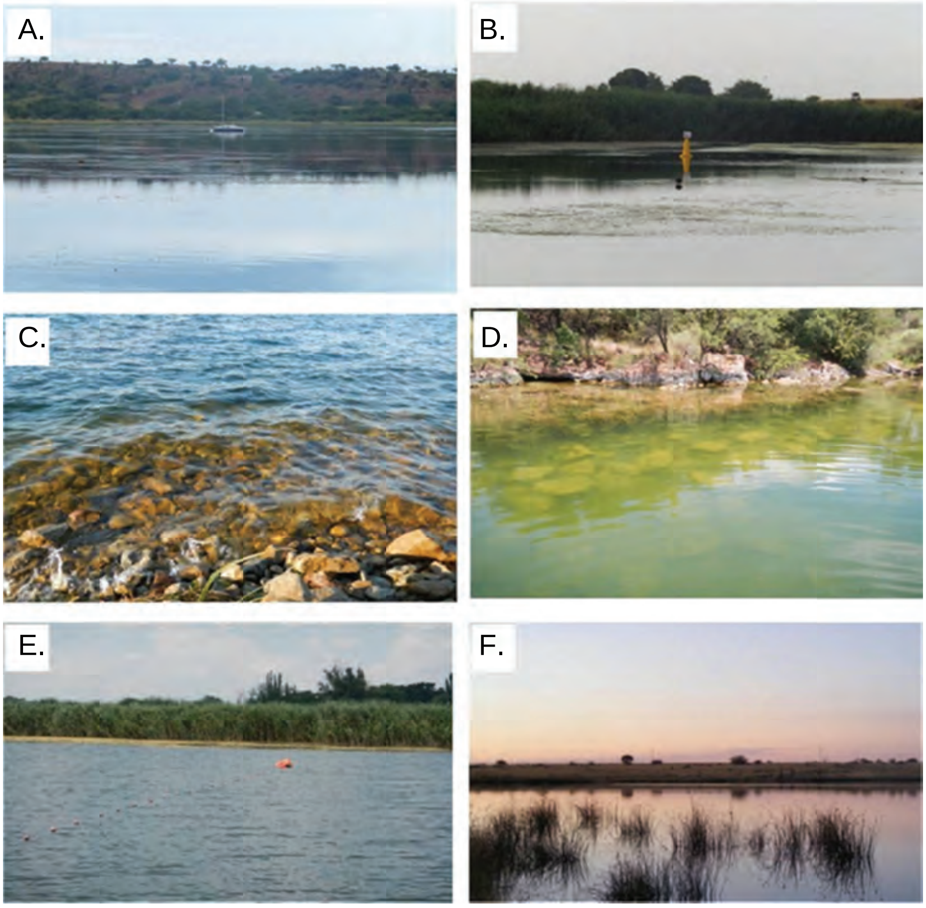


Figure 27: Photographs of habitat types available in Boskop Manmade Lake that may provide cover for the yellowfish in the study. These include; deep well vegetated areas (A-B), shallow areas dominated by cobble (C) and boulder (D) substrates, deep open water areas (E) and shallow areas with emergent vegetation (F).

5.2.2 Radio telemetry techniques

Remote monitoring stations

Locations for remote monitoring stations were initially identified using Google Earth and contour maps of the lake. Thereafter visual inspection of the proposed station erection sites were carried out, in proximity to important habitats types around the lake (Skelton, 2001). Onsite inspections a Garmin GPS was used to get exact GPS positions. Six remote monitoring stations were erected around Boskop Lake and were numbered from the base station in a clockwise direction around the lake (Table 7 and Figure 28). Thereafter assembly materials were transported to each location, and stations were erected.

Table 7: Remote monitoring stations around Boskop Dam including: GPS position, allocated number and station code.

GPS position	Allocated number	Station code
26°32'16.57"S & 27° 7'35.49"E	1	244
26°33'38.15"S & 27° 7'19.72"E	2	245
26°34'5.30"S & 27°6'51.74"E	3	251
26°33'43.78"S & 27° 6'44.21"E	4	241
26°31'53.53"S & 27° 7'21.89"E	5	253
26°32'44.80"S & 27° 6'51.85"E	6	247

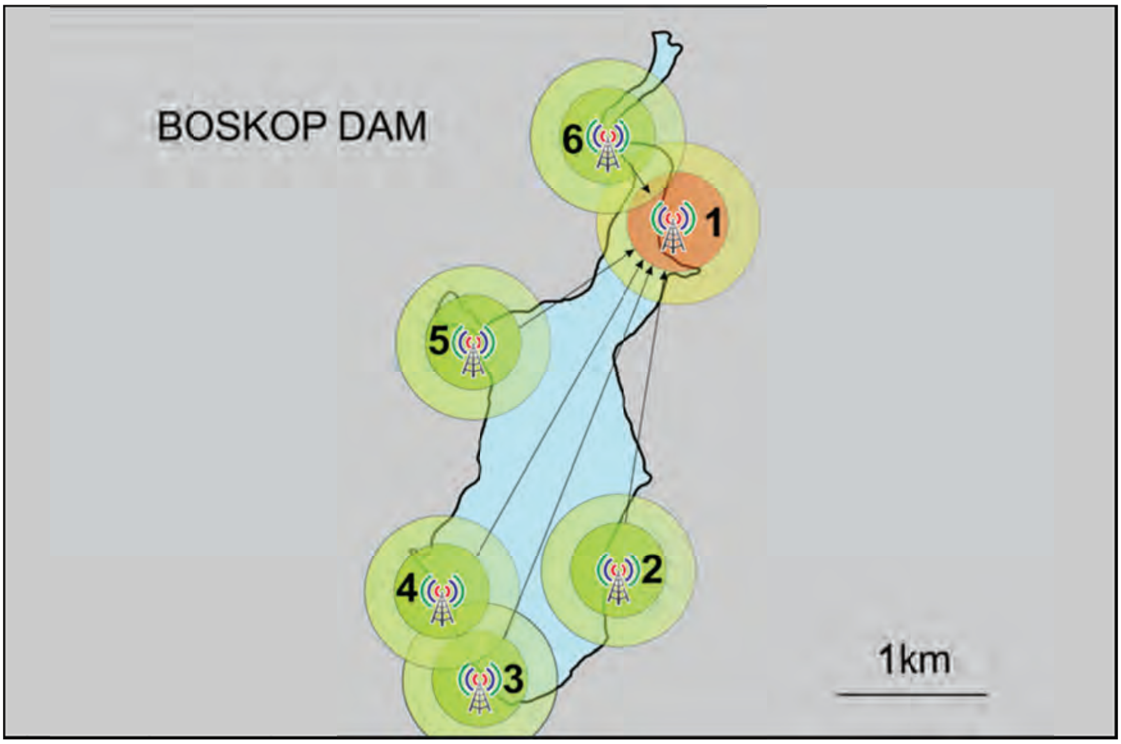


Figure 28: Map of remote base (orange) and relay (green) monitoring stations erected around Boskop Lake for the study.

Tracking methods

The following external WW radio tags were used in the study:

- WW-tag Series III – External fish mount tag with activity and temperature peripheral sensory components. Total mass: 20 g (+/-1.5 g)
- WW-tag Series V – External fish mount tag with activity, temperature and depth peripheral sensory components. Total mass: 20 g (+/-1.5 g).

- WW-tag Series VI – External fish mount transceiver with activity, temperature, depth and memory peripheral sensory components to save data obtained while the WW-tag is not within transmission range. The stored data is then transmitted when connection to a receiver is established. Total mass: 20 g ($^{+}$/-1.5 g).

The lifespan of the WW-tags used in the study exceed 365 days (based on a battery life expectancy with an 80% safety factor) on 10 minute default transmission scenarios.

Capture methods

For this case study the population of Orange Vaal smallmouth yellowfish (*Labeobarbus aeneus*) in the Boskop manmade lake were considered to be suitable for the tagging experiment (Figure 29). All methods used to capture yellowfish for this study were evaluated to prevent unrepresentative sampling and biased statistics (Rogers and White, 2002). Sampling methods included various netting techniques, angling techniques and the use of electro-shocker (electro narcosis). Netting techniques included large mesh gill nets that ranged between 93-120 mm so as to target only large individuals and minimise by catch. Gill nets were deployed in suitable habitats and monitored until visible movement indicated that fishes had entered. As soon as movement was observed fishes were immediately removed. Large fyke net traps 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. Cast nets were also used and involved a person walking or drifting up and down the study area and throwing the cast net in “suitable” areas. Electro fishing techniques were used in relatively shallow (<1.5 m) wadable areas. Three types of angling disciplines were used in this study. Fly-fishing techniques where anglers used artificial flies made from synthetic material to represent natural food of yellowfish. The second fishing technique included bait fishing. Fisherman using this technique rigged their lines with two or more hooks using worms, bread, sweet corn or crabs as bait. Suitable areas were chosen, usually close to a current where their rods would be rested on a tripod until a fish picked up the bait and jerked the line. Artificial lures were also used to target yellowfish.

Figure 29: A typical Orange Vaal smallmouth yellowfish (*Labeobarbus aeneus*) from the Boskop manmade lake, which was tracked in the study (note the attached Wireless WIldlife tag).

Tagging methods

Tags that were used in the study were attached externally to fishes following the 2% tag to body mass rule (Knights and Lasee, 1996; Winter, 1996; Koehn, 2000). This rule implies that tag mass used must not exceed two percent of the mass of the fish tagged. This ensures that the effect of the mass of the tag, attached to a fish is negligible, and that it does not affect the behaviour of the tagged fish. Once suitable yellowfish were captured they were immediately submerged into the collapsible tagging container. Care was taken to keep the fish in the water at all times and as a rule during the tagging procedure and physical handling was minimised. To begin the tagging process the out flowing tap on the container was closed and the bilge pump supplying fresh water was disconnected from the battery. Thereafter 10 ml of a pre-mixed bottle containing 2-phenoxy ethanol (0.4 $ml.l^{-1}$) was added to the tagging container. The tagging procedure was initiated when clean water was used to replace the water and 2-phenoxy ethanol mixture to initiate the recovery procedures, when signs of narcosis became evident. Signs of narcosis included; disorientation, decrease of the operculum movement, sluggish movement and on occasion the inability of the fish to maintain its position in the container which caused the anesthetised fish to roll over.

Tagging equipment was cleaned in ethanol prior to each use. In the anaesthetised state, two surgical needles were pushed through the musculature of the middle of the fish at the base of the dorsal fin (Figure 30). Nylon (0.5 mm) lines with plastic stoppers at one end were then threaded through the surgical needles (Figure 30D). Antibiotics (Terramycin containing oxytetracycline ®) are administered onto the line through the surgical needles and the needles are then removed leaving the line through the fish (Figure 30E). The ends of the nylon line, opposite to the stoppers, are then pushed through the holes of the radio tag which is positioned firmly against the fish (Figure 30F). Copper sleeves were then used to affix the tag to the fish and allow for the excess nylon line to be removed (Figure 30G-H). An antibiotic (Terramycin containing oxytetracycline ®) is then injected in the muscle (1 ml/kg) (Figure 30I), Betadine and or fish wound care gel (Aqua Vet) was administered to areas were fish have been touched (Figure 30J) and onto any wounds (Figure 30K) minimise infections. After tagging was completed descriptive measurements (total, fork and standard lengths and girth) as well as the mass of the tagged fish was recorded. The tagged yellowfish is left in the circulating water in the container until it revived (Figure 30L). A profile photograph was taken (Figure 30M) and yellowfish were fully revived and released back in close proximity to the capture location (Figure 30N-O).

Figure 30: Tagging process following capture and sedation of the yellowfish (A). Tagging procedures includes pushing surgical needles through the muscle at the base of the dorsal fin (B-C), nylon line with plastic stoppers are then threaded through the surgical needles (D). Needles are removed (E) and the tag is attached (F), copper sleeves are used to affix the tags (G-H), Terramycin, Betadine and wound care gel is used to treat and prevent infections (I-K), yellowfish are photographed, fully revived (L-M), and released (N-O).

Tracking and Monitoring

Yellowfishes were monitored directly after tagging, to establish their behavioural response to the tagging procedure and ensure survival. It is widely advised that a certain time period should be allocated before collecting data, as behaviour of fish in the first 24 hours of tagging may show recovery from anaesthetic and surgical procedures (Bridger and Booth, 2003). Thereafter tracking and monitoring of yellowfishes were done at specific and random intervals. For this study specific monitoring surveys was done according to the lunar cycle, where surveys would commence with full and new moon phases (Table 8). In addition random surveys were carried out throughout the study and were used to tag fishes, repair equipment and document behaviour in events such as cold fronts, rainfall and sudden changes in flows.

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

Study area	Specific/ Random	Season	Month	Survey dates	Moon phase	Aim
Boskop Dam	Random	Summer	Sep-11	6-7	First quarter	Erect remote monitoring stations
Boskop Dam	Random	Summer	Oct-11	5-6	First quarter	Tagging
Boskop Dam	Specific	Summer	Nov-11	4-16	Full moon	Tagging
Boskop Dam	Specific	Summer	Jan-12	23-30	New moon	Tagging
Vaal River	Random	Summer	Feb-12	10-12	Last quarter	Erecting remote monitoring stations
Vaal River	Random	Summer	Feb-12	15-16	Last quarter	Tagging
Vaal River	Specific	Summer	Feb-12	20-21	New moon	Tagging
Vaal River	Specific, 24hour	Summer	Feb-12	25-27	New moon	Document behaviour in rainfall/flow changes
Vaal River	Random	Summer	Feb-12	27-29	First quarter	Tracking and monitoring/Tagging
Vaal River	Random	Summer	March	14-16	Last quarter	Tracking and monitoring/Tagging
Boskop Dam	Random	Autumn	May-12	23	New moon	Maintenance check
Vaal River	Random	Autumn	May-12	24	New moon	Maintenance check
Vaal River	Random	Autumn	May-12	30	First quarter	Erect new remote monitoring stations
Vaal River	Specific	Winter	Jun-12	19-21	New moon	Tracking and monitoring/Tagging
Vaal River	Specific	Winter	Jul-12	3-5	Full moon	Tracking and monitoring/Tagging
Vaal River	Specific	Winter	Jul-12	18-20	New moon	Tracking and monitoring/Tagging
Vaal River	Random	Winter	Jul-12	26-27	First quarter	Cold front
Vaal River	Specific, 24 hour	Winter	Aug-12	1-3	Full moon	Cold front
Vaal River	Specific	Winter	Aug-12	13-15	New moon	Tracking and monitoring/Tagging
Vaal River	Random	Spring	Sep-12	7-9	Last quarter	First summer rains/flow changes
Vaal River	Random	Spring	Sep-12	29-30	Full moon	Document spawning

Manual tracking surveys involved initial queries of the data management system for the general availability of tags that are in range of a remote monitoring station. After identifying a suitable tagged fish to track manually its remote monitoring transmission scenario (6 transmissions per hour) were changed to tracking mode (1 transmission per second). The receiver would then display which tags are transmitting to which remote monitoring station. If a tag transmits frequently (transmits every 10 minutes) to a certain remote monitoring station, transmitting frequency could be changed to tracking mode (transmitting every second). Alternatively the mobile tracking receiver could be programmed to set a pending request (transmission) to change the transmission frequencies of tags within range of the receiver. Once the transmitting frequency of the tags changed (tag number displayed in green block), the manual tracking approach was implemented to locate the tag (accuracy <2 m). The manual tracking approach involved searching for the tag from the remote monitoring receiver that had been receiving transmissions prior to the transmission scenario change. The detection range of the tags from the manual receiver could exceed 500 m depending on the depth of the tag, elevation of the directional antennae above the water and occurrence of obstacles that may affect line of sight communications between tags and receivers. Once located the tagged fish were tracked for at least 12 consecutive 10 minute intervals. During these tracking surveys the movement (displacement) of the tagged fish, indicators of activity and various environmental variable states were recorded. These variables included; availability of habitat types, weather variables, disturbance to wildlife impacts, presence of predators and or predator activity, presence of prey items and or prey activity (such as insect hatches) and any other information that may have affected the behaviour of the tagged yellowfish.

5.2.3 Environmental variables

For this study some water quantity variables as well as habitat states, lunar cycles and weather variables were monitored. Water physic-chemical variables included: temperatures (^{o}C), pH and oxygen levels (mg/l) obtained from Department of Water Affairs' data logging stations in the Boskop Dam. Atmospheric variables including barometric pressure, rainfall and air temperatures were also monitored throughout the study from data obtained from local weather stations; Boskop Dam: C2R001Q01 UWQ and Vaal River: 04362041: Klerksdorp South African Weather Service and a calibrated SILVA ADC summit and SILVA ADC pro weather stations/anemometer. To evaluate the effect of lunar cycles on fish behaviour dedicated surveys planned and undertaken during new and full moon periods. Habitat types were classified using Hirschowitz et al. (2007). In addition to these habitats consideration, 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 where applicable. 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 was either collected from a Hummingbird ® 789CI side scan fish finder or from manual observations identifying different depths, substrates and flows, thereafter data is transferred onto a computer to create maps and further analysis.

5.2.4 Statistical evaluation of adult yellowfishes behavioural data collected throughout the study

Behavioural data were collected by evaluating movement in relation to changing environmental variables as anecdotal events, using field data collection sheets for manual monitoring surveys and remotely via the data management system. Field data collection sheets for manual monitoring surveys generally document the season, date, time, and tag number, GPS location of the tagged fish, movement (displacement) and activity of the animal, associated substrate, habitat, weather and moon phases. Data obtained from the remote monitoring systems through the WW data management system with internet based interface includes: location, activity, depth, and temperature of tags, which were in range of a remote monitoring station. This remote data could be accessed and downloaded from the data management system in a *.csv file format and then analysed.

The data generated by this biotelemetry study included movement and location data, that was mapped using a handheld GPS *e-Trex*® together with detailed aerial photographs. Spatial and temporal trends were then analysed using ARC GIS®. Using this approach each individual's spatial area use including: high area use, preferred areas and the relationships between location and environmental variables could be evaluated (Hodder et al., 2007). Relationships between the movement of yellowfishes in maximum displacement per minute (MDPM) and changes in the environmental conditions including: seasons, discharges, substrate types, habitat biotypes, cover (Kleynhans, 2007), atmospheric pressures and water temperatures were statistically analysed by the approach adopted by O'Brien et al. (2012). This approach used a mix-model analysis of variance (ANOVA) together with a coefficients model (Littell et al., 1996) and a Akaike's Information Criteria (AIC) (Burnham and Anderson, 1998) and were statistically analysed using SAS version 9.3 (SAS Institute, Cary, NC).

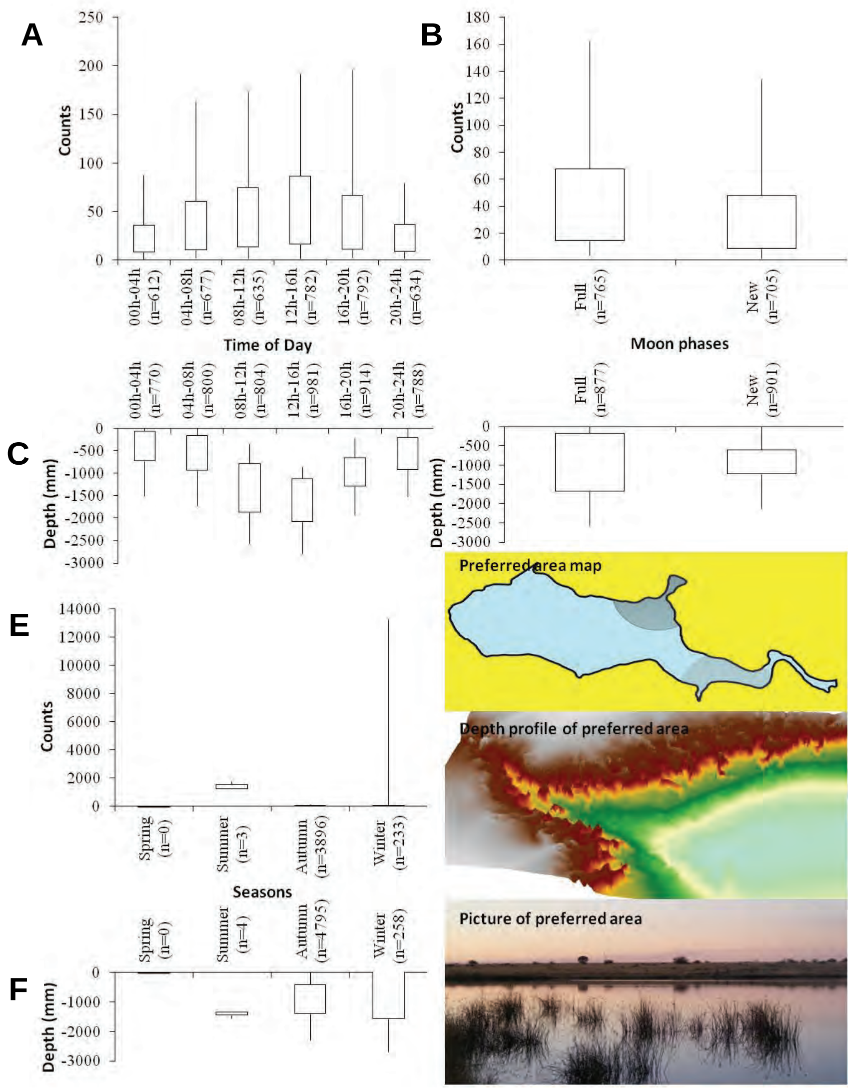
5.3 Results

The behavioural data available for the assessment was obtained from four individual *L. aeneus* that were tagged and tracked in the lake. Three of the four tags contained activity, temperature and depth peripheral components (WW Series IV tags) with the fourth tag not containing depth peripheral components (WW Series III tag). The tags were able to transmit to base stations at a maximum depth of about 2.5 m. From the study a total of 9153 data strings containing movement counts and temperatures for all tags and depth for three tags were recorded. The yellowfish made use of the entire lake and used and occupied a wide range of habitat types including vegetated areas, open water areas associated with boulders and other substrate types such as submerged trees. *Labeobarbus aeneus* numbers 40 and 43 exhibited low movement counts per minute <20 MC/m during the night 20h00-04h00, which increased >50 MC/m during day light periods from 08h00-20h00 (Figure 31). Highest mean movement counts >60 MC/m were observed during the 12h00-16h00 period. During this time period the yellowfish preferred deeper water >1.5 m. The same trend for moon phases was observed, where fish kept relatively deeper (>1 m) in full moon phases than they did during new moon phases (<1 m). Higher movement counts >300 MC/m were observed during spring and summer than during <300 MC/m autumn and winter. Very little seasonal data were collected throughout spring and summer, but autumn had high confidence with (n = 5029 fixes). Deeper water >1.5 m were preferred during autumn and winter than during summer <1 m. Tag number 36 (Figure 32) displayed the same movement trends as tag 40 and 43; however there is no depth data available for the tag.

Labeobarbus aeneus number 39 (Figure 32) followed the same low movement counts <50 MC/m during dark hours of the day 20h00-04h00 whereas mean movement counts were greater >1998 MC/m during periods from 08h00- 20h00. Highest movement counts >4000 MC/m were observed during the time period between 04h00-08h00. This fish preferred shallower water <1 m during day light hours of the day and preferred deeper water >1.5 m during dark hours. Higher mean movement counts >4000 MC/m were observed during new moon phases than during full moon phases <4000 MC/m. Shallower mean water depths <0.5 m were preferred during new moon phases than during full moon phases >1.5 m. Highest movement counts were observed during spring >4000 MC/m and summer >2000 MC/m were yellowfish also preferred shallower water <0.65 m in spring and summer <1.1 m.

Combined results (Figure 33) of all four tagged *L. aeneus* showed that movement counts were low <50 (MC/m) during dark hours of the day 20h00-24h00, whereas mean movement counts were highest >340 MC/m during light periods from 08h00- 20h00. During time period 08h00-20h00 *L. aeneus* preferred deeper water >1.5 m than during time period 20h00-24h00 were they preferred shallower water <1 m. New moon phases showed higher movement counts than full moon phases, and *L. aeneus* preferred shallower water <1 m during new moon phases than full moon phases. Higher movement counts were observed during spring and summer where *L. aeneus* also preferred shallower water <1 m than during autumn and winter were they preferred deeper water >1.5 m.

Manual tracking results revealed that *L. aeneus* in Boskop Dam congregates in shoals that can be seen roaming the dam. The home range of the single population of *Labeobarbus aeneus* as such extends across the dam (Tomasson *et al.,* 1985). In the study tag were tracked by all remote monitoring stations set up around Boskop Dam. During the study a high use or preferred area of the dam for *L. aeneus* was observed (Figure 34). This area is located within the range of remote monitoring station #5. The preference for this area was heightened during autumn and winter. This area had deep water of up to 8 m and consisted of various habitat types including rocky substrates, weeds, grass beds and reeds. During the study, Remote monitoring station #5, situated near this preferred area, recorded the bulk of the data (n = 4895).



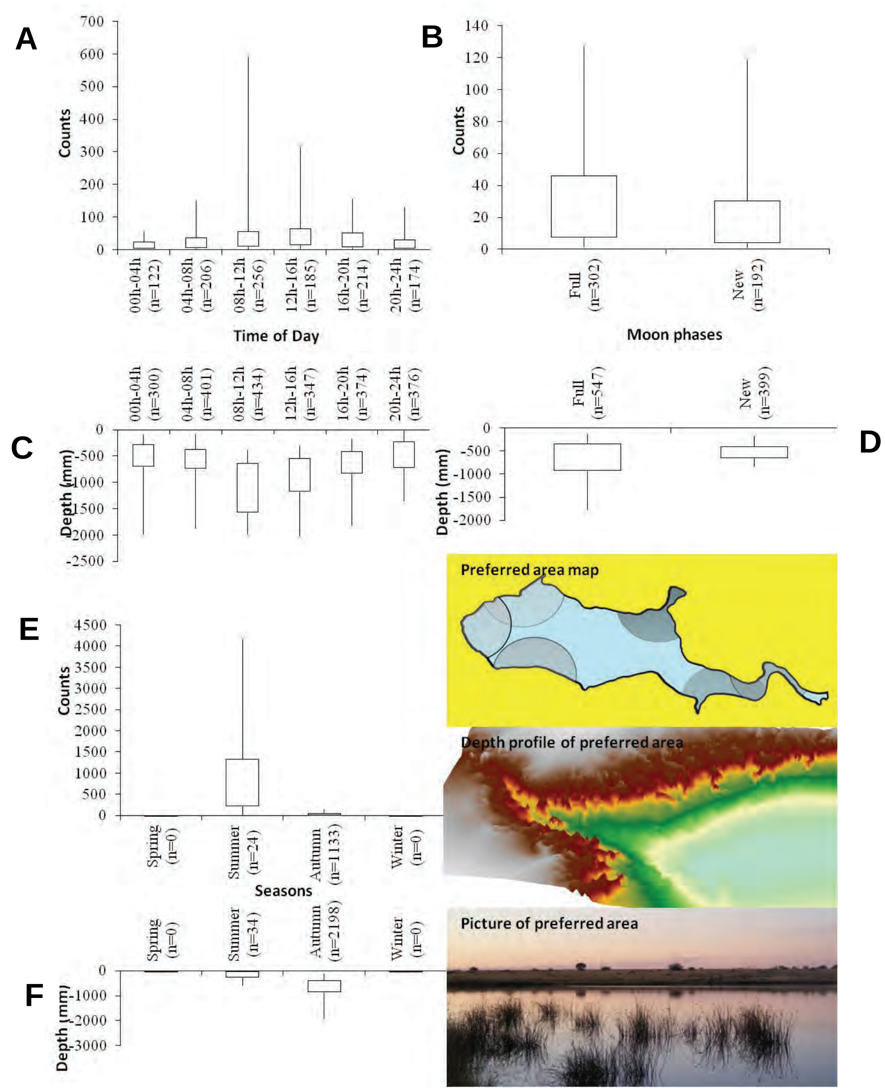
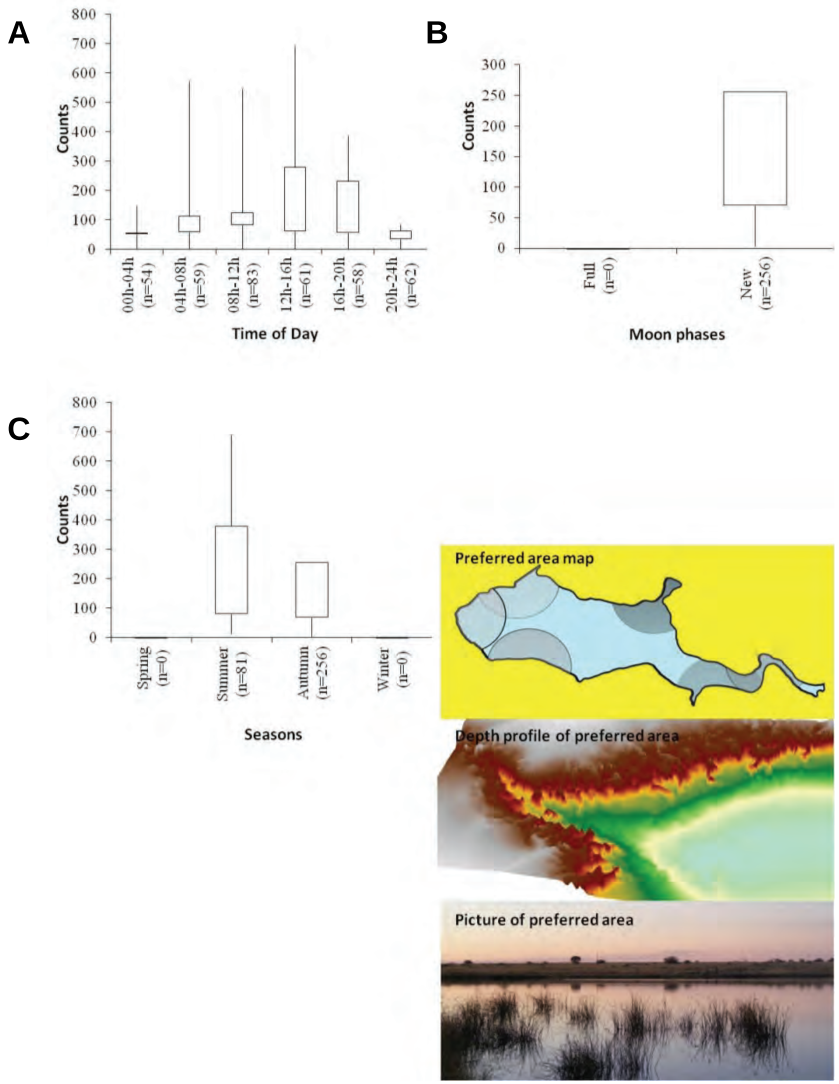


Figure 31: Graphical box and whisker plot presentation of *Labeobarbus aeneus* number 40 and 43. Y axis is movement counts per minute (MC/m) (A, B, E) and depth (mm) (C, D, F): plotted against, time of day, moon phases and seasons. Inserts is map of recorded locations for *Labeobarbus aeneus* with a depth profile and photograph of the preferred area. Box limits represent the 25th and 75th percentiles while whiskers represent 5th and 95th percentiles.



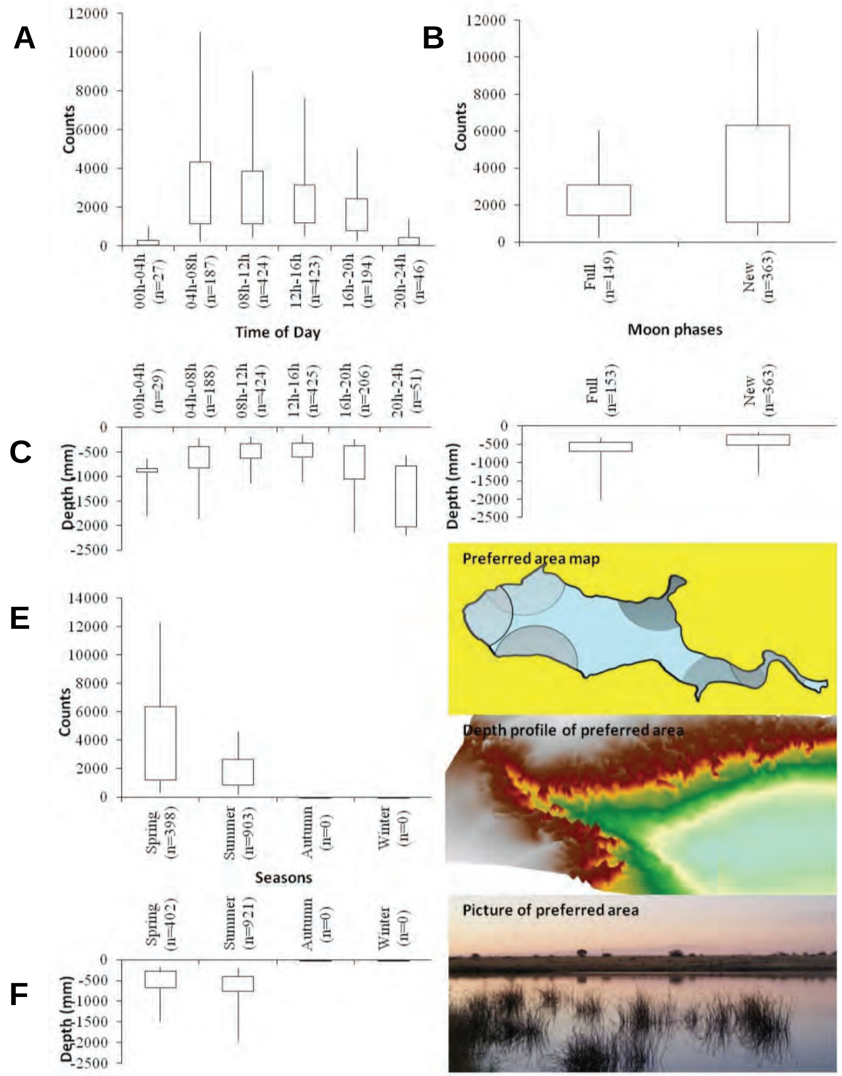


Figure 32: Graphical box and whisker plot presentation of *Labeobarbus aeneus* number 36 and 39. Y axis is movement counts per minute (MC/m) (A, B, E) and depth (mm) (C, D, F): plotted against, time of day, moon phases and seasons. Insert is map of recorded locations for *Labeobarbus aeneus* with a depth profile and photograph of the preferred area. Box limits represent the 25^{th} and 75^{th} percentiles while whiskers represent 5^{th} and 95^{th} percentiles.

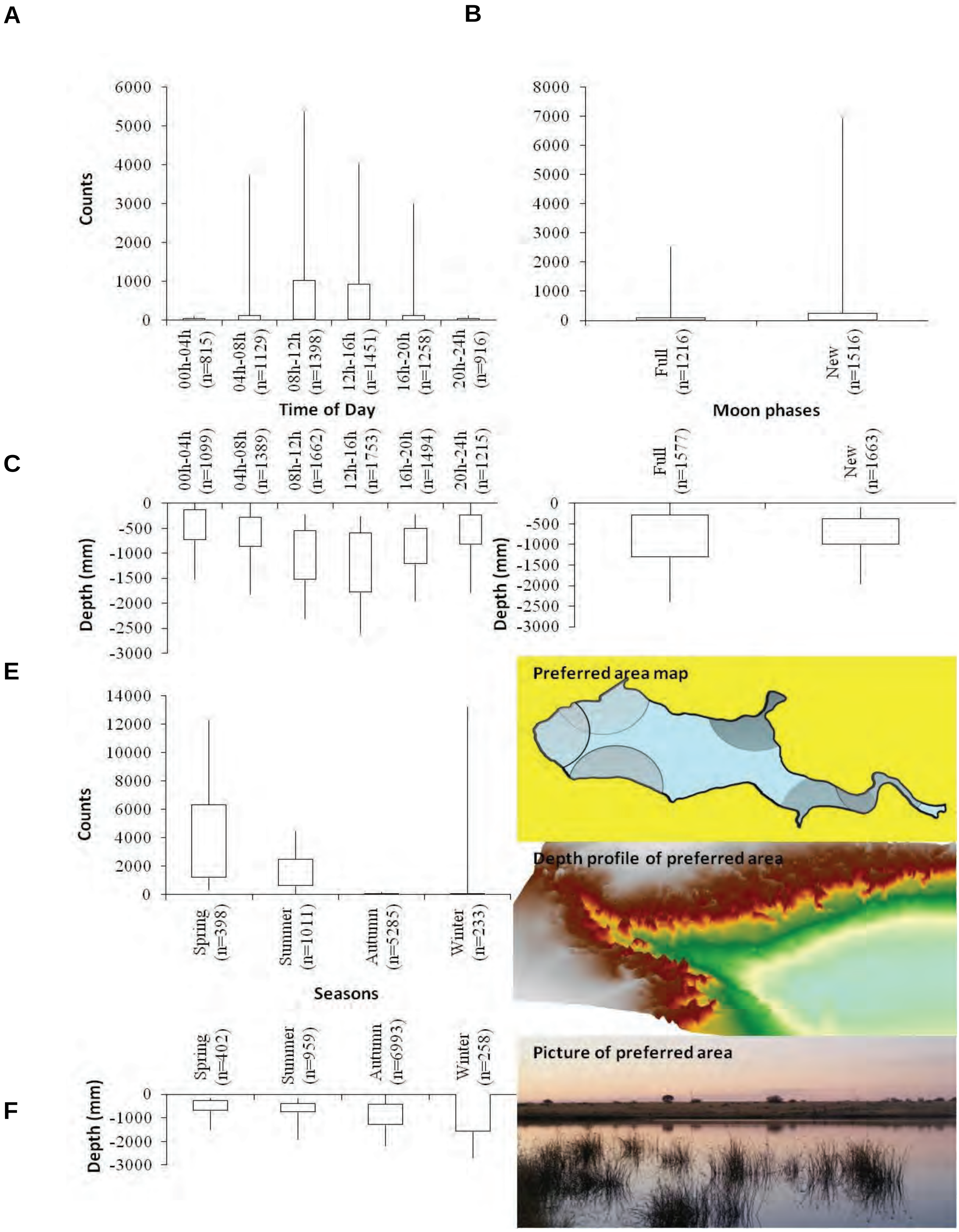


Figure 33: Accumulation of the behavioural findings for all *Labeobarbus aeneus* individuals considered in the study. Y axis is movement counts per minute (MC/m) (A, B, E) and depth (mm) (C, D, F): plotted against, time of day, moon phases and seasons. Inserts is a map of recorded locations for *Labeobarbus aeneus* with a depth profile and photograph of the preferred area. Box limits represent the 25th and 75th percentiles while whiskers represent 5th and 95th percentiles.

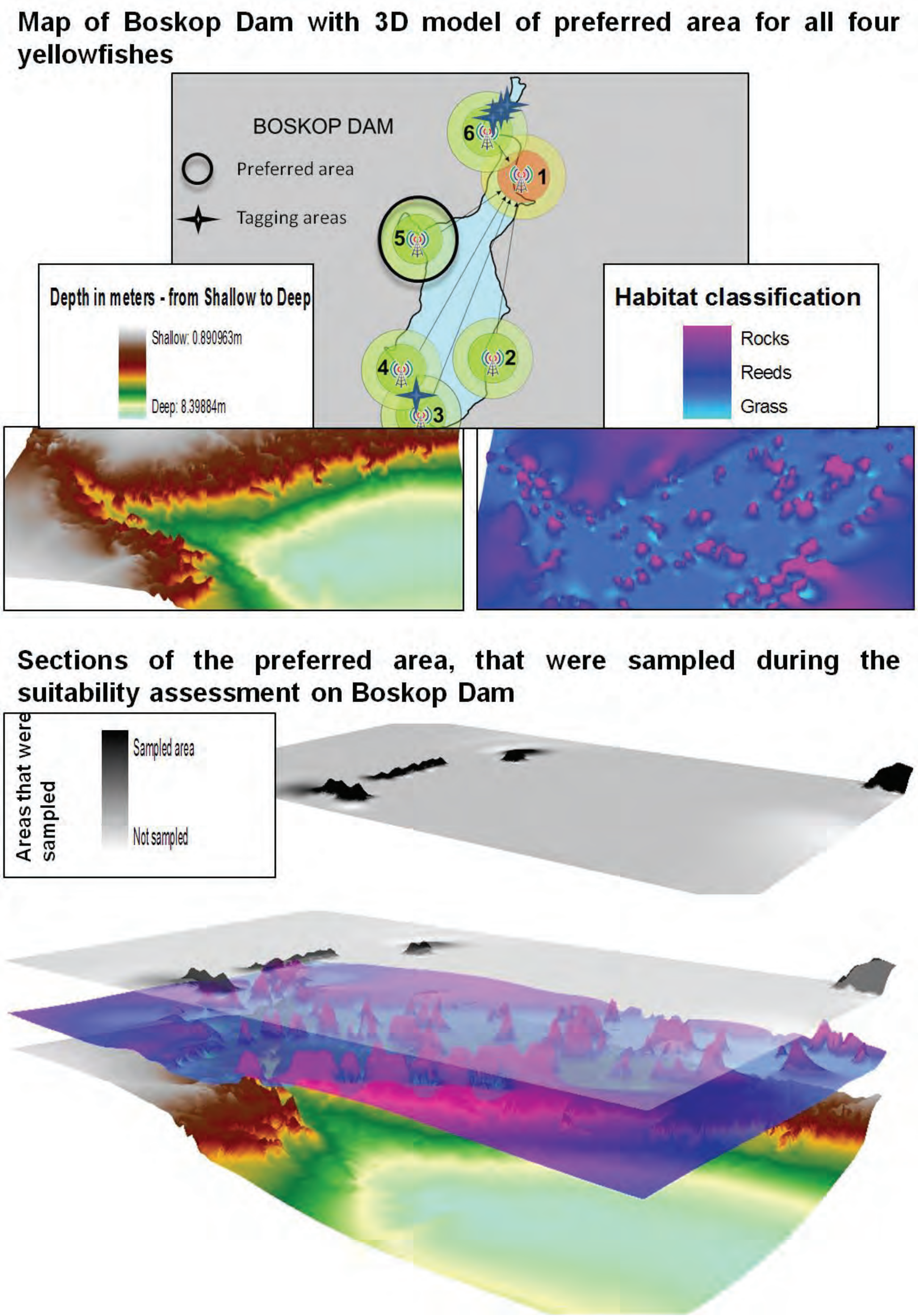


Figure 34: Map of the preferred location in Boskop Lake where the tracked *Labeobarbus aeneus* individuals frequented during the study, predominantly during autumn and winter. The 3D model includes depth, substrate and sampled sites information.

5.4 Discussion

In the study, WW radio telemetry systems were successfully used to characterise and evaluate the general movement behaviour of the adult *L. aeneus* individuals in Boskop Lake. The outcomes showed that the local *L. aeneus* population to be diurnal with increased movement during the day. The yellowfish preferred relatively deeper habitats during this time which corresponds to the habitat use of other cyprinid fishes in lentic ecosystems during the day (Godin, 1990; Sih, 1993). The increased movement of individuals observed during the day however suggests that the yellowfish were not holding during these periods but foraging as shown by O'Brien et al. (2012). This suggests that the *L. aeneus* population may use sight to forage for benthic algae and invertebrates (Mulder, 1971; Mulder, 1973; Gaigher and Fourie, 1984; Skelton, 2001). The possibility of the driving variable being light intensity was supported by findings from the increased movement and depth preference of the tagged yellowfish during full moon phases compared with new moon phases.

Findings showed that movement of the adult yellowfish increased during the warmer spring and summer seasons compared to the autumn and winter seasons. Similar movement changes of *L. aeneus* were observed by O'Brien et al., (2011) in the Vaal River. Lower movement counts were correlated with the use of deeper water in autumn and winter suggesting that *L. aeneus* forage less during these periods. This behaviour has been demonstrated by other cyprinids (Akhtar, 2002), that spend less energy moving around searching for food in these cooler months. Similarly, studies on *Tor Putitora* (mahsheer) another large barbine cyprinid indicate that they do not feed below 16°C and show very little movement (Akhtar, 2002). This has also been documented in other Cyprinid species including *Cyprinus carpio* (common carp) that do not feed at ≤ 10°C and reduce movement noticeably (Baily, 1985). In this study temperatures were that are linked to seasons were shown to affect movement of the *L. aeneus* where cooler temperatures resulted in reduced movements. Reduced temperatures have previously been shown to affect the physiology of *L. aeneus* (Eccles 1985).

In the study the yellowfish preferred two areas that were favoured by tagged individuals. These areas were shown to be preferred refuge areas which may also contain suitable spawning habitats. The preferred area where the Mooi River enters the lake contains a gravel bed dominated biotope on the southern part of the lake near remote monitoring station 2. This type of habitat has been shown by Groenewald (1951), Jubb (1966), Mulder (1971), Mulder (1973) and O'Brien and De Villiers (2011) to be suitable for spawning by

L. aeneus. Although no spawning activity of the tagged *L. aeneus* 39 and 40 were observed, these individuals congregated in this area with other *L. aeneus* individuals during spring which suggests that the shoal may have been preparing to spawn. Both of the favoured areas of the *L. aeneus* population are situated inside the Boskop Nature Reserve, protected area. It is therefore possible that *L. aeneus* prefer these protected areas for refuge from recreational angling and boating activities.

CHAPTER 6: THE EFFECT OF DIURNAL, LUNAR AND SEASONAL CYCLES ON THE MOVEMENT OF ADULT VAAL-ORANGE YELLOWFISHES (*LARBEOBARBUS AENEUS* AND *LARBEOBARBUS KIMBERLEYENSIS*) IN THE VAAL RIVER, FREESTATE.

6.1 Introduction

The Vaal River yellowfishes (*Labeobarbus kimberleyensis* and *L. aeneus*) are vulnerable to anthropogenic activities as the slow growing late maturing biology of the species suggests that recovery rates from impacted populations would be slow (Skelton et al., 1991; Granek et al., 2008; Ellender et al., 2012). Behavioural studies incorporating radio telemetry techniques have been used locally and abroad to characterise the behavioural response of many fishes in riverine ecosystems to changing environmental variable states (Barlow, 1993; Koehn, 2000; Rogers and White, 2007; O'Brien et al., 2012). The effects of moon cycles, temperatures and flows on yellowfish in the Vaal River are poorly understood and need attention (O'Brien and De Villiers, 2011).

Radio telemetry techniques have been used to characterise basic biological parameters of fishes such as movement and critical habitat requirements using a small number of individuals (Priede, 1991; Stormer and Maceina, 2009). Radio telemetry studies have also been used to evaluate the ecological consequences of changes in ecosystem conditions such as rapid increases in flows and temperatures changes. Although these methods are well established internationally, the approach has only recently received attention in developing countries including southern Africa (Økland et al., 2005; Næsje et al., 2007, Cowley et al., 2008; O'Brien et al., 2012).

In this chapter we evaluate the effects that diurnal, lunar, seasonal cycles and flow changes have on the behaviour of adult Vaal-Orange yellowfishes (*L. aeneus* (n = 14) and *L. kimberleyensis* (n = 3)) in the Vaal River, Free State.

6.2 Materials and methods

6.2.1 Study area

This portion of the study has been carried out in a reach of the middle Vaal River, within an access controlled wilderness area called Wag 'n Bietjie conservation area, close to Bothaville (Figure 35). Within this reach both *L. kimberleyensis* and *L. aeneus* are abundant

(O’Brien et al., 2011). Habitat diversity of the reach was considered to be representative of the middle reach of the Vaal River and included a high diversity of both deep (up to 5 m) and shallow areas (<0.5 m) with slow (<0.3 m/s) and fast (>0.3 m/s) flowing habitat types. Although some gauging weirs and other barriers that may affect the movement of yellowfish exist in the study area, all of the yellowfish monitored in the study had access to relatively large unobstructed reaches of the Vaal River (>75 km).

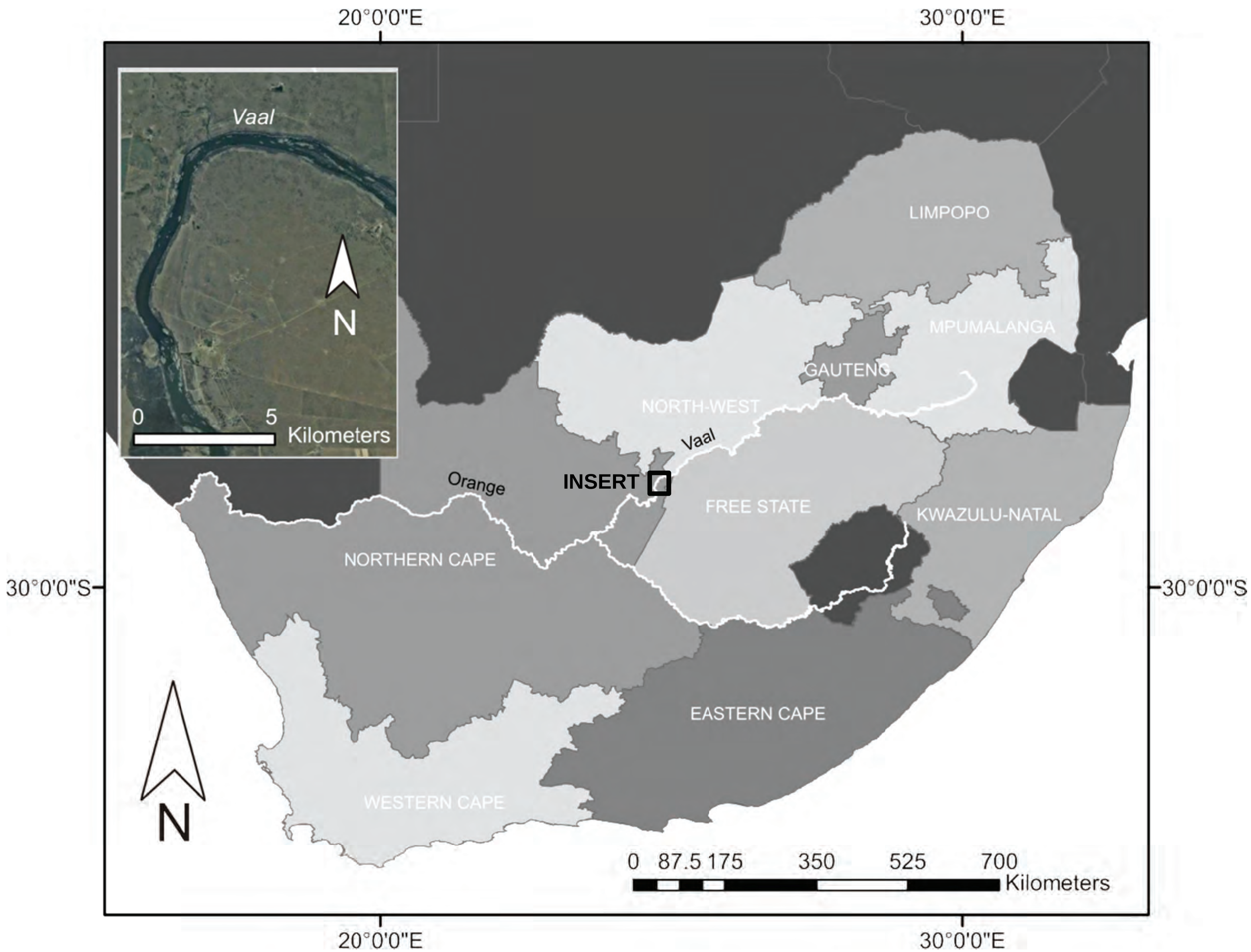


Figure 35: The reach of the Vaal River chosen for the radio telemetry evaluation of the Orange Vaal largemouth and smallmouth yellowfishes (*Labeobarbus kimberleyensis* and *L. aeneus*), on the border between North-West province and Free State province, South Africa.

The area contained a large diversity of habitat types including; deep pools undercut banks with submerged roots and trees, fast rapids, riffles with reeds and vegetation, sand, gravel beds with boulders and aquatic vegetation (Figure 36). This lotic system is situated in a summer rainfall region and receives an annual rainfall of 500-600 mm (Free State Tourism, 2010). In addition large parts of the Vaal River upstream has been transformed in many ways, these include; quality of water, quantity alterations, timing and duration of flows, habitat modifications and impacts associated with alien invasive species, however 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*., 2004).

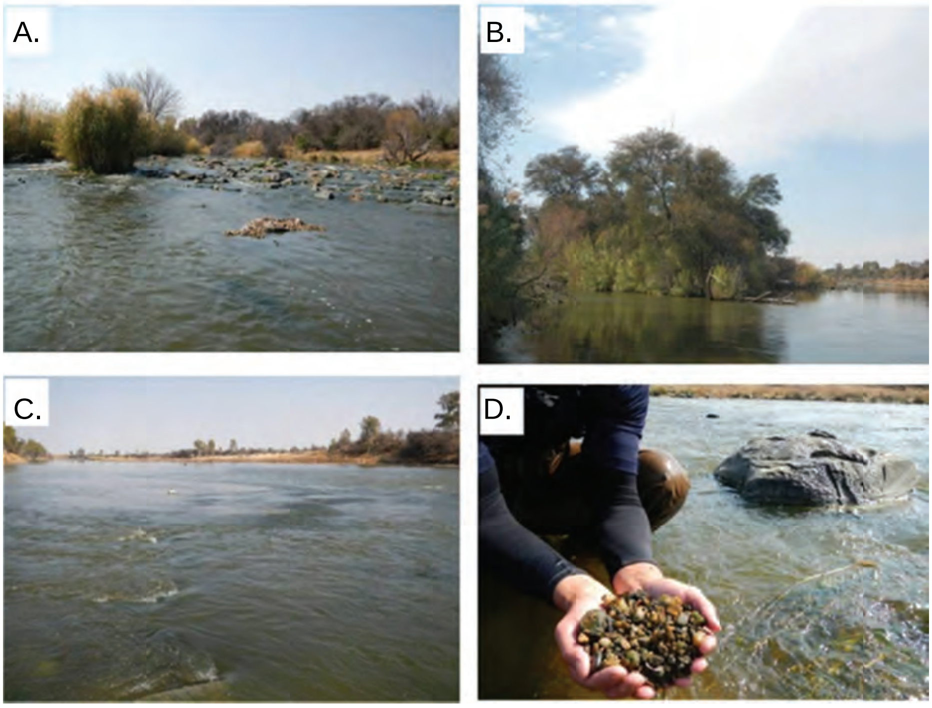


Figure 36: The Vaal River study area has a large diversity of habitat types including; riffles, runs and glides with fast to moderate flows (A), deep pools with abundant cover and substrate types (B) a broad main channel with a high diversity of depths, flows and substrate types (C) and extensive sand, gravel beds (D).

6.2.2 Radio telemetry techniques

In this study all the remote monitoring stations were erected within the Wag n Bietjie conservation area along the Vaal River (Table 9). The stations were positioned to establish a radio network coverage of the whole study area, the first remote monitoring station was set up on an elevated water tank ± 20 m. The remaining seven relay stations were positioned within range (line of site) of the base station, up to 5 km away. 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.

Table 9: Remote monitoring stations at the Vaal River including: GPS position, allocated number, station code and contact person.

GPS position	Allocated number	Station code
27° 9'37.96"S 26°27'10.04"E	1	249
27° 7'53.23"S 26°29'4.83"E	2	242
27° 9'18.02"S 26°27'5.09"E	3	253
27° 9'1.42"S 26°26'25.50"E	4	255
27° 9'1.85"S 26°26'3.57"E	5	245
27° 9'8.27"S 26°25'39.51"E	6	251
27° 9'16.65"S 26°25'33.89"E	7	243
27° 9'47.55"S 26°25'25.46"E	8	247

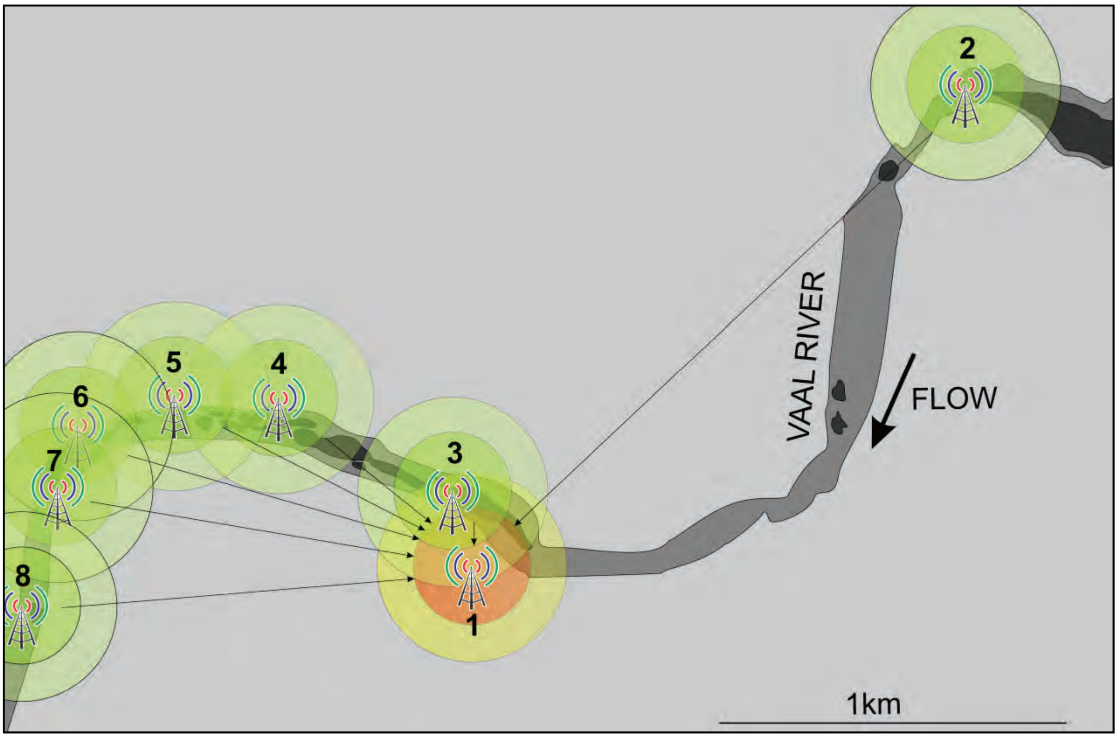


Figure 37: The Vaal River remote monitoring system, including: one base station (1) and 7 repeater stations (2-8).

Capture and tagging methods

The Orange Vaal yellowfishes (*Labeobarbus aeneus* (Figure 29) and *L. kimberleyensis* (Figure 38)) used in the study were captured using various netting and angling techniques and using an electrofisher (1 kV). The netting techniques included the use of monitored gill nets deployed in the evening and early morning, large fyke net traps and large seine nets. Seventeen yellowfishes used for the Vaal River portion of the study were sedated, measured, tagged and released back into the Vaal River after capture. The yellowfishes had an average mass of 2.49 kg. General information of each fish tagged was recorded on a data sheet for future reference (Table 10).

Figure 38: A typical Orange Vaal largemouth yellowfish (*Labeobarbus kimberleyensis*) from the Vaal River, which was tracked in the study.

Table 10: General information of yellowfishes captured, tagged, released and monitored in the Vaal River

Vaal River				(g)	(mm)	(mm)	(mm)	(mm)	
Species	Capture date	Capture method	Tag	Mass	Total length	Fork length	Standard length	Girth	Season
L. aeneus 1	15/02/2012	Fly-fishing	50	2350	580	520	500	310	Summer
L. aeneus 2	20/02/2012	Electro fishing	44	1800	520	470	450	240	Summer
L. aeneus 3	20/02/2012	Electro fishing	46	2300	570	540	470	300	Summer
L. aeneus 4	20/02/2012	Electro fishing	47	2100	490	445	405	270	Summer
L. aeneus 5	20/02/2012	Electro fishing	49	2500	568	525	490	330	Summer
L. aeneus 6	20/02/2012	Electro fishing	51	1400	520	450	420	220	Summer
L. aeneus 7	20/02/2012	Electro fishing	53	4000	680	625	580	390	Summer
L. aeneus 8	20/02/2012	Electro fishing	37	2100	560	490	420	305	Summer
L. aeneus 9	20/02/2012	Electro fishing	38	2500	580	535	500	380	Summer
L. aeneus 10	21/02/2012	Electro fishing	45	1900	540	480	455	290	Summer
L. aeneus 11	21/02/2012	Electro fishing	52	2500	570	525	500	330	Summer
L. aeneus 12	01/08/2012	Lure fishing	20	2400	568	511	487	370	Winter
L. aeneus 13	01/08/2012	Lure fishing	33	2800	570	520	480	380	Winter
L.aeneus 14	07/09/2012	Bait fishing	109	4550	670	610	560	380	Autumn
L. kimberleyensis	20/02/2012	Electro fishing	48	1150	485	430	400	240	Summer
L. kimberleyensis	18/07/2012	Gill nets 120 mm	54	2300	530	510	500	300	Winter
L. kimberleyensis	02/08/2012	Gill nets 120 mm	47	3800	560	520	510	320	Winter

6.2.3 Environmental variables and statistical analyses

Similarly to Chapter 4, for the daily movement assessment six periods divided into 4 hr natural breaks were selected for the study. These periods included 24h00-04h00, 04h00-08h00, 08h00-12h00, 12h00-16h00, 16h00-20h00, 20h00-24h00. The seasonality assessment made use of the summer season patterns for the Southern Hemisphere's subtropical zone, specifically for South Africa which is located between the 22nd and 34th horizontal degrees south of the equator (Gertenbach, 1980). As such for this study spring was considered to occur from September to November, summer occurs between December and February, autumn occurs between March and May and winter occurs between June and August. Relationships between the movement of yellowfishes and diurnal, lunar and seasonal cycles were statistically analysed by the approach adopted by O'Brien et al. (2012). This approach used a mix-model analysis of variance (ANOVA) together with a coefficients model (Littell et al., 1996) and a Akaike's Information Criteria (AIC) (Burnham and Anderson, 1998) and were statistically analysed using SAS version 9.3 (SAS Institute, Cary, NC) (refer to Chapter 5).

6.3 Results

Findings revealed that although some variation existed between individuals of the same species the majority of the *L. aeneus* individuals (numbers 20, 30, 46, 47, 49, 51, 52, 53) generally exhibited similar movement patterns throughout the study. The yellowfish were shown to be more active during the day compared to night time movements. Mean movement counts per minute of <55 MC/m were observed at night 20h00 – 04h00 which then increased to >61 MC/m between 08h00-12h00 and between 16h00-20h00 (Figure 39). High mean movement counts >77 MC/m were observed from mid-day from 12h00-16h00 and for *L. aeneus* numbers 46 and 47 with extremely high movement counts >400 (MC/m) between 08h00-12h00. During the active periods from 08h00 to 20h00 the adult *L. aeneus* individuals occupied relatively shallow habitats <0.9 m compared to inactive periods (>1.2 m) (Figure 39).

Moon phases were shown to affect the movement of the yellowfish in the Vaal River significantly ($p < 0.05$) (Figure 39). Results showed that movement increased during full moon phases (individuals 46 and 52) for example. During full moon periods the yellowfish occupied relatively shallow habitats (<0.9 m) compared with new moon low behavioural periods (>1 m). Some variation in depth preferences during moon phases were observed however such as individual 47 which preferred deeper water during full moon phases.

Seasonal variations in movement were also shown to be significant in this study ($p < 0.05$) (Figure 40). In this study the movement of the yellowfish was at its greatest during summer (average >200 MC/m). Thereafter during spring movement counts reduced to an average below <130 MC/m (n=2735), and continued to reduce in autumn and winter <100 (MC/m) (n=10105). In general the associated preferred habitats of the yellowfish included deep >1.2 m area during autumn and winter which changed to <0.7 m during summer and spring.

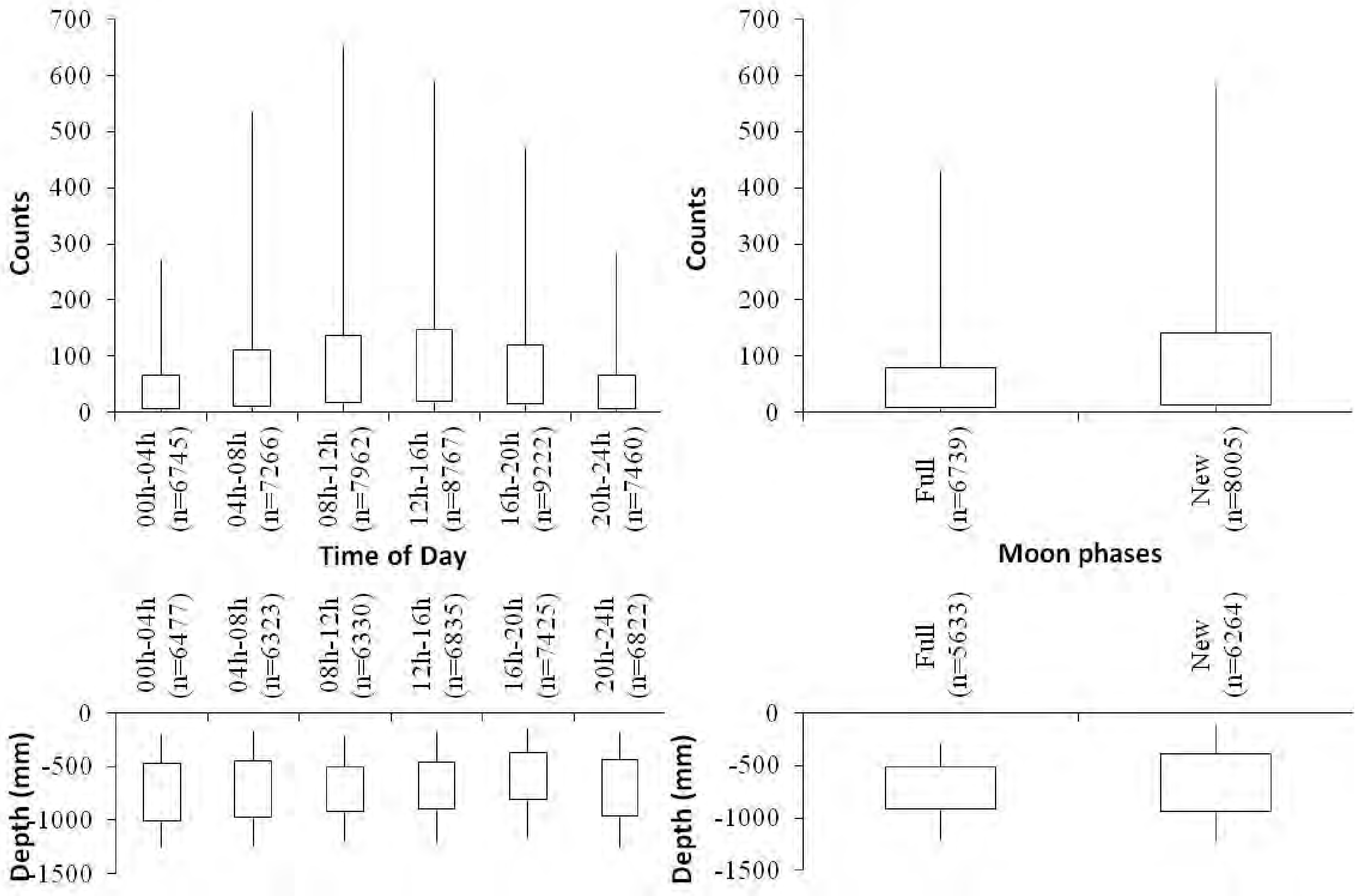


Figure 39: Variability of movement of the *Labeobarbus aeneus* tagged and tracked in the study due to diurnal cycles and moon phases. Box limits represent the 25th and 75th percentiles while whiskers represent 5th and 95th percentiles.

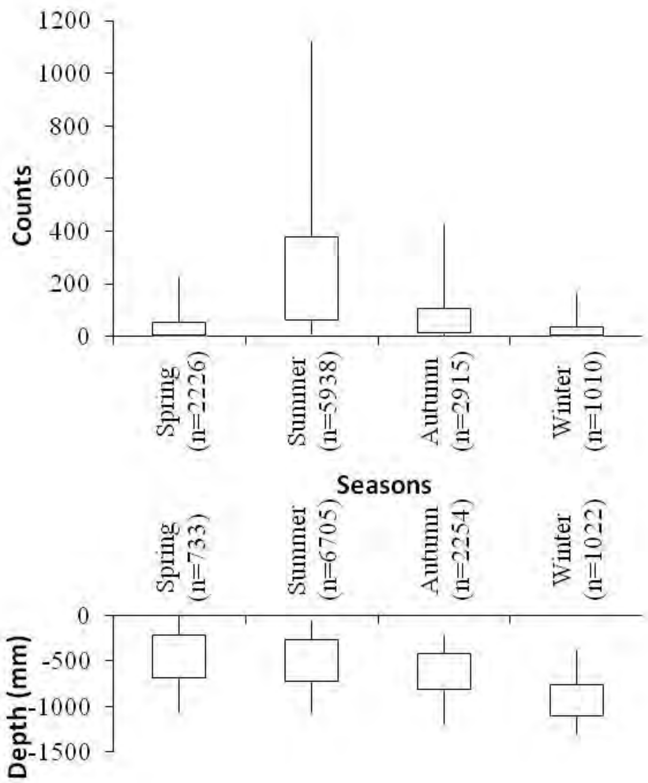


Figure 40: Variability of movement of all of the *Labeobarbus aeneus* tagged and tracked in the study between seasonal cycles. Box limits represent the 25th and 75th percentiles while whiskers represent 5th and 95th percentiles.

Although the *L. kimberleyensis* individuals moved significantly more ($p < 0.05$) that the *L. aeneus* individuals. The diurnal difference in movement was similar. The *L. kimberleyensis* individuals monitored in the study exhibited low mean movement patterns <122 MC/m during dark hours of the day 20h00-04h00 whereas mean movement counts more than doubled to >288 MC/m during daylight periods from 08h00-20h00 (Figure 41). Similarly during the day *L. kimberleyensis* individuals preferred deeper areas >1.33 m compared with relatively shallower habitats <1 m occupied during the night. Movement behaviour during moon phases; resulted in yellowfishes generally moving more >122 MC/m in full moon phases than during new moon phases <82 MC/m, but generally kept shallower <0.5 m in new moon phases than they did during full moon phases >0.8 m (Figure 41). Highest mean movement counts of these highly mobile yellowfishes exceeded >1200 MC/m during summer. No data could be collected for spring, however autumn showed low mean movement counts of 118 MC/m whereas winter movement counts were very low with only <50 MC/m being observed. In general deeper habitats >0.8 m were preferred during autumn than during summer, however shallow water was occupied during some periods in winter <0.5 m (Figure 42).

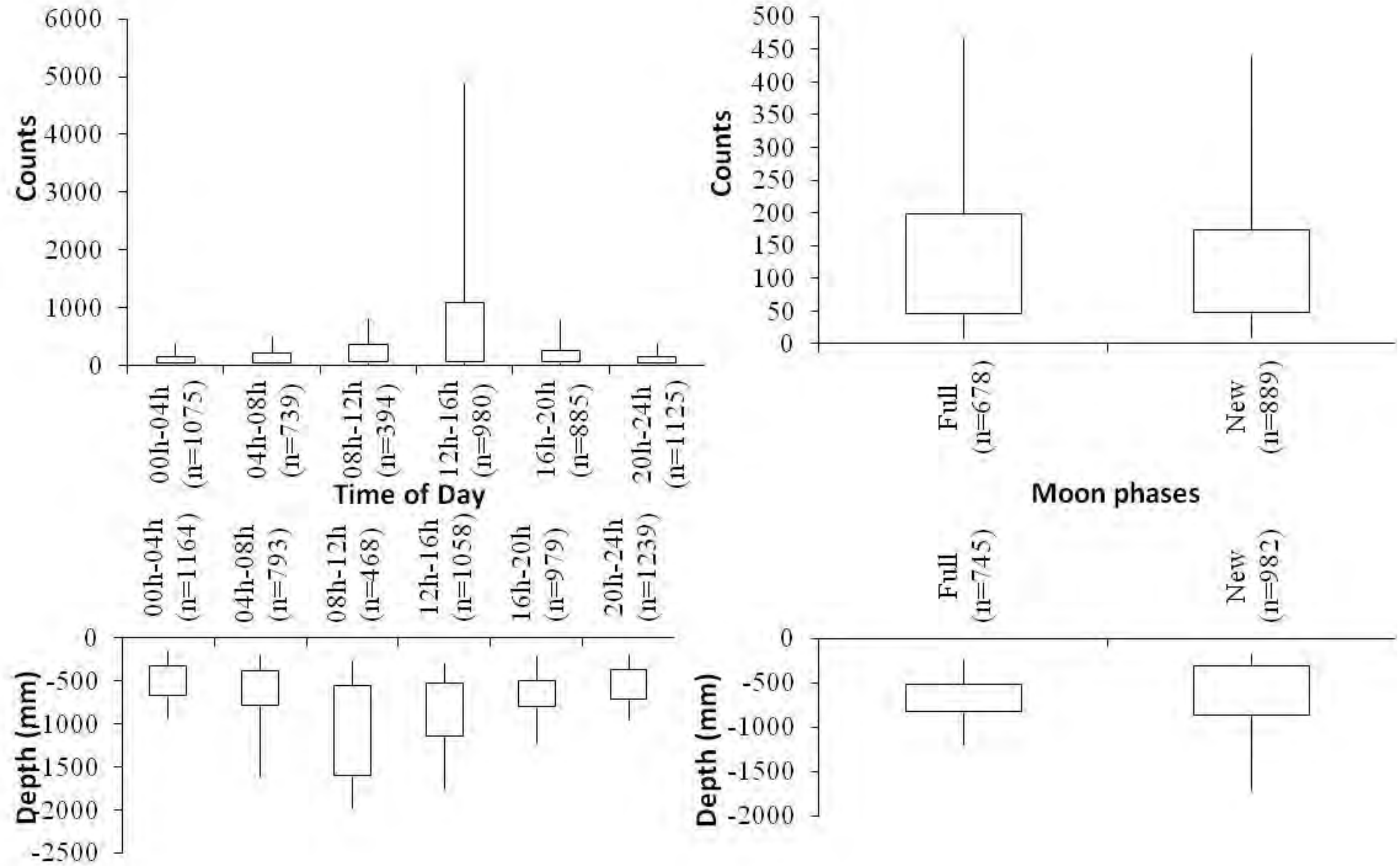


Figure 41: Variability of movement of the *Labeobarbus kimberleyensis* tagged and tracked in the study due to diurnal and lunar cycles. Box limits represent the 25th and 75th percentiles while whiskers represent 5th and 95th percentiles.

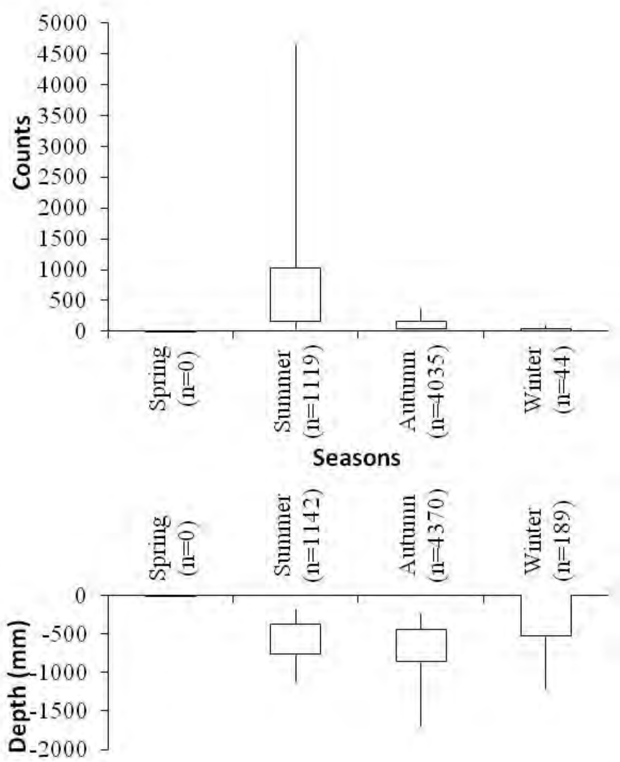


Figure 42: Variability of movement of the *Labeobarbus kimberleyensis* tagged and tracked in the study due to seasonal cycles. Box limits represent the 25th and 75th percentiles while whiskers represent 5th and 95th percentiles.

6.4 Discussion

A wide range of behavioural ecology aspects of many adult cyprindis including movement and the response to changing environmental variables has been evaluated using radio telemetry techniques (Clough et al., 1998; Økland et al., 2003; Penne and Pierce, 2008). The findings of this study revealed that the Vaal River yellowfish are diurnal fishes that forage primarily during the day which is associated with increases in movement during this time. Furthermore the movement of the yellowfishes increases in spring and summer from reductions in autumn and winter. Although this significant change in movement is associated with seasons the decreasing temperatures in winter are considered to be the driving variable of this change in movement. O'Brien et al. (2011) found that sudden temperature changes in winter cause disruptions to the routine behaviour of the Vaal River yellowfishes. These findings reaffirm that temperature changes associated with seasonal changes are important drivers of yellowfish behaviour in the Vaal River.

CHAPTER 7: HOW THE FUNCTIONALITY OF WIRELESS WILDLIFE DIGITAL RADIO TELEMETRY, FISH TRACKING SYSTEMS COMPARE WITH INTERNATIONAL SYSTEMS.

In this study comparisons were made between ATS radio telemetry systems applied by O'Brien et al. (2011) using yellowfish in the Vaal River, O'Brien et al. (2012) using tigerfish in the Schroda and Letsibogo manmade lakes and in Chapters 3 and 4 with WW radio telemetry systems (Chapters 3-6). Outcomes showed that commercial production of bidirectional transceivers or "smart tags" by WW for use on fish in inland waters allows for greater functionality compared to other commercially available systems such as systems offered by ATS as well as other manufacturers (Lotek telemetry systems) (ATS, 2013; Lotek, 2013). The most common radio tags used internationally are still based on analog radio systems that transmit pulses on a scheduled rate, where each tag on its own frequency (ATS F1900, F1905, F2000, F2110). There are however a number of new digital options available internationally that transmit their identification (ID) on the same frequency band (called coded transmitters, e.g. Lotek MST and MCFT2 series). One of the most advanced tags are the MST series of Lotek tags which can be programmed to send its ID, motion and temperature on a certain pre-programmed schedule (Lotek MST series[1]). The transmissions of all of these tags are however still one directional and cannot be configured in the field. In the wider context of wildlife telemetry, some bidirectional tags have been developed for use on terrestrial animals (e.g. EcoLocate, Markham et al. (2008)). However, these systems are mostly not commercially available and are not available for use with aquatic animals in aquatic ecosystems. Comparisons between ATS and WW technical support options, radio telemetry systems (general), receivers and transmitters/transceivers are presented in Table 11.

[1] http://www.lotek.com/mst-series-programmable-sensor-transmitters.htm

Table 11: Summary of the comparisons between Advanced Telemetry System (ATS) and Wireless Wildlife (WW) biotelemetry systems considered for use in inland aquatic ecosystems in South Africa.

		Advanced Telemetry System Equipment	Existing Wireless Wildlife (WW) Equipment	Continued WW developments
1. Technical support				
1.1	Availability of manufacturer for technical support	Based in the United States of America, although available telephonically and electronically support is limited due to the location of ATS.	Based in Potchefstroom WW experts are readily available for technical support at their offices and in the field.	WW are constantly developing systems to improve technical support to users
1.2	Flexibility of manufacturer to develop case specific equipment	Limited flexibility	Unlimited flexibility. WW are available to meet any realistic monitoring requirements if components are available.	NA
2. Biotelemetry systems (general).				
2.1	Frequency use and power output	ATS systems make use of 140 to 143MHz frequency which penetrates well through water at a power output of 25dB. Transmitters can be detected to a maximum depth of >4m.	WW systems make use of 400MHz digital systems which does not penetrate as well as lower (142MHz) frequencies. Comparative experiments in this study have shown that WW tags are currently limited to an operational range >2m depth (20dB). Specialised receivers compensates for penetration and power output resulting in similar range of signal detection.	Depending on demand for aquatic biotelemetry systems WW may consider reducing frequency whilst maintaining power output to improve systems.
2.2	Analog vs. digital systems	Analog systems. Although suitable for biotelemetry systems this approach requires each tag to transmit on a unique frequency limiting number of tags used in an area. Analogue systems limit availability of additional tag sensory components to activity, depth and temperature.	Digital systems using one frequency where each tag has unique coded signal. This allows for better usage of battery power (vs. analog systems) faster transmissions, two way communication between receiver and tags, unlimited number of tags used in a single study with better sensory component inclusion and better remote and manual tracking methods.	NA
2.3	Manual and remote tracking systems	ATS offers users with manual monitoring systems primarily with the option of erecting "listening" login stations in the field.	WW offers manual and remote monitoring systems where "listening" stations in the field transmit information in real time to an internet based data management system.	WW are continually developing monitoring methods.
2.4	Data management system	NA	WW offer a secure, password protected data management system which is guaranteed to maintain integrity of data. Data can be viewed/ primarily analysed by authorised guests and data owners but only downloaded by authorised owners.	WW are continually developing the data management system.
2.5	Algorithms for tag location	ATS equipment does not allow for tag location to be detected using algorithms	WW systems make use of algorithms from numerous "listening" stations to accurately identify the position of the tag remotely. In combination with depth sensors tags location and depth can remotely be monitored.	WW are developing this new technology.

Table 11 (continued): Summary of the comparisons between Advanced Telemetry System (ATS) and Wireless Wildlife (WW) biotelemetry systems considered for use in inland aquatic ecosystems in South Africa.

		Advanced Telemetry System Equipment	Existing Wireless Wildlife (WW) Equipment	Continued WW developments
3. Receivers				
3.1	Manual receivers	ATS make use of analog R2100, R4500 and the new R410 manual receivers. Receivers are robust but not waterproof which limits the use of the receivers during adverse weather conditions. Manual monitoring requires users to scan through range of known frequencies of tags.	WW makes use of small laptop based receivers and small programmable (via laptop) stand alone water proof manual receivers attached to the antenna.	WW are continually developing manual monitoring equipment.
3.2	Remote receivers	ATS systems allow for use of R4500 receivers set up in the field to monitor fish movements. These "listening stations" are complicated and require instalment of climate control, animal and vandalism proof protective boxes in the field with large deep cycle batteries. These "listening stations" and extremely expensive (R60 000) and vulnerable to increased flows etc. as the stations must be erected within reception distance from the transmitters.	WW makes use of a combination of base and relay stations that can be erected onto a pole limiting the vulnerability of the receivers. These smaller cost effective (R13000) stations have tamper and activity sensors with tracking devices built into them. Power requirements are met by a single small solar panel erected onto a pole. Receiver are attached directly to the solar panel and make use of a single Omni antennae compared to the two large Yogi antennas required by ATS.	WW are continually developing remote monitoring equipment.
4. Transmitters/trancievers				
4.1	Size of tags	ATS manufacture minute transmitters (<2g) for butterflies to large (>200g) GPS tags for mammals and reptiles. Fish tags range between 8g and 35g depending on battery size and additional sensory components.	WW manufacture small tags for fish/birds (<8g) to large (>120g) GPS tags for mammals and reptiles. For this study fish tags used range between 8g and 20g depending on battery size and additional sensory components.	WW are continually Woking on tag size.
4.2	Lifespan	5 days to many years depending on battery size and additional sensory components	One month to many years depending on battery size and additional sensory components. WW make more efficient use of battery power and allow for real-time alterations between manual tracking (30 transmissions.min^{-1}) and routine remote monitoring transmissions (minute to days).	WW are continually working on batteries and components to extend tag lifespan.
4.3	External attachment methods	Tags are provided with suitable stainless steel attachment wires, crimping sleeves and plastic washers for attachment.	Only tags are provided. Users are currently required to provide own attachment wires etc. For this study a neat attachment methods using nylon line has been developed which reduces tag fouling potential.	WW are considering providing attachment equipment with transmitters.
4.4	Internal implants	Implant and stomach tags are available with insulated "whip" antennas and protruding antennas.		NA
4.5	Additional peripheral sensor components for fish tags	ATS systems primarily allow for the location of the tag to be detected (using R2100 and R410 receivers). Additional sensors including water temperature, activity and depth are available but must be used with R4500s receivers.	WW provide a range of sensor that can be incorporated into tags including temperature, activity, depth, conductivity, pH, LED lights and memory which allows for data storage when the tag is out or range of receivers.	WW are continually developing availability of sensor components for tags.

GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Through the implementation of the objectives of the study the three aims were achieved. These included the providing WW with specifications to develop radio telemetry systems for use in inland surface aquatic ecosystems in South Africa (Aim 1). Wireless Wildlife then successfully developed and tested a range of suitable radio telemetry tags (with a range of peripheral sensory components) and receivers for use in inland freshwater ecosystems in South Africa (Aim 2). The functionality of this telemetry system was further tested through a developmental case study and four behavioural ecology applications in a range of lentic and lotic ecosystems in South Africa (Aim 3). The outcomes of the functionality tests allowed for comparisons to be made between the WW radio telemetry systems and an international system namely ATS radio telemetry systems (Aim 4).

The outcomes include the successfully used of the WW radio telemetry system to tag, track and or monitor (manually and remotely) >40 individual fishes in both lentic (Boskop Dam) and lotic (Vaal and Crocodile Rivers) ecosystems from a few days to more than one year. All of the WW radio telemetry system components were tested including the tags (with various peripheral components), manual and remote tacking techniques and the data management system. Noticeable outcomes of the study include the characterisation of the following:

- The areas used and depth profiles occupied the fishes were accurately monitored and successfully used to characterise the home ranges, habitat preferences and behavioural response of fishes to changing ecosystem variables (water quality, quantity, atmospheric and habitat variables) in lentic and lotic ecosystems. In this study the locations of tagged fish were primarily monitored with manual tracking techniques. Towards the end of this study the developments made in remote triangulation techniques by WW allowed for the general locations of tagged fishes to be monitored remotely as well. Wireless Wildlife now offer accurate triangulation options for the WW radio telemetry system. Communication ranges between tags and receivers are limited by depth (> 2 m) and distance from tags to receivers. In this study, WW developed various peripheral components for tags including data storage (memory) facilities. With the inclusion of data storage capabilities the location of the tagged fish cannot be obtained but other features such as depth profiles can be stored and downloaded when the tagged fish returns to the coverage area. Techniques to characterise the habitat preferences and or requirements of fishes in lentic and lotic ecosystems were demonstrated in the study by comparing the area use and depth profiles of tracked fishes with habitat availability. The study also demonstrated how changes in the behaviour of tagged fishes, including area use and depth profiles can be used to evaluate the consequences of changes ecosystem variable (such as flows) states.

- The movement of tagged fish, measured as MC/m from an accelerometer incorporated into tags as a peripheral component, and maximum displacement (m/min) that was manual recorded were successfully documented and used to characterise the behaviour of fishes in the study. This variable was established as the main behavioural variable/indicator for this fish behavioural monitoring tool to evaluate the behavioural response of fishes to changes in diurnal, lunar and seasonal cycles, habitat availability/states, flows and temperatures on the movement of adult yellowfish and or tigerfish were achieved. The approach demonstrated in the study included the use of statistical procedures to evaluate the significance of the behavioural responses to variable changes. This approach can be used to evaluate the environmental consequences of water quality, quantity and habitat alterations associated with excessive use of aquatic ecosystem service use.
- Aspects of the behavioural ecology of the fishes considered in the study were characterised. This includes information on the timing and location of spawning events, aspects of the feeding biology and general activity of tagged individuals. In addition, the study demonstrated the ability of the technique to evaluate inter- and intra-species interactions including individual behavioural variability in both lentic and lotic ecosystems (yellowfish), differences between species (yellowfish and tigerfish) and shoaling behaviour of yellowfish in the Boskop Manmade lake.

The WW radio telemetry system developed in the study has been shown to be robust, easy to implement, informative and suitable to answer a host of fish behavioural ecology and associated ecosystem conservation and management questions. In addition the approach has been shown to not only compare with international fish behavioural monitoring systems but has many advantages that make the approach more suitable for application in South Africa. In particular, the advances made in the remote behavioural monitoring systems, which include the use of a range of peripheral sensory components and the availability of local technical support makes the use of the WW radio telemetry system ideal for application in South Africa. With this technology South Africans now have access to a relatively cost affective fish behavioural monitoring tool locally with local technical and scientific support that can contribute to the conservation and management of fishes and the ecosystems they occur in.

For the continued development of telemetry tracking techniques in South Africa the following recommendations have been made:

1. Wireless wildlife should still be enabled to continue with the development of the WW radio telemetry system through more case studies in different inland ecosystems.
2. The WW radio telemetry system and the associated scientific methodology developed in this study to monitor the behavioural ecology of fish should be promoted.
3. The effects of the tagging process, the long term effects of the attached tags and alternative tagging methods (external vs. internal) should be evaluated.
4. In South Africa a large portion of the biological requirement information of many fishes, which is used as ecological indicator information to manage and conserve ecosystems is not based on data but inferred by specialists. The WW radio telemetry behavioural monitoring technique should be used to collect data to validate the known biological requirement information of large (> 250 g) fishes in South Africa thereby improving the use of this information to manage and conserve aquatic ecosystem.
5. The statistical techniques used in the study should be developed into a suite of well-presented, easily applied methodologies. This will allow future operators to analyse the findings of the study immediately which will optimise the usefulness of the approach and contribute to the validity of the technique.
6. A centralised archive of South African inland fish behavioural data should be developed where remote and manual behavioural data can accessed by stakeholders, analysed and stored to continually improve on our understanding of fish biology and ecology in South Africa.
7. The suitability of the WW radio telemetry system to contribute to the monitoring of water quality, flow, habitat (including barriers) and atmospheric variable states has been demonstrated in this study. This tool should be implemented to contribute to the development of a sustainable balance between the use and protection of ecosystems and monitor the effects of altered variable states.
8. The real time data management system with alert development capabilities of the WW radio telemetry system allows for real time behavioural monitoring of tagged fish with build in behavioural change indicators. This technique allows for the real time monitoring a range of environmental conditions with alert notifications being sent to managers when a previously characterised coordinated (many individuals) behavioural response of the tagged fish occurs in real time. This will allow managers to respond to changes in environmental conditions immediately.

REFERENCES

Akhtar, N. 2002. Studies on resource base, ecological diversity and threats to Game Fish Mahsheer in Himalayan-Foothill Rivers. Pakistan Agricultural Research Council (PARC), Islamabad. WWF Final Report.

Arnekleiv, J.V. and Karbol, M. 1996. The effects of induced floods on the upstream migration of adult brown trout, and the effects of water release of the postspawning downstream migration in a regulated Norwegian River. In E. Baras and J. C. Philippart (eds), Underwater Biotelemetry, Proceedings of the First Conference and Workshop on Fish Telemetry in Europe, Liege, Belgium: 172pp.

Arnekleiv, J.V. and Ronning, L. 2004. Migratory patterns and return to the catch site of adult brown trout (Salmo trutta L.) in a regulated river. River Research and Applications 20: 929-942.

Advanced Telemetry Systems (ATS) 2013 Tracking Systems: Fish. http://www.atstrack.com/Type-2-Tracking-Fish.aspx. Downloaded on 11 January 2013.

Bain, M.B., Finn, J.T. and Booke, H.E. 1988. Streamflow regulation and fish community structure. Ecology 69: 382-392.

Baras, E. 1992. Etude des strategies d'occupation du temps et de I'espace chez le barbeau fluviatile, (*Barbus barbus L*.) Cah. Ethol. 12:125-442

Baras, E., Togola, E.B., Sicard, B. and Bènech, V. 2002a. Behaviour of tigerfish *Hydrocynus brevis* in the River Niger, Mali, as revealed by simultaneous telemetry of activity and swimming depth. *Hydrobiologia* 483: 103-110.

Baras, E., B´enech V and G. Marmulla, 2002b. Outcomes of a pilot fish telemetry workshop for developing countries Hydrobiologia 483: 9-11.

Becker, A., Whitfield, A.K., Cowley, P. D., Järnegren, J. and Næsje, T. F. 2011. An assessment of the size structure, distribution and behaviour of fish populations within a temporarily closed estuary using dual frequency identification sonar (DIDSON) Journal of Fish Biology, 79(3): 761-775

Bennett, R. H., Childs, A. R., Cowley, P. D., Næsje, T. F., Thorstad, E. B and Økland, F. 2011. First assessment of estuarine space use and home range of juvenile white steenbras, *Lithognathus lithognathus.* African Zoology 46(1): 32-38

Berland, G., Nickelsen, T., Heggenes, J., Okland, F., Thorstad, E.B. and Halleraker, J. 2004. Movements of wild Atlantic salmon parr in relation to peaking flows below a hydropower station. River Research and Applications 20: 957-966.

Bloomer, P., Bills, I.R., Van Der Bank, F.H., Villet, M.H., Jones, N. and Walsh, G. 2007. Multidisciplinary investigation of differences and potential hybridization between two yellowfish species *Labeobarbus kimberleyensis* and *L. aeneus* from the Orange-Vaal system. *Follow-up study 2004-2007*. Yellowfish Working Group Report, Federation of Southern African Flyfishers, Johannesburg.

Bourke, P., Mangan, P. and Rodriguez, M.A. 1996. Diel locomotor activity of brook char, as determined by radio telemetry. J. Fish. Biol. 49: 1174-1185

Brand, M., Maina, J., Mander, M. and O' Brien, G. 2009. Characterisation of the social and economic value of the use and associated conservation of the yellowfishes in the Vaal River. *WRC report KV 226/09.* Water research Commission. Pretoria.

Brenden, T.O., Murphy, B.R., Hallerman, E.M. 2006. Effect of discharge on daytime habitat use and selection by muskellunge in the New River, Virginia. Transactions of the American Fisheries Society 135: 1546-1558.

Bridger, C.J. and Booth, R.K. 2003. The effects of biotelemetry transmitter presence and attachment procedures on fish physiology and behaviour. Reviews in Fisheries Science, 11(1):13-34

Bruton, M.N. 1985. The effects of suspensoids on fish. Hydrobiologia, 125; 221-241.

Bunn, S.E. and Arthington, A.H. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30: 492-507.

Bunt, C.M., Cooke, S.J., Katopodis, C. and McKinley, R.S. 1999. Movement and summer habitat of brown trout (Salmo trutta) below a pulsed-discharge hydroelectric generating station. Regulated Rivers: Research and Management 15: 395-403.

Burnham, K.P., Anderson, D.R. 1998. Model selection and inference: a practical information-theoretic approach. New York: Springer-Verlag.

Childs, A-R., Cowley, P.D., Næsje, T.F., Booth, A.J., Potts, W.M., Thorstad, E.B. and F. Økland. 2008a. Estuarine use by spotted grunter *Pomadasys commersonnii* in a South African estuary. *African Journal of Marine Science* **30(1)**: 123-132.

Childs, A-R., Cowley, P.D., Næsje, T.F., Booth, A.J., Potts, W.M., Thorstad, E.B. and F. Økland. 2008b. Do environmental factors influence the movement of an estuarine fish? A case study using acoustic telemetry. *Estuarine, Coastal and Shelf Science*. **78**: 227-236.

Childs, A-R., Cowley, P.D., Næsje, T.F., Booth, A.J., Potts, W.M., Thorstad, E.B. and F. Økland. 2008c. Home range of an estuarine-dependent fishery species *Pomadasys commersonnii* in a South African estuary. *Fisheries Management and Ecology* **15**: 441-448.

Cooke, S.J. and Schreer, J.F. 2003. Environmental monitoring using physiological telemetry: A case study examining common carp responses to thermal pollution in a coral fired generation station effluent. Water, Air and Soil Pollution: 142, 113-136

Cooke, S.J., Hinch, S.G. Wikelski, M., Andrews, R.D., Kuchel, L.J., Wolcott, T.G. and Butler, P.J. 2004. Biotelemetry: a mechanistic approach to ecology. Trends in Ecology and evolution. Vol. 19 No.6 June 2004.

Cowley, P.D., Kerwath, S.E., Childs, A-R., Thorstad, E.B., Økland, F. and T.F. Næsje. 2008. Estuarine habitat use by juvenile dusky kob *Argyrosomus japonicus* (Sciaenidae), with implications for management. *African Journal of Marine Science* **30(2)**: 247-253.

Davies, B. R. and Day, J. 1998. Vanishing Waters. University of Cape town Press. University of Cape Town.

De Moor, I.J. and Bruton, M.N. 1988. Atlas of alien and translocated indigenous aquatic animals in southern Africa. A report of the Committee for Nature Conservation Research National Programme for Ecosystem Research. *South African Scientific Programmes Report No. 144*. Port Elizabeth, South Africa. pp. 310.

De Villiers, P. and Ellender, B. 2007. Status of the Orange-Vaal largemouth yellowfish, *Labeobarbus kimberleyensis* (Gilchrist & Thompson, 1913). *Technical Report on the State of Yellowfishes in South Africa WRC Report No*. KV 212/08, 198.

Du Preez, H.H. and Steyn, G.J. 1992. A preliminary investigation of the concentration of selected metals in the tissues and organs of the tigerfish (*Hydrocynus vittatus*) from the Olifants River, Kruger National Park, South Africa.

Dubey, G. P. 1985. Conservation of dying King mahaseer the mighty game fish and its future role in reservoir fisheries. Punjab Fisheries Bulletin. Vol. IX No. 182

Dunn, J.E. and Gipson, P.S. 1977. Analysis of radio telemetry data in studies of home range. *Biometrics* **33**. 85-101.

Department of Water affairs and Forestry (DWAF) 2004. Internal Strategic perspective: Inkomati water management area. DWAF Report No: P WMA 05/000/00/0303

Eccles DH, 1985; The effect of temperature and mass on routine oxygen consumption in the South African cyprinid fish Barbus aeneus Burchell. J. Fish. Biol., 27: 155-165

Ellender, B.R., Weyl, O.L.F. and Winker, H. 2012. Age and growth and maturity of southern Africa's largest cyprinid fish, the largemouth yellowfish *Labeobarbus kimberleyensis. Journal of Fish Biology.* doi:10.1111/j.1095-8649.2012.03395.x, available online at wileyonlinelibrary.com.

Elliott, M., Whitfield, A.K., Potter, I.C., Blaber, S.J.M., Cyrus, D.P., Nordlie, F.G., and Harrison, T.D. 2007. The guild approach to categorizing estuarine fish assemblages: a global review. Fish and Fisheries, 8: 241-268.

Frissel, C.A., Liss, W.J., Warrren, C.E. and Hurley, M.D. 1986. A heirarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management, 10, 199-214.

Fouché, P.S.O. 2009. Aspects of the ecology and biology of Lowveld Large-scale Yellowfish (*Labeobarbus marequensis*, Smith 1843) in the Luvhuvhu, Limpopo River System. South Africa. PhD Thesis, Department of Biodiversity (Zoology), School of Molecular and Life Sciences, Faculty of Science and Agriculture, University of Limpopo – Turfloop campus.

Gaigher, I.G. and Fourie, P. 1984. Food habits of smallmouth yellowfish, Barbus Holubi, in Wuras Dam, a shallow turbid impoundment. *J. Limnol. Soc. Sth. Afr.* 10, 1-4.

Gallepp, G.W. and Magnuson, J.J. 1972. Effects of negative buoyancy on the behaviour of the bluegill, *Lepomis macrochirus* Rafinesque. Transaction of the American Fisheries Society 101:507-517. IN: Rogers, R.B., White, G.C. 2002. Analysis of movement and habitat use from telemetry data.

Gerber, R., Smit, N.J. and Wagenaar, G.M. 2012 Age, growth rate and size at sexual maturity of *Labeobarbus aeneus* (Teleostei: Cyprinidae) in the middle Vaal River, South Africa. Afr J Aquat Sci. 37(1): 49-58.

Gerhardt, A., 2007. Aquatic Behavioral Ecotoxicology—Prospects and Limitations. Human and Ecological Risk Assessment: 13: 481-491.

Gertenbach, W.P.D. 1980. Rainfall patterns in the Kruger National Park. Koedoe 22:35-43

Godin, JG. 1990. Diet selection under risk of predation. In Behavioural mechanisms of food selection (ed, R.N. Hughes), NATO ASI Series Vol.G20, pp.739-770. Springer-Verlag, Berlin.

Godin, JG. 1997. Behavioural ecology of teleost fishes. Oxford University Press.

Granek, E.F., Madin, E.M.P., Brown, M.A., Figueira, W., Cameron, D.S., Hogan, Z., Kristianson, G., De Villiers, P., Williams, E., Post, J., Zahn, S. and Arlinghaus, R. 2008. Engaging recreational fishers in management and conservation: global case studies. Cons. Biol. 5: 1125-1134.

Groenewald, .A. A.1961. A progress report on the culture of *Barbus holubi*, the Vaal river yellowfish, at the Provincial Fisheries Institue, Lydenburg. Transvaal Provincial Fisheries Research Institute, *Research Report*, 9-20.

Harrison, T.D. and Whitfield, A.K. 2004. A multi-metric fish index to assess the environmental condition of estuaries. *Journal of Fish Biology* 65, 683-710.

Harrison, T.D. and Whitfield, A.K. 2006. Application of a multimetric fish index to assess the environmental condition of estuaries. *Estuaries and Coasts, 29*, pp. 1108-1120.

Harrison, T.D. and Cooper, J.A.G. & Ramm, A.E.L. 2000. Geomorphology, Ichthyofauna, Water Quality and Aesthetics of South African Estuaries. Department of Environmental Affairs & Tourism, Pretoria, South Africa.

Hart, P.J.B. 1996. Behavioural ecology of teloest fishes. Department of biology, Mount Allison University. Sackville, New Brunswick, Canada, pp. 104.

Hasted, J. B. 1973. Aqueous Dielectrics. London, England.

Chapman & HallHauer FR, Lorang MS. 2004. River regulation, decline of ecological resources, and potential for restoration in a semi-arid lands river in the western USA. Aquatic Sciences 66: 388-401.

Heath, R.G.M. and Claassen, M. 1999. An overview of the Pesticide and Metal levels present in populations of the larger indigenous fish species of selected South African rivers. *WRC report No. 428/1/99*. Water Research Commission. Pretoria.

Hill, L., Vos, P., Moolman, J. and Silberbauer, M. 2001. Inventory of River Health Programme monitoring sites on the Olifants, Sabie and Crocodile Rivers. *WRC Report No. 850/2/01.* Water Research Commission, Pretoria.

Hill, L. 2005. Elands Catchment Comprehensive Reserve Determination Study, Mpumalanga Province, Ecological Classification and Ecological Water Requirements (quantity) Workshop Report, Contract Report for Sappi-Ngodwana, Submitted to the Department: Water Affairs and Forestry, by the Division of Water Environment and Forestry Technology, CSIR, Pretoria. Report No. ENV-P-C 2004-019 pp 1-98.

Hirschowitz, P.M., Birkhead, A.L. and James, C.S. 2007. Hydraulic modelling for ecological studies for South African Rivers. WRC Report no: K5/105. Water Research Commission. Pretoria.

Hodder, H.K., Masters, J.E.G., Beaumont, W.R.C., Gozlan, R.E., Pinder, A.C. Knight, C.M. and Kenward, R.E. 2007. Techniques for evaluating the spatial behaviour of river fish. Hydrobiologia (2007) 582:257-269

Hurber, M. and Krichhofer, A. Radio telemetry as a tool to study habitat use of nase (*Chondrostoma nasus* L.) in medium-sized rivers. Hydrobiologia; 1998; 371/372: 309-319.

Impson, D. and Swartz, E. *Labeobarbus kimberleyensis.* In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. www.iucnredlist.org. 2007, Downloaded on 29 January 2013.

IUCN Red Data List. 2007*. http://www.iucnredlist.org/search/details.php/2560/summ* IN: Impson N.D., Bills, I.R. & Wolhuter L. 2008. Technical Report on the state of Yellowfishes in South Africa 2007. *WRC Report KV212/08.* Water Research Commission. Pretoria.

James, N.C., Cowley, P.D. and A.K. Whitfield. 2007. Abundance, recruitment and residency of two sparid fishes in an intermittently open estuary in South Africa. *African Journal of Marine Science* **29(3)**: 527-538.

Jubb, 1966 Jubb, R.A. 1967. *Freshwater Fishes of Southern Africa*. A.A. Balkema, Cape Town.

Karr, J.R. & Dudley, D.R. 1981. Ecological perspectives on water quality goals. *Environmental Management* **5**: 55-68.

Kaushal, D.K., M.D. Pirolker and Y.R. Rao 1980. Observation on the food habits of T. putitora(Ham.) from Gobindasagar reservoir, Himanchal Pradesh. J. Inland Fish. soc. India. 12(1).

Kerwath, S.E., Gotz, A., Cowley, P.D., Sauer, W.H.H. and C.G. Attwood. 2005. A telemetry experiment on spotted grunter *Pomadasys commersonnii* in an African estuary. *African Journal of Marine Science* **27(2)**: 389-394.

Kerwath, S.E., Thorstad, E.B., Naesje, T.F., Cowley, P.D., Okland, F., Wilke, C. and C.G. Attwood. 2009. Crossing Invisible Boundaries: the Effectiveness of the Langebaan lagoon Marine Protected Area as a Harvest Refuge for a Migratory Fish Species in South Africa. *Conservation Biology* **23(3)**: 653-661.

Kleynhans, C.J. &, Louw, M.D. &, Thirion, C. & Rossouw, N. & Rowntree, K. 2005. *River EcoClassification: Manual for Ecostatus Determination*. First Draft for Training Purposes. Water Research Commission. Pretoria, South Africa.

Kleynhans, 1991 Kleynhans, C. J., 1991. Voorlopige riglyne vir die klassifisering van die Transvaalse vissoorte in sensitiwiteitsklasse. *Transvaalse Hoofdirektoraat Natuur en Omgewingsbewaring*, Werkswinkel, Skukuza. 12 pp.

Kleynhans, 1999 Kleynhans, C.J. 1999. The development of a fish index to assess the biological integrity of South African rivers. *Water Sa* ***25*** (3). IN: Hills L., Vos P., Moolman J. and Silberbauer M. 2001. Inventory of River Health Programme monitoring sites on the Olifants, Sabie and Crocodile Rivers. *WRC Report No:. 850/2/01.* Water Research Commission, Pretoria.

Kleynhans, 2007 Kleynhans, C. J. 2007. Module D: Fish Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2) Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No TT/330. Pretoria.

Knights, B. C. & Lasee, B.A. 1996. Effects of implanted transmitters on adult bluegills at two temperatures. *Transactions of the American Fisheries Society* 125,440-9.

Koch, B.S. 1975. 'n Visekologiese ondersoek van Boskopdam, Wes-Transvaal, met spesiale verwysings na die bevolkingsdigtheid van *Labeo capensis* en *Labeo umbratus* in verhouding tot die ander vishengelsoorte. M.Sc. dissertation. Rand Afrikaans University. Johannesburg.

Koehn, 2000 Koehn, J.D. 2000. Why use radio tags to study freshwater fish? Freshwater ecology

Kotze, P. J. 2002. The Ecological Integrity of the Klip River (Gauteng) and the Development of a Sensitivity-Weighted Fish Index of Biotic Integrity (SIBI). Ph.D Thesis. Rand Afrikaans University, Johannesburg.

Kramer, D.L., Rangeley, R.W. and Chapman, L.J. 1997. Habitat Selection: patterns of spatial distribution from behavioural decisions. IN: Godin JG.J. ed. 1997. Behavioural ecology of teleost fishes. *Oxford University Press*.

Leslie, B. J. 2007. Thresholds of Potential Concern for Large Scale Yellow Fish, a Project in the Crocodile River, KNP. Abstract in YFWG newsletter, 2007.

Linnik, V.D., Malinin, L.K., Wozniewski, M., Sych, R. and Dembowski, P. 1998. Movements of adult sea trout *Salmo trutta* L. in the tailrace of a low-head dam at Wloclawek hydroelectric station on the Vistula River, Poland. Hydrobiologia 372: 335-337.

Littell, R. C., Milliken, G. A., Stroup, W. W. and Wolfinger, R.D. 1996. SAS system for mixed models. SAS Institute, Cary, North Carolina.

Lotek. 2013. VHF Radio: Coded tags: http://www.lotek.com/vhf-radio-coded-transmitters.htm. Downloaded 11 January 2013.

Lucas, M.C. and Baras, E. 2000. Methods for studying spatial behaviour of freshwater fishes in the natural environment. *Fish and Fisheries*. **1**, 283-316.

Lucas, M.C. and Frear, P. A. 1997. Effects of a flow-gauging weir on the migratory behaviour of adult barbell, a riverine cyprinid. J. Fish Biol; 50: 382-396.

Mabunda, D., Pienaar, D.J., Verhoef, J. 2003. Introduction. In: Biggs, H.C., du Toit, J.T. and Rogers, K.H. (eds) The Kruger National Park: A century of management and research. *The Kruger Experience, ecology and management of savanna heterogeneity.* Island Press, Washington, USA.

Markham, A.C. and Wilkinson, A.J. 2008. EcoLocate: A heterogeneous wireless network system for wildlife tracking. In: Sobh, T., Elleithy, K., Mahmood, A. and Karim, M.A. (eds) Novel Algorithms and Techniques in Telecommunications, Automation and Industrial Electronics. Springer Science and Business Media B.V. 293-298.

Moore, G.E. 1965. Cramming more components onto integrated circuits. Electronics. 38(8): 115.

Mulder, P.F.S. 1971. ‘n Ekologiese studie van die hengelvis fauna in die Vaalrivier sisteem met spesiale verwysing na *Barbus kimberleyensis*, Gilchrist and Thompson. Unpublished PhD thesis, Rand Afrikaans University, Johannesburg.

Mulder, P.F.S. 1973. Aspects on the ecology of *Barbus Kimberleyensis* and *Barbus holubi* in the Vaal River. Zoologica Africana 8(1): 1-14.

Murchie, K.J. and Smokorowski, K.E. 2004. Relative activity of brook trout and walleyes in response to flow in a regulated river. North American Journal of Fisheries Management 24: 1050-1057.

Murchie, K.J., Hair, K. P. E., Pullen, Redpath, C.E., Stephens, H. R. and Cooke, S. J. 2008 Fish response to modified flow regimes in regulated rivers: research methods, effects and opportunities. River. Res. Applic. 24: 197-217

Næsje, T.F., Childs, A-R., Cowley, P.D., Potts, W.M., Thorstad, E.B., and F. Økland. 2007. Movements of undersized spotted grunter (*Pomadasys commersonnii*) in the Great Fish Estuary, South Africa: implications for fisheries management. *Hydrobiologia* 582:25-34.

Nel, J., Maree, G., Roux, D., Moolman, J., Kleynhans, N., Silberbauer, M. and Driver, A. 2004. South African National Spatial Biodiversity Assessment 2004: *Technical Report. Volume 2: River Component.* CSIR Report Number ENV-S-I-2004-063. Stellenbosch: Council for Scientific and Industrial Research.

O’Brien, G.C. and De Villiers, P. 2011. Aspects of the biology and ecology of the orange-vaal largemouth and smallmouth yellowfish in the Vaal River. *WRC Report TT508/11.* Water Research Commission, Pretoria.

O’Brien, G.C., Swemmer, R. and Wepener, V. 2009. Ecological integrity assessment of the fish assemblages of the Matigulu/Nyoni and Umvoti estuaries, KwaZulu-Natal, South Africa. 34(3): 293-302

O’Brien, G., Bulfin, J.B., Husted, A. and Smit, N.J. 2012. Comparative behavioural assessment of an established and a new tigerfish (Hydrocynus vittatus) population in two man-made lakes in the Limpopo River catchment; southern Africa. *African Journal of Aquatic Science* 2012, 37 (3).

O’Keeffe, J. and Rogers, K.H. 2003. Heterogeneity and management of the Lowveld Rivers. *The Kruger Experience, ecologay and management of savanna heterogeneity*

Organisation for Economic Co-operation and Development (OECD). 2003. Turning Science Into Business: Patenting and Licensing at Public Research Organizations, Paris: OECD.

Økland, F., Hay, C. J., Næsje, T. F., Nickandor N, and Thorstad, E. B. 2003. Learning from unsuccessful radio tagging of common carp in a Namibian reservoir. Journal of Fish Biology (2003) 62: 735-739

∅kland F., Thorstad E.B., Hay C.J., Naesje T.F. and Chanda B. 2005. Patterns of movement and habitat use by tigerfish (Hydrocynus vittatus) in the Upper Zambezi River (Namibia). Ecology of Freshwater fish 14:76-86

Paxton, B.R., 2004a. Catchment-wide movement patterns and habitat utilisation of freshwater fish in rivers: implications for dam location, design and operation, a review and methods development for South Africa. *WRC Report No. KV145/04.* Water Research Commission, Pretoria.

Paxton, B.R., 2004b. Tracking movement of large fish species through a river system: Methods Development. WRC Report No. KV 157/04. Water Research Commission, Pretoria.

Pienaar, U.V. 1978. The Freshwater fishes of the Kurger National Park. *Sigma Press.* Pretoria. 91pp

Priede, I.G. 1991. Telemetry in assessment of environmental effects on individual fishes, In Lucas, M.C., Diack, I., Laird, L. (eds), Interactions Between Fisheries and the Environment, Proceedings of the Institute of Fisheries Management 22nd Annual Study Course, Institute of Fisheries Management, Nottingham. 179-196.

Ramsey, F.L. and Usner, D. 2003. Persistence and Heterogeneity in Habitat Selection Studies Using Radio Telemetry. Volume 59, Issue 2, pages 332-340.

Robertson, M.J., Pennell, C.J., Scruton, D.A., Robertson, G.J. and Brown, J.A. 2004. Effect of increased flow on the behaviour of Atlantic salmon parr in winter. Journal of Fish Biology 65: 1070-1079.

Rogers, K. H. and O'Keeffe, J. 2003. River Heterogeneity: ecosystem structure, function and management. In: Biggs, H.C., du Toit, J.T. and Rogers, K.H. (eds). The Kruger National Park: A century of management and research. The Kruger Experience, ecology and management of savanna heterogeneity. Island Press, Washington, USA.

Rogers, R.B. and White, G.C. 2002. Analysis of movement and habitat use from telemetry data. IN: Brown, M and Guy, C., ed. 2007. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland: 625-676pp

Roux, F. 2006. Reproduction strategy of the small-scale yellowfish (*Labeobarbus polylepis*) and breeding behaviour in the Blyde and Spekboom rivers. Unpublished Masters of Science dissertation. University of Johannesburg. Aucklandpark.

Russell, I.A. 1997. Monitoring the conservation status and diversity of fish assemblages in the major rivers of the Kruger National Park. *Unpublished Ph.D. Thesis, University of the Witwatersrand, Johannesburg.*

Scholtem, M. 1995 Verteilungsdynamik and Nahrungokologie von Jungfischen in den Buchten der Sieg. Diplomarbeit Friedrich-Wilhelms-Universitat Bonn.

Scruton, D.A., Pennell, C.J., Robertson, M.J., Ollerhead, L.M.N., Clarke, K.D., Alfredsen, K., Harby, A. and McKinley, R.S. 2005. Seasonal response of juvenile Atlantic salmon to experimental hydropeaking power generation in Newfoundland, Canada. North American Journal of Fisheries Management 25: 964-974.

Scruton, D.A., Clarke, K.D., Ollerhead, L.M.N., Perry, D., McKinley, R.S., Alfredsen, K. and Harby, A. 2002. Use of telemetry in the development and application of biological criteria for habitat hydraulic modelling. Hydrobiologia, 483: 71-82

Sih, A. 1993. Effects of ecological interactions on forager diets: competition, predation risk, paratism and prey behavior. In Diet selection: an interdisciplinary approach to foraging behavior (ed. R.N. Hughes), pp.182-211. Blackwell Scientific Publ., Oxford.

Sisak, M.M., Lotimer, J.S. 1998, Frequency choice for radio telemetry: HF vs. VHF conundrum. Hydrobiologia 371/372: 53-59, 1998.

Skelton, P.H., Tweddle, D. and Jackson, P. 1991. Cyprinids of Africa. In Cyprinid Fishes, Systematics, Biology and Exploitation (Winfield, I. J. & Nelson, J. S., eds), London: Chapman & Hall. 211-239.

Skelton, P.H. 2000. Flagships and fragments – perspective on the conservation of freshwater fishes in Southern Africa. *African Journal of Aquatic Science*, 25: 1, 37-42

Skelton, P.H. 2001. A Complete Guide to the Freshwater Fishes of Southern Africa, 2nd Edition. Struik Publishers, Cape Town. 395pp.

Stadtlander, T., Weyl, O.L.F. and Booth, A.J. 2011. New distribution record for the Asian tapeworm *Bothriocephalus acheilognathi* Yamaguti, 1934 in the Eastern Cape province, South Africa. Afr J Aquat Sci. 36(3): 339-343.

Stanford, J.A., Ward, J.V. and Liss, W.J. 1996. A general protocol for restoration of regulated rivers. Regulated Rivers: Research and Management 12: 391-413.

Stasko, A.B. and Pincock, D.G. 1977. Review of underwater biotelemetry with emphasis on ultrasonic techniques. *Journal of the Fisheries Research Board of Canada.* **34**, 1261-1285.

Stephen, D.W. and Krebs, J.R. 1986. Foraging theory. Princeton University Press, Princeton. IN: Kramer, D.L., Rangeley, R.W., Chapman, L.J. 1997. Habitat Selection: patterns of spatial distribution from behavioural decisions. IN: Godin JG.J. ed. 1997. Behavioural ecology of teleost fishes. *Oxford University Press*.

Stormer, D.G. and Maceina, M.J. 2009. Habitat use, home range, and movement of shoal bass in Alabama. N Am J Fish Manag. 29; 604-613.

Taylor, M. H. 1984. Lunar Synchronization of Fish Reproduction. *Transactions of the American Fisheries Society*. Volume 113(4): 484-493.

Thorstad, E.B., Hay, C.J., Naesje, T.F. and Økland, F. 2001. Movements and habitat utilisation of three cichlid species in the Zambezi River, Namibia. Ecology of Freshwater Fish 10:238-246.

Thorstad**,** E.B., Hay, C.J., Næsje, T.F., Chanda, B. and Økland, F. 2003. Space use and habitat utilisation of tigerfish and the two cichlid species nembwe and threespot tilapia in the Upper Zambezi River. Implications for fisheries management. – NINA Project Report 24. 23 pp.

Tómasson, T., Cambray, J.A. and Jackson, P.B.N. 1984. Reproductive biology of four large riverine fishes (Cyprinidae) in a man-made lake, Orange River, South Africa. *Hydrobiologica,* **112** (3) 179-195.

Trefehten, R.S. 1956. Sonic equipment, for tracking individual fish. U.S. Fish and wildlife Service, Special Scientific Report-Fisheries No. 19. 11ppWinter, 1996

Van Aardt, W.J. and Erdmann, R. 2004. Heavy metals (Cd, Pb, Cu, Zn) in mudfish and sediments from three hard-water dams of the Mooi River catchment. 218p. Van As and Combrinck

Van As, J.G. and Combrinck, C. 1979. Die invloed van omgewingsfaktore op die vertikale verspreiding van die Cladocera en Copepoda in Boskopdam, Transvaal. Wet. Bydr. vd P U vir CHO. Series B. Nat. Wet 95:1-30.

Van Ommering, R., van der Linden, F., Kramer, J. and Magee, J. 2000. The Koala Component Model for Consumer Electronics Software, IEEE Computer. 78-85.

Van Wyk, F., 2001. An Integrated Manual for the Management, Control and Protection of the Vaal River Barrage Reservoir. Unpublished M.Sc Thesis. Rand Afrikaans University. Aucklandpark: 23 pp.

Venter, J.A., Fouché, P.S.O., Vlok, W., Moyo, N.A.G., Theron, S. and Grobler, P. 2009. Background Report: Southern barred minnow (*Opsaridium peringueyi*). *WRC deliverable report*. Water Research Commission. Pretoria.

Vörösmarty, C.J., Sharma, K.P, Fekete, B.M., Copeland, A.H., Holden, J., Marble, J. and Lough, J.A. 1997. “The Storage and Aging of Continental Runoff in Large Reservoir Systems of the World,” Ambio 26(4): 210-219.

Weyl, O., Stadtlander, T. and Booth, A.J. 2009. Establishment of translocated populations of smallmouth yellowfish, *Labeobarbus aeneus* (Pisces: Cyprinidae), in lentic and lotic habitats in the Great Fish River system, South Africa. Afr Zool. 44(1); 93-105.

Winter, J. 1996. Advances in underwater biotelemetry. In: Murphy, B.R. and Willis, D.W. (eds) Fisheries Techniques. 2nd edition. American Fisheries Society, Bethesda, Maryland. pp 555-590.

Wootton, R.J. 1984. Introduction: tactics and strategies in fish reproduction. In: Potts, G.W. and Wootton, R.J (eds). Fish reproduction. Strategies and tactics. Academic press, London. 1-12.

Wireless Wildlife (WW) 2013 Products. http://wireless-wildlife.co.za/products.html. Downloaded on 11 January 2013.