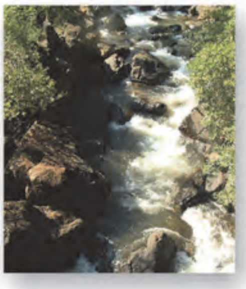
Manual to Monitor FISH BEHAVIOUR AND WATER VARIABLES Remotely in Real Time in South African Inland Aquatic Ecosystems

GC O'Brien, FJ Jacobs, IF Botha & M O'Brien

WATER RESEARCH COMMISSION

TT 613/14





MANUAL TO MONITOR FISH BEHAVIOUR AND WATER VARIABLES REMOTELY IN REAL TIME IN SOUTH AFRICAN INLAND AQUATIC ECOSYSTEMS.

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WATER RESEARCH COMMISSION
Wireless WILDLIFE
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FISH-TRAC

MANUAL TO MONITOR FISH BEHAVIOUR AND WATER VARIABLES REMOTELY IN REAL TIME IN SOUTH AFRICAN INLAND AQUATIC ECOSYSTEMS

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

Radio telemetry involves the use of radio waves to transmit information between devises across an open or remote space. From the late 1950s radio telemetry techniques have been used to track fish to monitor the movements, behaviour and space use of fishes. These techniques have more recently been used extensively to evaluate problems associated with fish migration and the ecological consequences of water quality and quality variables state alterations. Although radio telemetry techniques are still ideally suited for use in riverine ecosystems that have background acoustic noise (contain riffles and rapids), today other platforms, including acoustic telemetry systems for example, are available for use in rivers, lakes, estuaries and in marine ecosystems. In South Africa numerous universities, the South African Institute for Aquatic Biodiversity and conservation organisations including Mpumalanga Tourism and Parks agency and the South African National Parks have and/or are using telemetry techniques to track fish in their natural environments.

The South African inland fish tracking programme (FISHTRAC) makes use of radio telemetry tracking techniques developed and tested by Wireless Wildlife Pty., Ltd. to track fish tagged with small transceivers (tags) in riverine and lake ecosystems. This system allows researchers, technicians, etc. to find and track tagged fish manually and or remotely (via the internet) and monitor water depth, temperature and some quality variable states of river and lake ecosystems. The size of the tags affect the minimum size of fish that can be used in telemetry studies (>500 g) and last up to three years. This manual has been designed for managers, conservationists and researchers who are interested in using radio telemetry techniques established through the FISHTRAC programme in South Africa. The manual provides users with information to obtain radio telemetry equipment and use it appropriately to track fish in our river and lake ecosystems, and to monitor the ecological consequences of water quality and quantity variable changes for the management and conservation of our ecosystems and the animals that live in them.

The FISHTRAC system is reliable, easy to implement and capable of addressing a range of ecosystem management and conservation questions. The FISHTRAC framework includes an: (1) Inception Phase, (2) Planning Phase, (3) Analysis Phase and (4) Outcomes Phase which, if implemented correctly, as demonstrated in this manual, should allow users to implement these techniques with minimal error. In the manual we have highlighted the value of using past experiences (case studies and literature) and specialist who use these methods routinely for assistance.

We recommend that this manual be used to contribute to the: (1) awareness of the value of characterising the biology and ecology of fishes and the river and lake ecosystems they live in, (2) conservation and management of river and lake ecosystems, and the animals within these systems, and (3) development of radio telemetry techniques in South Africa.

Many of the FISHTRAC scientists or behavioural ecologists are available to provide assistance with a radio telemetry study. Contact them!

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We, the authors, would like to acknowledge the contributions made to this manual through formal and informal discussions, workshops and meetings held with various managers, conservationists, biologists, anglers, etc. Some of these stakeholders include: Mr. M Burnette (formerly University of Johannesburg), Mrs. L Cronje (KZN Ezemvelo Wildlife), Mr. BM Madikizela (Water Research Commission), Mr. D MacFadyen (De Beers Consolidated. Mines), Mr. D Pienaar (SANPARKS), Mr. B Leslie (SANPARKS), Mr. F Roux (Mpumalanga Parks and Tourism Agency), Dr. AR Deacon (formerly, SANPARKS) Dr. SA Mitchell (Eon Consulting), Dr. O Weyl (South African Institute for Aquatic Biodiversity), Dr. P Cowley (South African Institute for Aquatic Biodiversity), Dr. A Childs (South African Institute for Aquatic Biodiversity), Mr. P De Villiers (Cape Nature), Dr. N Kleynhans (Department of Water Affairs, Resource Quality Services), Dr. P Fouche (University of Venda), Mr. WR Aken (Golder and Associates) and Prof. NJ Smit (North West University). In addition we would like to acknowledge the comments made by participants of the World Fish Migration Day (2014) and FISHTRAC manual training workshop held at Ablert Falls Man-Made Lake on the 23rd to 26th of May 2014. We also appreciate the services of Mr. T Pike from Groundtruth for hydrological assistance at the workshop. Finally we would also like to acknowledge the comments provided by Jonathan Bolland and Nicola Baker from the Hull International Fisheries Institute.

TABLE OF CONTENTS

EXECUTIVE SUMMARY v
ACKNOWLEDGEMENTS vi
TABLE OF CONTENTS vii
LIST OF FIGURES ix
LIST OF APPENDICES x
INTRODUCTION 1
INCEPTION PHASE 6
Objectives of the study 6
Scope of the study 7
Hypotheses 7
Resource requirements 8
PLANNING PHASE 9
Evaluate available information 9
Experimental design 10
Study area suitability assessment 10
Fish suitability assessment 11
ANALYSIS PHASE 12
Remote monitoring network set up 12
Wireless Wildlife tags 13
Water probe deployment 14
Capture, tag & release of fish 17
Monitor recovery 20
Remote and manual tracking 21
Data collection & evaluation 25
Uncertainty evaluations 26
OUTCOMES PHASE 27
Biological considerations 27
Ecological considerations 27
Hypothesis assessment 27
Reporting 27

Outcome communication 27

CASE STUDIES AND LESSONS LEARNED 28

1.1 Case Study 1: Vaal River yellowfish behavioural study 2006-2008 by the University of Johannesburg, Centre for Aquatic Research.. 28

2.1 Case Study 2: Letsibogo Dam tigerfish recruitment, Botswana by Digby Wells and associates and the University of Johannesburg, Centre for Aquatic Research (2009-2010). 28

3.1 Case Study 3: Schroda Dam tigerfish ecology study South Africa, by Digby Wells and associates and the University of Johannesburg, Centre for Aquatic Research (2009-2011). 30

4.1 Case study 4: Okavango tigerfish angling stress survival experiment, Botswana by University of Johannesburg, Centre for Aquatic Research (2010). 31

5.1 Case Study 5: Vaal River yellowfish behavioural study by North West University, Water Research Group (2011-2013). 32

6.1 Case study 6: Crocodile River yellowfish and tigerfish behavioural study, KNP by the University of Johannesburg, South African National Parks and North West University (2011-2013). 33

7.1 Case study 7: Crocodile River crocodile ecology experiment by the University of Johannesburg, South African National Parks and North West University (2012). 34

8.1 Case study 8: Water quality and quantity monitoring in the Senqu River, Lesotho by the Institute of Natural Resources NPC. 35

9.1 CASE STUDY 9: Mine offset lake suitability assessment for yellowfish by Anglo-American and North West University. 36

CONCLUSIONS AND RECOMMENDATIONS 37

REFERENCES 37

APPENDICES 40

LIST OF FIGURES

Figure 1: The FISHTRAC programme is based on the radio telemetry information transmission between transmitters and receiver. 1

Figure 2: Schematic representation of the FISHTRAC radio telemetry programme to monitor the real time, remote behaviour and behavioural response of fishes to changing water quality and quantity variable states in river and lake ecosystems in South Africa. 4

Figure 3: FISHTRAC programme framework to direct the use of real time, remote behaviour and behavioural response of fishes to changing water quality and quantity variable states in river and lake ecosystems in South Africa 5

Figure 4: Photograph of a notice board used to deter theft/vandalism of remote stations. 13

Figure 5: FISHTRAC remote base and relay stations (A & B) and examples of remote monitoring networks set up on river ecosystems with mountainous topography (C) and in a flat area (D)..................... 15

Figure 6: Radio telemetry transceivers (tags) produced by Wireless Wildlife Pty. Ltd., for the FISHTRAC programme. Examples include fish external attachment tags (A), Fish internal implant and oesophageal tags with (B) and without (C) antenna, abiotic probe tag (C) and reptile (D) tag. 16

Figure 7: Schematic diagram to show where to deploy abiotic probes. Efforts should be made to avoid the high velocity, deep areas in the main channel and side channels used. 17

Figure 8: Schematic representation of the three common fish tagging techniques proposed to be considered in a radio telemetry behavioural monitoring study in South Africa by the FISHTRAC Programme. These tagging techniques include external procedures (A), oesophageal (B) and internal (C) procedures. 19

Figure 9: Schematic flow chart of the tracking approach established for the FISHTRAC programme. Purple balloon represents the planning phase and the maroon balloons represent the analysis phase. 22

Figure 10: Examples of the manual tracking receivers used to track fish in the FISHTRAC programme. Including the Wireless Wildlife mobile notebook receiver system (A), the programmable weather proof receiver system (B) and the WW model aircraft receiver (C). In addition a photograph (D) of a flickering Light Emitting Diode (LED) tag on a fish to verify detection accuracy. 24

Figure 11: Fish movement data collected from multiple stations over 140 day tracking experiment in the Vaal River to demonstrate simple triangulation techniques. 25

Figure 12: Logos and labels of univariate and multivariate statistical software packages, and spatial data evaluation programme used locally and internationally to evaluate/display data from radio telemetry studies. 26

Figure 14: Positions of the fourteen tigerfish monitored in Letsibogo Dam throughout the study (Tomschi et al., 2009). 29

Figure 13: Summary of the behavioural response of yellowfish in the Vaal River to changes in environmental variable states (O'Brien and De Villiers, 2010; O'Brien et al, 2013). 29

Figure 15: Avivorous behavioural strategies adopted by Hydrocynus vittatus in the Schroda Dam man-made lake. (a) Flight path of the prey Hirundo rustica, (b) surface pursuit strategy of H. vittatus to overcome surface image shift due to light refraction (angle θ) and (c) direct aerial strikes by adult H. vittatus that compensate for the image shift (not drawn to scale, O'Brien et al., 2013). 30

Figure 16: Tagged tigerfish from the Okavango study ready to be released into the river after being revived from anaesthesia (Smit et al., 2009). ... 31
Figure 17: Remote radio telemetry network coverage areas for the Boskop Dam and Vaal River during the yellowfish behavioural study (Jacobs, 2013). ... 32
Figure 18: Graphs of the depth (above) and temperatures (below) of the yellowfish and tigerfish in the Kruger National Park study. ... 33
Figure 19: Graph of the activity (accelerometer omni-direction movement) of a tagged crocodile in the Crocodile River. ... 34
Figure 20: Use of depth (mm) data from an abiotic water probe to model the habitat of the senqu River using River 2D hydraulic/hydrology modelling techniques. ... 35
Figure 21: Signal strength readings from six radio tracked yellowfish (Labeobarbus aeneus) from 1 December 2012 to 15 December 2012 in the AngloAmerican yellowfish facility. Arrows highlight daily periods from 5 December to 15 December when all of the tagged yellowfish only moved into coverage range during the night. Having storage capacity on the tags ensures that peripheral data is collected during periods when fish are out of range. ... 36

LIST OF APPENDICES

APPENDIX A: Internal tagging procedure from a suitably anesthetised fish ready for tagging (A), make abdominal incision and insert needle for antenna (B),insert tag and push antenna through needle (C), remove needle (D), suture wound (E), apply wound care gel (F) which turns into a gel when in contact with the water (G), revive and release (H). ... 40
APPENDIX B: External tagging procedure including, preparation for tagging by testing equipment (A), cleaning and laying out equipment (B), preparation of anaesthesia (C) and procedures (D) until signs of anaesthesia are evident (E). Then needles are inserted through the musculature of the fish below the dorsal fin (F) and insertion of tagging wires (G). Here we demonstrate the creation of a saddle using copper/bronze sleeves (H), this is a more reliable technique but limits fish movement. Now we do not close the saddle but use sleeves to clamp the attachment wires to the fish. The fish is then revived during which we photograph the individuals and then release the fish (I, J & K). ... 41
APPENDIX C: Example of a data sheet used to direct data capturing during a manual tracking survey. .. 42
APPENDIX D: Example extract of manual tracking data collected by Burnette (2013). ... 43
APPENDIX E: Example extract of remote tracking data collected by Burnette (2013). ... 44

ACRONYMS/ABBREVIATIONS

ADC – Analogue to Digital Converter
CPU – Central Processing Unit
FISHTRAC – South African inland fish tracking programme
GPS – Global Positioning System
GSM – Global System for Mobile Communication
LED – Light Emitting Diode
LoE – Line of Evidence
RF – Radio Frequency
SAIAB – South African Institute for Aquatic Biodiversity
WW – Wireless Wildlife
WWDMS – Wireless Wildlife Data Management System

INTRODUCTION

Fish are fascinating animals that dominate the rivers and lakes of South Africa. They provide us with food, angling/recreation opportunities and form an important part of our natural environment. In southern Africa more than 350 species of fishes exist, some of which are in great need of protection along with the ecosystems they live in. The use of radio telemetry techniques to monitor behaviour of fishes to characterise their biology and ecology has been available since the 1950s. Today telemetry methods are being used extensively to monitor how the changes in water quality, quantity and habitat effect the behaviour of fishes in marine and freshwater ecosystems globally. This use of fish behaviour to evaluate the ecological consequences of environmental variable state alterations has been of great value to water resource users, regulators and conservationists locally and internationally (Cooke et al, 2004; Cowley et al, 2008; O'Brien et al, 2013). *The potential value of using fish behaviour to effectively and accurately evaluate the ecological consequences of water quality, quantity and habitat variable alterations, in real time, in South Africa has the potential to revolutionise the way we monitor and manage our resources in the country.* The South African Inland fish tracking programme (FISHTRAC) has been established to contribute to this endeavour of developing the use of radio telemetry monitoring techniques in freshwater ecosystems in South Africa so that fish behaviour can be used to contribute to the management of our freshwater ecosystems. The FISHTRAC programme incorporates the use of locally manufactured radio telemetry technology to monitor the behaviour of our indigenous fishes, and selected water quality and quantity variable states of the rivers and lakes in the country.

Radio telemetry incorporates the use of radio waves to transmit information between two independent instruments/devises across an open or remote space. The approach which is often only referred to as "telemetry" was developed in the 1930s and is now extensively used across the globe. The approach makes use of transmitters, receivers and or transceivers which can either transmit or receive information or both.

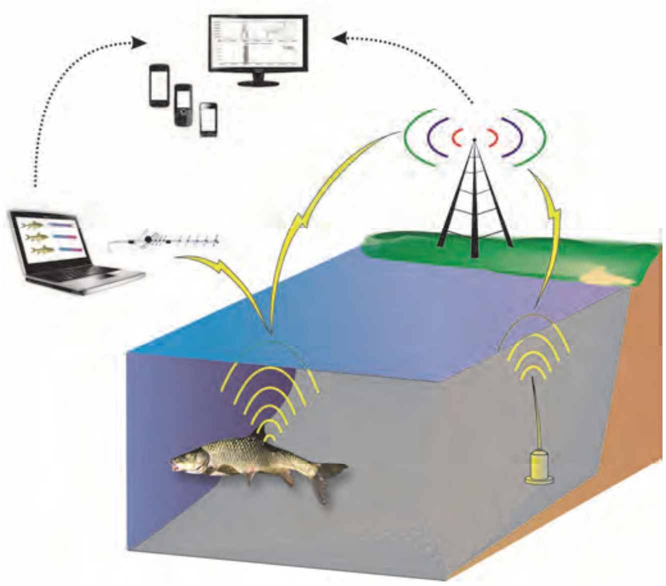


Figure 1: The FISHTRAC programme is based on the radio telemetry information transmission between transmitters and receiver.

From the formal establishment of the use of radio telemetry techniques to monitor fish behaviour in 1956 over 500 published accounts of the development of and use of the radio telemetry to monitor the behaviour of fishes in inland freshwater ecosystems is available. Radio telemetry approaches have been established to monitor the movements, behaviour and space use of fishes including home range or habitat use of fishes (Lucas and Baras, 2001). In addition the approach has been used to evaluate problems associated with fish migration, including the evaluation of fish responses to obstructions the efficiency of fish passage studies, survival during migration, energy expenditure during foraging and migration responses to flow alterations in riverine ecosystems. These techniques have also been used extensively to evaluate the ecological consequences of water quality and other non-living environmental variables state alterations (Lucas and Baras, 2001; Cooke et al., 2004a: O'Brien et al., 2013a; 2013b). Today analogy and digital radio telemetry systems are available and used for an extremely wide variety of uses. The development of radio transmitters (tags) to monitor fish behaviour in their natural environments has been one of the most important advances for studying fish behaviour (Lucas and Baras, 2001).

The FISHTRAC programme makes use of radio telemetry tracking techniques developed by Wireless Wildlife Pty., Ltd. to track the location, movement, activity and habitat use of fish tagged with small transceivers (tags)(O'Brien et al., 2012). Within the FISHTRAC programme the "smart" tags or transceivers can receive and transmit information obtained by components that are built into the tags. This allows the tag to transmit digital coded messages which are used to locate the tags or fish. The tagged fish can be tracked manually or remotely using Wireless Wildlife (WW) technology continuously for up to 3 years! Due to the size of the tags (based on current technology) fish larger than 500 g are usually used in the FISHTRAC programme which may limit the study to adult individuals. A feature of the FISHTRAC programme includes the use of the behavioural response of fishes monitored in real time, remotely to changes in water quality and quantity variable changes (O'Brien et al., 2011). To achieve this, the FISHTRAC programme incorporates selected water quality and quantity variable monitoring techniques. The FISHTRAC programme has been developed through a range of case studies across southern Africa over a ten year period by group of established ecologists with support and direction from many local and international scientists and water resource managers (Figure 2). The FISHTRAC programme does not replace, but builds onto established fish behavioural monitoring methods which have been established in southern Africa (Paxton, 2004). The programme incorporates manual and remote monitoring systems (Figure 2). The "smart" transceivers "tags" used in the FISHTRAC programme can have their transmission scenarios changed which allows for manual and routine remote tracking while optimising the battery life of the tags. The manual system involves monitoring abiotic probes and or tracking tagged fish using mobile hand held receivers. Abiotic probes can be deployed into rivers/lakes and store data (depth, temperature, conductivity, etc.) collected by peripheral sensors incorporated into the tags which can be stored by the tag and then or downloaded by a mobile receiver. Tagged fish can be tracked using this approach so that the movement, activity and habitat associations (etc.) of the tagged fish can be made. The manual system allows tagged fish to be detected using triangulation techniques to within 1 m and monitored for extensive periods. Fish can be manually tracked using a manual receiver from land, a boat or from the air. The remote monitoring systems allow fish to be tracked in real time using base and relay receiver stations which are deployed into the study area. These small (A4 size) stations easily mounted on poles/trees in the field and are solar powered. These stations transmit data automatically to a data management system which can be accessed remotely via the internet using a smart phone, tablet or computer. The remote monitoring data is available immediately following transmission (usually between 10-30 min) from tags that are in range (up to 1 km) of a station. If the fish is too deep (>2 m) or out of range of a station the data is stored on the tag and downloaded when the fish moves into coverage of a station or if tracked manually. The data collected can then analyse the data and generate important life cycle biology and ecology information about the tagged species and can use the method to evaluate the effect of pollution and habitat alterations to freshwater ecosystems.

The FISHTRAC programme now includes an established four phase framework for the programme which includes an Inception phase, Planning phase, AnalysIs phase and Outcomes phase (Figure 3). This manual has been designed to allow field technicians, conservationists and scientists to implement the FISHTRAC programme. On occasion we recommended that a FISHTRAC professional, radio telemetry and or fish biologist be contacted to assist with a specific task in this manual. This will has been indicated with of the associated "*ask for help*" symbol. Additional insight into some components of the manual which we consider to be useful has also been included under the "insight" icon which is always associated with an insight information box. This manual presents the FISHTRAC programme approach in detail and provides explanatory information and examples where applicable. In addition an overview of the approaches adopted and findings of some case studies from southern Africa have been included.

Ask for help icon

Insight icon

WHY FISH BEHAVIOUR?
Fundamentally, the value of this radio telemetry technique includes the ability to monitor fish behaviour for extended periods of time in their "natural" environment. Fish behaviour includes the cumulative interaction of a variety of biological and physical factors and represents the fish's visible response to internal (physiological) and external (environmental, social) factors, relating one organism to another. We use this visible response from a fish to understand what it knows (Morris 2005). The behavioural response of fish has been shown to be as much as 100 times more sensitive to changes in environmental variable states (water quality, quantity and habitat alterations, etc.) than other measures such as population and community shifts and or lethality measures (Godin, 1997; Gerhardt, 2007).

FISH BEHAVIOURAL ECOLOGY RESEARCH IN SOUTH AFRICA:
Take note that in South Africa there are many groups of researchers who have and are currently using the behavioural ecology of fishes to address ecosystem and species conservation and management issues. These groups include but are not limited to some Universities, the South African Institute of Aquatic Biodiversity and some conservation institutions including Mpumalanga Tourism and Parks agency and the South African National Parks.

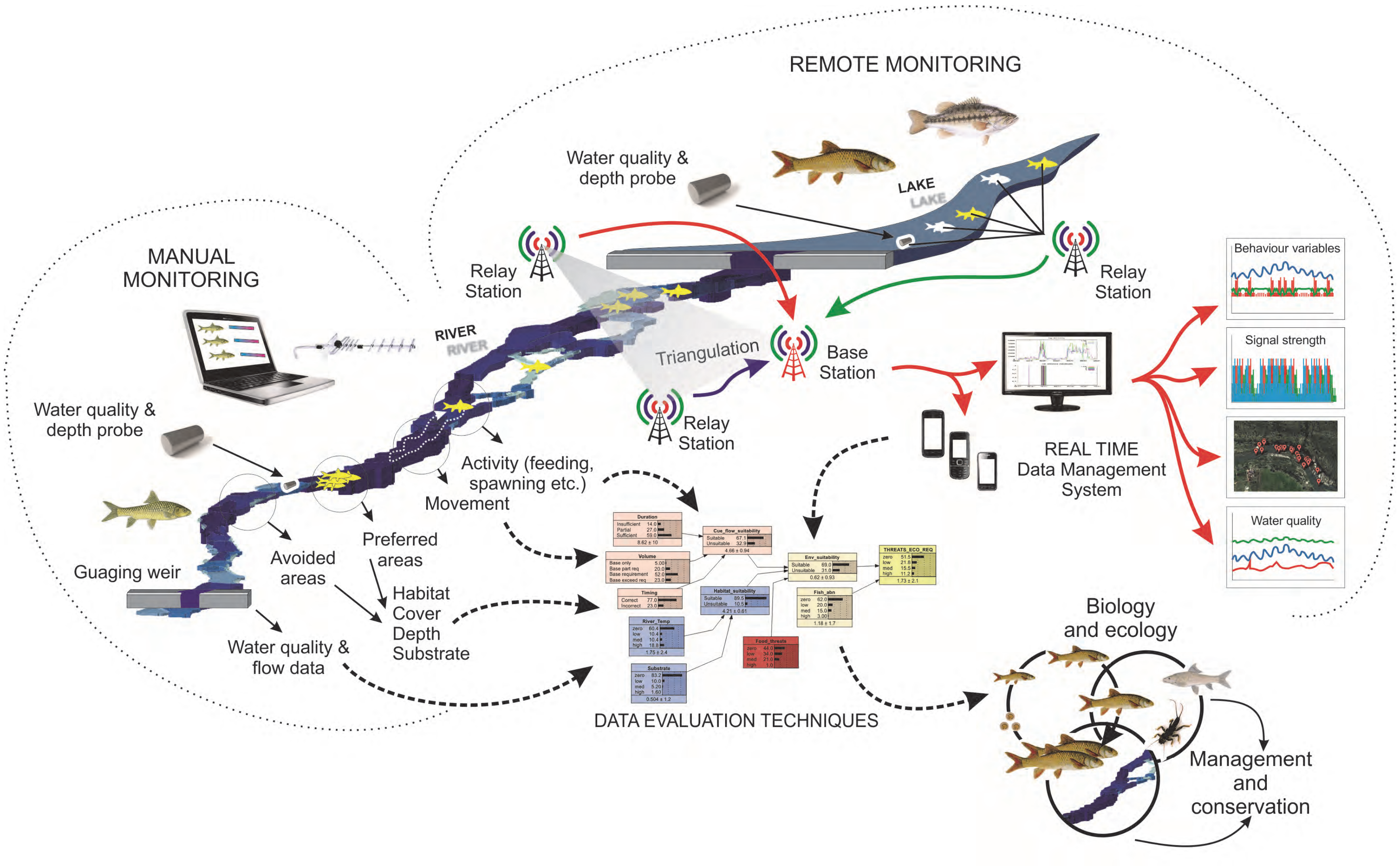


Figure 2: Schematic representation of the FISHTRAC radio telemetry programme to monitor the real time, remote behaviour and behavioural response of fishes to changing water quality and quantity variable states in river and lake ecosystems in South Africa.

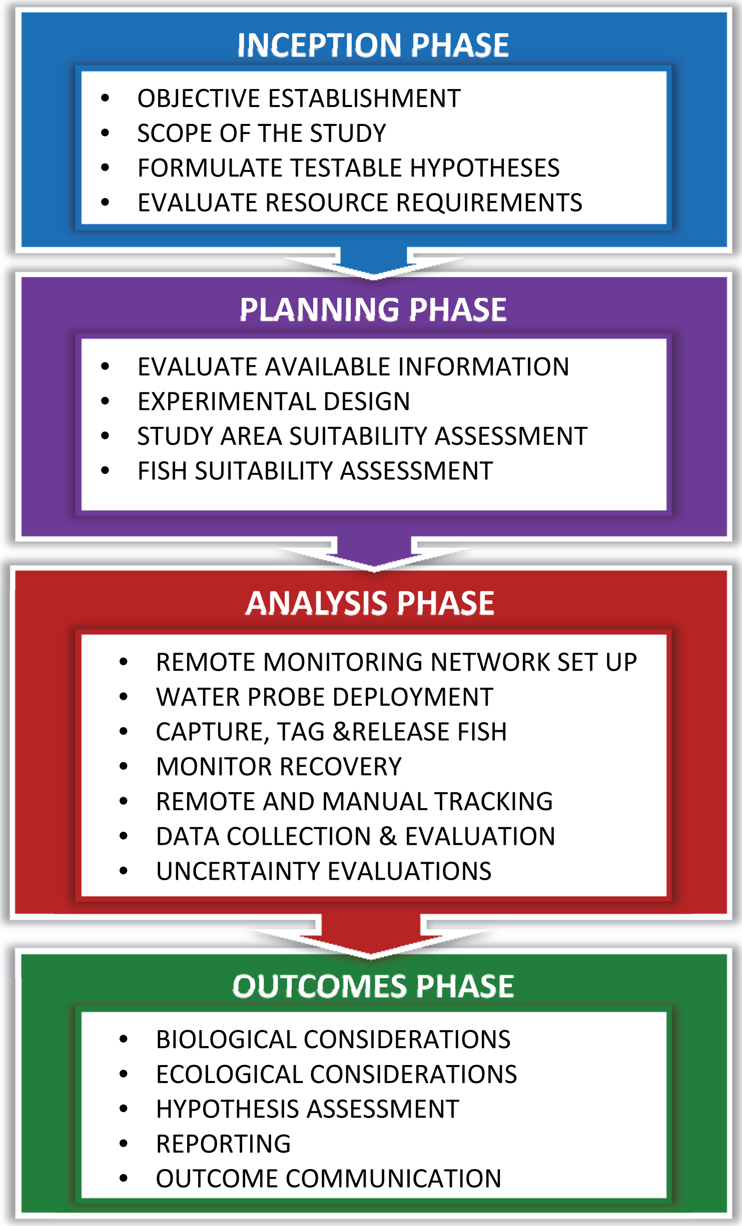
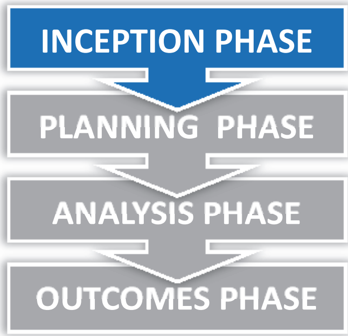


Figure 3: FISHTRAC programme framework to direct the use of real time, remote behaviour and behavioural response of fishes to changing water quality and quantity variable states in river and lake ecosystems in South Africa

INCEPTION PHASE

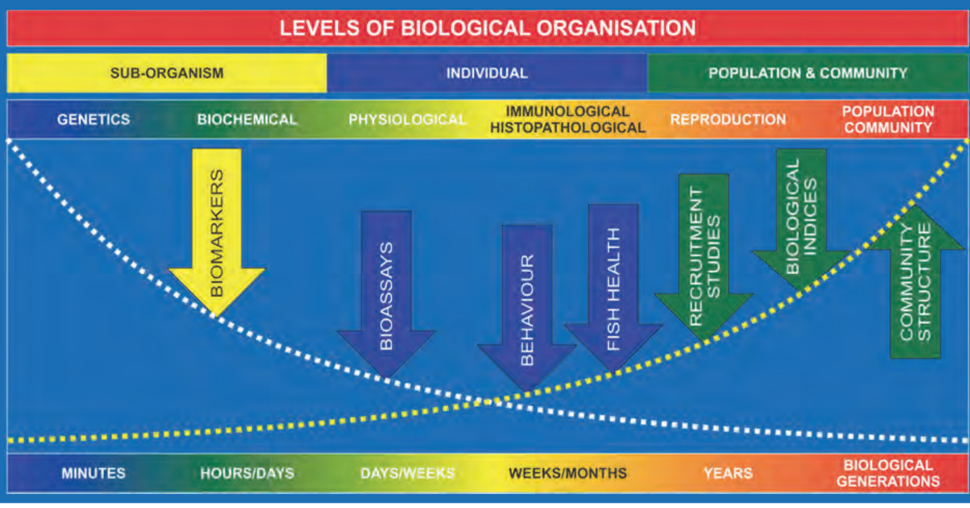


The inception phase of the FISHTRAC programme includes the justification of establishing a radio telemetry study to address a known conservation and or management issue. As is the case in any study a cost-benefit evaluation of carrying out a FISHTRAC study should be carried out. This process includes considerations of the advantages and disadvantages of using radio telemetry approaches to address conservation and or management questions. The inception phase results in the establishment of objectives of the study, scope of the study, hypothesis and resource requirements to carry out a study.

Objectives of the study

Establishing the objectives of a study is one of the most important aspects of any FISHTRAC study and should not be overlooked. To ensure that a FISHTRAC study is relevant and effective as possible, it is important to ensure that decision making needs of environmental managers and stakeholders concerned with the study are met. This requires stakeholder engagement where ecosystem conservationists, regulators, users and scientists can be consulted within a legislative context. Through this process specific objectives for the study can be established which will direct the rest of the FISHTRAC process. *This approach promotes stakeholder buy-in which is of great value to a project and can make the difference between the successful or unsuccessful implementation of management and conservation recommendations identified from the study.*

FISH AS ECOLOGICAL INDICATORS?
Take note that there are many measures or tools that use fish as ecological indicators to address ecosystem conservation and or management issues. Many of these measures often refer to as different lines of evidence (LoEs), which consider fish on different levels of biological organisation. Appropriate tools should be selected for the research, conservation and or management issue being addressed.



Scope of the study

The scope of any study should be based on and understanding of available literature and knowledge of the problem being addressed. The scope of a study should be based on what the literature says, does not work, is missing, works, or what needs special attention and caution for different approaches. Many radio telemetry specialists and or fish behavioural ecologists are available to contribute to this process (*ask for help*). *Many thousands of radio telemetry monitoring studies have been carried out. Some successful and others unsuccessful, it is therefore highly recommended that special attention should be given, when evaluating all the available information.*

TYPES OF RADIO TELEMETRY FISH BEHAVIOURAL STUDIES?
The types of radio telemetry studies include fundamental exploratory or descriptive studies that were most common in early literature and were usually accomplished without forming testable hypotheses (Rogers and White, 2007). The strength of these studies includes baseline characterisations of the home ranges of species, movements and learning about what the fish does. This type of study is usually not designed to find out why fish behave in a particular manner (Rogers and White, 2007). More recently, correlative studies that link changes in fish behaviour (and as such fish wellbeing) to changes in environmental features are being undertaken (Rogers and White, 2007). Within this type of applied study, attention is given to documenting relationships which may not always imply cause and effect (Rogers and White, 2007). Finally radio telemetry studies also include manipulative studies with temporal and spatial controls. This popular approach is concerned with the cause of behavioural responses of fish (Rogers and White, 2007). These manipulative studies must be very carefully planned to make sure useful results are obtained, as they are the relatively expensive and time consuming studies.

Hypotheses

To focus a radio telemetry study and optimise data collection efforts we promote the incorporation of clearly testable hypotheses into any FISHTRAC study. A hypothesis (plural hypotheses) is a proposed explanation of a probable outcome of a scientific study. Hypotheses should be based on (but not limited to) previous observations that cannot satisfactorily be explained with the available scientific theories. A clearly defined hypothesis is:

- a positive statement that can be tested and proved resulting in the acceptance of the hypothesis or,
- a negative statement that can be tested and disproved resulting in the rejection of the hypothesis.

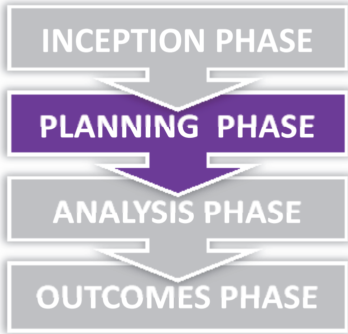
EXAMPLE HYPOTHESES USED IN THE FISHTRAC PROGRAMME:

- FISHTRAC radio telemetry systems **can be** used to monitor the behaviour of adult fish in riverine and lake ecosystems in South Africa continuously and remotely. *Outcome: statement proved = hypothesis accepted*.
- FISHTRAC radio transceivers attached externally to yellowfish **will have** a negative effect on the health and behaviour of yellowfish. *Outcome: statement disproved = hypothesis rejected*.
- Yellowfish in Boskop Dam **will be** active during day light hours only. *Outcome: statement disproved = hypothesis rejected*.
- The habitat use, movement and activity of yellowfish in manmade lakes will be influenced by changes in temperature. *Outcome: statement proved = hypothesis accepted*.
- The activity of adult yellowfishes in rivers will be relatively greater during early morning and late afternoon periods. *Outcome: statement disproved = hypothesis rejected*.
- Rapid increases in flows, >30 $m.s^{-1}$ within a 12 hour period, in rivers will significantly reduce the movement of tigerfish. And, frequent rapid increases in flows will negatively affect the wellbeing of tigerfish populations in river ecosystems. *Outcome: statement proved = hypotheses accepted*.

Resource requirements

One of the most important factors project leaders of a radio telemetry study should considered before initiating a study is funding and time constraints. In the context of the objectives of the study, the required scope of the study and the hypotheses established for a study, if funding and or time constraints hamper the collection of sufficient data or limits the sample size required for a study, then even employing the best radio telemetry technology will not improve the quality of research (Rogers and White, 2007). If for example equipment costs and human resource availability restrictions threatens the ability to answer proposed questions, the project leader should consider narrowing the scope of the study to one species, one sex, or a single system for example. It is far better to answer one question properly than to address many questions poorly, especially if resources are limited (Rogers and White, 2007). Consider that radio telemetry systems are relatively expensive (when compared to other methods that use fish as ecological indicators) where the cost of local tags range between approximately US$200 and US$1000 with manual and remote base and relay receivers costing between US$800 and US$2000.

PLANNING PHASE



The planning phase of the FISHTRAC framework highlights the value of carefully planning a radio telemetry study – *if you fail to plan you may plan to fail*. We have already shown how a study can be limited by time and financial resources, but careful planning can also ensure the optimal use of these limited resources which could make the difference between success and failure of a study. Planning should always be based on available information and *learn from past experiences*. The planning phase of the FISHTRAC programme includes; (1) an evaluation of available information section, (2) experimental design section, (3) study area suitability assessment and fish suitability assessment. Through the developmental phase of the FISHTRAC programme these planning issues were identified as aspects that fundamentally require consideration in any radio telemetry study.

Evaluate available information

The established philosophy of science allows us to stand on the proverbial *shoulders of giants*. There is allot to learn from past radio telemetry case studies, which can provide guidance on tagging techniques, tracking techniques, data collection and analysis and most importantly what we know about the behavioural ecology of our fishes and its use. Telemetry techniques (radio and acoustic) have only relatively recently been established in southern Africa (refer to insight box), so apart from some limited laboratory based fish behavioural studies and a few visual observation studies very little is known about any behavioural ecology of our freshwater fishes (Paxton, 2004; Roux, 2006; Venter et al., 2009; O'Brien et al., 2013a). Despite the known value of biotelemetry techniques, to date only a few dedicated freshwater fish behavioural ecology studies have been carried out in southern Africa. One important recent product of the FISHTRAC programme which is worth considering is the "Remote and manual radio telemetry methods to monitor and use fish behaviour in South Africa's inland waters" by O'Brien et al. (2013). This technical manual provides includes:

- The design and production of WW radio telemetry tracking system for fish in inland aquatic ecosystems in South Africa.
- Tests the functionality of the WW radio telemetry tracking systems for fish through a range of case studies.
- Compares the WW radio telemetry tracking system to internationally available systems.

FRESHWATER FISH RADIO TELEMETRY RESEARCH IN SOUTHERN AFRICA:
Only a few dedicated inland fish behavioural ecology studies have been carried out in southern Africa. These studies have largely been restricted to; (1) the upper Zambezi system by the Namibian Ministry of Fisheries and Marine Resources with the Norwegian Institute for Nature Research (Thorstad et al., 2001; Thorstad et al., 2003; Økland et al., 2005 for example), (2) estuarine fish behavioural research in the eastern cape primarily by the South African Institute of Aquatic Biodiversity (Næsje et al., 2007; Childs et al., 2008a; 2008b; 2008c; Cowley et al., 2008 for example), and through (3) the Mpumalanga Parks and Tourism in the Lowveld (Roux, in preparation) and finally (4) through the FISHTRAC programme (Burnette, 2013; Jacobs, 2013; O'Brien et al., 2012; O'Brien et al., 2013a; 2013b; O'Brien et al., 2014 for example).

Experimental design

The planning phase advocates careful preparation and the structuring of a radio telemetry study. In the experimental design phase the aim and objectives of the study, scope of the study and hypotheses are unpacked in the context of the available resources. This section usually results in the preparation of an inception report. For this adequate time should be afforded to the establishment of procedural steps for the study to address the objectives of the study. This should include the development of a work plan, time plan, and allocation of resources to tasks and establishment of deadlines for the study. We also advocate the use of specialist behavioural ecologists (*ask for help*) during this phase to ensure that every effort is made to optimise planning efforts. Inevitably these types of projects require adaptive management approaches which suggest that *some room for changes* is allowed. This usually includes the provision of time for unforeseen delays for tasks in your time plan. These projects are usually dependent on and often affected by seasonal events, flows and other dynamic ecological processes.

Study area suitability assessment

One of the most important determinants of a successful radio telemetry project is the choice of the study area. This component is often overlooked. Careful evaluation of a proposed study area should be made as some areas that appear to be suitable may not be adequate to answering the proposed hypothesis. On occasion, the study question limits the choice of study areas. This could occur for example when a point source impact is being assessed. Here obviously the study area must include the location of the impact but should possibly include the extent of the home range of the population being evaluated. On other occasions the selection of suitable study area affects the functionality of the FISHTRAC system. This may include for example the importance of selecting a study area where the maximum depth does not exceed the transmission range of the tags used, especially if the tags do not have memory storage options. Take note that this approach is fundamentally based on the behavioural ecology of the subject (tagged fish) which requires the project manager to *let the subject tell its own story*. We have found that the initial consideration of how representative a study area is of the reach of river being evaluated or how common the species in question is within the reach being considered.

Others have promoted, and we have found value in the use of habitat suitability evaluation techniques/indices to contribute to the suitability of the study areas being considered. Other factors that should be considered when choosing an appropriate study area should include:

- ease of access to the study area,
- travel costs to the study area,
- study area must be protected from excessive disturbance to wildlife/poaching activities,
- historical information available from the study area,
- effectiveness of radio tracking due to topography, and
- safety of researchers.

Finally, the value of local knowledge should never be underestimated. Local researchers, conservationists, recreational users of the ecosystem (including anglers), and field workers who spend time in the study area can provide helpful and valuable information to direct the study (*ask for help*).

Fish suitability assessment

Before a radio telemetry study is initiated we suggest that the project team initially carry out a fish suitability assessment or adequate individual availability assessment. There are many examples of projects that were established, tags were purchased and then the team experiencing extreme difficulties in capturing suitable individuals for the experiment. Take note that most radio telemetry tags (including WW tags) are sealed, disposable (after the study) units that have internal batteries. Although most tag manufacturers have developed techniques to “switch” off the transmitters for storage, all batteries have a “shelf life” due to the self-discharge properties of batteries. As a rule tags should be used as soon as possible after purchase. Ask the tag manufacturers for guidance (*ask for help*). The size of availability individuals for projects usually directs the selection of suitable tags. An international 2% tag to body mass guideline has been established for radio telemetry studies (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. During this step consideration of the methods used to capture fish for a radio telemetry study should be carefully evaluated to prevent excessive harm/damage to individuals used and unrepresentative sampling and biased statistics (Rogers and White, 2007). For example gill nets may be very effective, but they sample only active (moving) individuals in deep water, and there might be a risk of only tagging a more mobile sub-population of the population you are interested in. It is important to make use of various sampling methods over different time periods to ensure that a whole population are represented by monitored fish (Rogers and White, 2007). Methods that we have successfully used to collect fishes for radio telemetry studies have included: monitored gill nets, fyke nets, cast nets, electro-fishing (electro-narcosis) and angling techniques.

ANALYSIS PHASE

The analysIs phase involves implementing the study which has been presented as seven sub-step process in the FISHTRAC radio telemetry framework including; (1) remote monitoring network set-up, (2) water probe deployment, (3) capture, tagging and release strategies, (4) recovery monitoring considerations, (5) remote and manual tracking/monitoring techniques, (6) data collection and evaluation and (7) uncertainty evaluations.

Remote monitoring network set up

The remote monitoring network includes the spatial area established by deployed remote receivers (base and relay stations) within which tags can transmit their data to the receivers (Figure 5). Remote monitoring stations include WW base stations, and repeater stations (Wireless Wildlife International Pty. Ltd., Potchefstroom). These self-sustaining, solar powered receivers are deployed into the study area to establish a coverage network over the study area (Figure 5 A&B). These stations have a radio frequency (RF) link to the tags, and between themselves. Each station can store up to two years of data and or remotely send data using existing Global System for Mobile Communication (GSM, referred to as cell phone network) or radio networks. This allows for real time remote monitoring of tagged individuals and abiotic water probes. Data downloads from remote systems is available in real time through a secure internet based Wireless Wildlife Data Management System (WWDMS) that is password protected in an easily displayed format (www.wirelesswildlife.co.za). The remote monitoring system with numerous relay stations allows for a large area with numerous fish being monitored continuously. Variability in topography affects reception range so initially we suggest WW be requested (*ask for help*) to provide range maps (Figure 5 C&D for example) and network assessments for a study after which some ground truth validations should be made.

REMOTE AND OR MANUAL TRACKING/MONITORING OPTIONS:
The FISHTRAC radio telemetry monitoring system incorporates manual and remote monitoring options. Both options have advantages including; the ability to detect the exact (accuracy <1 m) location of a tagged individual during manual tracking experiments so that habitat use/preferences associated with these locations for example can be made, and the ability to monitor routine peripheral information including data on activity (movement), temperature, depth and other parameters over extended periods of time using remote systems. ***One of the major innovations of the FISHTRAC programme includes the ability to download remote data in real time using the Wireless Wildlife Data Management System (WWDMS).***

Summary of the procedural steps that should be considered to establish remote monitoring networks:

1. An effective communication network/s (GSM or RF) needs to be identified for the study.
2. A suitable site should be selected for the base station/s to communicate with the WWDMS for real time data delivery, on occasion this station/s needs to be erected within the network coverage area which might be removed (>10km) from study area. Relay station/s which do not transmit data to the WWDMS need to subsequently be in range (line of sight may be required) of the base station/s. *Take note that in some areas where no real time communication to the WWDMS is needed the stations can store information obtained from the tags which can later be manually downloaded with mobile base stations.*
3. Obtain low confident range maps from WW and then test the range/ground truth study area in advance. Other variables such as local geology, water depth distributions, structures and conductivity for example can affect communication range.
4. Once the ranges are established possible areas to erect stations should be identified.
5. Stations could be erected far from one another, as long as there is a clear line of sight to base station. Take advantage of elevations and where necessary use poles, etc. to increase the elevation of the antenna. We have also found value in attaching "warning" or information boards onto the receivers to deter theft and vandalism (Figure 4). We have also learned to include a Global Positioning System (GPS) tag into the base and relay stations to retrieve stolen stations.
6. Consider that these elevated stations can often act as good "lightning rods" so where you may gain a few hundred meters of coverage you may lose the whole network. Consider also that river and lake levels can rise unexpectedly, so it may be worth insuring base and relay stations.

Figure 4: Photograph of a notice board used to deter theft/vandalism of remote stations.

Wireless Wildlife tags

Wireless wildlife has produced a range of transceivers (tags) for the FISHTRAC programme (Figure 6). These tags have been developed for external attachment and internal and oesophageal implants (refer to tagging section for tagging approach) for fish, water probes and reptile probes with GPS components. The tags are available in various sizes (usually dependent on battery size) and range in mass from 9 g to 20 g (fish tags) and >100 g for abiotic tags and reptile tags. Peripheral components which can be incorporated into the tags include activity (omnidirectional accelerometer), temperature, depth, Light Emitting Diode (LED) lights and for the bigger tags GPS for accurate location determination. Wireless wildlife are constantly developing the functionality of tags and the range of peripheral components.

WIRELESS WILDLIFE TRANSCEIVERS (TAGS):
Wireless Wildlife 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 built-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. With the ability to change the modes of the WW tags less power is required from the tags that remain in default remote monitoring mode where one signal is transmitted every ten minutes, compared to traditional transmitters that are permanently in manual tracking modes that transmit every 30s. This allows for an increase in the power output of the WW tags (up to 100 mW) and the inclusion of additional monitoring components (temperature, depth, activity, etc. sensors) to be included into relatively small (<16 g) tag that lasts for more than 12 months and can be attached to large >1.5 kg adult fish. *For more information consider O'Brien et al., 2013a.*

Water probe deployment

Within the FISHTRAC programme the WW-500 CDT remote water monitoring probe has been extensively used and tested to provide supporting environmental variable data to the fish behaviour data. The WW-500 CDT probe has been designed to monitor conductivity, depth and temperature remotely in real time. This probe has also been used and is available for use in other water resource monitoring projects. Similarly the water monitoring probe makes use of radio telemetry communication systems to communicate with mobile or remote receivers. This data can either be transmitted immediately via GSM or RF to the WWDMS or be stored on the remote receiver or on the tag itself, as is the case with fish tags. The water monitoring probes (Figure 6) are sealed tags that have been potted into a cylindrical shape with attachment points available on the tag. Although robust we have taken extra precautions to protect the probes by mounting them in a small (120 mm) section (3-5 mm thick) of a steel pipe with a base plate. In some of the case studies where these probes were used large boulders were mobilised by high flows which posed a threat to the probes.

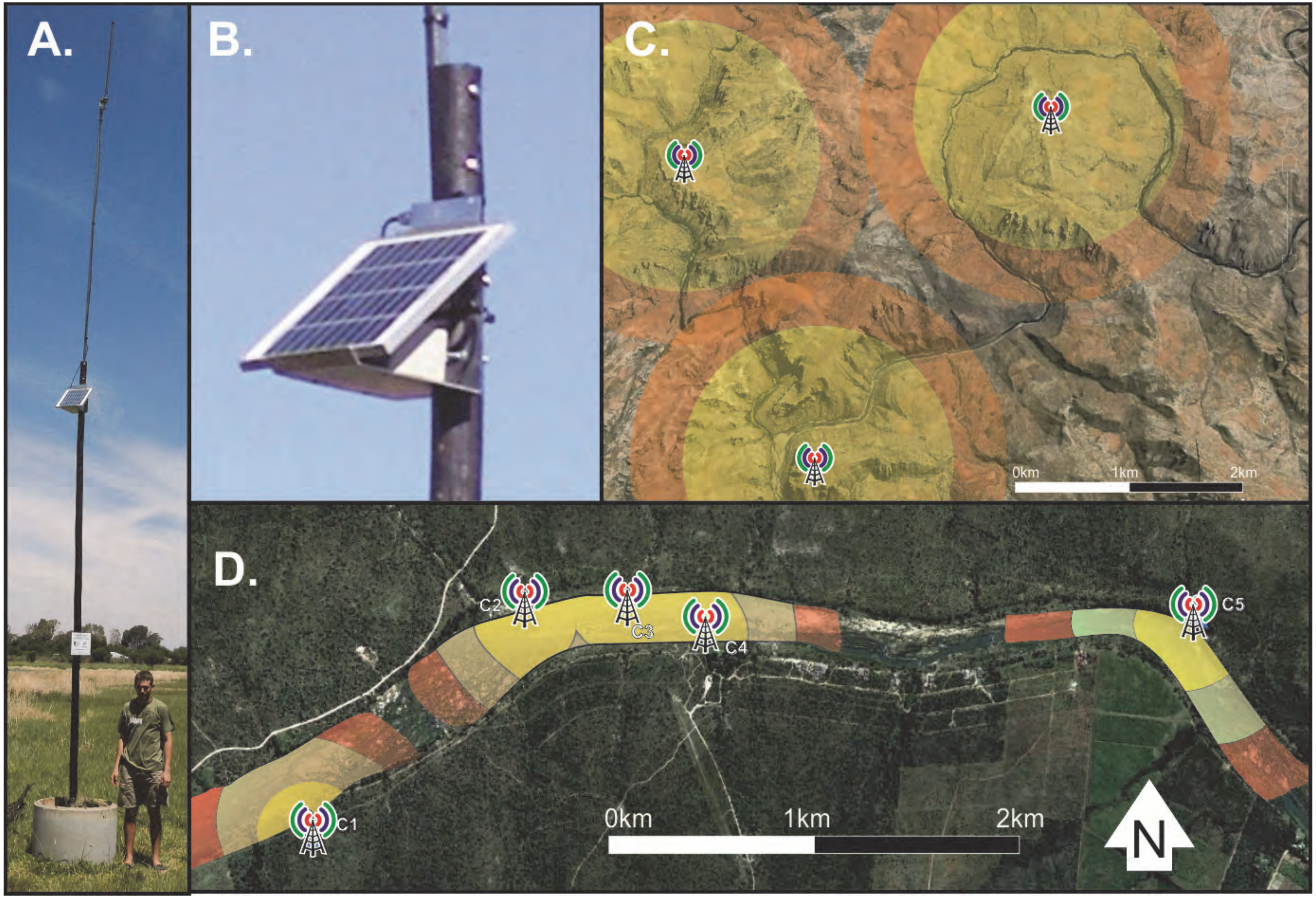


Figure 5: FISHTRAC remote base and relay stations (A & B) and examples of remote monitoring networks set up on river ecosystems with mountainous topography (C) and in a flat area (D).

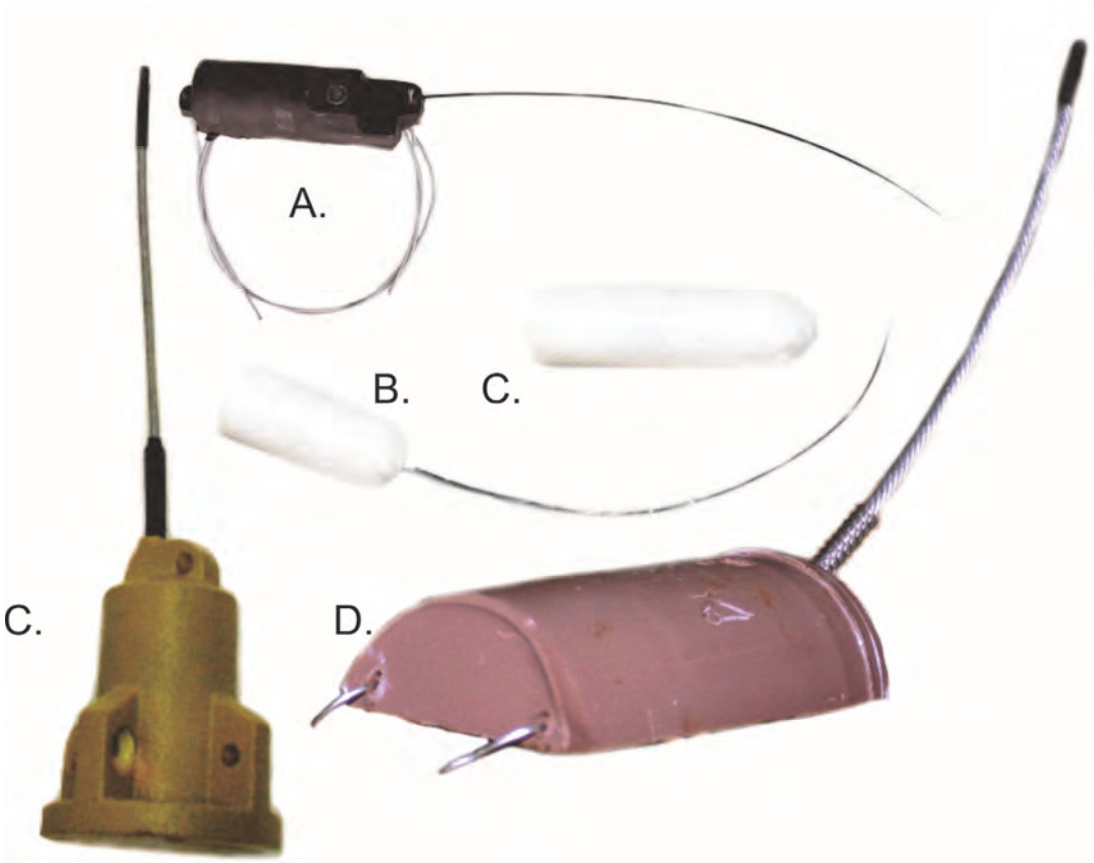


Figure 6: Radio telemetry transceivers (tags) produced by Wireless Wildlife Pty. Ltd., for the FISHTRAC programme. Examples include fish external attachment tags (A), Fish internal implant and oesophageal tags with (B) and without (C) antenna, abiotic probe tag (C) and reptile (D) tag.

Depth, flow and substrate movement characteristics of ecosystems should be considered prior to probe deployment. In order to function correctly probes must remain submerged and be free of excessive sedimentation which may affect pressure readings, etc. In rivers, probes should not be deployed into the deep main channel of a river where possible (Figure 7). Available structure/substrates should be considered and or artificial mounting weights/boulders can be placed in rivers, etc. to provide adequate attachment points. The benefit of being able to totally submerge probes aids in hiding the probes to avoid vandalism and or theft. Consider also using porous steel pipes with concrete bases to secure probes for long-term monitoring.

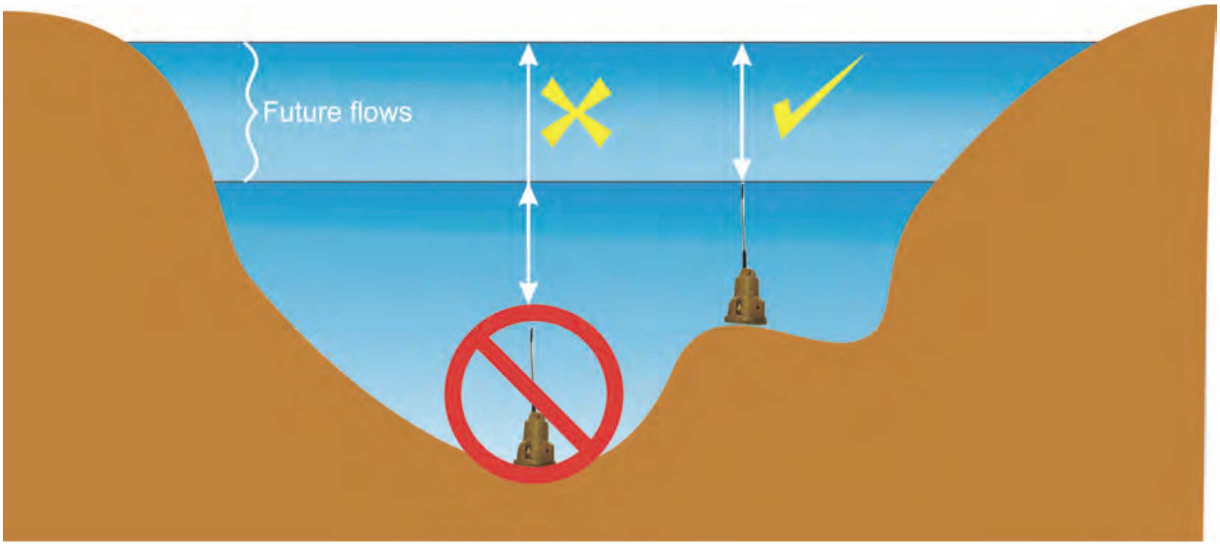


Figure 7: Schematic diagram to show where to deploy abiotic probes. Efforts should be made to avoid the high velocity, deep areas in the main channel and side channels used.

Capture, tag & release of fish

The importance of not only capturing a suitable fish but tagging and releasing the fish successfully in a radio telemetry study cannot be over stated. We suggest that inexperienced practitioners contact experienced researchers for assistance (*ask for help*). Again careful preparation and practice is required to succeed. In addition to just capturing a suitable fish for a radio telemetry experiment, stress levels of that individual must be minimised so the use of suitable fish anaesthesia techniques is advocated. Unfortunately some individuals succumb to this invasive process and either do not survive the tagging process or develop infections and do not recover suitably for suitable analysis. This is why the monitoring of the recovery of the tagged fish is important! Refer to the next section for more information.

Here is an overview of the three most common tagging techniques that could be used to tag fish with radio telemetry tags including external attachment techniques, oesophageal (stomach tagging techniques) and surgical (internal) implanting methods (Figure 8):

- External attachment methods are normally quick and easy, least invasive and requires minimal handling time of a fish. This therefore increases its chances of survival (Bridger and Booth, 2003; O'Brien et al., 2013a). As a rule, fish should be kept in water at all times to prevent unnecessary injury. To begin the tagging process sedation in the form of chemical anaesthesia is necessary, until signs of narcosis become evident (O'Brien et al., 2013a). Before-hand tagging equipment should be cleaned in ethanol. In the anaesthetised state, two hypodermic needles are pushed through the musculature of the individual at the base of the dorsal fin. Attachment wires are then threaded through the needles after which needles are carefully removed. The external tag is then seated firmly against the fish while crimping pliers are used to crimp the sleeves on the attachment wire on the opposite side. The external attachment procedure should take a maximum of 10 min to complete (Figure 8A and APPENDIX B).

- Oesophageal (stomach/Intergastric insertion) techniques involve pushing the transmitter into a fish's mouth, down the pharynx past the cardiac sphincter and into the stomach of the fish (Bridger and Booth, 2003; O'Brien et al., 2013a). *Take note that some fish do not have a "true" stomach but a "pseudo-stomach" which makes these species unsuitable for this tagging technique*. This is the quickest method (possible in 30 seconds) of tagging an individual and usually involves very little anaesthesia, experience or handling time. One of the advantages this method has over external tags is that it eliminates the risk of snagging and dragging causing imbalance in swimming (Bridger and Booth, 2003; O'Brien et al., 2013a). Individuals are lightly anesthetized after which a lubricated (glycerine) plexiglass tube is inserted through the mouth of the fish. The transmitter is inserted lightly into plexiglass tube and pushed into the abdominal cavity, a rod is then used to expel the transmitter after which the tube is removed. Radio transmitter requires that antennas (should be bent prior to insertion) be outside the fish through using the opening in a gill arch. The antenna trailing along the body posteriorly may cause abrasion and infections around the mouth cavity, but are less likely to get infected than external tags (Bridger and Booth, 2003). The main concern for using this method is regurgitation as the longest recorded retention time was 68 days under field conditions and is therefore not the preferred option for long term studies (Figure 8B).
- Internal (surgical) implantation: This method also prevents fouling of external tags and limits drag forces similar to oesophageal tags, but requires a longer holding time, more anaesthesia and high levels of expertise (Bridger and Booth, 2003; O'Brien et al., 2013). This approach may also result in high infection rates and mortalities. Here we strongly advocate expert support (*ask for help*). This method requires a heavy dosage of anaesthesia after which the fish is placed in foam lined V-shape holding container. Continuous gill irrigation is necessary throughout the whole procedure and the skin needs to be kept moist at all times. An incision according to the size of the tag is made on the ventral side to allow insertion of the tag in the peritoneal cavity after which the incision is closed with 3-5 independent sutures. In the FISHTRAC Programme we advocate the use of fish wound care gel available from Sterkspruit Veterinary Clinic (www.sterkspruitveterinaryclinic.co.za). Antibiotics should also be injected into the stomach cavity prior of the last suture to assist in healing and prevent infections. The antenna can trail out posteriorly from the incision by taking a needle and pushing it through the body wall of the fish away from the incision to create a channel for the antenna to pass through (Bridger and Booth, 2003; Figure 8C; APPENDIX A).

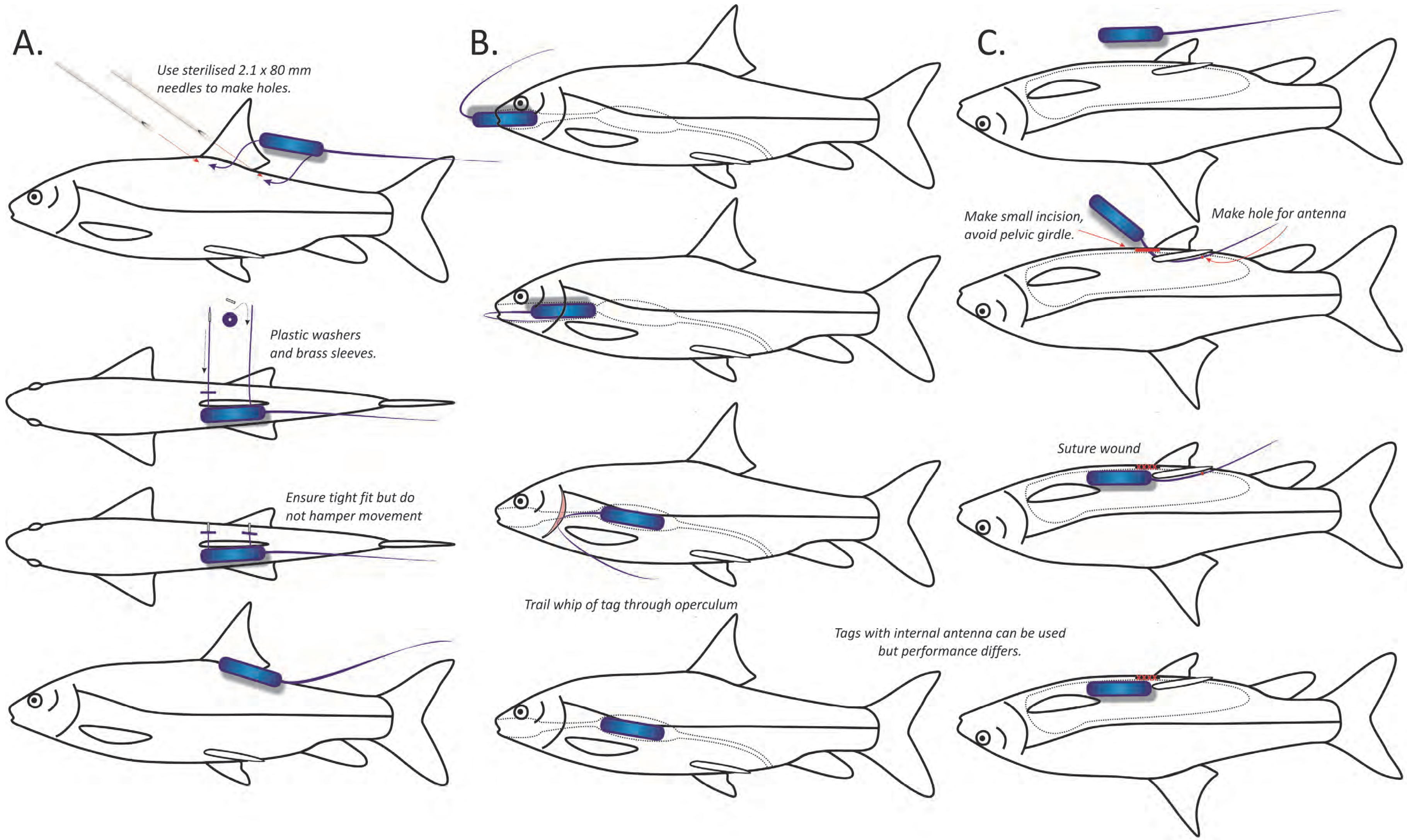


Figure 8: Schematic representation of the three common fish tagging techniques proposed to be considered in a radio telemetry behavioural monitoring study in South Africa by the FISHTRAC Programme. These tagging techniques include external procedures (A), oesophageal (B) and internal (C) procedures.

Monitor recovery

Studies using dummy transmitters in laboratory conditions and through field trials have shown that radio telemetry tracking methods can have negligible effects on the feeding, growth, swimming and or condition of fish if applied correctly (Moore *et al.* 1990; Martin *et al.* 1995; Swanberg and Geist 1997; Cooke and Bunt 2001). This has allowed researchers to assume that fish can exhibit "normal behaviour" after they have survived for a certain period after tagging (Rogers and White, 2007). To this end, researchers must strive to use the smallest possible transmitters able and to allow as much time as possible for the tagged fish to recover from the tagging process. In the FISHTRAC programme we have made some interesting observations which may be useful to consider when implementing a radio telemetry study:

- We have observed that different species respond differently to the capture, tagging and tracking procedures. To date we have used many predators such as tigerfish, Orange-Vaal largemouth yellowfish and largemouth bass (O'Brien et. al., 2012; 2013a; 2013b; Jacobs, 2013; Burnette, 2013), and omnivorous/herbivorous species including Orange-Vaal smallmouth yellowfish, largescale yellowfish, mudfish and tilapians (O'Brien et. al., 2012; 2013a; 2013b; Jacobs, 2013; Burnette, 2013 for example). We have found that the predators are generally relatively more sensitive to the capture, tagging and tracking procedures. These species generally take more time to initiate "normal" behavioural patterns. In addition, we have observed fishes in systems that have a high abundance of natural predators such as crocodiles, fish eagles and or otters start exhibiting "normal" behaviour which includes the use of refuge areas sooner. Very little evidence is available to suggest that larger individuals respond differently to the tagging and tracking process, but we do know that larger individuals in South Africa are more susceptible to capture stress (Smit et al., 2011).
- We have also observed that fish that are adequately anesthetised during the tagging process exhibit a significant reduction in movement for the first few (usually two to five days) days after being released. These fishes then appear to recover relatively faster to the procedure and exhibit "normal" behaviour in as few as seven days. Individuals that were not anesthetised exhibited immediate "flight" responses after the tagging process, as opposed to the significant reduction in movement, and only exhibited "normal" behaviour after at least 10-14 days.
- It is also important to note that in the of all of the many hundreds of fishes that have been tagged and tracked during the development of the FISHTRAC programme only five individuals are known to have been captured by predators (one by a fish eagle and another by a crocodile) or man (three tigerfish caught in gill nets), but none of these events occurred within the "recovery period".
- At least 5% of the fish tagged during the development of the FISHTRAC programme did not survive the tagging process (tags have mortality indicators and or were recovered), and an additional 5% of the tags used failed during the "recovery" period.

We propose that two weeks be allowed for Cyprinids, Cichlids and tigerfish tagged in summer to recover from the tagging process. The recovery time required for fish tagged in winter has been highly variable, so for fish tagged in winter and other families we promote regularly tracking immediately after the tagging process and that only when an extensive amount of data (> six weeks) is available the time used by the individuals to "recover" from the tagging process be established. International guidelines seem to support the two week recover period requirement but this is dominated by studies carried out in Europe and North America (Knights and Lasse 1996; Paukert et al. 2001). If possible a very valuable addition to any telemetry study would be to monitor the behaviour and health of captive fish from the same population studied in a controlled environment. If this type of control experiment is available the representative size and abundance of individuals used should be adequately assessed (Rogers and White, 2007).

Remote and manual tracking

However, as indicated remote and manual tracking techniques have their own advantages and as such we promote the use of both techniques where possible. We acknowledge that some research questions only require the application of one of these tracking techniques. The WW system allows tags to be tracked manually and remotely by changing the transmission sequence of tags from a default routine remote sequence (once every 5 min to hourly transmission usually) to a manual tracking mode which includes transmissions of only some components every second. This feature allows the system to optimise the use of the tags batteries. To change the tag from remote to manual modes, the tags receive a mode switching command from a receiver (both are actually transceivers) during a "standby" phase which the tag enters into every 5 min or so (this too can be programmed). This can be achieved via the real time, remote WWDMS. After the manual tracking exercise is completed by turning the manual receiver off or changing the command via the WWDMS the default remote mode is reverted to. This ensures that if a tagged fish that was being tracked manually moves out of detection range, the tag will automatically revert to the remote mode and continue to store data in order to save battery. In areas where tags are in remote transmission mode and operators need the transmission changed a manual WW mobile notebook receiver system and or WW model aircraft receiver can be used to change the transmission modes. The WW model aircraft receivers have proved to be very effective in detecting "lost" fish/tags with increased elevation and the associated detection range. This also allows for effective tracking in remote areas. A schematic flow diagram of a standard tracking programme developed through the FISHTRAC programme (adapted from O'Brien and De Villiers, 2011) is provided in Figure 9.

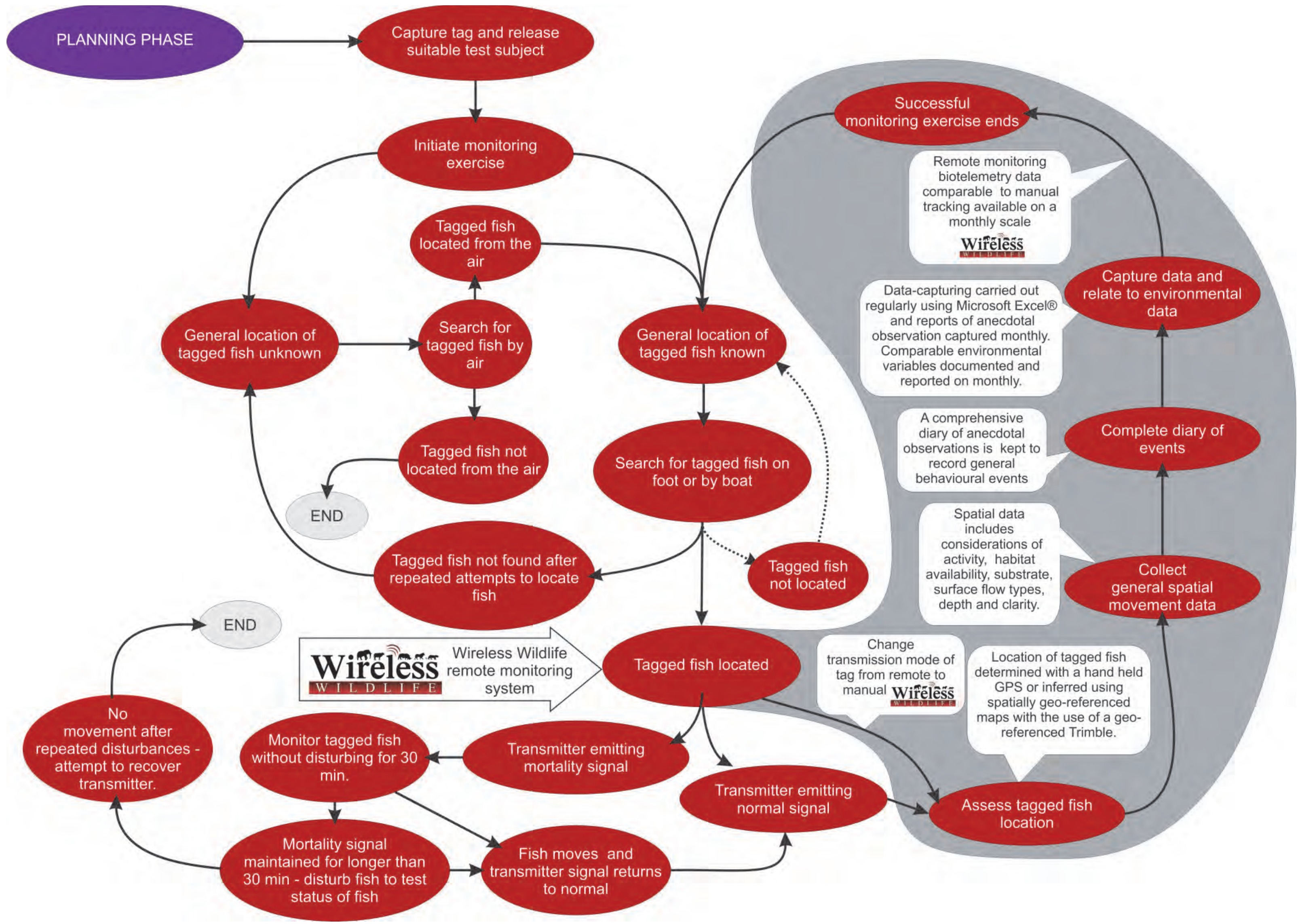


Figure 9: Schematic flow chart of the tracking approach established for the FISHTRAC programme. Purple balloon represents the planning phase and the maroon balloons represent the analysis phase.

Manual tracking options:

- Manual tracking systems include the use of hand held intelligent digital receivers (Hawk GSM-DL) and directional yagi antennas (Figure 10). With these systems the real time, accurate (<1 m) positioning and depth (with peripheral depth components) of tagged fish can be tracked. Two types of manual tracking receivers are available for the FISHTRAC Programme, these include the WW mobile notebook receiver system (Figure 10A) which can be used to change the mode of the tags and manually track numerous tags at the same time, and a programmable weather proof receiver system (Figure 10B) which consists of a programmable receiver built into the grip of a yagi-antenna which can be used to manually track one tag at a time. As indicated on occasion a model aircraft receiver can be used to track "lost" fish (Figure 10C). During the developmental phases of the FISHTRAC programme the accuracy of the manual tracking techniques were tested using Light Emitting Diodes (LEDs) which were incorporated into tags. After the fish were "located" the LEDs were activated to verify the accuracy (Figure 10D).
- Both random and 24 hour surveys are promoted for manual tracking exercises. Through the development of the FISHTRAC programme we have learnt to optimise the information gathering opportunity from manual fixes by spending an extended (up to 40 min) at each location before moving onto another individual. Manual tracking exercises often make use of boats which can disturb the tagged fish, especially individuals which are frequently "harassed". We have found value in slow quiet approaches and using an anchor to position the boat approximately 20 m to 30 m from the tagged fish. After finding a tagged fish the researcher immediately captures bio-physical data for the observation (this represents observation a), ten minutes later another observation (observation b) is made which includes consideration of the maximum displacement between the location of the tagged individual to provide maximum displacement per minute (MDPM data), two more observations (observations c & d) are usually made following the same procedure. This movement variable is the most common behavioural variable used in manual tracking experiments. The type of bio-physical data collected from tracked fish includes: observation number information, survey type, tracked tag information, accurate time and date information, GPS location of the tagged fish and tracker, movement information (MDPM as m.min-1), total area covered/roamed (m), activity information, depth, substrate, cover feature availability, water quality information, weather information, moon phase information and photographs of important habitats, etc. The inclusion of a descriptive "diary of events" is also promoted to assist in later data evaluations. Important considerations for the diary of events may include; sketches of movement; any other fish activity; disturbance information; predator activity; feeding events such as insect hatches; and any other information that may contribute to the evaluation of the behaviour observed (consider an example of a data sheet in APPENDIX C. Data sheets should be copied and captured as soon as possible to reduce data capturing errors.
- Remote monitoring approaches: Remote networks collect and store or retransmit data to the WWDMS. Where 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 approximate location of the tag (referred to as triangulation) (Figure 11). 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 programme the general location of a fish has been established using triangulation by taking the average signal strength over a few data points. 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.

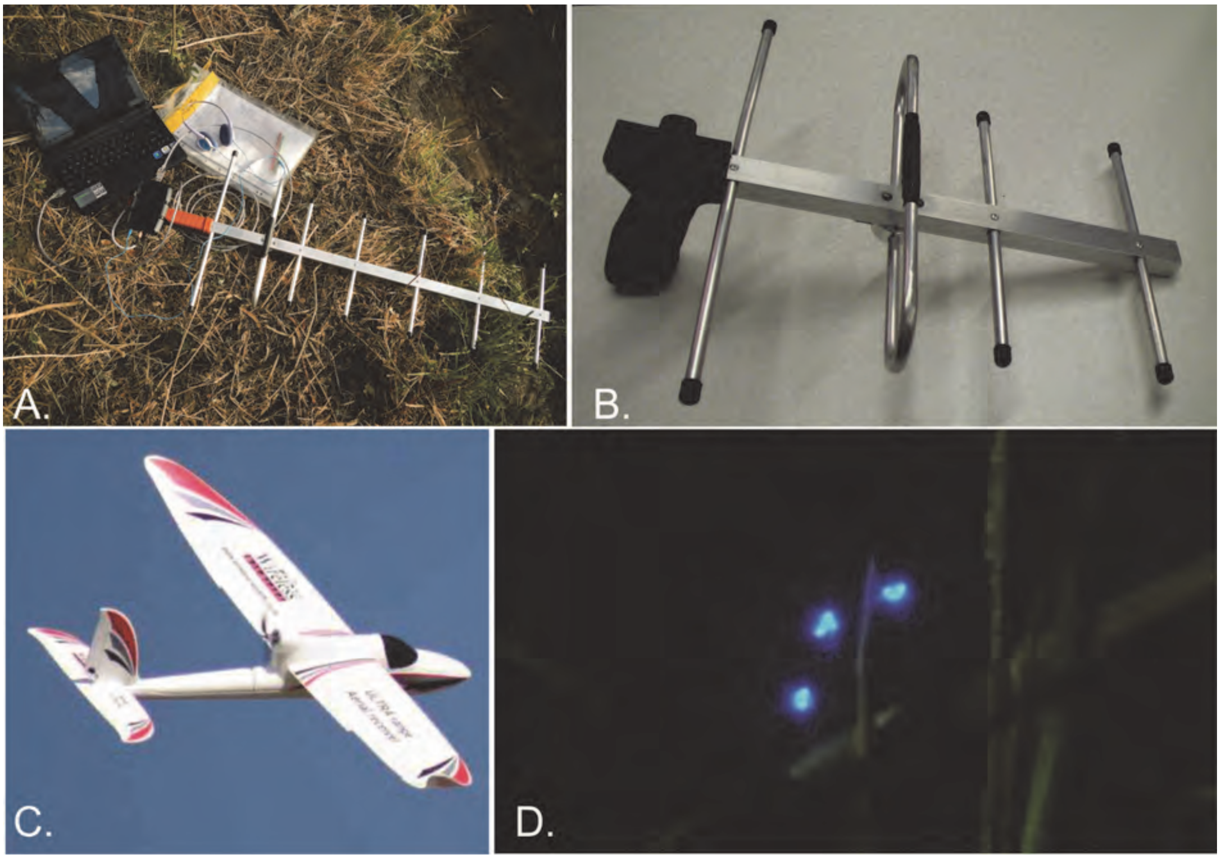


Figure 10: Examples of the manual tracking receivers used to track fish in the FISHTRAC programme. Including the Wireless Wildlife mobile notebook receiver system (A), the programmable weather proof receiver system (B) and the WW model aircraft receiver (C). In addition a photograph (D) of a flickering Light Emitting Diode (LED) tag on a fish to verify detection accuracy.

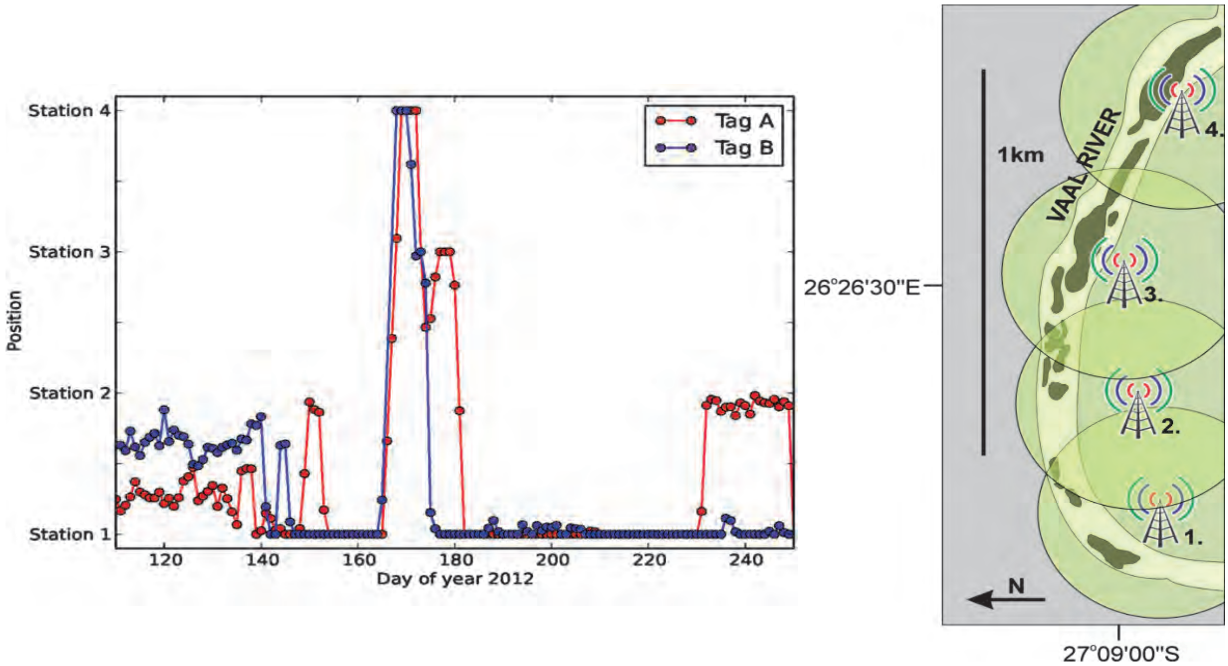


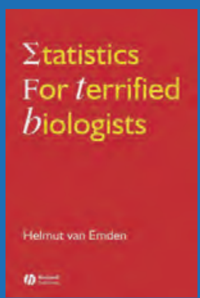
Figure 11: Fish movement data collected from multiple stations over 140 day tracking experiment in the Vaal River to demonstrate simple triangulation techniques.

Data collection & evaluation

Three main types of data are generated in traditional radio telemetry studies including manual and remote behavioural variable data and associated environmental data (habitat, water quality, weather, etc.). Manual behaviour and associated environmental data is collected manually, captured into a data processing format (we usually use Microsoft Excel©). *Take precautions to minimise capturing errors*. Usually a few hundred to a few thousand manual monitoring data "strings" are available in a study (APPENDIX D). Remote monitoring data is automatically stored onto the WWDMS. This password protected information can be accessed using through an online portal remotely (www.wirelesswildlife.co.za) (APPENDIX E). Many thousands of data strings may be collected using remote monitoring system depending on the number of tagged individuals and transmission frequency. Spatial information evaluation programmes such as Geographic Information Systems (GIS), SAS JMP and EONFUSION can be used to assist with and present spatial behavioural data (Figure 12). Other univariate and multivariate approaches have also been used extensively to statistically evaluate the behaviour-environmental variable state relationships (Figure 12). In the FISHTRAC programme we have used Microsoft Excel© extensively for descriptive evaluations of remote and manual behavioural and associated environmental data. We have also used Statistica for various univariate statistical evaluation techniques and SAS, "R", CANOCO and PRIMER for multivariate statistical analysis. Finally in the FISHTRAC programme we have used various probability modelling techniques including Bayesian Network modelling techniques using Netica (NORSYS) software. We suggest you consult with experienced ecologists and or statisticians and look at case studies to assist in your statistical evaluations of the radio telemetry data (*ask for help*).

Figure 12: Logos and labels of univariate and multivariate statistical software packages, and spatial data evaluation programme used locally and internationally to evaluate/display data from radio telemetry studies.

STATISTICAL METHODS FOR RADIO TELEMETRY STUDIES.



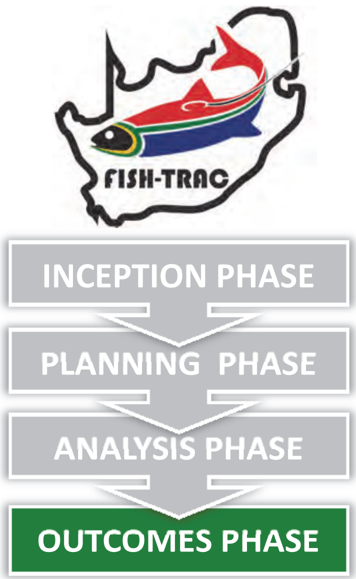
Many univariate and multivariate statistical techniques have been used and are available to evaluate data obtained from radio telemetry studies. Apart from reviewing existing radio telemetry studies there are many user friendly statistical manuals such as the "Statistics for terrified biologists" manual by van Emden (2008).

Uncertainty evaluations

The outcomes of a radio telemetry study should be considered by the researchers, conservationists and managers in context of the uncertainty associated with the collection of data, evaluation techniques and interpretation limitations. Every attempt should be made to document potential sources of uncertainty and the implications of these variables to the use of the outcomes of a study. *Take not that one of the most common areas of uncertainty in any behavioural study is that correlation does not necessarily imply causation.*

OUTCOMES PHASE

The final phase of the FISHTRAC framework for radio telemetry studies considers the importance of discussing the outcomes adequately, revisiting the hypotheses, reporting suggestions and outcome communication suggestions.



Biological considerations

The outcomes of a FISHTRAC study should initially be considered in the context of the known biology of the species used in the study and where possible contribute to the known biology of the species.

Ecological considerations

In addition to the biological considerations the known ecology of the species being tracked, including the relationships between other fishes and other bio-physical variables in the ecosystem should be considered. These considerations will direct the discussion towards answering the proverbial *so what* question. The discussion should then revisit the aims and objectives of the study and involve establishing recommendations to; (1) reduce uncertainty associated with the outcomes of the study, (2) direct future projects and (3) seek to answer new research/conservation/management questions.

Hypothesis assessment

The hypotheses should finally be revisited and evaluated in the context of the outcomes of the study and be accepted or rejected. The implications of the accepted/rejected hypotheses to the known biology and ecology and or conservation and or management of the species considered and or the ecosystem/s in which they occur should be presented.

Reporting

The reporting phase should also not be overlooked. The communication of the outcomes of any radio telemetry study is of great importance to stakeholders and national and international conservationists, managers and scientists. The structure of reports should also receive sufficient attention. Finally the audience of the report should be considered (conservationists, managers, scientist and or anglers for example) when preparing a report.

Outcome communication

This part of the study may involve interactive activities to distribute information on the success and content of the project to interested stakeholders. These may include workshops, publications, and presentations at conferences, newsletters, press releases and or book and manual development.

CASE STUDIES AND LESSONS LEARNED

Here we have provided a summary of nine case studies undertaken through the FISHTRAC programme to date. For more information please consider the reference to each case study.

1.1 **Case Study 1:** Vaal River yellowfish behavioural study 2006-2008 by the University of Johannesburg, Centre for Aquatic Research.

This study considered the home ranges, habitat use, migrations and general behavioural aspects of the biology and ecology of the Orange-Vaal Largemouth and Smallmouth yellowfishes (O'Brien and De Villiers, 2010; O'Brien et al, 2013). This study is the first behavioural study of yellowfish in the Vaal River using radio transmitters to characterise habitat preferences and movement patterns. A total of 22 adult *Labeobarbus kimberleyensis* and 13 adult *Labeobarbus aeneus* individuals were tracked for up to 16 months from 23 September 2006 to 16 May 2010. Radio telemetry revealed that yellowfish established routine daily behavioural patterns through which the habitat preferences and movement of the species could be established. Home ranges of the yellowfish ranged from 1 km to more than 12 km in the Vaal River depending on the species and habitat availability. Habitat preferences varied between species and included deep slow-flowing habitats with associated cover features particularly in winter for *L. kimberleyensis* and shallow fast-flowing habitats particularly for *L. aeneus* in spring, summer and autumn. Changes in flows, habitat availability and atmospheric pressure affected the movement of yellowfish. The biology and ecology of the yellowfish in the Vaal River is noticeably more complicated and dynamic than previously documented. We recommend that the behavioural ecology of these and other yellowfish populations in the Vaal River should continue to be characterised, and the use of the movement of yellowfish be developed as an indicator of ecosystem change (Figure 14).

2.1 **Case Study 2:** Letsibogo Dam tigerfish recruitment, Botswana by Digby Wells and associates and the University of Johannesburg, Centre for Aquatic Research (2009-2010).

In this study a small population of tigerfish (n=16) were captured in the Schroda man-made lake in South Africa and relocated to the Letsibogo man-made lake to evaluate the suitability of the lake for a tigerfish population and the potential for the population to control local alien invasive fishes (Tomschi et al., 2009). Both lakes are located in the Limpopo catchment in southern Africa where tigerfish are rare and now locally protected. From this study the home range, habitat use/preferences and behavioural patterns of the relocated tigerfish were evaluated to provide ecosystem suitability information to managers. From the outcomes the lake is suitable for tigerfish who would actively predated on available fishes which includes alien invasive fishes. One interesting outcome included the restricted home ranges of the tigerfish which remained close to the release point for the duration of the study (**Figure 13**). Additional interesting outcomes included the preferred use of a new habitat in the Letsibogo Lake that were not available in the source lake and interesting hunting and predator avoidance strategies (O'Brien et al., 2012).

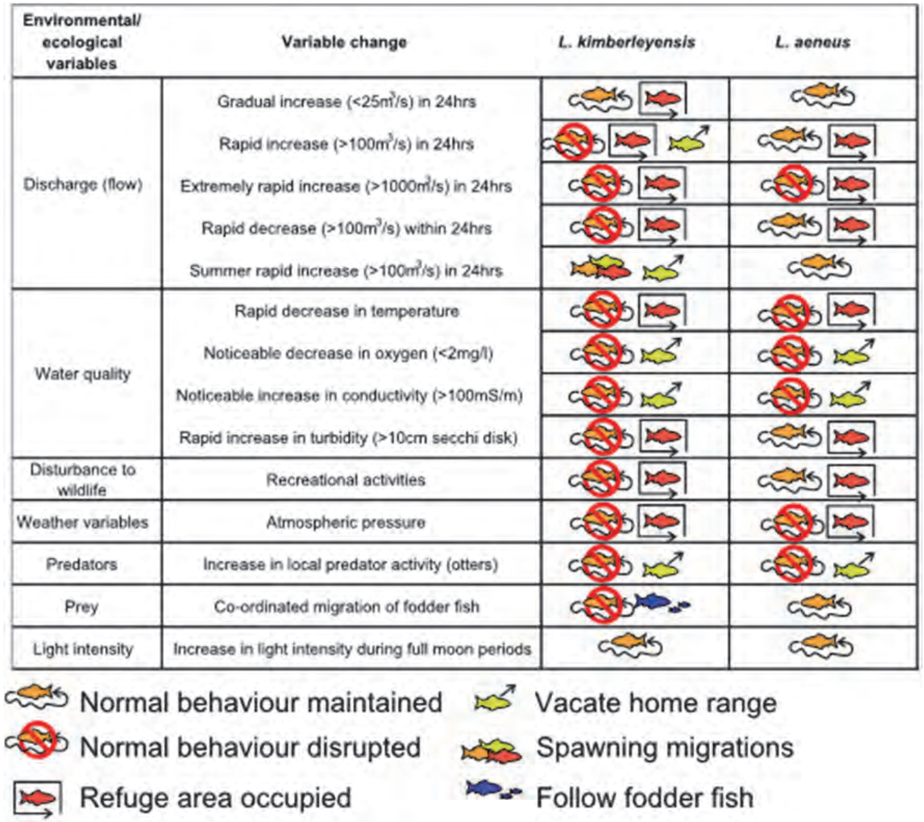


Figure 14: Summary of the behavioural response of yellowfish in the Vaal River to changes in environmental variable states (O'Brien and De Villiers, 2010; O'Brien et al, 2013).

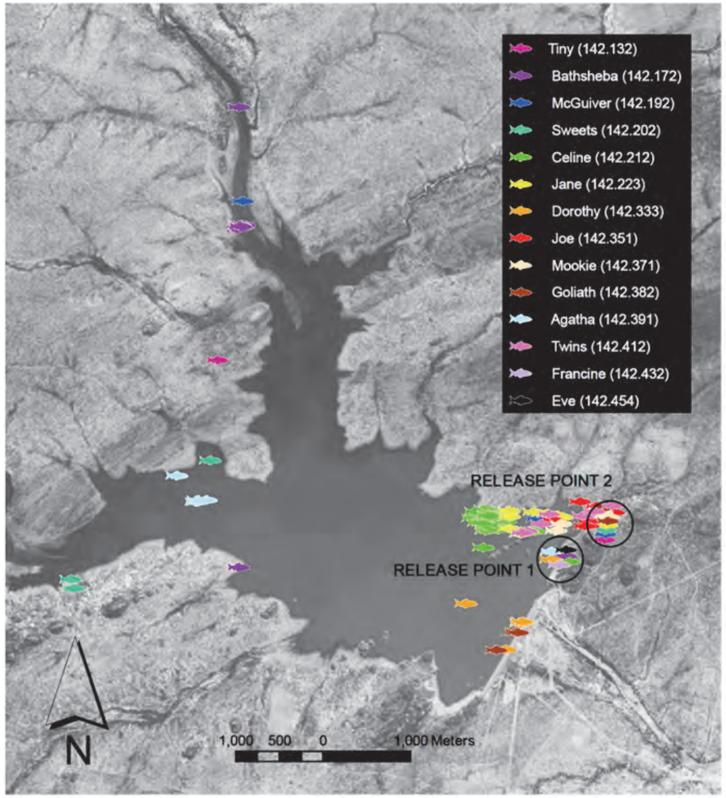


Figure 13: Positions of the fourteen tigerfish monitored in Letsibogo Dam throughout the study (Tomschi et al., 2009).

3.1 **Case Study 3:** Schroda Dam tigerfish ecology study South Africa, by Digby Wells and associates and the University of Johannesburg, Centre for Aquatic Research (2009-2011).

Tigerfish, *Hydrocynus vittatus* are amongst the most socially, economically and ecologically important fish species in southern Africa. The aim of this study was to monitor the behavioural ecology of the local tigerfish population using radio telemetry techniques (n=20) to contribute to our understanding of the behavioural ecology of the species. The results showed that the lake is ideally suited for the tigerfish which was established nine years prior to the study. Time spent feeding, competition between tigerfish and habitats used suggest that the local population is highly stressed (O'Brien et al., 2012). This was supported with the discovery of unique avivorous predatory behaviour of individuals in the population (Figure 15, O'Brien et al., 2013). The telemetry technique implemented led to this discovery which has dramatically altered our understanding of the resilience of tigerfish populations. The study also included the documentation of a spawning event within the lake which provided important information on the spawning requirements of the local population and how we should manage lake ecosystems in the region.

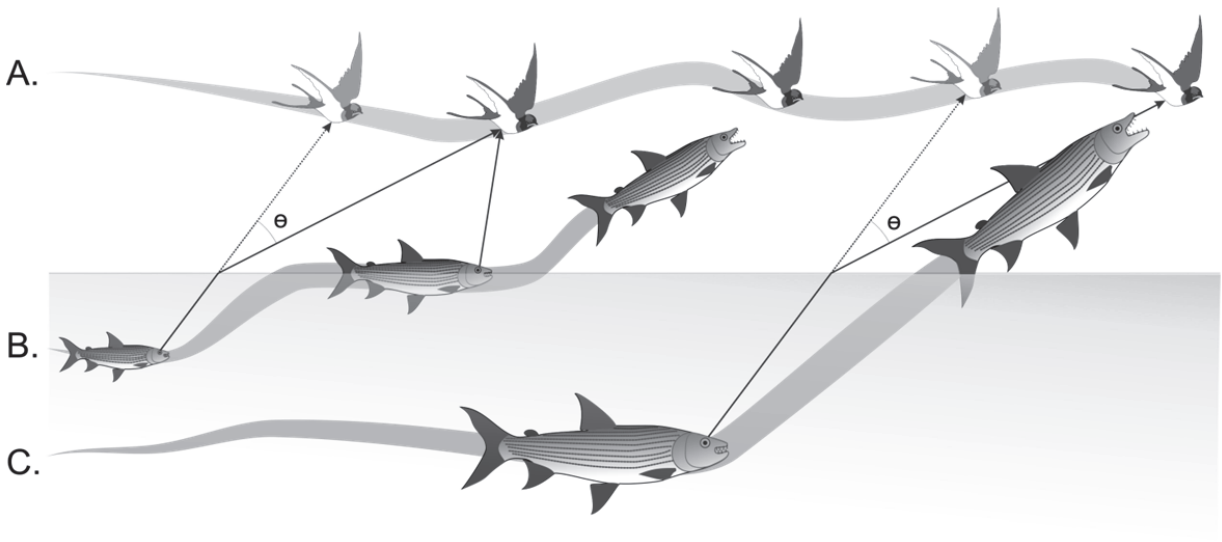


Figure 15: Avivorous behavioural strategies adopted by Hydrocynus vittatus in the Schroda Dam man-made lake. (a) Flight path of the prey Hirundo rustica, (b) surface pursuit strategy of H. vittatus to overcome surface image shift due to light refraction (angle θ) and (c) direct aerial strikes by adult H. vittatus that compensate for the image shift (not drawn to scale, O'Brien et al., 2013).

4.1 **Case study 4:** Okavango tigerfish angling stress survival experiment, Botswana by University of Johannesburg, Centre for Aquatic Research (2010).

This experiment involved capturing, tagging and tracking the initial response of tigerfish in the Okavango River to the capture and tagging process. This study formed part of a greater study to evaluate the effect of angling on tigerfish in the Okavango River (Smit et al., 2009). Interesting outcomes from this study included the importance of reviving tigerfish from tagging processes adequately to avoid predation from crocodiles. From this experiment in particular, and the research undertaken by Burnette (2013) where a fish eagle caught and ate a tagged tigerfish and from O'Brien et al. (2013) who showed that Otter activity affects fish behaviour, the importance of understanding the predator strategies in telemetry projects has been highlighted (Figure 16).

Figure 16: Tagged tigerfish from the Okavango study ready to be released into the river after being revived from anaesthesia (Smit et al., 2009).

5.1 Case Study 5: Vaal River yellowfish behavioural study by North West University, Water Research Group (2011-2013).

In this study the behavioural ecology of the Orange-Vaal River yellowfishes were characterised and compared between lentic (lake) and lotic (river) ecosystems in South Africa (Jacobs, 2013). In this study 18 *Labeobarbus aeneus* and 3 *L. kimberleyensis* were fitted with radio transmitters and tracked in Boskop Dam and 14 *L. aeneus* and 3 *L. kimberleyensis* were tagged and tracked in the Vaal River. Yellowfish were monitored for eleven months using a remote monitoring system for the first time (*Figure 17*), together with manual monitoring techniques. In this study peripheral tag components (depth, activity and temperatures) were also used for the first time as well as data storage options. Analysis of the data collected showed that the yellowfish establish distinct daily behavioural patterns with specific depth and activity profiles during the day. Outcomes also included significant behavioural responses to different habitat and temperature states and the establishment of home ranges and high use areas in the study area. This study confirms that remote radio telemetry methods can be used to characterise the behavioural ecology of yellowfish species. In addition, the study has improved the knowledge of how environmental variables may affect the behaviour of yellowfish species.

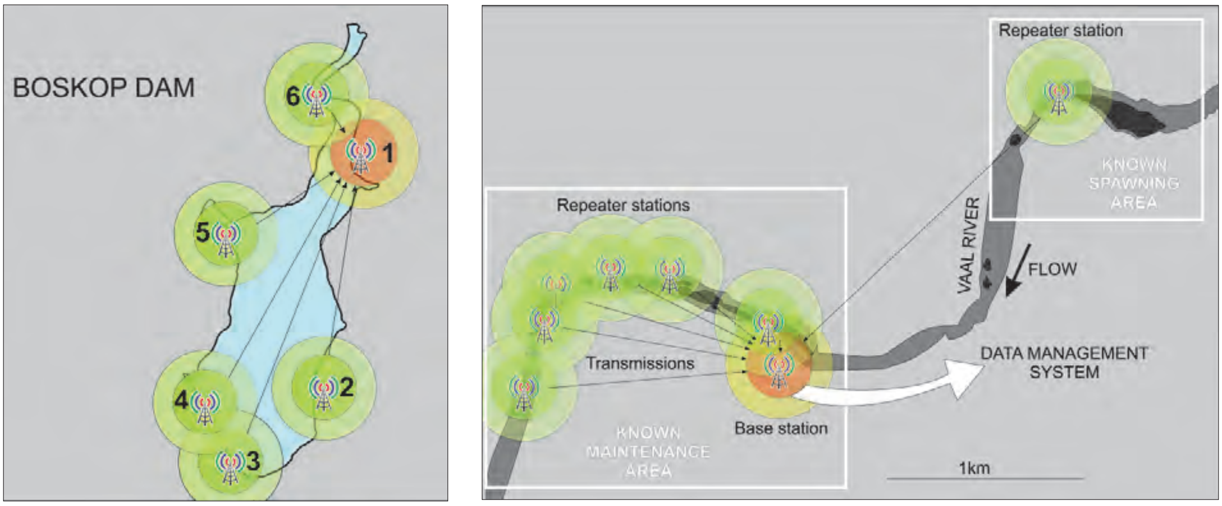


Figure 17: Remote radio telemetry network coverage areas for the Boskop Dam and Vaal River during the yellowfish behavioural study (Jacobs, 2013).

6.1 Case study 6: Crocodile River yellowfish and tigerfish behavioural study, KNP by the University of Johannesburg, South African National Parks and North West University (2011-2013).

In this study the habitat preferences of adult low-veld largescale yellowfish (*Labeobarbus marequensis*) and tigerfish (*Hydrocynus vittatus*) were evaluated in the Crocodile River, Kruger National Park. The aim of this study was 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. 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 American Advanced Telemetry System tags and seven *L. marequensis* and 10 *H. vittatus* were attached with Wireless Wildlife tags. In the study, 479 manual fixes were obtained from 15 individuals and 39505 remote monitoring strings were obtained. Spatial distributions of the tagged fish were generally confined to the focus area of the study area, (± 2 km). 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. An interesting outcome included some behavioural differences between yellowfish and tigerfish (*Figure* 18). 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. These findings reveal that excessive increases in flows (>60 m^3/s) cause significant disruptions to the behaviour of yellowfish in the Crocodile River. The increase in frequency of these events may threaten the wellbeing of the yellowfish population in the Crocodile River. This study recommend that long term monitoring of these fish populations be carried out.

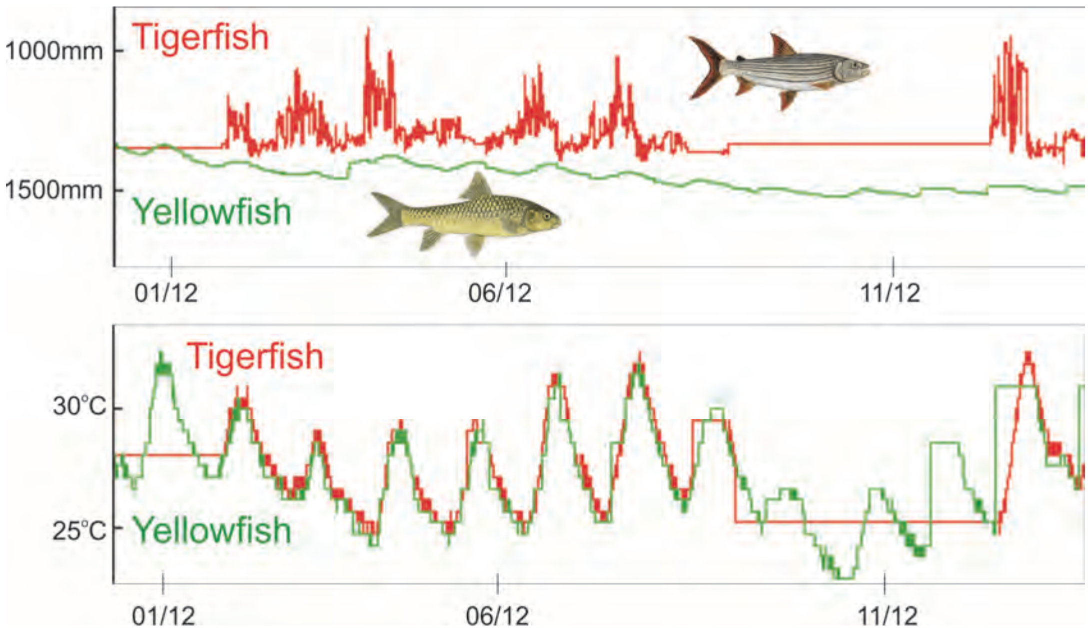


Figure 18: Graphs of the depth (above) and temperatures (below) of the yellowfish and tigerfish in the Kruger National Park study.

7.1 Case study 7: Crocodile River crocodile ecology experiment by the University of Johannesburg, South African National Parks and North West University (2012).

In this experiment the functionality of the Wireless Wildlife tags for use on other aquatic animals was tested by tagging and tracking a Nile crocodile in the Crocodile River during the study carried out by Burnette (2013). The tag attached to the crocodile included a Global Positioning System (GPS) device which allowed the position of the crocodile to be obtained when the crocodile was on the water surface and on the bank. In addition to the GPS the tags used included temperature and movement (accelerometer) monitoring components. In this study the daily behaviour of the tagged crocodile was evaluated. Interesting outcomes included the relationship between movement and increasing temperatures (Figure 19), and the differences in activity while the crocodile was in the water and out of the water. The study are highlighted the limited home range of the tagged crocodile, the preferred basking areas and refuges and the use of a bridge for cover as soon as construction was completed. The experiment demonstrated that the Wireless Wildlife tags are suitable for application on other aquatic animals.

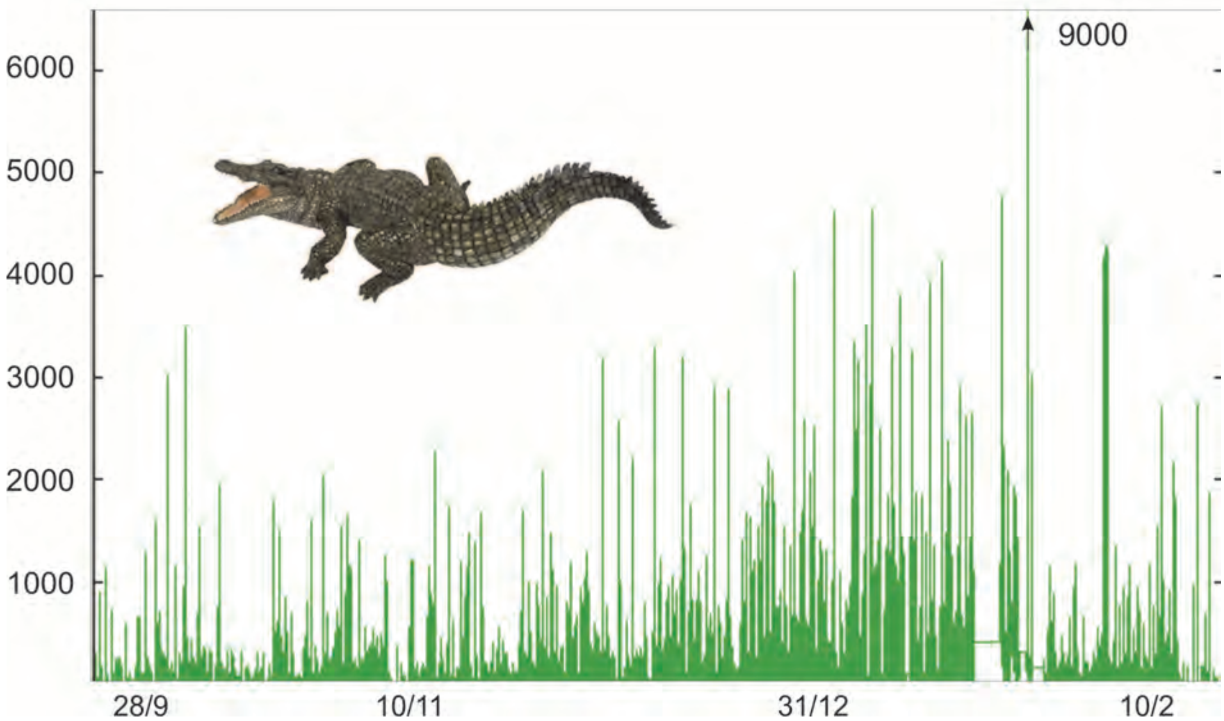


Figure 19: Graph of the activity (accelerometer omni-direction movement) of a tagged crocodile in the Crocodile River.

8.1 Case study 8: Water quality and quantity monitoring in the Senqu River, Lesotho by the Institute of Natural Resources NPC.

In this experiment the functionality of the abiotic probe was tested by deploying a probe with a depth, conductivity and temperature sensors into two sites in the Senqu River in Lesotho (LHDA, 2014). The tags were deployed onto hydraulic transects in the river for which flow-duration curves were established to that the depth could be used to calculate the discharge at the site. IN this case study this information was of great value because we were able to link discharge modelling accurately to ecological response of the biological component of the study to evaluate the effect of habitat availability based on flows (Figure 20). In addition to the depth data the associated conductivity and temperature information associated with this habitat state information was available. This demonstrated the functionality of the abiotic probes to generate data to characterise the state of these variables to relate to biological measures in real time, remotely. This highlights the potential for the approach to be used as a real time early warning monitoring system.

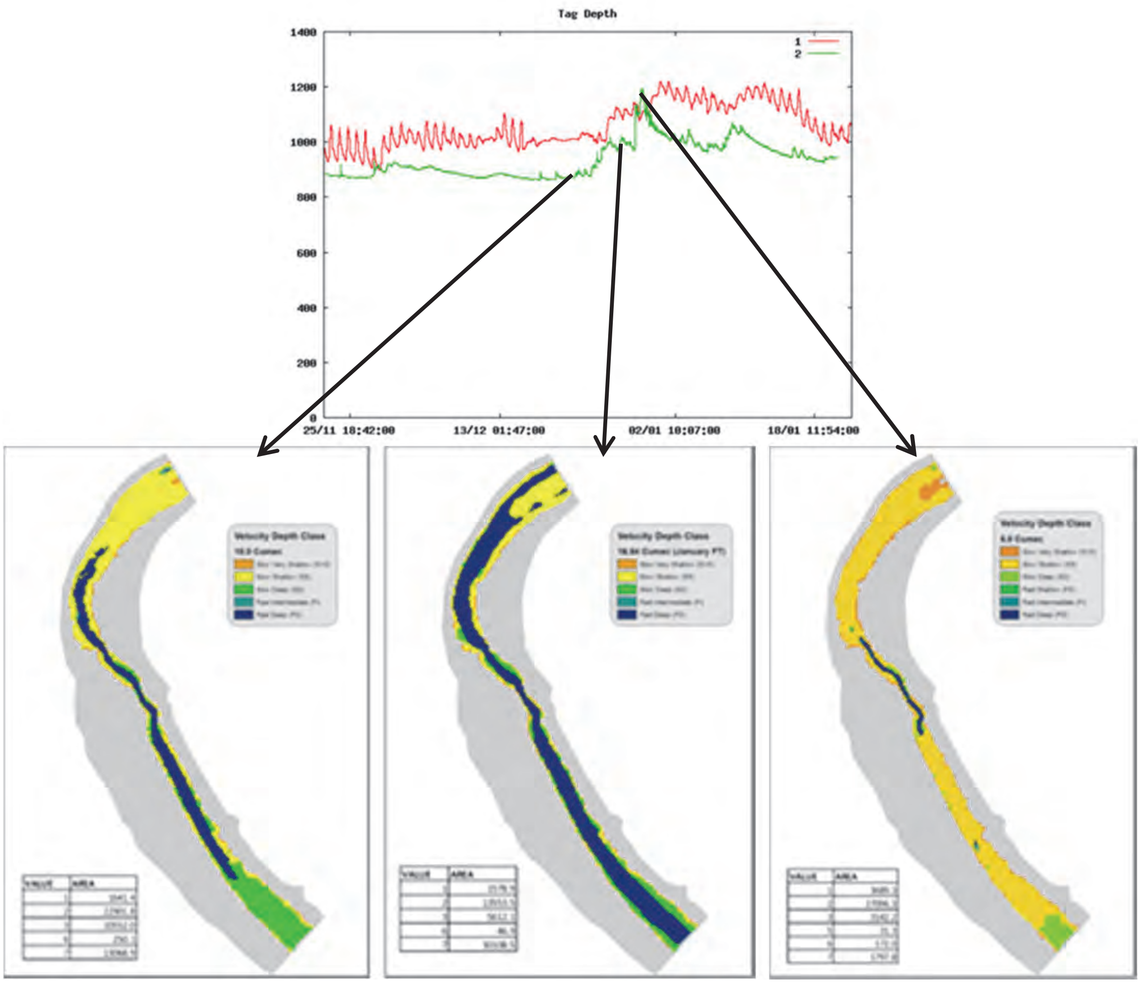


Figure 20: Use of depth (mm) data from an abiotic water probe to model the habitat of the senqu River using River 2D hydraulic/hydrology modelling techniques.

9.1 **CASE STUDY 9:** Mine offset lake suitability assessment for yellowfish by Anglo-American and North West University.

This study was established to evaluate the suitability of a rehabilitated lake to maintain a yellowfish population for conservation endeavours. The aims of this study include:

1. Establish suitable local Vaal River yellowfish populations in the rehabilitated lake.
2. Carry out a biotelemetry study of the yellowfish population in the rehabilitated lake.
3. Provide management guidelines for the establishment of protected yellowfish populations in rehabilitated lake and similar offset ecosystems.

Wild smallmouth yellowfish were collected from the Vaal River and relocated to the rehabilitated lake tagged, released and monitored in real time for at least one year. Some of the ecological components considered included feeding biology of the yellowfish, seasonal movement and activity and the behavioural response of the population to changing environmental parameters such as water quality, atmospheric pressure and disturbance to wildlife activities. The tags used in this study included storage capacities which allowed data to be collected and stored on the tags while the tags were out of range of the receivers (Figure 21). This study showed that the FISHTRAC manual monitoring technique is versatile and suitable for applied research to answer many ecosystem management problems.

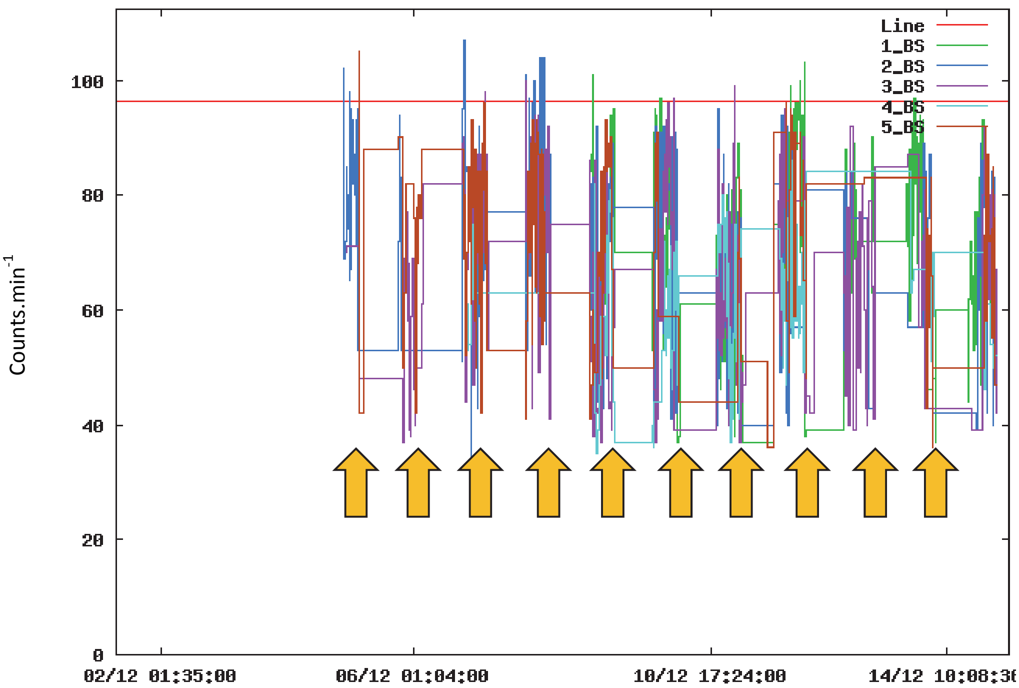


Figure 21: Signal strength readings from six radio tracked yellowfish (*Labeobarbus aeneus*) from 1 December 2012 to 15 December 2012 in the AngloAmerican yellowfish facility. Arrows highlight daily periods from 5 December to 15 December when all of the tagged yellowfish only moved into coverage range during the night. Having storage capacity on the tags ensures that peripheral data is collected during periods when fish are out of range.

CONCLUSIONS AND RECOMMENDATIONS

In South Africa many of our rivers and lakes are highly populated and often not able to suitable the fishes and other aquatic animals that are important to us and provide us with many benefits. Society would look to government, the custodians of these ecosystems to manage our resources in an appropriate, equitable manner. All of us however are collectively using our ecosystems and as such should get involved in the management and if required conservation of our ecosystems. This manual has been designed for managers, conservationists and researchers who are interested in using radio telemetry technology techniques established through the FISHTRAC programme. This manual has been designed to provide users with information to obtain radio telemetry equipment and use it appropriately to track fish in our river and lake ecosystems and monitor water quality and quantity variables to contribute to the management and conservation of our ecosystems and the animals that live in them. The FISHTRAC system is reliable, easy to implement, informative and capable of answering a range of ecosystem management and conservation questions. The FISHTRAC framework includes an Inception Phase, Planning Phase, Analysis Phase and Outcomes Phase which if implemented correctly, as demonstrated in this manual, should allow most users to implement these techniques with minimal error. In this manual we have highlighted the value of using past experiences (case studies and literature) and specialist who use these methods routinely for assistance.

We recommend that this manual be used to contribute to the; (1) awareness of the value of characterising the biology and ecology of river and lake ecosystems in South Africa, (2) conservation and management of river and lake ecosystems, and the animals within these systems and (3) development of radio telemetry techniques in South Africa. We also strongly recommend that FISHTRAC scientists or behavioural ecologists be contacted to contribute to the planning, implementation and evaluation of radio telemetry studies.

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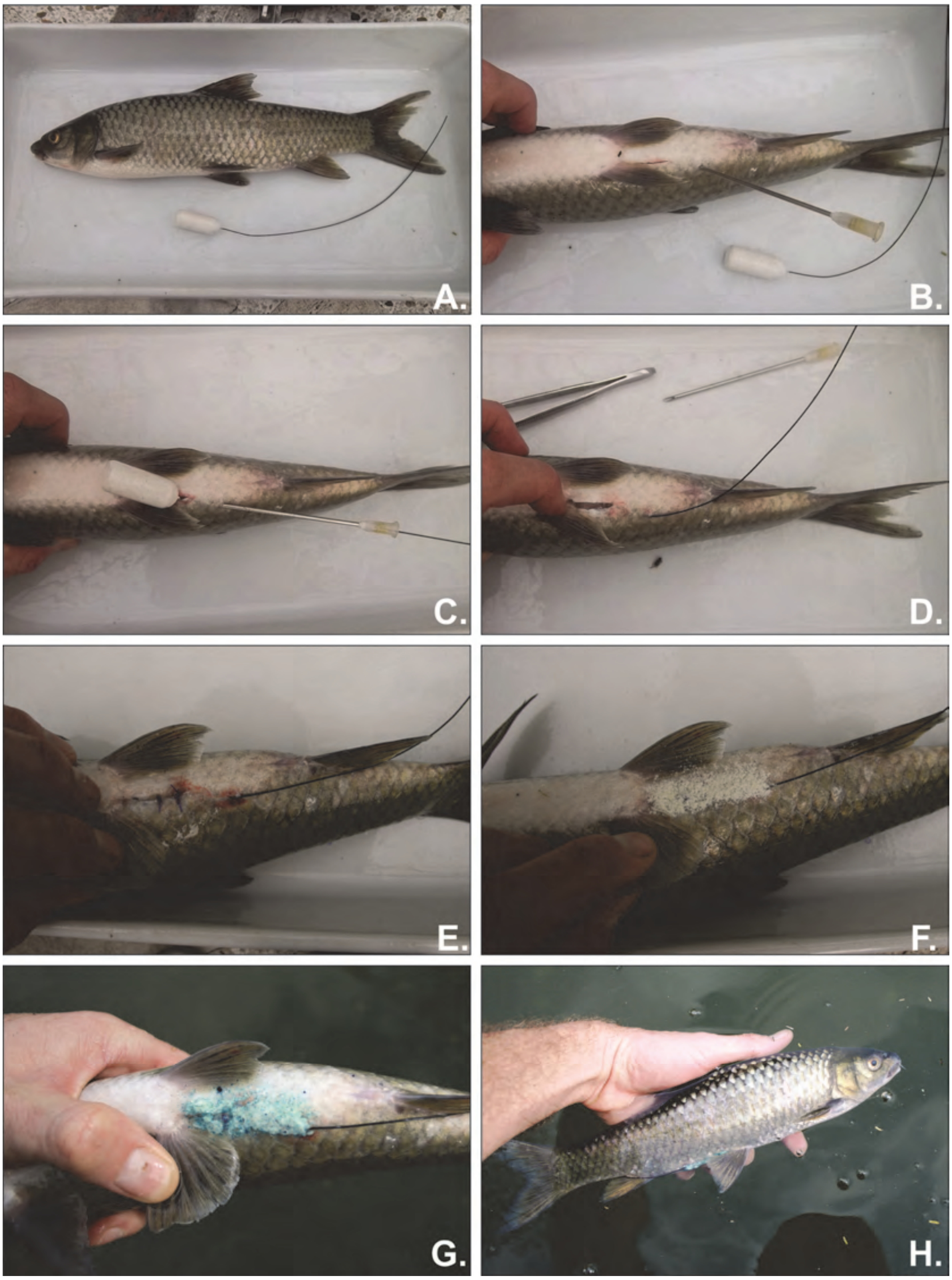
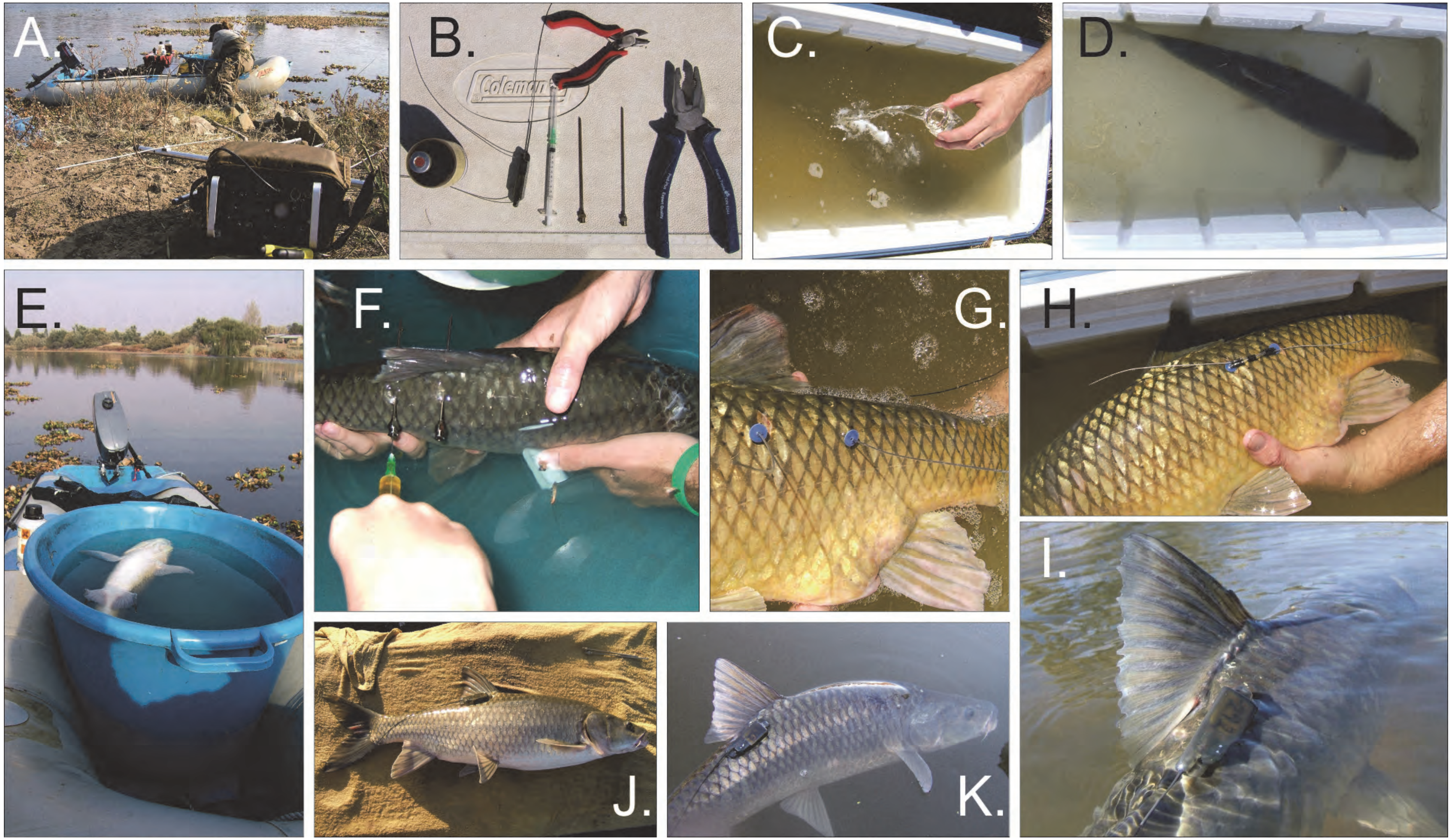
APPENDICES



APPENDIX A: Internal tagging procedure from a suitably anesthetised fish ready for tagging (A), make abdominal incision and insert needle for antenna (B),insert tag and push antenna through needle (C), remove needle (D), suture wound (E), apply wound care gel (F) which turns into a gel when in contact with the water (G), revive and release (H).



APPENDIX B: External tagging procedure including, preparation for tagging by testing equipment (A), cleaning and laying out equipment (B), preparation of anaesthesia (C) and procedures (D) until signs of anaesthesia are evident (E). Then needles are inserted through the musculature of the fish below the dorsal fin (F) and insertion of tagging wires (G). Here we demonstrate the creation of a saddle using copper/bronze sleeves (H), this is a more reliable technique but limits fish movement. Now we do not close the saddle but use sleeves to clamp the attachment wires to the fish. The fish is then revived during which we photograph the individuals and then release the fish (I, J & K).

1	Observation no.						DIARY OF EVENTS:
2a	Random survey						
2b	24hr survey						
3	Tag no.						
4	YYYY-MM-DD HH:MM:SS						
5	GPS	-dd.dddddd (LAT (S))					
6		dd.dddddd (LON(E))					
7	MDPM (m.min-1)						
8	AREA COVERED (m)						
9a	Holding	Disturbance					
9b		Flow					
9c		WQ					
9d		Natural					
9e		Weather					
10a	Flight	Disturbance					
10b		Predator avoidance					
11a	Fourage	Surface					
11b		Column					
11c		Substrate					
12a	Hunting	Surface					
12b		Column					
12c		Substrate					
13	Spawning migrations						
14a	Substrate	Silt					
14b		Mud					
14c		Gravel & sand					
14d		Cobble					
14e		S-Boulder					
14f		Bedrock					
15a	Surface types	Barely perceptable					
15b		Smooth & turbulent					
15c		Ripple surface					
15d		Undular or broken					
15e		Free falling etc.					
16a	Habitat	Under cut bank					
16b		Root wads					
16c		S-trees					
16d		Column					
16e		Marginal Veg					
16f		Aquatic Veg					
16g		Riffle					
16h		Rapid					
16i		Glide					
16j		Pool					
17a	Season	Spring					
17b		Summer					
17c		Autumn					
17d		Winter					
18a	Moon phases	New moon					
18b		1st quarter					
18c		2nd quarter					
18d		3rd Quarter					
18e		Full moon					
19a	Weather	Sunny clear					
19b		partly clouded					
19c		Overcast					
19d		Rain					
20		Pressure (mb)					

APPENDIX C: Example of a data sheet used to direct data capturing during a manual tracking survey.

APPENDIX D: Example extract of manual tracking data collected by Burnette (2013).

Observations	Tag number	Date	Time	GPS S	GPS E	Area (m)	MDPM (Maximum Displacement Per Minute)	Main activity	Other activity	Main substrate	Other substrate	Habitat available	Other habitat available	Depth (mm)	Clarity (mm)	COLOUR	WEATHER
								ACTIVITY SCORES: Holding (1), Feeding (2), Spawning (3), Migrating (4), Flight (5) and Other (6)		SUBSTRATE SCORES: Silt (1), Sand (2), Gravel (3), Cobble (4), Boulder (5), Bed rock (6)		HABITAT AVAILABILITY SCORES: Under cut bank/Roots (1), Dead/submerged trees (2), Substrate - Gen (boulders etc) (3), Substrate - Rocky outcrop (4), Substrate - Rift (5), Marginal Veg - REEDS (6), Marginal Veg - TREE (7), Marginal Veg - SHRUBS (8), Aquatic Veg - TRUE (9), Aquatic Veg - Fil. (10), Coloum (13) and Islands (14).				Clear (**1**) Opaque (**2**) Light brown (**3**) Dark chocolate (**4**)	Clear (**1**) Overcast (**2**) Cloudy (**3**) Light rain (**4**) Heavy Rain (**5**)
1a	214	17/09/2009	1245	-25.224345	31.425250	8	1.6	2	1	2	6	1	6	1500	1000	1	2
1b	214	17/09/2009	1304	-25.224345	31.425350	8	1.6	2	1	2	6	1	6	1500	1000	1	2
1c	214	17/09/2009	1426	-25.224345	31.425250	8	1.6	2	1	2	6	1	6	1500	1000	1	2
1d	214	17/09/2009	1440	-25.224345	31.425350	8	1.6	2	1	2	6	1	6	1500	1000	1	2
1a	232	17/09/2009	1330	-25.224210	31.431000	2	0.4	1	2	5	2	3	13	2000	1000	1	2
2a	232	18/09/2009	1028	-25.224210	31.431000	1	0.2	1	2	5	2	3	13	2000	1000	1	2
2b	232	18/09/2009	1035	-25.224210	31.431000	1	0.2	1	2	5	2	3	13	2000	1000	1	2
2c	232	18/09/2009	1045	-25.224210	31.431000	1	0.2	1	2	5	2	3	13	2000	1000	1	2
1a	51	18/09/2009	844	-25.224389	31.424592	8	1.6	2	1	2	6	4	3	2000	1000	1	2
1b	51	18/09/2009	856	-25.224350	31.424950	30	6	5	0	2	6	4	3	2000	1000	1	2
1c	51	18/09/2009	930	-25.224345	31.425350	25	5	6	0	2	6	1	6	1500	1000	1	2
1d	51	18/09/2009	938	-25.224345	31.425350	25	5	2	1	2	6	1	6	1500	1000	1	2
2a	214	18/09/2009	940	-25.224330	31.426020	35	7	5	1	2	6	3	6	1500	1000	1	2
2b	214	18/09/2009	950	-25.224330	31.426020	1	0.2	1	2	2	6	3	6	1500	1000	1	2
2c	214	18/09/2009	1005	-25.224330	31.426020	4	0.8	1	2	2	6	3	6	1500	1000	1	2
2d	214	18/09/2009	1017	-25.224330	31.426020	4	0.8	1	2	2	6	3	6	1500	1000	1	2
1a	153	18/09/2009	1105	-25.378870	31.724710	1	0.2	1	2	2	5	3	6	1900	1000	1	2
1b	153	18/09/2009	1115	-25.378870	31.724710	2	0.4	1	2	2	5	3	6	1900	1000	1	2
1c	153	18/09/2009	1125	-25.378870	31.724710	3	0.6	1	2	2	5	3	6	1900	1000	1	2
1d	153	18/09/2009	1135	-25.378870	31.724710	2	0.4	1	2	2	5	3	6	1900	1000	1	2
2a	153	18/09/2009	1145	-25.378870	31.724710	2	0.4	1	2	2	5	3	6	1900	1000	1	2
3a	232	18/09/2009	1153	-25.224210	31.431000	1	0.2	1	2	5	2	3	13	2000	1000	1	2
3b	233	18/09/2009	1203	-25.224210	31.431000	1	0.2	1	2	5	2	3	13	2000	1000	1	2
3a	214	18/09/2009	1220	-25.224345	31.425250	8	1.6	1	2	2	6	3	6	1500	1000	1	2
3b	214	18/09/2009	1233	-25.224345	31.425350	10	2	1	2	2	6	3	6	1500	1000	1	2
3c	214	18/09/2009	1247	-25.224345	31.425250	10	2	1	2	2	6	3	6	1500	1000	1	2
3d	214	18/09/2009	1300	-25.224345	31.425350	10	2	1	2	2	6	3	6	1500	1000	1	2
2a	51	18/09/2009	1220	-25.224345	31.425350	25	5	2	1	2	6	3	6	1500	1000	1	2
2b	51	18/09/2009	1233	-25.224345	31.425350	28	5.6	2	1	2	6	3	6	1500	1000	1	2
2c	51	18/09/2009	1247	-25.224300	31.425450	26	5.2	2	1	2	6	3	4	2000	1000		2
2d	51	18/09/2009	1300	-25.224345	31.425350	27	5.4	2	1	2	6	3	6	1500	1000	1	2
1a	92	18/09/2009	1621	-25.224860	31.422890	1	0.2	2	1	5	2	4	17	1000	1000	1	2
1b	92	18/09/2009	1634	-25.224860	31.422890	1	0.2	2	1	5	2	4	17	1000	1000	1	2
1c	92	18/09/2009	1645	-25.224860	31.422890	1	0.2	2	1	5	2	4	17	1000	1000	1	2
1d	92	18/09/2009	1651	-25.224860	31.422890	1	0.2	2	1	5	2	4	17	1000	1000	1	2
1a	113	18/09/2009	1621	-25.224860	31.422890	1	0.2	2	1	5	2	4	17	1000	1000	1	2
1b	113	18/09/2009	1634	-25.224860	31.422890	1	0.2	2	1	5	2	4	17	1000	1000	1	2
1c	113	18/09/2009	1645	-25.224860	31.422890	10	2	2	1	5	2	4	17	1000	1000	1	2
1d	113	18/09/2009	1651	-25.224820	31.424930	56	11.2	2	1	2	6	13	16	1000	1000	1	2
4a	214	19/09/2009	1045	-25.224345	31.425250	4	0.8	1	2	2	6	3	6	1500	1000	1	2
3a	51	19/09/2009	1045	-25.224345	31.425350	4	0.8	2	1	2	6	3	6	1500	1000	1	2
4a	232	19/09/2009	1058	-25.224210	31.431000	1	0.2	1	2	5	2	3	13	2000	1000	1	2
3a	153	19/09/2009	1116	-25.378870	31.724710	8	1.6	1	2	2	5	3	6	1900	1000	1	2

APPENDIX E: Example extract of remote tracking data collected by Burnette (2013).

Remote data automatically downloaded from the WWDMS						Explanatory information used for multivariate statistical assessment																	
TAG	DATE	TIME	MOVEMENT	DEPTH	TEMPERATURE	DISCHARGE	LMAR	HVIT	RECOVERY DAY 1	RECOVERY DAY 2-3	POST RECOVERY	00h-04h	04h-08h	08h-12h	12h-16h	16h-20h	20h-24h	SPRING	SUMMER	AUTUMN	LOW FLOWS	MODERATE FLOWS	HIGH FLOWS
41	2011/11/26	05:16:57	1087156	429	22.40	37	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
41	2011/11/27	01:27:11	3879	432	24.78	37	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
41	2011/11/27	02:17:17	1248	430	24.78	37	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
41	2011/11/27	02:47:21	1003	429	24.30	37	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
41	2011/11/27	03:07:15	174139	430	24.78	37	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
41	2011/11/27	14:11:17	32144	431	30.00	37	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
41	2011/11/27	14:18:37	32432	429	30.47	37	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
41	2011/11/27	14:29:38	28128	437	30.47	37	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
41	2011/11/27	14:42:56	43581	444	30.94	37	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
41	2011/11/27	15:06:12	2291	439	30.47	37	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
41	2011/11/27	15:16:13	1218	430	30.47	37	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
41	2011/11/27	15:26:13	48	432	30.47	39	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
41	2011/11/27	17:16:25	516	428	29.05	42	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
41	2011/11/27	17:26:26	1139	428	29.05	55	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
41	2011/11/27	17:36:27	779	428	29.05	62	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
41	2011/11/27	17:46:28	1077	431	28.57	62	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
41	2011/11/27	17:56:28	965	429	29.05	62	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
41	2011/11/27	18:06:29	1813	435	28.57	62	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
41	2011/11/27	18:26:31	1323	435	28.57	62	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
41	2011/11/27	18:36:33	2733	430	28.10	50	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
41	2011/11/27	19:16:38	709	436	28.10	35	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
41	2011/11/27	19:26:39	332	438	28.10	35	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
41	2011/11/27	19:36:40	1239	436	28.10	35	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
41	2011/11/27	19:56:43	603	436	27.62	35	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
41	2011/11/27	20:06:44	883	436	27.62	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/27	20:26:46	358	439	27.62	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/27	20:36:47	286	438	27.62	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/27	20:56:49	585	436	27.15	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/27	21:06:52	242	433	26.67	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/27	21:26:54	305	429	26.67	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/27	21:36:55	195	429	26.20	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/27	22:27:01	93	428	26.67	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/27	22:47:04	871	429	26.67	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/27	23:07:06	31	429	26.20	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/27	23:17:07	333	430	26.20	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/27	23:27:09	61	430	25.73	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/27	23:37:10	65	432	26.20	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/27	23:47:11	60	430	26.20	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/27	23:57:12	115	431	26.20	35	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	2011/11/28	00:07:14	311	431	25.73	35	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
41	2011/11/28	00:47:19	191	431	25.73	35	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
41	2011/11/28	00:57:20	141	430	25.73	35	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
41	2011/11/28	01:07:22	673	433	25.73	35	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
41	2011/11/28	01:27:25	1012	434	25.25	35	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
41	2011/11/28	01:37:26	152	429	25.25	35	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
41	2011/11/28	01:47:27	78	431	25.73	35	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
41	2011/11/28	01:57:28	311	431	25.25	35	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
41	2011/11/28	02:07:30	301	429	25.73	35	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
41	2011/11/28	02:17:31	1090	431	25.25	35	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0