The conservation ecology of the African tigerfish *Hydrocynus vittatus* in the Kavango River, Namibia

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ABSTRACT

The primary objective of this thesis was to investigating African tigerfish *Hydrocynus vittatus* to assess if freshwater protected areas could be a suitable conservation and management tool for this species in Namibia. This was addresses by using annual gill net survey data collected from 1997 to 2016 to assess the current status of tigerfish in the Zambezi and Kavango Rivers. The Zambezi River had a higher CPUE in weight (1.21 ± 1.83 kg/net-night) and numbers (9.67 ± 14.65 fish/net-night) compared with the Kavango River (0.50 ± 1.58 kg/net-night and 2.04 ± 3.38 fish/net-night). High inter-annual variation from 1997 to 2016 in CPUE in weight or numbers within each of the two river systems, showed no clear temporal trends. Hence, the prediction that tigerfish populations are declining was not supported by this assessment. CPUE, both in terms of numbers and weight, was, however, significantly higher in the FPA in the Kavango River compared with unprotected sites. This finding highlights the potential importance of freshwater protected areas (FPAs) as a fisheries management tool. To evaluate FPAs as a possible conservation and management tool, understanding tigerfish movement is important.

Previous mark-recapture experiments on tigerfish were largely unsuccessful, therefore, estimates of tag retention and tagging-related mortality which are essential for mark-recapture experiments, needed to be established. Mortality and tag loss were estimated from 15 tigerfish marked using Hallmark model PDL plastic-tipped dart tags and released into a 1 730 m^2 earthen pond. Tigerfish were inspected bi-monthly for the presence or absence of tags. No mortality was observed during the experiment. All marked tigerfish had lost their tags after 10 months and 50% tag loss was estimated at 3.9 months. The high tag loss rate indicates that PDL plastic-tipped dart tags are not suitable for long-term studies on this species. Because of the high tag loss of the relatively cheaper plastic tipped dart tags, the more expensive radio telemetry methods were

considered for long-term monitoring to establish movement of tigerfish. The effect of radio tags on tigerfish behaviour has not been assessed previously. Therefore an experiment aimed to document immediate and long-term movement consequences of radio tagging tigerfish in the Kavango River, from June to October 2016. To study the immediate behavioural effects of tagging, 49 tigerfish were tagged with external radio transmitters and monitored for three consecutive days post-release. Thereafter, to identify long-term effects, 19 of these tigerfish were again monitored for seven consecutive days during the same time-period, 25 to 47 days after being radio-tagged. Immediately after tagging, the tigerfish exhibited more downstream (57 - 62 %) than upstream movements (32 – 36 %). There was no significant difference in their mean (± SD) distance of downstream movements (2303 ± 2786 m) compared with upstream movements (1277 ± 1796 m). The total immediate distance moved was negatively correlated with water temperature and positively correlated with fish size. To compare immediate and long-term effects the movements of the 19 individuals were analysed separately. These tigerfish also had more downstream than upstream movements, with 58 % of detections being downstream, 37 % upstream and 5 % with no change, a similar behaviour to all tigerfish monitored initially. After approximately three to six weeks the tigerfish had similar numbers of up- and downstream movements, being 38% downstream, 44% upstream, and 18% stationary. Mean downstream (488 ± 766 m) and upstream (905 ± 2365 m) distances travelled during the long term experiment were significantly shorter than immediately after release. This difference in movements of tagged tigerfish between the two tracking periods suggests that radio tagging and/or the associated handling have an immediate effect on tigerfish behaviour.

After evaluating the effect of radio tagging tigerfish, radio telemetry was used to assess whether FPAs are a suitable management tool for tigerfish. To test this 35 tigerfish were radio

tagged and monitored approximately every 12 days constantly throughout the study period for 123 to 246 days from July/October 2016 to May 2017 in the Kavango River. Monitored tigerfish displayed at least two river use patterns. They were either relatively stationary with high site fidelity using less than 33 km of the river, or they used considerably larger areas of the river, up to 397 km upstream and 116 km downstream from their tagging positions. These long distances movements encompassed three countries including Angola, Namibia and Botswana. Twenty-three (66%) of the tigerfish used an area less than the length of the primary study area of 33 km, whereas 12 tigerfish (34%) used a river length larger than the study area. Fourteen (40%) spent more than 80% of the time monitored in this area, and 18 (51%) stayed within the area at least 50% of the monitored time. Based on the area use of the 35 monitored tigerfish a protected river area of at least 10 km, could protect at least 50% of tigerfish for at least 75% of the time. These findings suggest that freshwater protected areas may be an effective tool to sustainably manage tigerfish populations in the Kavango River.

The river use recorded during this study indicates that a portion of the tigerfish population may be migratory while others exhibit residential behaviour. Migratory and residential behaviours are important within the same species as it promotes genetic diversity and are considered highly important in the formulation of conservation and management strategies, especially concerning the protection of local tigerfish stocks and special habitats. Findings from this study showed that tigerfish utilized at least 523 km of the Kavango River which encompasses three countries which emphasis the need for local and international collaboration which should be seen as priority areas. Data from this investigation on tigerfish river use should be used to make scientifically sound, evidence-based, fisheries management decisions in order to provide sustainable utilisation of this highly important fish species in Namibia.

PREFACE

The data described in this thesis were collected in the Republic of Namibia from January 2015 to August 2017. Experimental work was carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Prof Colleen T. Downs and co-supervision of Dr Gordon C. O'Brien and Dr Olaf L.F. Weyl.

This thesis, submitted for the degree of Doctorate of Philosophy in Science in the College of College of Agriculture, Engineering and Science, University of KwaZulu-Natal, School of Life Sciences, Pietermaritzburg campus, represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others, it is duly acknowledged in the text.

Francois J. Jacobs
December 2017

I certify that the above statement is correct and as the candidate's supervisor I have approved this thesis for submission.

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Prof Colleen T. Downs
Supervisor
December 2017

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DECLARATION 1 - PLAGIARISM

I, Francois J. Jacobs, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
4. This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
    a. Their words have been re-written but the general information attributed to them has been referenced
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5. This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections.

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DECLARATION 2 - PUBLICATIONS

DETAILS OF CONTRIBUTION TO PUBLICATIONS that form part and/or include research presented in this thesis.

Publication 1

Jacobs FJ, Weyl OLF, Khaebeb FH, Hay CJ, Naesje TF, O'Brien GC, and Downs CT (2017)

The status of African tigerfish *Hydrocynus vittatus* (Castelnau, 1861): A review of 17 years of monitoring in Namibia. African Journal of Aquatic Sciences.

Author contributions:

FJJ conceived paper with OW, FHK, CH, TN, GOB and CTD. FJJ collected and analysed data, and wrote the paper. OW, FHK, CH, TN, GOB and CTD contributed valuable comments to the manuscript.

Publication 2

Jacobs FJ, Weyl OLF, Libala NS, O'Brien GC & Downs CT (2017)

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Author contributions:

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Publication 3

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Author contributions:

FJJ conceived paper with TN, EU, OW, CH, GOB and CTD. FJJ collected and analysed data, and wrote the paper. TN, EU, OW, CH, GOB and CTD contributed valuable comments to the manuscript.

Publication 4

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Are freshwater protected areas suitable for management and conservation of African tigerfish *Hydrocynus vittatus*?

Journal of Fish Biology.

Author contributions:

FJJ conceived paper with TN, EU, OW, DT, CH, GOB and CTD. FJJ collected and analysed data, and wrote the paper. TN, EU, OW, CH, GOB and CTD contributed valuable comments to the manuscript.

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"*U laat hom heers oor die werk van U hande, U het alles aan hom onderwerp: skape en beeste, alles; selfs die diere in die veld, die voëls in die lug, en die visse in die see wat die oseane deurkruis" Psalm 8*

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Last but not least: The Deputy Director of Inland Fisheries and Aquaculture, Mr. Renier Burger and his whole family Marinda, Renèe, Ester and Dawid for their support during this project. Know that you and your family are a blessing to us and we are ever grateful.

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CHAPTER 1

1.1 General introduction

The changing global landscape and its challenges faced by communities, society and the environment are largely dependent on the well-being of inland fisheries (Cooke et al. 2012, Lynch et al. 2016). Inland fisheries provide food for billions of people and livelihoods for millions of people worldwide, from less than 0.01% of the total volume of water on earth (Stiassny 1996, Cambray and Bianco 1998). Remarkably, inland fisheries are still overlooked as priority conservation and management areas (Stiassny 1996, Cambray and Bianco 1998, Lynch et al. 2016). Furthermore, as much as 65% of all freshwater inland habitats are moderately to highly threatened by anthropogenic stressors, as a result many important fisheries have been lost (Bruton 1995, Vörösmarty et al. 2010). Declines in African tigerfish *Hydrocynus vittatus* (Castelnau 1861) populations have been reported for numerous freshwater ecosystems (Jackson 1961, Gaigher 1967, Kenmuir 1973, Hay et al. 1996, Gagiano 1997) and recently, extensive exploitation of tigerfish populations was reported for northern Namibia (Cooke et al. 2016) which is a cause for concern. Tigerfish are considered important predators in the food-web ecology and their decline could result in the loss of ecosystem services and food security. It is therefore imperative to ensure viable management tools are developed or implemented before their decline become irreversible.

In this chapter, I outline the need for management of inland fisheries and then focus on the current status regarding inland fisheries in Namibia, making reference to freshwater protected areas (FPA's) as a possible management tool. The behaviour of tigerfish which is a flagship species are then reviewed. The northern perennial rivers of Namibia which contains important populations of tigerfish, are then described as the study area. Research needs for managing this species are discussed and an outline of the thesis is provided.

1.2 Need for management of inland fisheries

Inland aquatic ecosystems are generally among the most diverse ecosystems on earth and comprise of lakes, rivers, canals, streams, reservoirs and any other land locked waters, including saline water bodies such as the Caspian Sea (Cooke et al. 2012, Youn et al. 2014, Lynch et al. 2016). Within these ecosystems, an estimated 13 000 freshwater species to 15 000 freshwater and estuarine species from the known 33 400 fish species occur (Levêque et al. 2008). Inland fisheries contribute to at least 40% of the worlds reported finfish production (Lynch et al. 2016) and their importance to communities (Abbott et al. 2015, Lynch et al. 2016, Winemiller et al. 2016), the economy (Cambray and Bianco 1998, Cooke and Cowx 2004, Cooke et al. 2016) and ecological processes (Stiassny 1996, Winemiller and Jepsen 1998, Jennings et al. 1999, Myers and Worm 2003, Tweddle 2010) are well documented.

Fisheries in Africa are probably one of the most underappreciated natural resources on the continent, as over 200 million, of Africa's 1 billion people, regularly consume fish, with approximately half of this from inland fisheries (UNEP 2010). In Africa, areas with the highest richness of freshwater biodiversity are usually also associated with the greatest concentration of rural poor, whom are directly dependent on healthy fish biodiversity and freshwater ecosystem services (Darwall et al. 2011). Neiland and Béné (2008) estimated the annual value of inland fisheries in west and central Africa at ±US $295 million and that as much as ±227 000 full-time fishermen could be employed and their families maintained by this resource. Furthermore, it is estimated that for every African fisherman there are approximately five people who are linked to the fisheries value chain (e.g. via processing, preservation, transport, marketing, production and maintenance of boats and gear) (Tveldten et al. 1996, Welcomme 2011, Youn et al. 2014). Abbott et al. (2015) further showed that the value chain may be largely underestimated due to the lack of monitoring abilities where small scale artisanal fisheries are directly consumed or sold through informal markets and rarely reported. Although the use of these resources has increased exponentially with the population growth and associated economic development, relatively little information about any aquatic ecosystems in Africa exists, and even less information on the sustainable use or yields of fisheries (Stiassny 1996, Tveldten et al. 1996, Welcomme 2011).

Communities depending on fish resources are, however, threatened by the rapid changing economic and revolutionary shifts, where newer and faster ways to use fish and the ecosystems surrounding the fresh water resources, are being discovered and unsustainably implemented (Cooke et al. 2016, Lynch et al. 2016, Winemiller et al. 2016). Winemiller et al. (2016) for example showed that hydropower, flood mitigation, agriculture and aquaculture ventures can provide short term financial gain, employment and improved infrastructure, however, these stresses, when governed poorly, have detrimental effects on the inland fisheries sectors.

The downward trend of inland fisheries have recently been reported for numerous southern African countries including: Malawi, Zambia, Zimbabwe, Namibia and Botswana (Abbott 2005, Tweddle et al. 2015). These countries contain important freshwater resources of the Zambezi River basin including the Barotse, Caprivi and Kafue floodplains, and Lakes Kariba, Malawi and Malombe, where numerous management interventions failing to halt the decline in catches following rapidly increasing fishing effort and the use of environmentally damaging fishing gears (Tweddle et al. 2015, Cooke et al. 2016). The rapid population growth combined with very limited alternative livelihoods in rural areas further forces communities to continue fishing despite low returns (Tweddle et al. 2015, Cooke et al. 2016).

Without appropriate management of inland fisheries, communities may be faced with overexploitation of fish resources which will result in the decline in productivity of the water resource and ultimately, degradation of the resources itself (Munro and Scott 1985, Vörösmarty et al. 2010, Lynch et al. 2016). Management interventions for sustainable inland fisheries differ substantially between different regions, but southern Africa, particularly Namibia contains some of the most important inland fisheries resources in Africa (Hay et al. 1996, Tveldten et al. 1996, Næsje et al. 2001, Tweddle et al. 2015).

1.3 Threats to inland fisheries in Namibia

Namibia is mostly an arid country with vast dry landscapes, but in its patchy wetlands it contains surprisingly important fisheries and about 153 described fish species (Froese and Pauly 2016). Namibia has five major perennial river systems (Fig. 1.1) namely, the Zambezi River, Kwando - Linyanti - Chobe River system, Kavango River, Kunene River and Orange River (Holtzhausen 1991, Tveldten et al. 1996). In periods of exceptionally good rainfall these rivers can fill up other important water bodies such as the Zambezi River filling Lake Liambezi, the Kavango River can fill Lake Ngami in Botswana, and the Kunene River can overspill into the Oshana Delta in Owambo, eventually converging to Lake Opono and via the Ekuma River into Etosha Pan (Holtzhausen 1991). The interior of Namibia is scattered with intermittent westward flowing rivers and numerous impoundments, most of which support some fish species (Fig. 1.1). These are, however, largely introduced (e.g. *Micropterus salmoides* Lacepède 1802) or translocated indigenous species that support subsistence and recreational anglers (Bethune and Roberts 1991, Holtzhausen 1991, Okeyo 2004). The numerous cave systems and sinkholes found in the Karstveld are also important in terms of conservation for species such as the blind cave catfish *Clarias cavernicola* (Trewavas 1936), and *Tilapia guinasana* (Trewavas 1936) which are endemic to Namibia (Bethune and Roberts 1991, Holtzhausen 1991, Curtis et al. 1998).

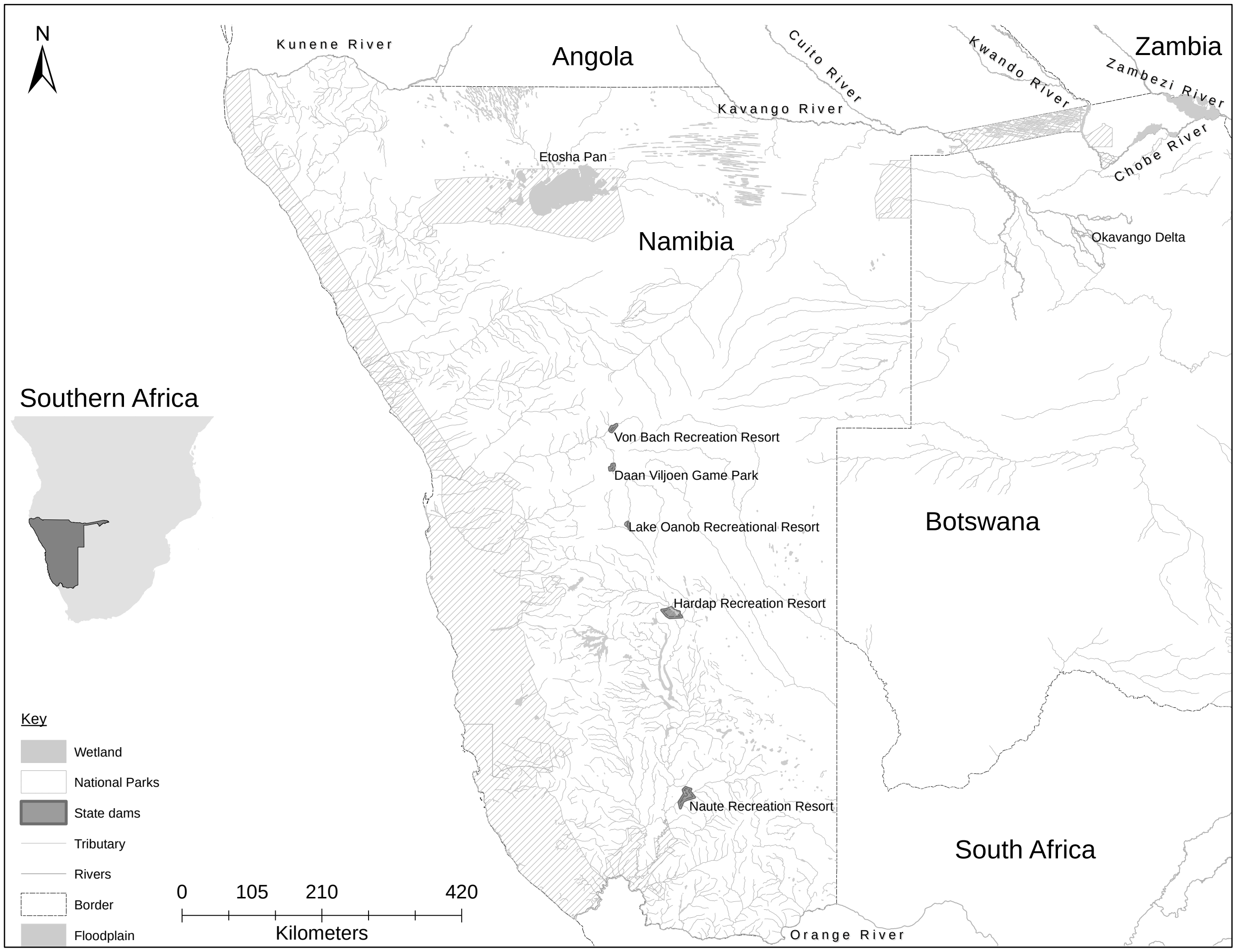

Figure 1.1: Namibia has numerous west flowing temporary rivers and impoundments that support mostly recreational fisheries. The perennial river systems include the Zambezi River, Kwando - Linyanti - Chobe River system and Kavango River in the north and north east, the Kunene River in the north-west and the Orange River forming the border between Namibia and South Africa.

The inland fisheries sector in Namibia is not recognised as an important role player in the gross national product (GNP), but regarding subsistence and employment, it is considered to be an important renewable resource (Tveldten et al. 1996, Tweddle et al. 2015, Cooke et al. 2016). The most important fisheries exists in the floodplain systems of the Zambezi River, Kwando-Chobe-Linyanti River system and Kavango River in the north and north-eastern parts of the country (Tweddle et al. 2015). These seasonal wetlands are the main ecosystems from which most freshwater fishes in Namibia are sourced from (Tveldten et al. 1996, Hay et al. 2000, Tweddle et al. 2015).

These rivers and their associated floodplain habitats are complex ecosystems that swell during and after the rains, causing the water-covered areas to increase in size constantly, whereas the fishes that live in them and the people utilizing this resource are challenged to respond in an adaptive manner (Winemiller and Jepsen 1998, Welcomme 2011). Currently there is a scarcity of reliable figures depicting the sustainable yields within these rivers and associated floodplains (Hay et al. 2000, Cooke et al. 2016). Tveldten et al. (1996) estimated the yield for the Zambezi region (formerly Caprivi) that include the Zambezi River, the 200 km^2 Lake Liambezi and the Kwando system to be around 1,500 t/year. These figures changed when Lake Liambezi dried up and dropped the total production to around 800-900 t/year (Tveldten et al. 1996). This figure seems to have been greatly underestimated as Tweddle and Hay (2011) showed the annual yield of around 5000 t/year in the Zambezi River system. The yield from the Kavango River has been estimated at somewhere between 840 and 3000 t/year (Tveldten et al. 1996).

To improve management and reliability of data on inland fisheries in Namibia, a national fish monitoring programme was established which aimed to monitor the fish stocks in the perennial rivers by creating an up to date time series database that include both biological and socio-economic parameters (Hay et al. 2000). Annual surveys were initiated by the Ministry of Fisheries and Marine Resources in the Kavango River in 1984 (Hay et al. 2000), the Zambezi River and Kwando-Linyanti-Chobe system from 1993 (Hay et al. 2002, Næsje et al. 2004), the Kunene River from 1990 (Hay et al. 1997) and the Orange River from 1995 (Næsje et al. 2007).

Since the start of these fish monitoring programmes in Namibia various socio-economic surveys revealed that inland fisheries sector play a major role in the riparian communities for employment and subsistence of which the total value chain of the fish commodity is still largely unknown and underestimated (Tveldten et al. 1996, Abbott et al. 2015). This is a cause for concern as the Namibian human population is growing at an unprecedented rate and is predicted to reach 3 million by 2031 (Central Bureau of Statistics 2006). The regions that face the highest rate of population growth are the Ovambo (i.e. Oshana, Omusati, Ohangwena, Oshikoto) and Kavango, of which the latter is more dependent on inland fisheries (Hay et al. 2000).

Tveldten et al. (1996) carried out a comprehensive socio-economic study on the utilization of inland fisheries in this region. From this study it was noted that 80% of the people in the Kavango region live within 5-10 km from the river and a large number of these communities depend on fish as their only source of protein. During this study an estimated 165 000 people lived in the Kavango Region and in a time span of 35 years it is predicted that this number will increase by 35%, estimating the total population at 472 994 in 2031 (Central Bureau of Statistics 2006). The population growth in this region, will cause conflicts between communities, commercial and recreational water users that all have to utilize the same already stressed water resources. These conflicts have already appeared in other populated areas that depend on fish for their livelihoods (Tweddle et al. 2015, Cooke et al. 2016).

In addition to population growth, the Zambezi River system has also experienced encroachment from migrant fishers on its water resources due to a high demand for fish in Zambian urban areas as well as the Democratic Republic of the Congo (DRC) (Abbott et al. 2015, Tweddle et al. 2015, Cooke et al. 2016). These migrant fisher have no interest in long-term sustainability and they compete with local fishers, who depend on fish for food security as a vital component to their livelihoods (Abbott et al. 2015, Cooke et al. 2016). The destruction caused by a commercialized industry further forced communities to make use of environmentally destructive and unsustainable fishing methods (e.g. drifting gillnets and beach seine netting) in order to account for the declining catches and the need to provide sufficient nutrition for their families (Tweddle et al. 2015). The increased fishing effort using these methods depleted the larger bodied fishes such as tigerfish and cichlids which are considered both highly important subsistence and recreational species (Marshall 1987, Thorstad et al. 2004, Økland et al. 2005). The depletion of these charismatic species may also have caused changes in food web structures, that could influence the productivity of the river in the long term, however, this has not been explored yet (Cooke and Cowx 2004). Not only will this have an impact on local communities who depend on fish as a source of food security, but it also had a negative effect on the angling tourism industry and in turn the economy of the country (Cooke et al. 2016).

Namibia's northern perennial rivers including the Zambezi and Kavango Rivers are arguably the premier tiger fishing destinations in Africa (Hay et al. 2000, Tweddle 2010, Tweddle et al. 2015). Local angling lodges on the Zambezi River for example received 4 000 anglers that caught an estimated 38 000 tigerfish in 2010 (Cooke et al. 2016). This recreational angling industry is responsible for up to 70% of revenue to these lodges that have major local economic importance (e.g. employment as fishing guides, chefs and cleaners), especially in rural areas (Cooke et al. 2016).

The consequence of a declining tigerfish fisheries to both subsistence fisherman, riparian communities and the economy surrounding the fisheries were fast becoming a concern as increased conflicts occurred between stakeholders of the fisheries resources (Tweddle et al. 2015). Recently, the first community-based fish protected areas were established within the Sikunga (Sikunga channel) and Impalila (Kasaya channel) conservancies on the Zambezi River, Namibia, but its effect has yet to be evaluated (Cooke et al. 2016). These protected areas may be the only viable option that can ensure tigerfish populations remains viable and promote the often understudied relationship between conservation and the human dimension (Bower et al. 2015).

The continual management of the fish stocks, within rivers and floodplains, are of utmost importance for the communities that depend on it for their livelihoods and the associated economic spinoffs from these resources (Tveldten et al. 1996, Welcomme 2011, Youn et al. 2014). The Ministry of Fisheries and Marine Resources are responsible for conducting annual biological surveys that assess community structures, catch per unit effort, and some ecological parameters, an in depth understanding of fish biology and ecology, especially top predator fish species is of vital importance for effective management of these river systems (Rosenfeld and Hatfield 2006). There is, however, a need for improved management tools to ensure that tigerfish populations remain viable in the northern perennial rivers of Namibia.

1.4 Freshwater protected areas (FPAs) as a management tool for tigerfish

Tigerfish are considered a migratory fish species and Riede (2004) showed that migratory fish species are almost twice as likely to become endangered compared with non-migratory fish species. Although tigerfish migrations remain largely speculative, synchronized movement of many individuals in populations have been documented (Jackson 1961, Badenhuizen 1967, Gaigher 1967, Bowmaker 1973, Kenmuir 1973, Langerman 1980). The limitations in technology during previous studies, did not allow researchers to document detailed movement patterns and migrations of tigerfish. Therefore, tigerfish migrations were predominantly based on author observations and anecdotal reports. This lack of knowledge on tigerfish movement and migrations have resulted in limited management interventions. Today, however, significant technological advances in the field of marking techniques give researchers the advantage of tracking fishes on a regular basis and the possibility to collect a variety of data directly from fishes in their natural environments that allow for the development of better management and conservation measures (Koehn et al. 2000). One of the most promising integrated management and conservation approaches for freshwater fish species is the use of freshwater protected areas (FPAs).

Freshwater protected areas are defined geographical areas that have been recognised for management or conservation usually through legal bodies (e.g. government) but, other effective means such as local authorities have also been used (Tweddle et al. 2015). In a southern African context, most FPAs exist as a result of reserves and protected areas initially established for biodiversity conservation and by default served as fisheries reserves (Abell et al. 2008). While FPAs main focus has traditionally been on maintaining source populations of freshwater fish species to ensure that the population will persist (Rosenfeld and Hatfield 2006). There is also a need to link protected areas with the rest of the landscape through ecological, societal and environmental processes (Crofts 2004). The FPAs do not in any way guarantee against natural variability in fish size, abundances, health and recruitment success which are influenced by numerous internal and external factors including human stressors (e.g. pollution, illegal fishing) but, it can reduce some stressors to support recruitment and offer habitat protection (Bower et al. 2015). The FPAs has often been criticised as being too small and managed by experts as a site, rather than as areas with extended biogeographical units which includes the socio and economical aspects of a region as a whole (Suski and Cooke 2007). Funding for pro-active management of a protected area is often limited which concentrates management on the key feautures, rather than on the ecological processes which could secure protection of the species and habitats in the longer term (Crofts 2004). In addition, there are a number of challenges faced by establishing effective FPAs. Factors such as whether the FPA adequately represent the biographic region, are the species protected across migration routes and can the protected area be mainstreamed into benefitting the local, regional and international society? Which are important factors that needs to be considered. Even more, FPAs are often considered inappropriate for the protection of migratory fish species, as they consistently migrate to new areas (Suski and Cooke 2007).

Numerous FPAs with the intention of preserving freshwater fishes, however, has been proven as an effective management tool (Bower et al. 2015). In Lake Eerie, north America for example, specifically designed FPAs to protect largemouth bass *Micropterus salmoides* during spawning and post spawning periods have been shown to improve catch per unit effort (Sztramko 1985); and the rehabilitation of exploited lake trout *Salvelinus namaycush* (Walbaum 1792) populations in Lake Superior and Huron in Canada were largely attributed to a no fishing FPA (Schram et al. 1995, Reid et al. 2001). In Lake Kariba (Zimbabwe) a FPA contained both larger sizes and abundances of several freshwater fish families (Sanyanga et al. 1995). Hay et al. (2000) and Peel (2012) have shown that the Mahangu Game Park in the Kavango River had higher catch rates compared with other parts of the Kavango River.

The usefulness of FPAs as a management tool has, however, received little attention for any African migratory freshwater fish species and have not been assessed for tigerfish. Cooke et al. (2012) identified 10 factors that limit successful conservation of riverine species of which three are particularly relevant to tigerfish. These factors include the lack of knowledge of natural history, movement and migration behaviour, lack of knowledge on the amount of connectivity required to facilitate these behaviours, and the lack of knowledge on the relationship between conservation and the society. Effective FPAs around the world has evolved into using integrated approaches that are linked to civil society, cultural heritage and modern culture, politics and economic development (Crofts 2004). This has resulted in three main approaches to formulate effective FPAs. The biosphere reserve approach, the bioregional planning approach and the ecosystem approach (Croft 2004). In Namibia where conservation of biological diversity, sustainable use of natural resources and equitable sharing of genetic resources are included in the national developmental plans, numerous policies, acts and intergovernmental agreements. The ecosystem approach may be a suitable guideline to formulate effective FPAs for the management and conservation of tigerfish.

Therefore, understanding the population dynamics and area use of tigerfish could provide valuable information on the life history, important spawning habitats and productive feeding zones which is critical for inclusion in effective FPAs (Matthes 1968).

1.5 The African tigerfish

The African tigerfish (Castelnau 1861) is one of the most charismatic species found within freshwater ecosystems. The most striking characteristics about this species are the large, protruding, sharply pointed teeth (Fig. 1.2a) and dark lateral stripes (Fig. 1.2b) that run along the length of their bodies (Castelnau 1861). Tigerfish occupies a major functional role as predators in the transfer of energy (Winemiller and Jepsen 1998) and are considered important subsistence (Tweddle et al. 2015), commercial (Kenmuir 1973) and recreational fish species (Cooke et al. 2016). Tigerfish have also been idealised by sport fishers and McCormick (1949) described them as the fiercest fish that swims, even more than the piranha *Pygocentrus* spp. of the Amazon, the barracuda *Sphyraena* spp. and the bluefish *Pomatomus* spp. of the Atlantic Ocean. Although this may seem sensational, Jackson (1961) studied the feeding behaviour of tigerfish and described them as fierce and ferocious predators that may even be responsible for retarding speciation in African freshwater fish species.

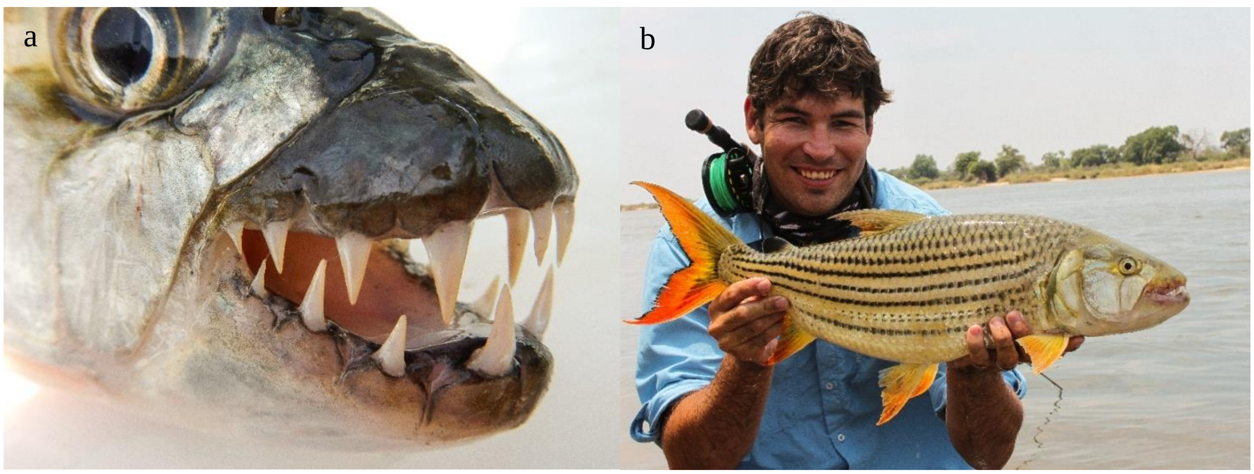

Figure 1.2: The African tigerfish *Hydrocynus vittatus* with (a) large protruding, sharply pointed teeth, and (b) fusiform body, yellow/red tinted fins, deeply forked caudal and dark parallel lines visible.

Since the first recorded account of tigerfish by Castelnau (1861), this species has been the subject of many studies compared with other African freshwater fishes. Some aspects of tigerfish food and feeding behaviour (Bell-Cross 1965, Jackson 1961), food-web ecology (Winemiller and Kelso-Winemiller 1994), habitat preferences (Gaigher 1970, Bowmaker 1973, Gagiano 1997), population dynamics (Badenhuizen 1967, Marshall 1985) age and growth (Gaigher 1967, Balon 1971, Gerber et al. 2009) have been well documented.

The movement of tigerfish has, however, been largely neglected. This is problematic as the information on fish migrations, area use (Lucas et al. 2001) and behaviour (Lucas and Baras 2000) is important for understanding, protecting and managing freshwater systems (Thorstad et al. 2013). Successful management of tigerfish therefore depends on knowledge of area use (Thorstad et al. 2013). This gap in our understanding may reflect a lack of interest in behavioural studies and failure to acknowledge the importance of tigerfish which is often excluded from regional and international conservation strategies in Africa. These issues are further compounded by the inherent difficulties of gathering data in often remote locations which undoubtedly contribute to our poor understanding of one of Africa's top predatory freshwater fish species.

1.6 Species description

Tigerfish have a green-golden coloured head with strong bony cheeks and muscular jaws, each carrying a series of 8 large, protruding and sharply pointed teeth (Brewster 1986). They have a fusiform body with yellow to blood red tinted fins with black trailing edges and a deeply forked caudal and conspicuous black stripes (Castelnau 1861). Their scales are large with 44-48 found in the lateral line and 15-16 around the caudal peduncle (Castelnau 1861). Interestingly, tigerfish have cavities (Fig. 1.3) within their maxillary bones for replacement teeth (Begg 1972). Tigerfish are often caught without any teeth presumably in a tooth shedding phase, but still exhibiting normal feeding behaviour as they are caught using artificial lures that resemble prey (Fig. 1.3).

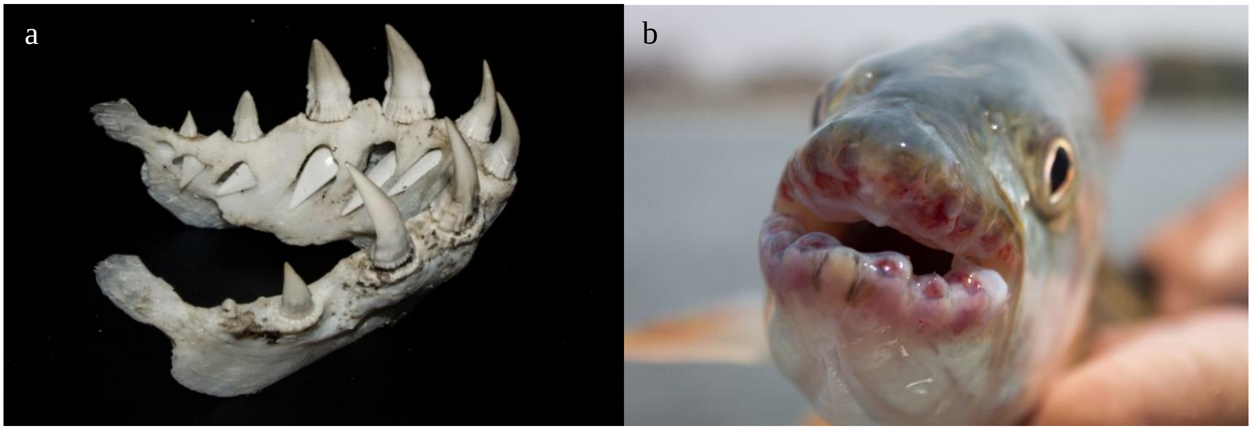

Figure 1.3: Skinned top jaw (a) of the African tigerfish reveals the strong bony jaw, carrying a series of 8 large, protruding and sharply pointed teeth with replacement teeth embedded in cavities within the maxillary bones. Tigerfish caught without any teeth (b) presumably in its tooth shedding phase, but still capable of attacking artificial lures that resembles prey.

1.7 Classification

The tigerfish (*Hydrocynus* spp.) belongs to the order Characidae which is a large family of freshwater fishes found throughout Africa and the Neotropics (Brewster 1986). There are currently five recognised *Hydrocynus* species all endemic to Africa. *Hydrocynus forskahlii* (Cuvier 1819) and *H. brevis* (Günther 1864) are west African species with range to the Niger River; *H. goliath* (Boulenger 1898) occurs in the Congo River basin; *H. tanzaniae* (Brewster 1986) occurs in the Ruvu and Rufiji-Ruaha drainage basins and *H. vittatus* (Castelnau 1861) is considered mostly an southern African species occurring throughout the Okavango and Upper and lower Zambezi ecoregions (Jubb 1952, Abell et al. 2008, Goodier et al. 2011).

The scientific placement of the genus *Hydrocynus* has been controversial. In general, the classification of Characins seems to be problematic. Roberts (1966) divided the African Characidae into two sub-families namely Hydrocyninae (include *Hydrocynus*) and Alestiinae (include all other African characids), thereafter Géry (1968) included these two sub-families into Alestidae which only included the Neotropic taxa (Brewster 1986). Brewster (1986) then reviewed *Hydrocynus* and concluded that Alestes should be a sister group of *Hydrocynus* as there was no association between Bryconaethiops and Alestes as documented by Géry (1968). Orti (1997) classified *Hydrocynus* closer to Petersiini than Alestes and suggested that the genus *Hydrocynus* be placed in sister position whereas Murray and Stewart (2002) concluded that Hydrocyninae should not be considered a valid subfamily and *Hydrocynus* should be included in Alestidae (include the genera *Alestes*, *Brycinus*, *Bryconaethiops* and *Hydrocynus*).

Hydrocynus spp. are relatively easy to distinguish from other freshwater fish species due to their prominent teeth, dark lateral stripes and adipose fin (Brewster 1986). Apart from the two relatively larger species at adult stages *H. goliath* and *H. tanzaniae* there has also been much confusion regarding *H. vittatus*, *H, forskahlii* and *H. brevis* which is complicated by the fact they occur in sympatry (Skelton 1990, Goodier et al. 2011). Brewster (1986) for example concluded that *H. vittatus* was the same species as *H. forskahlii* from the Nile-Sudanic region (west and north Africa), after which Paugy and Guegan (1989) rehabilitated the name *H. vittatus* and confirmed that it is indeed two different species (Paugy and Guegan 1989, Skelton 1990). There are numerous synonyms in the literature for *H. vittatus* which include those of *Hydrocyon lineatus* (Boulenger 1905), *Hydrocyon vittatus* (Jubb 1952, Jackson 1961, Crass 1962) and *H. forskahlii* (Brewster 1986). In the context of the present thesis, the common name tigerfish refers specifically to *H. vittatus*.

1.8 Distribution

Tigerfish is widely distributed throughout Africa and inhabit almost all of the larger river systems, such as the Nile, Niger, Volta, Congo, Zambezi, Okavango and Limpopo (Jackson 1961). More broadly, their range extends from the Nile-Sudanian River systems of northeast Africa and extends to West Africa (Senegal) and into the lower Guinea Cross and Sanaga basin. They are also found widely in central Africa throughout the Congo River which almost crosses the entire central Africa along its 4 700 km length. Their range also includes large water bodies such as Lake Bangweulu, Lake Mweru, Lake Tanganyika, Lake Chad, Lake Victoria, Lake Kariba, Lake Cahora Bassa and numerous small impoundments where they have been translocated (Griffith 1975). In southern Africa they occur in the Kavango River system, Zambezi River ecoregions and Limpopo ecoregion and lowland reaches south to the Pongola River, although historical ranges extended as far down as the Mkuzi River which flows into Lake St. Lucia in Natal (Jubb 1952). They are notably absent from the Kunene River system, Kafue, Lake Malawi and the upper Save-Runde Rivers (Griffith 1975, Goodier et al. 2011).

1.9 Food and feeding behaviour

Tigerfish is among the top piscivores in African freshwater ecosystems (Jackson 1961). Their functional role as predators in the transfer of energy between eutrophic floodplains and the main river is crucial in maintaining ecosystem functionality (Winemiller and Jepsen 1998). Kenmuir (1975) and Steyn et al. (1996) showed that young tigerfish (< 5 mm) display photokinetic periodicity where the young inhabited surface waters during the day possibly to reach the planktonic soup (e.g. *Volvox spp.*) with appropriate food particles (Matthes 1968). The diet of juvenile tigerfish, up to approximately 50 mm in fork length (FL), consists mainly of zooplankton.

As the fish grow (50-60 mm FL), their diet changes from zooplankton to small aquatic insects (especially Hemiptera and Ephemeroptera nymphs) and progressively to larger insects (Holden 1970, Kenmuir 1975). At lengths of about 60-70 mm FL tigerfish become almost entirely ichthyophagous supplementing their diets with invertebrates, molluscs and occasionally crustaceans (Jackson 1961, Kenmuir 1975). Adult tigerfish have also been shown to exhibit avivory behaviour (O'Brien et al. 2014). In Lake Kariba, tigerfish have also been shown to change their diets according to the environment and prey species availability (Kenmuir 1973, Marshall 1985, Marshall 1987). Furthermore, Jackson (1961) reported that tigerfish attacked the wound of a Nile crocodile *Crocodylus niloticus* (Cuvier 1802) that had been shot in the head, presumably the tigerfish responded to the blood in the water and was attracted to the flesh of the crocodile. Similarly, tigerfish have been observed feeding on a dead hippopotamus *Hippopotamus amphibius* (Linnaeus 1758) (pers. obs. F. Jacobs). It seems that tigerfish is predominantly an opportunistic predator that will change its diet depending on available prey items. This was also observed by Gagiano (1997) who noted that in the Olifants and Letaba Rivers, adult tigerfish fed almost exclusively on invertebrates because fish prey was scarce.

Tigerfish of similar sizes usually roam in schools whereas larger fish become more solitary (Jackson 1961). They generally hunt in packs and can often been seen in feeding frenzies where they prey on a variety of smaller bodied species including robbers (*Brycinus spp.* and *Micralestes spp.*) or minnows (*Enteromius* spp.) but have also be shown to be cannibalistic (Bell-Cross 1965, Gaigher 1967). From stomach content analyses, tigerfish are known to prefer prey of ≤ 40% of its own body size, although they have occasionally been documented to take larger prey (Jackson 1961). Prey up to 64% of the body length of tigerfish have been recorded by Matthes (1968) and Winemiller and Kelso-Winemiller (1994) reported the predator prey ratio between 7% and 62%

(mean 27%). Jackson (1961) witnessed how a 210 mm *Labeo altivelis* had been bitten in half then ingested remains were found in the stomach contents of a 45.5 cm FL tigerfish. There seems to be some variation in preference of feeding behaviour between *Hydrocynus* species. *Hydrocynus brevis* are prone to mutilating large fish whereby they feed by biting pieces from the posterior or ventral portions of prey items often repeatedly attacking even after the prey fish has floated to the surface (Lewis 1974). This behaviour has also been observed for *H. vittatus* whereby a 3 kg sharptooth catfish *Clarius gariepinus* (Burchell 1822) was captured and had chunks bitten into its body and its tail sliced off 1/3 of its body length (pers. obs. F. Jacobs). Matthes (1968) suggested that tigerfish usually attack from behind mutilating the posterior end of prey before ingesting whereas (Gagiano 1997) observed prey species bitten in the middle of the body before turned and swallowed.

1.10 Spawning behaviour

Tigerfish are considered potamodromous, because they migrate between freshwater habitats to spawn (Bowmaker 1973). It has generally been accepted that tigerfish spawning migrations are linked to a combination of physical and chemical factors usually associated with flooding events which inundates nutrient rich floodplains (Jackson 1961, Kenmuir 1973, Langerman 1980). Merron (1988) suggested that spawning events of tigerfish in the Okavango River takes place prior to annual floods to ensure juveniles have optimum use of flooded areas for both protection and feeding. Jackson (1961) recorded a two month old juvenile tigerfish in the Okavango early November, which suggest that tigerfish spawned earlier than previously thought. This suggested that the female gonads matured during abnormal seasons (austral winter) or low flow conditions.

This may supports findings by Van Zyl (1992) that there may be two breeding cycles for tigerfish which was also noted by Kenmuir (1973).

Roux (2014) found evidence of possible spawning habitats at water abstraction pumps that create slow moving water presumably favourable for spawning of tigerfish. Tigerfish seem to have highly selective spawning habitats with coarse sand and the absence of fast flowing water, with a depth of approximately 1.4 m (Roux 2014). In general spawning habitats were situated in close proximity to possible nursery areas that contained floating macrophytes and submerged vegetation (Roux 2014). Roux (2014) also suggested that tigerfish can make use of deep backwater side channels for annual spawning events as a precautionary strategy to ensure survival.

Currently, various speculations exist on the spawning migration of tigerfish which remain poorly understood (Steyn et al. 1996, Roux 2014). What is known about spawning processes in tigerfish is that they are egg scattering lithopelagophil and have high fecundity with an estimated 780 000 ova produced in large females (650-700 mm FL) (Steyn et al. 1996). Tigerfish eggs have also been shown to be negatively buoyant and slightly adhesive for benthic or epibiotic incubation possibly on sandy substrates (Steyn et al. 1996). To date, the spawning event and behaviour of tigerfish during spawning have not been documented in the wild (Roux 2014).

1.11 Growth and maturity

Tigerfish has always been considered a fast growing species that can reach lengths of up to 140-180 mm FL in their first year and > 200 mm FL in their second year within riverine conditions (Jackson 1961). In Lake Kariba, Badenhuizen (1967) documented growth rates of 160-200 mm FL in the first year and > 300 mm FL in the second year. Similarly, Kenmuir (1973) also documented tigerfish growth between 170-210 mm FL in the first year and 260-320 mm FL in the second year in Lake Kariba. However, Gaigher (1967) found relatively slower growth rates in the Incomati River system (South Africa) and documented a growth rate of 90 mm FL in the first year and 170 mm FL in the second year, and 250 mm FL in the third year. Males have previously been found to mature at 300-400 mm FL or two years of age whereas most breeding females mature at lengths exceeding 400 mm FL approximately four years of age (Hay et al. 2000, Skelton 2001). The presumed reason for relatively fast growth rates in tigerfish is the high mortality rates (up to 84%) in the first year of growth, due to the high numbers of associated predators (Jackson 1961, Balon 1971, Kenmuir 1975). Consequently this fast growth rate presumably allows tigerfish to avoid predation by larger fish (Jackson 1961). Furthermore, the growth rates of *H. vittatus* from various river and dam systems differ and therefore the relative maximum sizes also differ throughout systems (Gaigher 1967). The slowest growth rate seems to be that of the Incomati River system, which was documented by Gaigher (1970). Tigerfish in Lake Kariba are possibly the largest in southern Africa (max 16.1 kg IGFA world record) compared with those caught in other dams and river systems (Jubb 1952). Bell-Cross (1965) sampled tigerfish with mass of 7.4-8.8 kg in the Upper Zambezi River system, Pienaar (1978) collected tigerfish weighing 5.4-5.9 kg in the Sabie, Crocodile and Letaba Rivers and tigerfish ±7 kg have been sampled in the Olifants River by Gagiano (1997). Van Zyl (1992) estimated that tigerfish attained a maximum age of 10 years and 62 cm FL in the Kavango River. Gerber et al. (2009) recorded tigerfish up to 7 kg (86 cm TL) and the current Crockango Fishing Club record for the Kavango River stands at 8.27 kg (Pers. comm. E. Atkinson). There is however, evidence that previous studies may have overestimated the growth rates of tigerfish. Gerber et al. (2009) using otoliths to age tigerfish in the Okavango River in Botswana also demonstrated that the longevity of these fish was up to 20 years.

1.12 Movement behaviour

Movement behaviour of tigerfish is not well researched. Gaigher (1967) proposed that tigerfish undertake long distance migrations, possibly associated with annual spawning activities and an intolerance for cold water. Badenhuizen (1967) proposed that tigerfish migrate from Lake Kariba to breeding grounds in shallow rivers connected to the lake and Kenmuir (1973) witnessed shoals of migrating tigerfish in the Sanyati Gorge (Lake Kariba). During a behavioural study by Økland et al. (2005) in the Zambezi River, large scale movement (>1000 m) was recorded for approximately 50 % of the tagged tigerfish whereas the other half undertook complex individual movements. Økland et al. (2005) concluded that area use varied among individuals and had a 95% probability of locating tigerfish within an average area of 276,978 m^2. Radio tagged tigerfish were recorded predominantly in the main stem of the Zambezi River (95% of fixes) and habitats utilised included backwaters, permanent swamps and floodplains (Økland et al., 2005). Tigerfish tracked during the latter study preferred open water areas and did not seem to use vegetation as they were never recorded under vegetation (Økland et al. 2005). Neither season, age nor different length classes could explain the variation in movement patterns among individuals which suggests movements were probably related to feeding opportunities (Økland et al., 2005). O'Brien et al. (2012) also documented two area use types for tigerfish in man-made impoundments. Some tigerfish (55%) remained in close proximity to the release location, whereas others used deep open water (O'Brien et al. 2012). Similarly, Baras et al. (2002) identified fidelity to a specific habitat with isolated home ranges with large rocks and depths ranging from 60 cm to100 cm for *H. brevis* in the Niger River, Mali. Roux (2014) also recorded relatively small scale area use (mean 730 m) for radio tagged tigerfish which was attributed to survival strategies in the Incomati River system. Thirty eight of the studied tigerfish stayed in defined home range of 48 846 m^2 which changed according to seasons, life history and habitat availability (Roux 2014). Different depths were utilised by the tigerfish and they showed major differences between summer (1.51 m) and winter months (2.17 m) with a mean depth of 1.87 m (range 0.80 m to 3.41 m) during the study period (Roux 2014). Tigerfish preferred slow deep (<0.3 m/sec, >0.5 m) habitats (52.6%), followed by slow shallow (<0.3 m/sec, <0.5 m) (41.08%), fast shallow (>0.3 m/sec, <0.5 m) (3.44%) and fast deep habitats (>0.3 m/sec, >0.5 m) 2.88% (Roux 2014).

Apart from anecdotal reports behavioural studies focusing on area use, movement and habitat utilisation have been restricted to the Incomati River System (Roux 2014), the Upper Zambezi (Økland et al. 2005) and man-made impoundments within the Limpopo River catchment (O'Brien et al. 2012, O'Brien et al. 2014).

1.13 Conservation and management

Tigerfish are currently listed as least concern on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (IUCN 2017). Tigerfish is listed as least concern as this species has a wide distribution and is generally considered common and abundant (IUCN 2017). Tigerfish has also been listed as least concern for north eastern, eastern, southern, western and central Africa but, have been depleted locally in areas such as the Zambezi River in Namibia (Cooke et al. 2016, IUCN 2017). The exclusion of tigerfish from these international conservation strategies may not necessarily mean that tigerfish populations are in a similar state across regions as river system could have different water quantity, quality, fishing pressure and the loss of habitat which could influence local populations (Gaigher 1967, Tweddle et al. 2015, Cooke et al. 2016). Gaigher (1967) indicated a change in the tigerfish reproductive prospective as they could not migrate freely and had inadequate space for spawning due to the construction of weirs and the scarcity of water in the Incomati River. Kenmuir (1973) reported that gillnet fishing has the most damaging effect on the tigerfish population in Lake Kariba. The use of smaller gillnets and illegal netting in the river systems, as the seine nets, especially the smaller sizes, not only yields the adult stock but also the egg pool (Kenmuir 1973). Recently, Cooke et al. (2016) reported on decreased trophy tigerfish being captured in the Zambezi River which not only effects the viable breeding populations but causes a negative effects on the important value chain from this species. Currently, there is no management or conservation tools available for tigerfish in the Kavango River.

1.14 Techniques to study freshwater fishes

The management and conservation of freshwater fish stocks is greatly dependent on the understanding of fish populations and community processes (Lucas and Baras 2000, Cooke et al. 2004). One of the most preferred methods for studying these processes is the use of tag or mark-recapture methods (Pine et al. 2003). The development of these methods have allowed researchers to monitor and study freshwater fishes more effectively, over extended periods and across vast distances within their natural environments (Lucas et al. 2001). There are basically two categories, namely capture dependent and capture independent methods. Capture dependant methods refers to sampling of marked fish (mark-recapture) or unmarked fish to assess the species abundance using catch per unit effort (CPUE) over an certain period of time to gather information about population structures, dispersal, mortality, distribution and general movement patterns (Lucas and Baras 2000). Capture dependent techniques are usually applied where long-term studies are in place, as they have low technical requirements and equipment costs. However, where there are serious ecological or specific management issues and high-resolution information of selected individuals are needed, capture fishes may also be tagged with transmitters (Koehn et al. 2000).

Transmitters allow researchers to follow individuals throughout their natural environment without having to recapture a fish to provide the necessary information (Lucas and Baras, 2000).

Capture independent methods include visual observation, video techniques, hydroacoustics, and automated fish counting (Knights and Lasee 1996, Lucas and Baras 2000). In general, there are few rivers in southern Africa where capture independent methods can successfully be used, thus capture dependent methods to obtain fisheries data is widely used. Today researchers are presented with a wide range of methods and techniques available for both tagging and marking fish (Koehn 2000). The type of tagging or marking method used should, however, receive careful attention as the results could be influenced by charactristics such as, species of fish, habitat, size of fish and the ease of application (Koehn, 2000, Thorstad et al. 2013).

1.14.1 Catch per unit effort

Despite CPUE being one of the most common methods used to assess the status of fish stocks, CPUE data are notoriously problematic (Maunder et al. 2006). Some of the major problems faced by using CPUE data is that it only accounts for a component of the population that is vulnarable to the fishing gear used, which may be proportional to this component of the population instead of the total population. In addition, the vulnerability of the fishery depends on gear selectivity, age and size of fish and the fishing method used (Maunder et al. 2006). Catch per unit effort is rarely proportional to abundance over a exploitation history or geographic range as numerous factors can also affect catch rates. Even though standarization of CPUE data is commonly applied in fisheries analyses, the resulting index of relative abundance provides limited information on the effect of fishing pressure (Maunder et al. 2006). Therefore, CPUE data can generally not be used in isolation to assess and manage fisheries communities or ecosystems (Maunder et al. 2006).

1.14.2 Capture-recapture techniques

Capture dependent (capture-recapture) methods, using external physical tagging (e.g. dart, T-bar tags, Visual implant tags VI-tags) is one of the most common models for fishery scientist to determine the movement, growth, mortality, survival and capture probability of fish species (Pine et al. 2003). Numerous estimators that dependent on assumptions such as closed demographic populations, if tags are individual specific or not, and the observation and reporting of dead or live fish, are available (Pine et al. 2003, Booth and Weyl 2008). Catch-mark-recapture (CMR) techniques to obtain data are widely used in many freshwater fish species mainly because of the relatively low costs involved, however, the low percentage of tagged fish being recaptured is problematic in formulating proper management decisions (Koehn et al. 2000).

1.14.3 Telemetry techniques

The more expensive telemetry methods are usually applied where there are serious ecological or management questions (Koehn et al. 2000, Lucas and Baras 2000). Both ultrasonic and radio tags can provide high-resolution information of selected individuals and is the preferred method for monitoring the behavioural ecology of freshwater fishes (Thorstad et al. 2013). Being a popular method since the 1950s, technological advancement has improved tagging techniques as well as seen major developments in state of the art tags (Winter et al. 1978, Knights and Lasee 1996, Koehn et al. 2000, Lucas and Baras 2000, Cooke et al. 2004). Typically, these studies record information on position, area use and/or measurements of environmental and physiological parameters wirelessly by use of a mobile receiver or stationary loggers (Thorstad et al. 2013). This method has the advantage of the fish not having to be recaptured to obtain information (Thorstad et al. 2013). Its application is endless and have widely been used in studies assessing effects of fishing regulations, catch and release angling, migration barriers, protected areas, water pollution, hydropower stations and more recently in aquaculture practices (Thorstad et al. 2013, Habib et al. 2014). However, the use of both these tags requires a large financial input, high level of experience and expertise, limitation on fish size and limitations on the number of fish that can be tagged. Fishes can be fitted with tags, either internally (implant) or externally, depending on the species, expertise of person tagging, cost, type of tag and characteristics of environment in which study is being done (Koehn, 2000).

1.14.4 Attachment techniques

The mark or tagging attachment technique are the most important aspect of any behavioural study, as it should not affect the normal physiology or behaviour or cause mortalities of experimental fishes (Bridger and Booth 2003). Marking or tagging techniques that include the use of relatively low cost dart, T-bar tags, Visual implant tags VI-tags are usually applied with minimum effort and handling time of experimental fishes. High mortality rates are not associated with these techniques, but, the uncertainty of the rate of tag loss are considered a fundamental requirement for CMR models (Booth and Weyl 2008). These estimates are best obtained in controlled experimental environments and should be done before considering these tagging techniques. For intensive freshwater fish studies, in areas without thick vegetation, externally attached radio tags have an overall advantage over ultrasonic or implant tags (Koehn et al. 2000). In addition. externally attached tags generally have the lowest mortality rate when compared to implant tags (Koehn et al. 2000). External radio tags can also be applied to more fish species, because of fewer biological limitations (Koehn 2000, Bridger and Booth 2003). Furthermore, Økland et al. 2003 conducted an experiment using surgical implant tags on common carp *Cyprinus carpio* and experienced a 100

% mortality rate in a Namibian reservoir, and concluded that externally attached tags are possibly more suitable for warm tropical waters in Africa.

1.15 Movement and population studies of tigerfish

1.15.1 Catch-mark-recapture studies

In southern Africa, CMR studies on tigerfish have been largely unsuccessful. Early investigations into mark and recapture techniques for tigerfish in Lake Kariba by Langerman (1980) involved using T-bar anchor tags and fluorescent spray marking. Both these techniques were reported ineffective for estimating biomass in Lake Kariba (Zimbabwe) due to impracticality and low recapture rates (Langerman 1980). Furthermore, Gagiano (1997) was unable to recapture any of the > 1000 African tigerfish tagged using T-bar anchor tags in the Olifants and Letaba Rivers, South Africa, over two years. Similarly, Roux (2005) recaptured only one of the 700 individuals that were tagged with visual implant tags (VI-tags) in the Luvuvhu River, South Africa. In this case, the only recapture was made two days after the release of the individual so was of little value. In contrast, Booth and Weyl (2008) conducted a double tagging experiment in the Glen Melville Reservoir, South Africa on African sharptooth catfish *Clarias gariepinus* Burchell 1822 to demonstrate that plastic tipped dart tags had a 100% initial retention and 2% tag loss p.a. over a study period of four years (Booth and Weyl 2008). In a growth zone validation experiment conducted at KIFI, Peel et al. (2016) found that 77 % of 22 T-bar tagged *Oreochromis andersonii* Castelnau 1861, and 25% of 16 tagged *Coptodon rendalli* retained their tags between 11 and 14 months in an earthen pond. As none of these tagging studies on tigerfish conducted any prior tag retention experiments it is unclear whether the low recapture rates were as a result of tag-loss, mortality or other factors (e.g. dispersal) and the data are of little value.

1.15.2 Radio telemetry use on tigerfish

Despite the advantages of using radio telemetry only three movement behaviour studies have been conducted on tigerfish. Økland et al. (2005) charactirised the movements and habitat utilisation of tigerfish in the Zambezi River (Namibia) during the low, rainy season and high-water period; O'Brien et al. (2012) presented a comparative behavioural assessment associated with the establishment of a tigerfish population in a man-made facility and Roux (2014) documented tigerfish survival strategies in the Incomati River system. All previous behavioural monitoring studies used radio transmitters from Advanced Telemetry Systems (Inc.,Isanti, MN, USA) which were externally attached to the tigerfish. The radio tags used were considered acceptable, as all tigerfish were alive as they were tracked and no transmitter loss was recorded (Økland et al. 2005). Therefore, external radio transmitters from ATS is considered effective for behavioural studies on tigerfish in African rivers. These studies all concluded that in general radio telemetry is a feasible method for studying behavioural ecology aspects of tigerfish. The effects on tigerfish movement behaviour resulting from the attachment techniques has not been explored yet, and should be considered for investigation. Apart from these radio telemetry studies on tigerfish, movement behaviour remains largely unexplored and reports on migrations, area use and movement patterns are mostly anecdotal.

1.16 Study areas

Each of the study areas used to carry out different parts of this thesis are discussed in detail within each of the four following chapters. In brief: Chapter 2; the status of African tigerfish *Hydrocynus vittatus* (Castelnau, 1861): A review of 17 years of monitoring in Namibia, was carried out using data collected at three sampling stations in the Zambezi River (Katima, Kalimbeza and Impalila) and four sampling stations in the Kavango River (Musese, Rundu, Cuito and Kwetze, Fig. 1.4). To assess the retention of plastic-tipped dart tags in tigerfish in Chapter 3 an earthen pond at the Kamutjonga Inland Fisheries Institute was used and the radio telemetry portion of the study in both Chapter 4 (Immediate and long-term behavioural consequences of radio-tagging tigerfish) and Chapter 5 (Are freshwater protected areas suitable for management and conservation of African tigerfish?) were conducted in the Kavango River. The primary study area within the Kavango River extended from Popa Falls Game Park downstream to the Botswana border (Fig. 1.4).

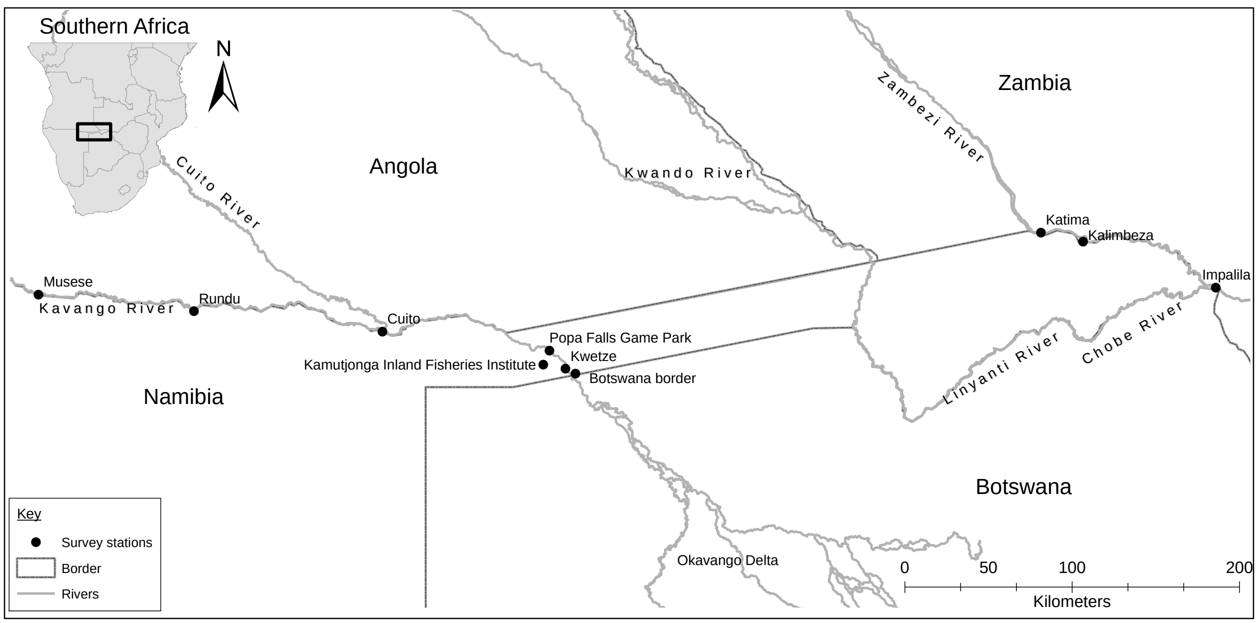

Figure 1.4: Locations of sampling stations in Namibia for the annual experimental gill net surveys to investigate the status of *Hydrocynus vittatus* from 1997 to 2016. Three stations were sampled in the Zambezi River (Katima, Kalimbeza and Impalila) and four stations were sampled in the Kavango River (Musese, Rundu, Cuito and Kwetze). For the tag retention study an earthen pond at Kamutjonga Inland Fisheries Institute was used and the radio tagging portion of the study was conducted mainly from Popa Falls Game Park downstream to the Botswana border in the Kavango River.

1.17 Research requirements

Although some ecological aspects of tigerfish are well documented more data are needed on population dynamics and area use patterns of this highly socio-economic important fish species (Økland et al. 2005). Overexploitation of commercially important large cichlids (e.g., *Oreochromis andersonii* (Castelnau 1861), *O. macrochir* (Boulenger 1912) and *Coptodon rendalli* (Boulenger 1987) have been well documented and attributed to excessive fishing effort and the use of environmentally destructive and unsustainable fishing methods (Tweddle 2010, Tweddle et al. 2015, Cooke et al. 2016). This is problematic as the symptoms of overfishing (decreased catch rates and fish size) are likely to impact on the livelihoods of local fishing communities as well as the tourist industries and could negatively influence the economy in rural areas (Tweddle et al. 2015, Cooke et al. 2016). Despite the subsistance (Tweddle 2010), commercial (Abbott et al. 2015, Tweddle et al. 2015) and recreational (Cooke et al. 2016) importance of tigerfish, very little information is available on current populations and the assessment of tigerfish stocks is urgently required. The use of catch per unit effort (CPUE) data from fisheries independent surveys is a common method for assessing fisheries stocks (Maunder et al. 2006). As CPUE only measures the component of the population which is caught, this metric is dependent on the vulnerability of the species to gear used, size and age of fish and horizontal and vertical distribution of fish (Maunder et al. 2006), standardised surveys could be used to remove some of the impact of these factors (Maunder and Punt 2004). Such surveys are however only an indication of the relative status of the stock and infer little on the behaviour of the fish.

There are relatively few data on any tigerfish area use patterns despite, tigerfish being one of Africa’s top predatory freshwater fish species (Jackson 1961). Similarly, although studies of tigerfish as indicators of aquatic health are increasing (Smit et al. 2009, Van Dyk et al. 2009, McHugh et al. 2011, Smit et al. 2013, Tate 2013, Gerber et al. 2016a, Gerber et al. 2016b, Gerber et al. 2017) data on the area use ecology within this species are lacking (Økland et al. 2005, Roux 2014). Unravelling area use of tigerfish in African rivers could be facilitated by using mark and recapture studies. In southern Africa, mark-recapture studies on tigerfish have been largely unsuccessful (Langerman 1980, Gagiano 1997). As none of these studies conducted prior tag retention experiments it is unclear whether the low recapture rates were as a result of tag-loss, mortality or other factors (e.g. dispersal). The use of these relatively low cost tags for mark-recapture studies for understanding the movement patterns, growth, population sizes and abundance of this species is important from an ecological perspective but also essential to guide fisheries management interventions (Pine et al. 2003).

Specialised tracking techniques, such as radio telemetry, are the most effective methods for studying area use of freshwater fish species (Thorstad et al. 2013). Økland et al. (2005) recorded both small and large scale area use of individual tigerfish in the Zambezi River whereas Baras et al. (2002), O'Brien et al. (2012) and Roux (2014) reported relatively small scale individual area use for tigerfish. These findings may show evidence that a proportion of the tigerfish population may not use large areas to carry out life histories. This could possibly explain findings by Cooke et al. (2016) of overexploitation of local tigerfish populations in the Zambezi River, Namibia. The use of FPAs might therefore be a useful management tool (Suski and Cooke 2007, Bower et al. 2015, Cooke et al. 2016). As the efficiency of FPAs depends on the residency of the target species within it, FPAs are often criticised as not being relevant for migratory fish species (Croft 2004, Suski and Cooke 2007). Research into the area use of tigerfish is therefore an urgent requirement.

1.18 Aims and Objectives

The main aim of the study was to investigate tigerfish population trends and movements, and to assess if freshwater protected areas could be a suitable conservation and management tool for this species in Namibia.

The study therefore had the following objectives and sub-objectives:

1) To use 17 years of fisheries independent monitoring data collected by the Ministry of Fisheries and Marine Resources from the Zambezi and Kavango Rivers to identify possible population trends, variations in size structures and changes in abundances over the sampling period. The sub-objectives were:
    a. To determine changes in CPUE trends over the past 17 years in the Zambezi and Kavango Rivers.
    b. To investigate tigerfish CPUE trends between sampling stations in each of the two rivers.
    c. To understand how a station on the Kavango River situated in a protected area had a higher CPUE, compared to other stations within the same river.
    d. To determine if protected areas could be a useful management and conservation tool for tigerfish.
2) To determine the tag loss rate of relatively inexpensive PDL plastic tipped dart tags and provide insights into a tagging/marking method best suited for behavioural monitoring studies of tigerfish. The sub-objectives were:
    a. To estimate the survival rate of handling and dart tagging tigerfish in an experimental pond.
    b. To determine the tag loss rate by monitoring tigerfish bi-monthly for a period of 10 months.
    c. To identify possible causes of tag loss in tigerfish during the experimental period.

d. To recommend the best tagging method that should be used for behavioural monitoring studies in tigerfish

3) To investigate if external radio tagging as the preferred method for long-term behavioural studies would have an immediate effect on the post-release behaviour of tigerfish.

   a. To study this, 49 tigerfish were tagged using external radio transmitters in the Kavango River

   b. To monitor tigerfish movements for three consecutive days post-release to determine immediate effects.

   c. To monitor nineteen of these fish again 25 to 47 days after tagging to determine long-term effects.

   d. To make a comparison between post-release and long-term behaviour following tagging.

4) To assess the usefulness of FPAs as a management tool for African tigerfish by monitoring their behaviour.

   a. To study this, 49 tigerfish were tagged using external radio transmitters in the Kavango River

   b. To monitor radio tagged tigerfish every 12 days from July 2016 to May 2017.

   c. To calculate the area use of radio-tagged tigerfish in the Kavango River.

   d. To predict the proportion of the monitored tigerfish which could possibly be protected by setting up different lengths of protected areas

   e. To provide scientifically sound, evidence-based data that can assist fisheries management decision makers.

Thesis Structure

The remainder of this thesis comprises five chapters, four of which are experimental and formatted for publication in peer-reviewed journals. There is some inevitable repetition, since these chapters are intended to be published separately in international peer reviewed journals.

- Chapter 2 uses 17 years of fisheries independent monitoring data from the Zambezi and Kavango Rivers to describe the current status of African tigerfish *Hydrocynus vittatus* (Castelnau, 1861) in these rivers.
- Chapter 3 is the first tag retention study conducted on tigerfish and provide insights into a tagging/marking method that can be used for behavioural monitoring studies
- Chapter 4 describes the short and longer-term behavioural responses of radio tagging wild tigerfish
- Chapter 5 investigates the area use of tigerfish to predict if freshwater protected areas could be a useful management tool in the Kavango River

The concluding chapter puts the main results from this study into a broader context.

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CHAPTER 2

The status of African tigerfish *Hydrocynus vittatus* (Castelnau, 1861): An assessment of 17 years of monitoring in the Zambezi and Kavango rivers, Namibia

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2.1 Abstract

Inland fisheries, and especially African tigerfish *Hydrocynus vittatus* fisheries, make a substantial contribution to provide food security and stimulation of the local economy. It has been suggested that tigerfish populations in the northern perennial rivers of Namibia have experienced declines in catch rates. The Ministry of Fisheries and Marine Resources conducted annual gill net surveys in the Zambezi and Kavango Rivers from 1997 to 2016. Tigerfish data collected during these surveys were used to assess the current status of tigerfish. Catch per unit effort (CPUE) was not uniform among rivers. The Zambezi River had a higher CPUE in weight (1.21 ± 1.83 kg/net-night) and numbers (9.67 ± 14.65 fish/net-night) compared with the Kavango River (0.50 ± 1.58 kg/net-night and 2.04 ± 3.38 fish/net-night). High inter-annual variation from 1997 to 2016 in CPUE in weight or numbers within each of the two river systems, showed no clear temporal trends. Hence, the prediction that tigerfish populations are declining was not supported by this assessment. CPUE, both in terms of numbers and weight, was, however, significantly higher in the freshwater protected area in the Kavango River compared with unprotected sites. This finding highlights the potential importance of freshwater protected areas as a fisheries management tool.

Keywords: Catch per unit effort, freshwater protected area, Kavango River, management, migrations, tigerfish, Zambezi River

2.1 Introduction

The tigerfish genus (*Hydrocynus* spp.) are large characins that are widely distributed across African drainage basins, but are restricted to relatively warm and oxygen-rich habitats in rivers and lakes (Bell-Cross 1965, Jubb 1952). The genus comprises five biogeographically isolated species (Goodier et al. 2011). *Hydrocynus forskahlii* (Cuvier 1819) and *H. brevis* (Günther 1864) are West African species; *H. goliath* (Boulenger 1898) is a Congo River basin endemic; *H. tanzaniae* (Brewster 1986) occupies the Ruvu and Rufiji-Ruaha drainage basins in Tanzania, and *H. vittatus* (Castelnau 1861) is a southern African species (Jubb 1952; Goodier et al. 2011).

In Namibia, tigerfish occur mainly in the Zambezi, Kwando, Chobe and Kavango rivers (Holtzhausen 1991; Thorstad et al. 2002; Abbott et al. 2007). These rivers are associated with large grassland floodplains and a seasonal cycle of flooding (Welcomme 1976; Winemiller and Jepsen 1998; Moore et al. 2007). These floodplain rivers are considered to have complex food webs in which tigerfish is an apex predator, and an important contributor to the transfer of energy from the floodplain into the main river (Winemiller and Kelso-Winemiller 1994; Winemiller and Jepsen 1998; Jackson et al. 2001). Tigerfish are considered to be a rheophilic group of species generally preferring open water areas (Jackson 1961; Økland et al. 2005), but also using the floodplain during periods of inundation (Økland et al. 2005). Tigerfish breed during the summer, but the actual spawning time has not been documented in the wild (Steyn et al. 1996; Roux 2014).

Tigerfish are an important component of artisanal fisheries where they contribute to food security and rural livelihoods (Thorstad et al. 2002; Abbott et al. 2015; Tweddle et al. 2015). Tigerfish are also popular target fish for recreational anglers, an activity that in northeast Namibia is estimated to contribute up to 70% to the revenue received by tourist lodges (Cooke et al. 2016). Situated mostly in remote areas, these lodges are often the only source of paid employment for local communities and provide an important economic contribution to these areas (Tweddle et al. 2015; Cooke et al. 2016).

Because of their ecological and economic importance in the region, there is a need for managing exploitation of this species to ensure that its social and economic contributions are sustained. This is particularly pertinent as anglers have reported declines in catch rates of tigerfish in northern Namibia (Tweddle et al. 2015). Declining catch rates of the commercially important large cichlids (e.g., *Oreochromis andersonii* (Castelnau 1861), *O. macrochir* (Boulenger 1912) and *Coptodon rendalli* (Boulenger 1987) are documented (Tweddle et al. 2015), and have been attributed to excessive fishing effort and the use of environmentally destructive and unsustainable fishing methods (Tweddle 2010; Cooke et al. 2016). However, tigerfish have received little attention. This is problematic as the consequences of overfishing (decreased catch rates and fish size) are likely to impact on the livelihoods of local fishing communities as well as the tourist industry (Tweddle et al. 2015; Cooke et al. 2016). As a result, an assessment of the current status of tigerfish in Namibia is urgently required.

The use of catch per unit effort (CPUE) data from fisheries independent surveys is a common method for assessing fisheries (Maunder et al. 2006). There are, however, limitations to using CPUE data. Major problems may include CPUE data only document a component of the targeted population that is vulnarable to the specific fishing gear used. The data obtained may therefore, be a selected proportion of the population instead of the total available population. In addition, CPUE data may depend on gear selectivity, age and size of fish, the fishing method used and numerous environmental factors can have an effect on catch rates (Maunder et al. 2006). Although standarization of CPUE data is commonly applied in fisheries analyses, data can generally not be used in isolation to assess and manage fisheries communities or ecosystems (Maunder et al. 2006).

In Namibia, the Ministry of Fisheries and Marine Resources (MFMR) has conducted standardised annual gill net surveys in the Zambezi and Kavango Rivers. In the present study, the tigerfish portion of the catch data from these surveys during 1997 to 2016 were assessed to describe the past and present status of tigerfish in the two rivers. To do this, the relative abundance, biomass, and size structure of tigerfish were used to test the predictions that there is a declining temporal trend in tigerfish CPUE in the two monitored rivers and, that tigerfish abundance (measured as CPUE) is higher in an area with low fishing effort.

2.2 Materials and methods

2.2.1 Study area

This study utilised gill net survey data that were routinely collected by the MFMR at set sampling stations in the Namibian section of the Zambezi and Kavango Rivers located in the Upper Zambezi floodplain and Okavango Aquatic Ecoregions (Abell et al. 2008).

2.2.2 The Zambezi River

The Zambezi River is the largest river in southern Africa and has a catchment area of 1320000 km^2 with a cumulative annual flow of 97000 million m^3 (Moore et al. 2007; Tweddle 2010) (Fig. 2.1). The river origins in the northwest of Zambia from where it flows 2575 km through eight countries on its way to the Indian Ocean (Tweddle 2010). The river is divided into three regions namely the Upper, Middle and Lower Zambezi (Moore et al. 2007). The Zambezi River system includes many floodplains which supports a rich ichthyofauna (Moore et al. 2007). Some of these large floodplains include the Central Barotse floodplain and Caprivi floodplains located in the upper Zambezi. In addition to the Kafue floodplains in the middle Zambezi and the Elephant and Ndinde marshes on the lower Shire (see review by Tweddle 2010).

In Namibia, the Zambezi River enters north of Katima Mulilo, forming a 120 km border between Zambia and Namibia, which extends southwards to Impalila Island. Three sites were sampled in the Zambezi River. Katima sampling station (17° 29'S, 24°17'E) consisted mainly of deep pools with bends and a wide mainstream (Hay et al. 2002). The mainstream at the Katima sampling station, ranged from shallow < 1 m areas to deep pools of up to ± 7 m. The river was relatively wide and had a width of 300-800 m. The Katima sampling station consisted mainly of sandy and rocky bottom substrates. Small rapids and rocky outcrops becomes pertinent at this station, especially during the low flow season. The Kalimbeza sampling station (17° 32'S, 24°31'E) is a large slow flowing channel and had a width of 100-200 m. This station had predominantly a sandy bottom substrate with few rocky habitats. This sampling station also had a large variety of depths which ranges from < 1 m to deep pools of ± 5 m and were associated with numerous large floodplains. The Impalila sampling station (17° 45'S, 25°11'E) had a width of 200-300 m and sandy and rocky bottom substrate dominated this station. Mambova Falls is a large rapid situated close to the Impalila sampling station and consisted of numerous rocky outcrops with pebbles prominent in the area. The Zambezi Rivers rises sharply in the month of January with one or more flood-peaks during February to April (Van der Waal & Skelton 1984). The sampling stations have an annual variation in water level of 7-8 m and the adjacent floodplains are inundated from February to June (Van der Waal & Skelton 1984).

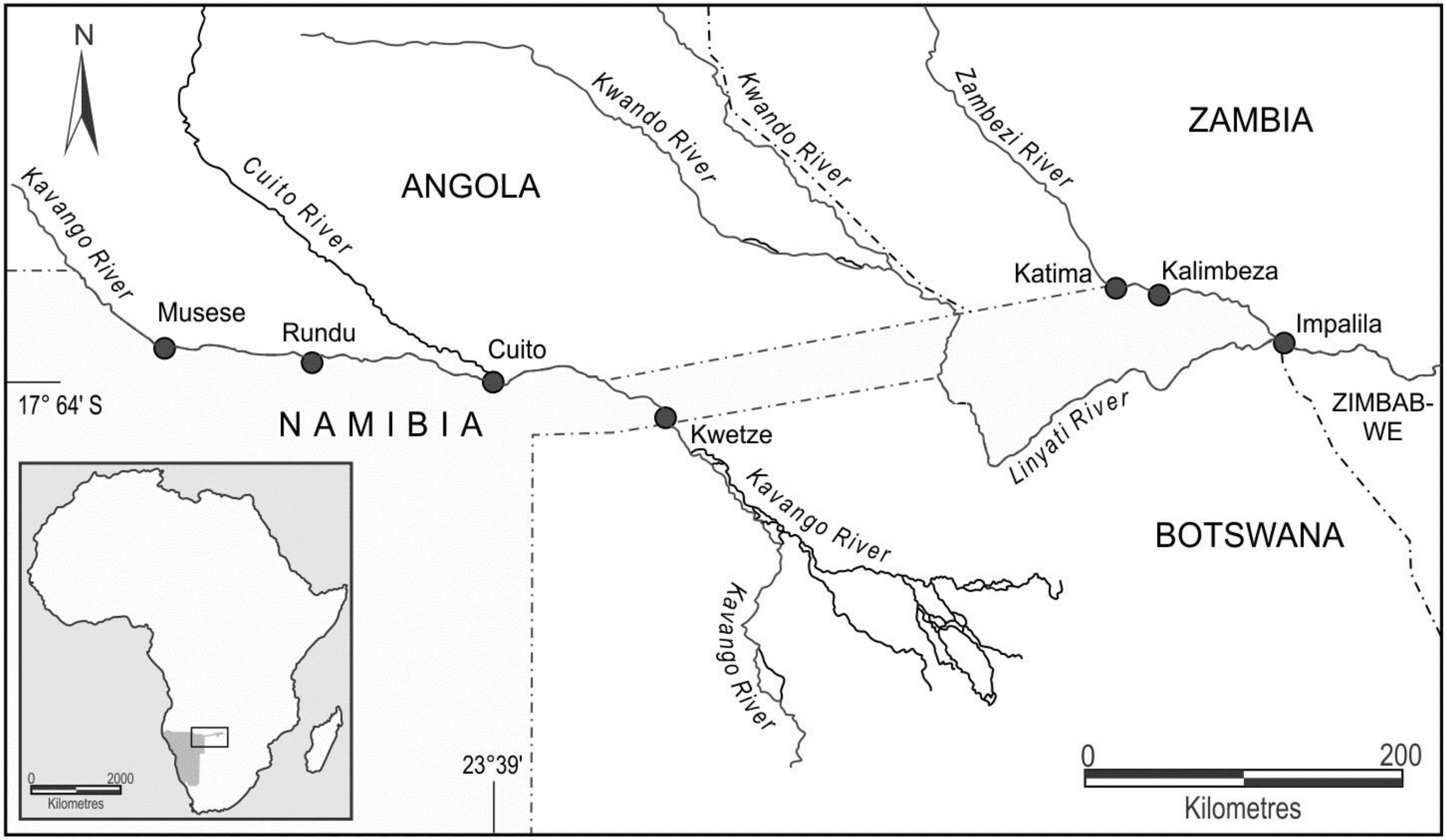

Figure 2.1: Locations of sampling stations in Namibia for the annual experimental gill net surveys to investigate the status of *Hydrocynus vittatus* from 1997 to 2016. Three stations were sampled in the Zambezi River (Katima, Kalimbeza and Impalila) and four in the Kavango River (Musese, Rundu, Cuito and Kwetze).

2.2.3 The Kavango River

The Kavango River originates from a series of headwater streams on the southern slopes of the Angolan highlands and drains a total catchment area of 115000 km^2 (McCarthy and Ellery 1998). From the sources, streams flow south-south east to form the large mainstream. In Angola, it continues southwards to Namibia where it turns eastwards to form the 415 km long border between these two countries (Hocutt and Johnson 2001). The Cuito River is a major tributary, which enters the Kavango River before it turns south and flows for about 53 km before it reaches the Namibia/Botswana border. The Kavango River enters Botswana from the north (the Panhandle) before it terminates in the 15000 km^2 Okavango Delta (McCarthy and Ellery, 1998; Hocutt and Johnson, 2001). During high floods the Okavango Delta extend well into the Kalahari and forms the Lake Ngami and Makgadikgadi Pan (Tweddle 2010). Only during years of exceptionally high flood levels does the Okavango Delta overflow via the Selinda spillway into the Chobe/Linyanti system connected to the upper Zambezi River (Tweddle 2010).

The Kavango River were sampled at four stations. The Musese sampling station (17°49’ S 18°55’ E) was characterized by shallow waters with sandy and rocky substrates that generated numerous well oxygenated rapids. Musese was in the mainstream of the Kavango River, and the water was usually clear with no aquatic vegetation. This sampling station had a width approximately 100 m), and the depth varied between 0.3 and 3.0 m. The Rundu sampling station (17°53’ S 19°46’ E) included the densely human populated areas around Rundu town (Fig. 1). This station primarily contains well developed floodplains with several oxbows and backwaters, although, sampling was conducted predominantly in the mainstream of the river which were approximately 100-200 m wide. The substrate was mostly sandy with some rocky outcrops. The depth varied largely within this station and ranged from < 1m at rapids to > 12 m in deep pools.

The Cuito sampling station consisted mostly of rocks and sandy and gravel substrates. This station similar to the Rundu station contained well developed floodplains with several oxbows and backwaters, although, sampling was conducted predominantly in the mainstream. Sampling was conducted below the Cuito River which and were approximately 100-200 m wide at the sampling station. The sampling station, Kwetze (18°13' S 21°45'E) was situated in the Mahangu Game Park where no fishing was allowed. This area was the only designated freshwater protected area (FPA) in the Kavango River. The sampling station was mainly situated in the mainstream which was approximately 100-200 m wide which had clear flowing water with a depth of up to 7 m and a sandy substrate, with some rocky areas. This area also contained large nearly stagnant backwaters (2-3.5 m deep) with reeds along the shore.

2.2.4 Monitoring surveys

Survey data were obtained from 18 annual years of surveys that were conducted in the months of May/June for the Zambezi River and August/September in the Kavango River from 1997 to 2016 in Namibia. Gillnets were set at sunset (ca 18h:00) and retrieved at sunrise (ca 06h:00) with a mean fishing time of 12 h. Gillnets had nine multifilament (6 ply) fleets, which comprised of 10 m long × 2 m deep panels of stretched mesh 22, 28, 35, 45, 57, 73, 93, 118 and 150 mm, resulting in a total net surface area of ~180 m^2. Gillnet fleets were deployed at the same location at each river station during all sampling occasions. All tigerfish collected were counted, weighed and their length measured. Each tigerfish was weighed whole (M_T) to the nearest 0.1 g using a calibrated balance and measured to the nearest mm fork length (L_F). The daily water-level data were recorded by the Ministry of Agriculture, Water and Forestry at the Katima hydrological measuring station for the Zambezi River. Daily water discharge data for the Kavango River were recorded by the

University of Botswana and the Okavango Research Institute, Botswana, at the Mohembo hydrological measuring station.

2.2.5 Length-weight relationship

Length-weight relationships were calculated using the equation $W = aL^b$, according to Froese (2006), where W was the total body mass (M_T) and L the length (L_F) in mm. The values for parameters *a* (coefficient related to body form), and *b* were estimated by linear regression on the transformed equation: $\log(W) = \log(a) + b \log(L)$ (Britton and Harper 2006; Panda et al. 2016). The non-parametric Kolmogorov-Smirnov two-sampled test (SPSS 20, Inc., Chicago, Illinois) was used to test for normality of data. Thereafter the non-parametric Mann-Whitney U (SPSS 20) was used to calculate differences in the length and weight of tigerfish between river systems.

2.2.6 Catch Per Unit Effort (CPUE)

Catch per unit effort (CPUE) in terms of weight and number of tigerfish caught in the experimental gill nets were calculated annually for each station. Catch per unit effort was standardised to number or weight of fish $fleet^{-1}$ net $night^{-1}$. The residuals of CPUE data were explored for normality after which a Pearson's product-moment correlation coefficient was computed to assess the relationship between year and habitat on CPUE in weight and number respectively for each station (SPSS 20). To evaluate if there was a relationship between water discharge and CPUE in weight and number a regression analyses were performed (SPSS 20). The CPUE data were not normally distributed and contained a high proportion of zero observations. To compare sampled stations within each river the non-parametric Kruskal-Wallis H test (SPSS 20) was used and to compare the respective CPUE between the Zambezi and Kavango Rivers the Mann-Whitney U test was used (SPSS 20).

To evaluate if the mean size of the tigerfish changed over time the Pearson's product-moment correlation was used.

2.3 Results

The gill net sampling effort differed in the two rivers as it consisted of 511 net nights in the Zambezi River and 319 net nights in the Kavango River (Table 1). These surveys from 1997 to 2016 yielded a total sample of 5594 tigerfish with a combined body weight of 780.0 kg. The Zambezi River portion of the catches consisted of 4942 tigerfish (88%) which had a total weight of 620.2 kg (80%), while the Kavango River catches consisted of 652 tigerfish with a total weight of 159.8 kg (Table 2.1).

2.3.1 Length structure

The nine gill net mesh sizes used (22-150 mm) were the same at all fishing locations and in years. Samples comprised tigerfish ranging from 47 mm to 683 mm FL. The length weight relationships were M_T =0.00001 $L_F{}^{3.020}$ (r^2 =0.96, F_{1218}, p = 0.001) for the Zambezi River and M_T =0.000008 $L_F{}^{3.176}$ (r^2 =0.98, F_{1681}, p = 0.001) for the Kavango River. In general, the mean tigerfish collected in the Kavango River (55 - 630 mm, mean length 204 ± 99 mm; mean weight 245 ± 551 g) were larger compared with the tigerfish collected in the Zambezi River (47 – 683 mm, mean length 177 ± 72 mm; mean weight 125 ± 313 g) (Mann-Whitney U = 1416218, p = 0.001; U = 1403686, p = 0.001, respectively) (Table 2.1 and Fig. 2.2).

Table 2.1: Summary statistics for tigerfish samples in number (*n*), effort (net-nights), length and weight parameters (± SD), condition factor (*K*), and CPUE in terms of numbers and weight respectively of tigerfish caught in the Zambezi and Kavango Rivers for the period 1997 - 2016.

	Zambezi River	Kavango River
Total fish *n*	4942	652
Effort (net-night)	511	319
Mean length L_F (mm)	177 ± 72	204 ± 99
Mode length L_F (mm)	150	120
Length range L_F (mm)	47–683	5.5–630
Total weight M_T (kg)	620.2	159.8
Mean weight M_T (g)	125 ± 313	245 ± 551
Mode weight M_T (g)	34	26
Weight range M_T (g)	4–5839	4–5146
Mean condition (*K*)	1.29 ± 0.36	1.33 ± 0.19
CPUE (kg/net-night)	1.21 ± 1.83	0.50 ± 1.58
CPUE (fish/net-night)	9.67 ± 14.65	2.04 ± 3.38

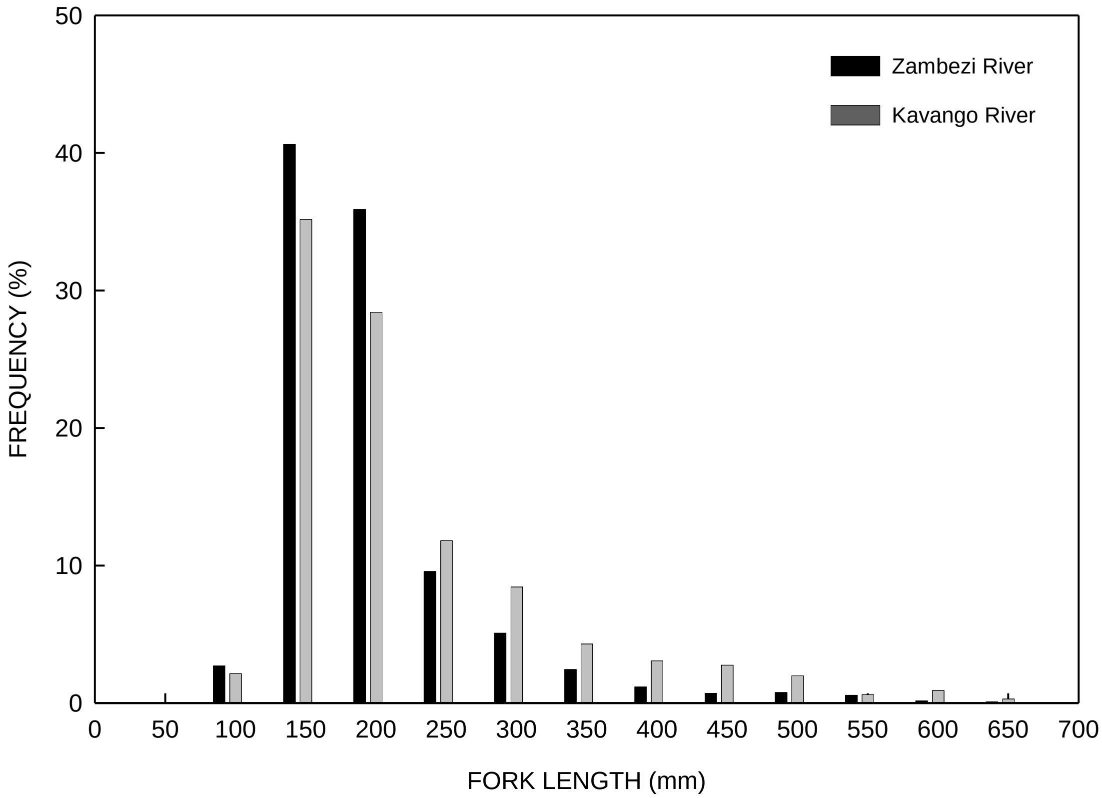

Figure 2.2: Length frequencies of tigerfish caught during annual gill net surveys of the Zambezi and Kavango Rivers in Namibia in the period 1997 - 2016.

2.3.2 Comparison of CPUE between rivers

Sixty four percent of all gill net sets contained at least one tigerfish, and CPUE in terms of weight and numbers both differed significantly between the rivers. CPUE in weight in the Zambezi River (1.22 ± 1.99 SD kg/net-night) was higher than in the Kavango River (0.50 ± 1.58 SD kg/net-night) (Mann-Whitney U = 42805, $p = 0.001$). CPUE in terms of numbers followed the same trend, as this CPUE in the Zambezi River (9.75 ± 23.34 SD fish/net-night) was higher than the Kavango River (2.04 ± 3.38 SD fish/net-night) (Mann-Whitney U = 39059, $p = 0.001$).

2.3.3 CPUE and water discharge

During the sampling surveys in the Zambezi River the mean water discharge was 2945 ± 1029 m^3/s (median 2871 m^3/s, min 1268 m^3/s, max 6269 cm^3/s). The CPUE in weight had a positive relationship with water discharge at the Impalila and Kalimbeza sampling stations (range: b = 0.0009 – 0.0005, r^2 = 0.352 – 0.41, p = 0.007 – 0.012). The CPUE in weight at the Katima station had a weak positive relationship with water discharge (b = 0.001, r^2 = 0.051, p = 0.353). In the Zambezi River the CPUE in terms of numbers had a weak negative relationship with discharge (range, b = -0.001, r^2 = 0.011 – 0.186) and there were no significant correlations (range: p = 0.084 – 0.772).

The Kavango River had a mean water discharge of 168 ± 30 m^3/s (median 166 m^3/s, min 114 m^3/s, max 303 cm^3/s). In the Kavango River CPUE in weight had a weak positive relationship with discharge (range, b = 0.001 – 0.004, r^2 = 0.001 – 0.050) and there was no significant correlations (range: p = 0.464 – 0.984). Catch per unit effort in number also had a weak positive relationship (range, b = 0.001 – 0.010, r^2 = 0.011 – 0.101) and also did not have a significant correlation (range: p = 0.241 – 0.657) for any of the stations sampled in the Kavango River.

2.3.4 CPUE in Zambezi and Kavango rivers over years

The changes in annual CPUE in weight and numbers respectively at each station in Zambezi and Kavango Rivers were studied from 1997 to 2016. The respective CPUEs varied among years at all stations. In the Zambezi River there were weak positive relationships in both CPUE in weights (range: r = 0.16 – 0.26) and numbers (range: r = 0.25 – 0.35) for all the stations sampled in the Zambezi River (Fig. 2.3 A, B). None of the stations showed any significant correlations between CPUE in weight or numbers over the sampled period (range: p = 0.297 – 0.319).

Similar to the Zambezi River, in the Kavango River there were weak positive relationships in both CPUE in weights (range: $r = 0.08 – 0.37$) and numbers (range: $r = 0.03 – 0.33$) for all the stations sampled (Fig. 2.4 A, B). Kwetze sampling station, in a no fishing area, had an increase in CPUE in weight over the sampling period ($p = 0.041$), but not in CPUE in terms of numbers ($p = 0.20$). None of the other sampled stations had significant correlations between CPUE in weights nor numbers respectively over the sampling period (range: $p = 0.169 – 0.906$).

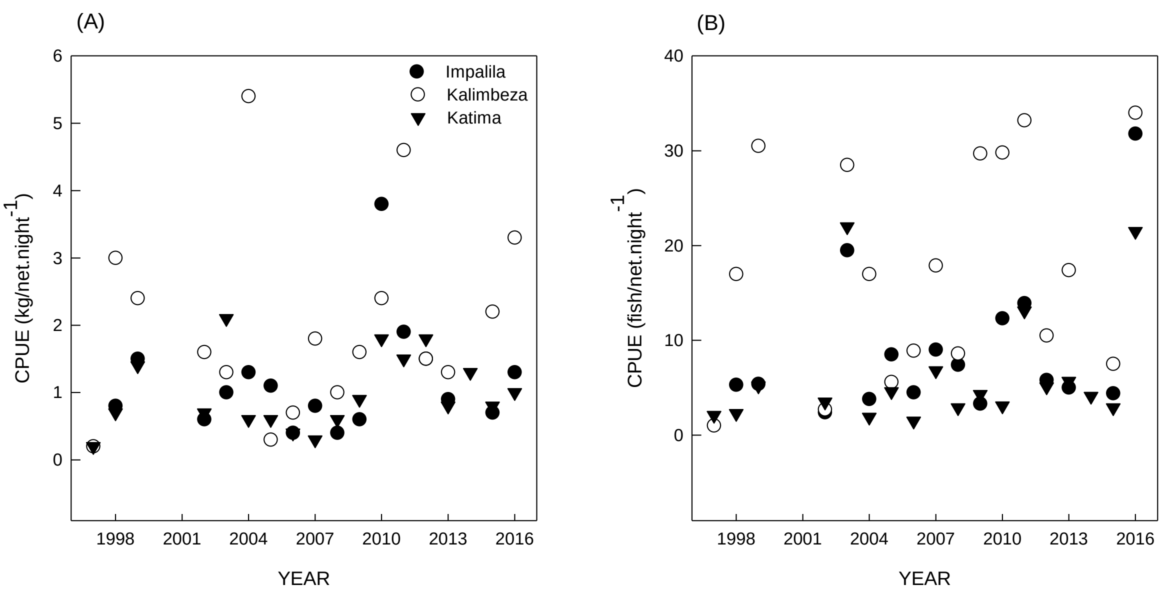

Figure 2.3: Catch per unit effort of tigerfish in terms of (A) weight and (B) number for Impalila, Kalimbeza and Katima stations in the Zambezi River over the period 1997 – 2016

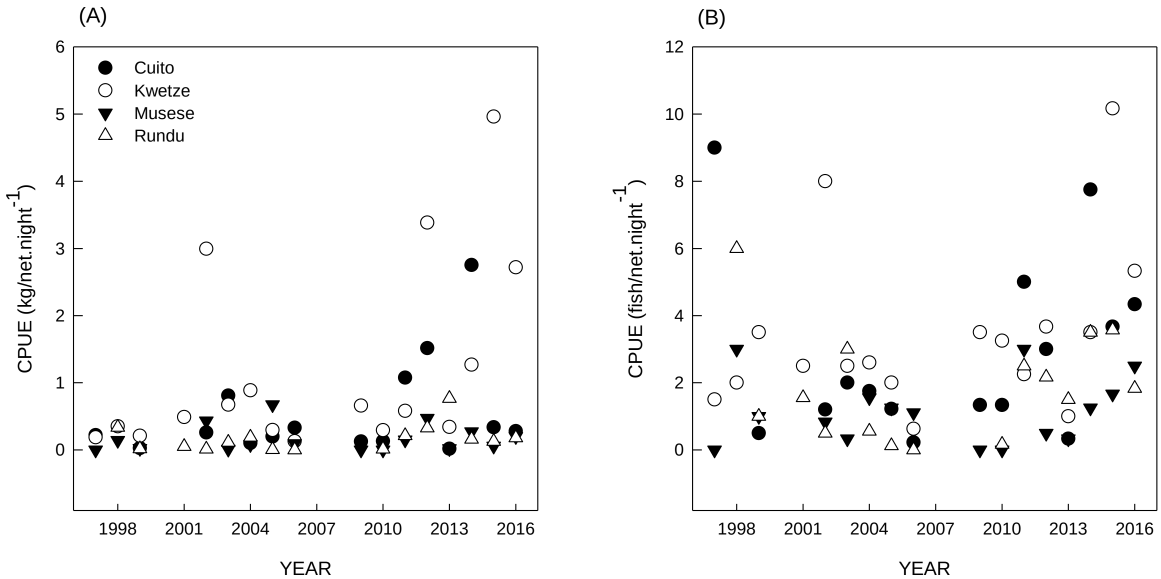

Figure 2.4: Catch per unit effort of tigerfish in terms of (A) weight and (B) numbers for Cuito, Kwetze, Musese and Rundu Stations in the Kavango River over the period 1997 – 2016.

2.3.5 CPUE in habitats

At each station the experimental gillnets were placed in both the mainstream and in backwaters. The number of sets in each habitat varied among stations and years depending on logistical factors, and no habitat were sampled more intensively in any periods from 1997 to 2016. In the Zambezi River there were weak positive relationships between CPUE in weight, both in the mainstreams (range: $r = 0.13 – 0.34$) and backwaters (range: $r = 0.10 – 0.29$). Similarly, the CPUE in terms of numbers, had a weak positive relationship both in mainstreams (range: $r = 0.21 – 0.32$) and backwaters (range: $r = 0.01 – 0.29$). None of these correlations between CPUE in weight and numbers respectively in mainstreams and backwaters were significant (range: $p = 0.169 – 0.992$).

Also in the Kavango River, the CPUE in weight had weak positive relationships for the mainstreams (range: $r = 0.11 – 0.51$) and backwaters (range: $r = 0.01 – 0.50$). Similarly, the CPUE in terms of numbers, had weak positive relationships both in mainstreams (range: $r = 0.02 – 0.49$)

and backwaters (range: $r = 0.28 – 0.53$). There were no significant correlations between CPUE in weight and numbers respectively in mainstreams and backwaters ($p = 0.074 – 0.927$).

2.3.6 Changes in size distribution

In the Zambezi River and Kavango Rivers there was no correlation between average fish size and year except in the protected area (Kwetze) in the Kavango River where relative fish size increased over the study period ($r = 0.57$, $p = 0.018$).

2.3.7 Within river variation

In the Zambezi River, CPUE did not differ among stations neither in weight (Kruskal-Wallis H test $x^2(2) = 0.37$, $p = 0.065$) nor numbers (Kruskal-Wallis H test $x^2(2) = 3.46$, $p = 0.091$). However, in the Kavango River, CPUE increased in a downstream direction. CPUE in weight at Kwetze (1.29 ± 2.91 S.D. kg/net-night) was higher than at Cuito (0.47 ± 1.05 kg/net-night), Musese (0.19 ± 0.49 kg/net-night) and Rundu (0.15 ± 0.41 kg/net-night) (Kruskal-Wallis H test $x^2(3) = 31.89$, $p = 0.001$). CPUEs in weight did not differ among Musese, Rundu and Cuito Stations (Kruskal-Wallis H test $x^2(2) = 4.31$, $p = 0.073$) (Table 2). CPUE in terms of number was also higher at Kwetze (3.30 ± 4.70 fish/net-night) than at Cuito (2.40 ± 3.81 fish/net-night), Rundu (1.50 ± 2.50 fish/net-night) and Musese (1.17 ± 1.50 fish/net-night) (Kruskal-Wallis H test $x^2(3) = 20.88$, $p = 0.001$). There were no differences in CPUE in terms of numbers between the Cuito, Rundu or Musese stations (Kruskal-Wallis H test $x^2(2) = 3.46$, $p = 0.082$) (Table 2). Weight and length of fish collected at Kwetze, (392 g ± 609 S.D.; 25.2 cm ± 10.9 S.D.) were larger compared with the other three sampled stations (Kruskal-Wallis H test, $x^2(3) = 100.06$, $p = 0.001$; $x^2(3) = 101.63$, $p =$

0.001, respectively) (Table 2.2). The lowest mean weight and length of tigerfish was at Rundu (100 g ± 321; 16.0 cm ± 5.6 S.D.).

Table 2.2: The respective catches in number (*n*), efforts (net-nights) and length and weight parameters (± S.D.), condition factor (*K*) and CPUE for weight and numbers respectively of tigerfish for the various stations in the Kavango River for the period 1997 - 2016.

	Musese	Rundu	Cuito	Kwetze
Total fish *n*	91	135	185	241
Effort (net-night)	78	90	77	74
Mean length L_F (mm)	180 ± 85	160 ± 56	184 ± 90	252 ± 109^{A}
Mode length L_F (mm)	142	151	120	230
Length range L_F (mm)	83 – 573	90 – 585	91 – 605	55 – 630
Total weight M_T (kg)	15.05	13.49	36.14	95.13
Mean weight M_T (g)	165 ± 445	100 ± 321	198 ± 611	392 ± 609^{A}
Mode weight M_T (g)	26.0	26.0	30.0	19.0
Weight range M_T (g)	6.5 – 3150	8.7 – 3414	10.3 – 5146	6.5 – 4493
CPUE (kg/net-night)	0.19 ± 0.49	0.15 ± 0.41	0.47 ± 1.05	1.29 ± 2.91
CPUE (fish/net-night)	1.17 ± 1.50	1.50 ± 2.50	2.40 ± 3.81	3.30 ± 4.70

2.4 Discussion

The tigerfish data obtained from annual gill net surveys from 1997 to 2016 were assessed during this study to test the prediction that there is a declining temporal trend in tigerfish CPUE in the Zambezi and Kavango Rivers. This prediction was rejected as no clear trends in tigerfish CPUE were observed over the study period. Although, this study used a relatively lengthy historical data set of 17 years, CPUE data collected through independent fisheries surveys does not ensure that the most relevant information about fish stocks are obtained. Therefore, the limitations of CPUE data is emphasised and it should not be used in isolation to provide management advice on the effect of fishing. Tigerfish abundance (CPUE) were, however, higher in a protected area in the Kavango River compared with unprotected areas, which may be indicative that areas with low fishing effort have higher yields than areas with higher fishing pressure.

Inland fisheries in Namibia are artisanal and recreational fisheries that predominantly utilize gill and seine nets but, also to some extent use traditional gears and rod and line (Tveldten et al. 1996; Cooke et al. 2016). These fisheries are considered important for food security, livelihoods provisioning and employment (Cooke et al. 2016). In addition, recreational fishing is an important contributor to the local economies as the tourist industry is often the only source of formal employment for local communities (Tweddle et al. 2015; Cooke et al. 2016). The full value of both these fisheries have yet to be quantified because fishing effort and catches are still largely unrecorded, and fisheries dependent catch and effort data were temporally and spatially disjunct (Moore et al. 2007; Tweddle 2010). Data that were available indicate that non-sustainable fishing practices and effort, driven by the increased commercialisation of the fishery, have resulted in a 90% reduction in the CPUE of large cichlid species in the fisheries of the Upper Zambezi (Tweddle et al. 2015). Furthermore, there is evidence that these fisheries are increasingly targeting tigerfish populations using specialised gear such as drifting gillnets and drag nets (Cooke et al. 2016). As tigerfish are important components of all fisheries, the current assessment provides an important baseline for their management of two northern perennial rivers of Namibia.

The reduction in CPUE of larger species is one of the main symptoms of overfishing (Welcomme 1999; Allan et al. 2005). Because of the high inter-annual variation in CPUE within rivers in the period 1997-2016, no clear temporal trend could be detected. As a result, the prediction that tigerfish populations are declining could not be supported by the available data. While this is likely to have been influenced by the low annual sampling effort, it is possible that tigerfish are more resilient to fishing compared to the cichlid species for which depletion has been demonstrated (Tweddle et al. 2015). In comparison to cichlids which are typical equilibrium strategists (Økland et al. 2007), tigerfish appear to follow a periodic life history strategy (Winemiller and Kelso-Winemiller 1994). As they are highly fecund, fast growing and appear to disperse over long distances (Kenmuir 1973; Steyn et al. 1996; Gerber et al. 2009), their populations are likely to respond more slowly to local overfishing than the those of resident cichlids. Furthermore, tigerfish are classified as non-guarding, egg-scattering lithopelagophil (Steyn et al. 1996). Hence, inter-annual recruitment variability is likely to be more highly influenced by environmental conditions such as the magnitude and duration of the flood pulse, and may mask local effects of fishing (Winemiller and Jepsen 1998).

No temporal trends were evident in CPUE in any of the two rivers, however in the Kavango River, the CPUE in the freshwater protected area Mahangu National Park, (the Kwetze sampling station) was higher than at the three unprotected sites (Musese, Rundu and Cuito). Therefore, the present study suggests higher tigerfish abundance and biomass in the FPA. Similar to this study, a no fishing reserve in Lake Kariba (Zimbabwe) was successful in increasing both the number and size of several freshwater fish species (Sanyanga et al. 1995). In Lake Superior and Huron no fishing areas played a large part in the rehabilitation of exploited lake trout *Salvelinus namaycush* (Walbaum 1792) populations (Reid et al. 2001), and in the Mekong River, Champasak Province in southern Laos, there is increasing evidence that protected areas benefit fish stocks, especially sedentary species, but also migratory ones (Sarkar et al. 2008).

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CHAPTER 3

Retention of plastic-tipped dart tags in African tigerfish *Hydrocynus vittatus*

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Short Note

Retention of plastic-tipped dart tags in African tigerfish *Hydrocynus vittatus*

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Estimates of tag retention and tagging-related mortality are essential for mark-recapture experiments. Mortality and tag loss were estimated from 15 tigerfish *Hydrocynus vittatus* marked using Hallmark model PDL plastic-tipped dart tags released into a 1 730 m² pond at Kamutjonga Inland Fisheries Institute, Namibia, and inspected bi-monthly for the presence or absence of tags. No mortality was observed during the experiment. All marked fish had lost their tags after 10 months and 50% tag loss was estimated at 3.9 months. The high tag loss rate indicates that PDL plastic-tipped dart tags are not suitable for long-term studies on this species.

Keywords: capture-mark-recapture, freshwater, tagging, tag retention, Namibia

The African tigerfish *Hydrocynus vittatus*, Castelnau, 1861, is an apex predator in African freshwater ecosystems (Jackson 1961; Marshall 1985) and forms an important component of recreational and artisanal fisheries (Økland et al. 2005; Cooke et al. 2016). As a result, an understanding the biology and ecology of this species is important from ecological and fisheries management perspectives.

Capture-mark-recapture (CMR) methods using external physical tagging are some of the most commonly applied methods in the assessment of movement, growth and population dynamics of fishes (Pine et al. 2003). In southern Africa, CMR studies on African tigerfish have generally been unsuccessful. Gagiano (1997) was unable to recapture any of the >1 000 African tigerfish tagged in the Olifants and Letaba Rivers, South Africa, over two years using T-bar anchor tags. Similarly, Roux (2005) recaptured only one of the 700 individuals tagged with visual implant tags (VI-tags) in the Luvuvhu River, South Africa. In this case, the individual was recaptured two days after its release. Because neither of these studies under took prior tag retention experiments, it is unclear whether their low recapture rates were as a result of tag-loss, mortality or other factors, such as dispersal. To reduce such uncertainty, estimates of the rate of tag loss or tag-related mortality are considered a fundamental requirement for CMR models (e.g. Pine et al. 2003; Booth and Weyl 2008). Consequently, the purpose of the current study was to conduct an experiment to determine tag retention and to document any tagging-associated mortality for African tigerfish.

The study was carried out between March 2016 and May 2017 under semi-natural conditions in an earthen pond at the Kamutjonga Inland Fisheries Institute (KIFI) (18° 9' S, 21°41' E), Namibia. The pond had a surface area of 1 730 m² and a maximum depth of 2 m. The substrate was a mixture of clay and gravel. The pond received water directly from the Kavango River and water levels were controlled by a very high frequency (VHF) level logger that switched on a pump and initiated an inflow of water when the water level fell to a pre-determined level. The mean water temperature was 25.5 ± 4.0 °C, and ranged from a low of 16.6 °C in July 2016 (austral winter) to a high of 35.2 °C in February 2017 (austral summer). Artificial floating structures were deployed for protection against avian predators, such as the African fish eagle *Haliaeetus vocifer*, Daudin, 1800. The pond was stocked with live redbreast tilapia *Coptodon rendalli,* Boulenger, 1896, as a natural food source.

Twenty African tigerfish (mean ± SD: 37.3 ± 7.0 cm FL; 795 ± 529 g) were captured by angling from the Kavango River, Namibia. After capture, fish were immediately placed in a 50-litre water-filled container into which 0.2 ml l^{-1} 2-phenoxy-ethanol had been added to achieve anaesthesia (O'Brien et al. 2012). During the anesthetised state, 15 fish were individually marked with elongated barb dart tags (model type PDL, Hallprint®, Australia) using a commercially available, stainless steel dart tag applicator (Hallprint®, Australia). Each tag was inserted directly beneath the dorsal fin at a 45° angle until the barb anchored securely between the pterygiophores of the fish, as has been done in other studies (Renfro et al. 1995). After tagging and taking standard morphometric measurements, the fish were transported 500 m from the capture site in a 1 000-litre aerated container to the experimental pond and there released. To assess for potential mortality associated with tagging, five control fish were not tagged, but were otherwise treated the same as the tagged fish.

Over the next 10 months, all African tigerfish released into the pond were individually caught bi-monthly (every two months) using a soft seine net and inspected for tag presence.

None of the African tigerfish died over the 10-month experiment. Tag loss, expressed as the cumulative number of fish that had lost their tags after each bi-monthly inspection, was modelled using a two-parameter logistic model of the form:

$$P(L_t) = (1 + e^{-(t - t_{L50} / \delta_L)})^{-1}$$

where $P(L_t)$ is the percentage of fish that had lost (L) their tags at time t, t_{L50} is the time when 50% of individuals had lost their tags and δ_L is the width of the ogive (Figure 1). All tagged fish had lost their individual tags by the end of this period and 50% tag loss (t_{L50}) was estimated at 3.94 months and δ_L was 1.13.

The results of the current study were within the bounds of those of other studies of tag loss in various freshwater fishes. High tag loss was reported in freshwater channel catfish *Ictalurus punctatus* Rafinesque, 1818, which shed 90% of Floy FD-67 tags after 12 weeks (Greenland and Bryan 1974). Koshinsky (1972) demonstrated that, in freshwater pike *Esox lucius* Linnaeus, 1758, plastic-tipped dart tag retention was 13% and mortality 12% over a two-year study. In a growth zone validation experiment conducted at KIFI, Peel et al. (2016) found that 77% of 22 T-bar tagged *Oreochromis andersonii* Castelnau, 1861, but only 25% of 16 tagged *Coptodon rendalli*, retained their tags for between 11 and 14 months in an earthen pond. Booth and Weyl (2008) conducted a double tagging experiment in Glen Melville Reservoir, South Africa, on African sharptooth catfish *Clarias gariepinus* Burchell, 1822 to demonstrate that plastic-tipped dart tags had a 100% initial retention and 2% tag loss per annum over a study period of four years (Booth and Weyl 2008).

While the mechanism of the relatively high tag loss rate in African tigerfish could not be determined during the current experiment, in other species high rates of tag loss have been attributed to tag placement (Keller 1971; Dunning et al. 1987), tag anchor type (Greenland and Bryan 1974; Crossland 1976) and aggressive behaviour from other fish (McAllister et al. 1992).

Keller (1971), for example, reported that an improper attachment position of Floy tags in brook trout *Salvelinus fontinalis* Mitchill, 1814 resulted in tag loss of up to 88%. McAllister et al. (1992) observed rainbow trout *Oncorhynchus mykiss* Walbaum, 1792, attacking external tags on these tagged fish, and even retrieved 52 Carlin tags from the stomach of a rainbow trout. Lister and Harvey (1969) reported tag loss resulting from Pacific salmon *O. tshawytscha* Walbaum, 1792 striking at tags. Armstrong and Blackett (1966) reported cutthroat trout *O. clarkia* Richardson, 1836, chasing tagged Dolly Varden *Salvelinus malma* Walbaum, 1792, and concluded that the yellow tubing of the tag acted as an attractant.

In the current study, three of the 15 plastic-tipped dart tags that were lost were recovered in the experimental pond. Although these tags were otherwise intact, external scratching was apparent, suggesting that biting by other fishes may have been a mechanism for dislodging the barb from between the pterygiophores, eventually causing shedding to occur.

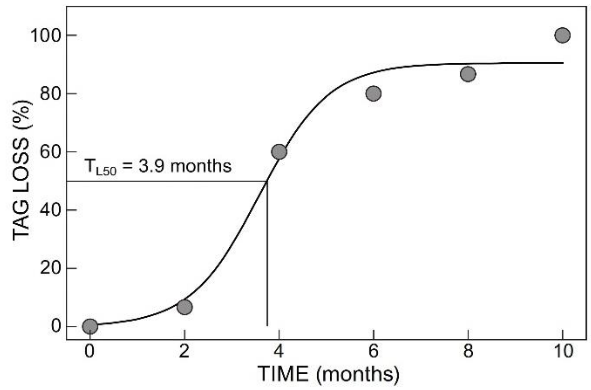

Figure 1: Logistic ogive fitted to the proportion (%) of tag loss in *Hydrocynus vittatus* from an experimental pond at Kamutjonga Inland Fisheries Institute, Namibia. Tag loss-at-50% at time (months) = T_{L50}

Because the observed high rates of tag loss are likely to be responsible for the low recapture rates in previous studies of African tigerfish (e.g. Gagiano 1997; Roux 2005) the use of plastic-tipped dart tags cannot be recommended for long-term assessments (e.g. movement) relying on the capture-mark-recapture of individuals, but might be useful for short-term experiments (e.g. population estimates). Because CMR studies are an important component of ecological and fisheries research, further research is recommended to determine the mechanism causing the high rates of tag loss associated with plastic-tipped dart tags, and to assess whether alternative anchor methods (e.g. lock-on spaghetti, Carlin, Monel strap or passive integrated transponder (PIT) tags) might be useful alternatives.

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CHAPTER 4

Immediate and long-term behavioural consequences of radio-tagging African tigerfish *Hydrocynus vittatus*

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4.1 Abstract

Biotelemetry is an effective tool to study fish movements. Few studies have examined the effects of external radio transmitters which is important, as a major assumption is that fish behaviour is not affected by the presence of radio tags. The aims of this study were to document immediate and long-term movement consequences of radio tagging tigerfish *Hydrocynus vittatus*. The study was performed in the Kavango River, Namibia, from June to October 2016. To study the immediate behavioural effects of tagging, 49 tigerfish with mean (± SD) length 549 ± 55.4 mm FL were tagged with external radio transmitters and monitored for three consecutive days post-release. Thereafter, to identify long-term effects, 19 of these tigerfish were again monitored for seven consecutive days during the same time-period, 25 to 47 days after being radio-tagged. Immediately after tagging, the tigerfish exhibited more downstream (57-62%) than upstream movements (32–36%). There was no significant difference in their mean (± SD) distance of downstream movements (2303 ± 2786 m) compared with upstream movements (1277 ± 1796 m). The total immediate distance moved was negatively correlated with water temperature and positively correlated with fish size. To compare immediate and long-term effects the movements of the 19 individuals were analysed separately. These tigerfish also had more downstream than upstream movements, with 58% of detections being downstream, 37% upstream and 5% with no change, a similar behaviour to all tigerfish monitored initially. After approximately three to six weeks the tigerfish had similar numbers of up- and downstream movements, being 38% downstream, 44% upstream, and 18% stationary. Mean downstream (488 ± 766 m) and upstream (905 ± 2365 m) distances travelled during the long term experiment were significantly shorter than immediately after release. This difference in movements of tagged tigerfish between the two tracking periods suggests that radio tagging and/or the associated handling have an immediate effect on tigerfish

behaviour. Hence, we conclude that research using external radio tagging needs to take into consideration that behaviour immediately after tagging might be influenced by the handling and tagging of the fish.

Keywords: behaviour, tigerfish, tagged, radio telemetry, with-in river movements, Kavango River

4.2 Introduction

Biotelemetry is an important tool for studies of fish ecology and behaviour (Bridger and Booth 2003; Koehn 2009; Thorstad et al. 2013). Radio telemetry can provide valuable information on freshwater fish movement patterns (Koehn et al. 2009), migrations (McMichael et al. 2010), habitat use (Økland et al. 2005), and mortality rates (Pine et al. 2003), and, hence, is an important method to improve the knowledgebase for management. The most critical assumptions telemetry studies are based on, are that catch, handling and tagging procedures have minimal effects on mortality, physiological stress or long-term behavioural alterations in the study period post-release (Thorstad et al. 2013). The alteration in behaviour as a result of radio transmitters presence have been investigated using swimming performance (Jones et al. 1974; Mellas and Haynes 1985), feeding behaviour (Baras et al. 2002), survival (Paukert et al. 2001; Huchzermeyer et al. 2013) and tag retention (Pine et al. 2003). Most of these studies have focused on surgical and gastric implantation, while fewer have focused on the effects from external radio tagging (Jepsen et al. 2015).

Hence, the importance of recognising the effects that external tagging may have on fish species are often overlooked by researchers (Thorstad et al. 2013), despite that knowing the effect of the tagging process and the tag itself will improve the confidence in the results of the study

(Ross and McCormick 1981). For example, Peake et al. (1997) detected a difference in swimming speed between tagged and untagged wild Atlantic salmon (*Salmo salar)* smolts using external tags, but found no difference in hatchery fish. In a similar experiment McCleave and Stred (1975) found reduced critical swimming speed of externally tagged smolts compared to untagged controls. Havn et al. (2015) and Mäkinen et al. (2000) studied the movement of *S. salar* after radio tagging and reported preference for downward movement, presumably associated with stress induced from catch, radio tagging and release.

Although laboratory experiments are probably the most accurate method to identify tagging effects, it often does not take into account factors in the wild as snagging, fouling, natural movement, increased predation risks or other environmental variables which may alter fish behaviour (Ross and McCormick 1981; Thorstad et al. 2013). Therefore, in the absence of an observed recovery period, it is important to know the expected duration of recovery to ensure collected data are indicative of natural behaviour of the fish (Bridger and Booth 2003).

In general, evaluations of the effects of the attachment of the tag only are complicated by other associated potential stress factors such as capture, handling, tagging, holding, and reviving concurred during the tagging process (Jepsen et al. 2015). Thus, in *in situ* studies one may observe a combination of different effects associated with tagging which can be species specific, and collecting this information is therefore considered important in radio telemetry studies (Bridger and Booth 2003; Jepsen et al. 2015).

The African tigerfish *Hydrocynus vittatus* (Castelnau 1861) is endemic to the African continent where it is one of the most sought-after recreational angling species (Murray and Stewart 2002; Goodier et al. 2011; Cooke et al. 2016). In addition, this species has important subsistence and commercial value and have an important part in the local economy where they naturally occur

(Økland et al. 2005; Cooke et al. 2016). Tigerfish also play an integrate part in maintaining river ecosystems, for example by preying on fish in inundated floodplains, and in that way transferring energy from floodplains to main river (Winemiller and Jepsen 1998).

Increased fishing pressure on this and other large species have resulted in an increasing need for their conservation and management (Tweddle et al., 2015; Cooke et al., 2016). Information on their behaviour could contribute towards developing more effective conservation and management strategies (Økland et al. 2005; Cooke et al. 2016). The behaviour of tigerfish has previously been investigated in southern Africa using external radio tags, but, none studied the possible behavioural alterations, immediate after tagging and in the long-term, from tagging this species (Økland et al. 2005; O'Brien et al. 2012; Roux 2014). Therefore, species specific information is needed on the possible effects tagging with radio transmitter may have on the behaviour of tigerfish (Cooke and Schramm 2007; Arlinghaus et al. 2009). Our study aimed to identify possible behavioural alterations of African tigerfish caused by external tagging and the associated handling procedures. We hypothesised that external radio tagging would have an immediate effect on the post-release behaviour of tigerfish. To study this, 49 tigerfish were tagged using external radio transmitters in the Kavango River, Namibia and their movements monitored for three consecutive days post-release to determine immediate effects. Nineteen of these fish where again monitored 25 to 47 days after tagging to facilitate a comparison between post-release and long-term behaviour following tagging.

4.3 Materials and methods

4.3.1 Study area

For full catchment description of the Kavango River please refer to Chapter 2 of this thesis. Radio tagging and tracking was conducted within the Mahango and Buffalo Core Areas of Bwabwata National Park (18°11’36″S 21°45 07″E, Fig. 4.1). The Mahangu Core area is situated on the western bank of the river and extends for 15 km whereas the Buffalo core area, extends for 22 km on the eastern bank (Taylor et al. 2017). The river’s width, ranges between 100 - 200 m and had a maximum depth of 7 m during the study. The water in the mainstream is clear but, there are numerous backwaters and seasonal floodplains that contain stagnant muddy water.

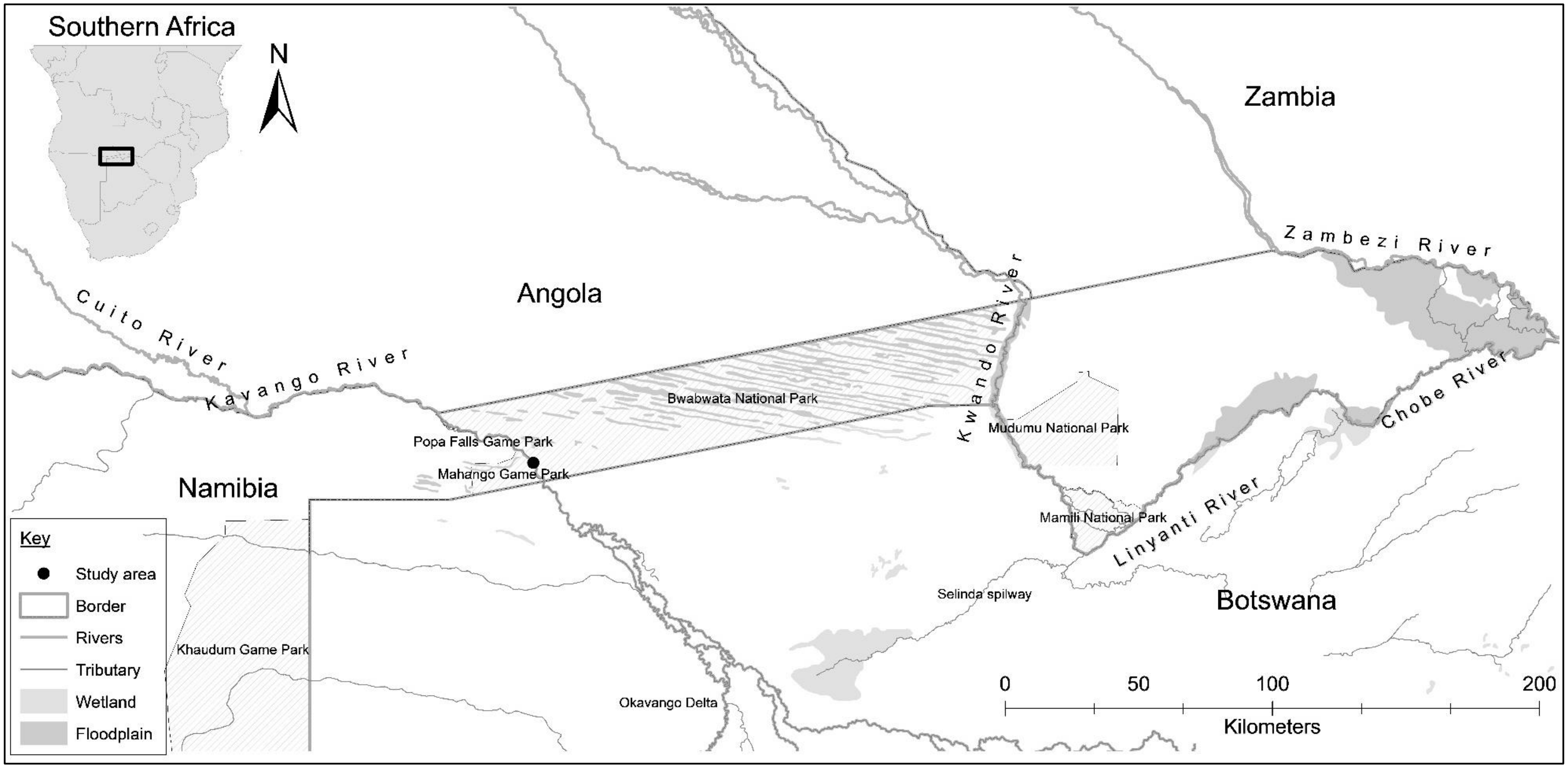

Figure 4.1: The radio tagging experiment of *Hydrocynus vittatus* was conducted in the Mahango Game Park in the Kavango River, Namibia.

4.3.2 Catch, tagging and handling

To study the immediate- and long-term consequences of radio tagging, 49 tigerfish were caught by angling from a boat using lures with single hooks (size 2/0 – 4/0), then immediately tagged and released between 21 June and 22 October 2016 (Table 4.1). Times from strike to landing (i.e. fight time) and time until release (i.e. handling time) were recorded using a stopwatch. After landing, fish were placed in a water filled container into which 2-phenoxy-ethanol, 0.3 ml/l, had been added as anaesthesia (O'Brien et al. 2012). Water replacement was started slowly after the anaesthetized state was reached. Radio transmitters, 16 g in the air and 55 x 20 x 11 mm (Model F2120 Advanced Telemetry Systems, Inc., Isanti, MN, USA), were externally attached according to the method described by Økland et al. (2005). Stainless steel hypodermic needles were inserted through the musculature two cm below the dorsal fin (Fig. 4.2a). The needles were spaced according to the width of the tag. Orthopaedic wires (0.65 mm diameter) were threaded through needles and used to firmly secure the tag by twisting and locking the ends of the wire against a plastic back-plate (Fig. 4.2b-d). After tagging, fork length (FL, nearest mm) and total body mass (g) were recorded for each individual. Weights of external transmitters never exceeded 1.5% of the fish weight. All fish were released at their capture site.

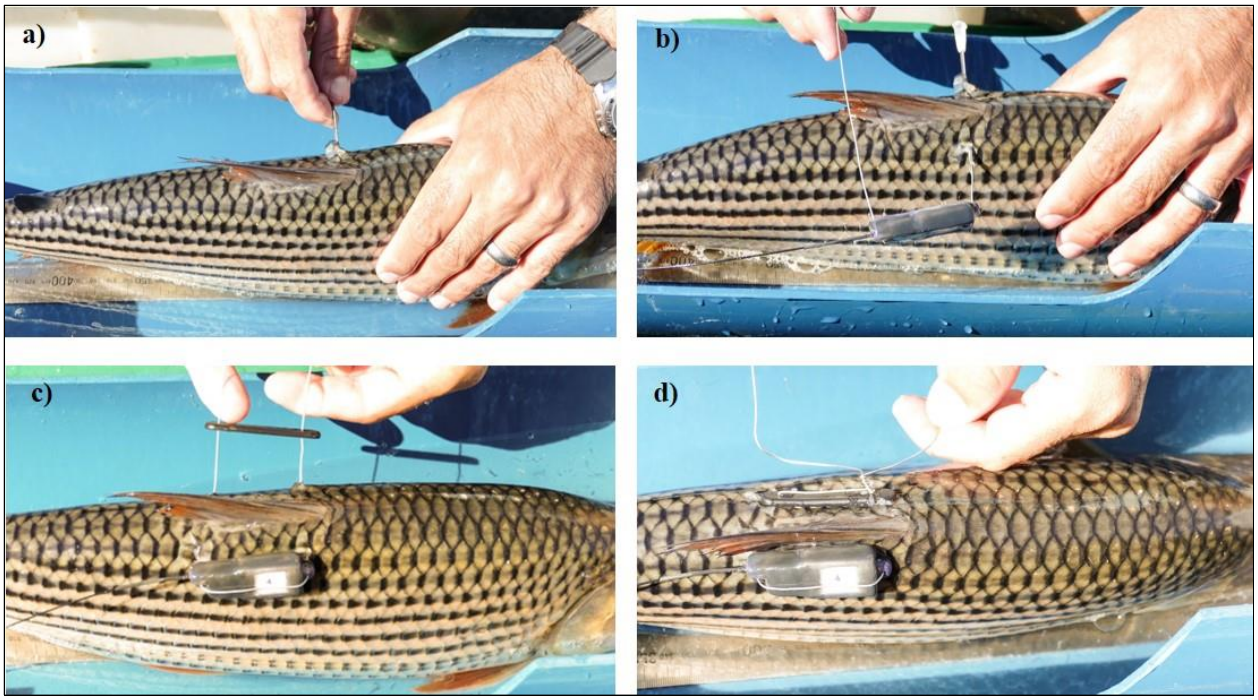

Figure 4.2: Stainless steel hypodermic needles were inserted through the musculature two cm below the dorsal fin (a), thereafter orthopaedic wires were threaded through needles (b) and used to firmly secure the tag by twisting and locking the ends of the wire against a plastic back-plate (c-d).

Table 4.1: Information on the 47 tigerfish tagged from June to October in 2016 and included in the study in the Kavango River, Namibia; including tag number, tagging date, fork length (mm), body mass (g), water temperature °C and water discharge at tagging and number of positional fixes during the three-days monitoring period immediately after tagging (3-days), and during seven-days tracking started 25 to 47 days (7-days) after tagging.

No.	Tagging date	Length (mm)	Body mass (g)	Water temperature °C	Water discharge m^3/s	3-days	7-days
1	21/06	535	2450	17.9	306	3	0
2	21/06	594	3240	17.9	306	3	7
3	23/06	535	2240	17.1	306	3	7
4	23/06	590	3540	17.7	306	3	7
5	25/06	558	3270	16.5	306	3	7
6	23/06	549	3210	18.2	306	3	7
7	25/06	490	1950	17.1	306	3	7
8	25/06	760	6011	17.5	306	3	7
9	28/06	603	4220	17.7	306	3	7
10	28/06	570	3320	17.7	306	3	7
11	17/07	525	2400	16.7	236	3	7

12	16/07	590	3080	16.6	236	3	7
13	17/07	510	2800	16.5	236	3	7
14	17/07	530	2300	16.7	236	3	7
15	19/07	490	2300	16.1	236	3	0
16	19/07	610	4008	16.1	236	3	0
17	19/07	483	1980	16.1	236	3	7
18	19/07	485	1890	17	236	3	0
19	19/07	485	1800	17	236	3	7
20	26/07	575	2990	16.1	236	3	7
21	26/07	550	2940	17.4	236	3	7
22	27/07	545	2550	17	236	3	7
23	27/07	510	2420	17	194	3	7
24	27/07	505	2300	17.4	194	3	N/A
25	28/08	580	3009	20.5	162	3	N/A
26	28/08	615	4200	20.5	162	3	N/A
27	02/09	485	2200	21	236	3	N/A
28	10/09	550	2630	21.5	162	3	N/A
29	10/09	615	4640	21.5	162	3	N/A
30	28/09	480	1900	23.9	162	3	N/A
31	28/09	588	3530	23.9	162	3	N/A
32	28/09	495	2200	23.9	162	3	N/A
33	28/09	568	3260	23.9	236	3	N/A
34	19/10	580	2390	24.3	133	3	N/A
35	19/10	570	3130	25.6	133	3	N/A
36	19/10	573	3250	25.9	133	3	N/A
37	19/10	490	1900	26	133	3	N/A
38	20/10	523	1800	25.9	133	3	N/A
39	20/10	505	1840	26.2	133	3	N/A
40	21/10	568	3800	25.8	133	3	N/A
41	21/10	589	3390	25.6	133	3	N/A
42	21/10	615	3860	26.4	133	3	N/A
43	22/10	505	2240	24.2	133	3	N/A
44	22/10	487	1950	24.2	133	3	N/A
45	22/10	500	1500	24.7	133	3	N/A
46	22/10	530	2720	25.6	133	3	N/A
47	22/10	655	3900	26.5	133	3	N/A

4.3.3 Tracking

The tigerfish were tracked from a boat using a portable receiver (Model R2100 Advanced Telemetry Systems, Inc., Isanti, MN, USA) connected to a 4-element Yagi antenna. Tagged tigerfish were located using signal strength triangulation with a precision of ± 10 m, hence movements less than 10 m were classified as stationary. Immediate effects were determined by tracking and positioning the 47 tagged tigerfish for three consecutive days immediately after release in the tagging period from 21 June to 22 October. To assess whether movement behaviour immediately after release differed from longer-term behaviour, 19 of the original sample of tigerfish were tracked for seven consecutive days from 22 to 28 August 2016 and their movement patterns were compared with those immediately after release. Each daily tracking survey covered the same 33 km stretch of the river from Popa Falls Game Park (18°07' S 21°35'E) to the lower end of Mahangu Game Park (18°15' S 21°47'E) (Figure 4.1).

4.3.4 Water temperature and discharge

Water temperatures were recorded using a HOBO Pro v2 data logger (Onset, Bourne), programmed to log temperature at 1 h intervals between 21 June 2016 and 23 October 2016. The daily water discharge data were recorded by the University of Botswana and the Okavango Research Institute, Botswana at the Mohembo hydrological measuring station.

4.3.5 Data analyses

Distance of movements for each individual during tracking periods were calculated using the 'locate features along routes' tool in ArcMap 10.5 (Geographic Information Systems, Environmental Systems Research Institute, Inc., Redlands, CA, USA). The Pearson's product-moment correlation coefficient was computed to assess the relationship between water temperature and water discharge. Water temperature and water discharge levels changed over the tagging period, and the non-parametric Mann-Whitney U test (SPSS 20) was used to calculate difference in movements among tigerfish tagged during 21 June to 27 July and 28 August to 22 October 2016. A multiple linear regression model with power transformed response variable (Tukey's ladder of powers, $\lambda = 0.2$; trans = x^λ) was used to test the effect of the duration of fight time and handling time, fork length, and water temperature at time of tagging on total distance moved for individual fish during the three-day tracking period. A maximal model without interactions was fitted and simplified by backwards stepwise deletion of non-significant parameters until a minimal adequate model was found. Non-parametric Chi-Square test and Kruskal-Wallis H test (SPSS 20) were used to estimate any differences between up and down movements during the initial three-day tracking period.

To test if there were a difference in movement pattern due to the difference in time between tagging and tracking within the 7 day-tracking period, the fish were divided into two groups. Group 1 was tagged from 21 June to 28 June and group 2 was tagged from 17 July to 27 July 2016. Movement data was log-transformed to meet the assumptions of normality (Shapiro-Wilk *W* test). The variance (F-test), mean (Welch t-test) and distribution (Kolmogorov-Smirnov) of the movements between the two groups were tested.

Non-parametric Chi-Square test and Kruskal-Wallis H test (SPSS 20) were used to estimate any differences between up and down movements during the initial three-day and seven-day-tracking period. Thereafter the non-parametric Mann-Whitney U test (SPSS 20) was used to calculate difference in movements between the two tracking periods.

4.4 Results

4.4.1 Water temperature and discharge

During radio tagging the mean (± SD) water temperature 20.6 ± 3.9 °C (median 18.2 °C, min 16.1 °C, max 26.5 °C) and mean water discharge was 207.4 ± 66.1 m^3/s (median 236.0 m^3/s, min 133.0 m^3/s, max 306.1 m^3/s). During the three-day study period the mean (± SD) water temperature was 21.1 ± 3.2 °C (median 20.5 °C, min 16.2 °C, max 27.9 °C) and mean water discharge was 166.2 ±

36.7 m^3/s (median 169.7 m^3/s, min 82.2 m^3/s, max 248.4 cm^3/s). The water temperature during the 19 three-day and seven-day periods in the long-term effect study was 16.8 ± 0.6 °C (median 18.0 °C, min 16.2 °C, max 19.8 °C) and 21.1 ± 0.7 °C (median 21.1 °C, min 19.7 °C, max 22.8 °C), respectively. In the same periods, the water discharge were 204.6 ± 25.2 m^3/s (median 196 m^3/s, min 168 m^3/s, max 248 m^3/s) and 165.2 ± 3.0 m^3/s (median 163 m^3/s, min 160 m^3/s, max 172 m^3/s). Water temperature increased as water discharge decreased and were strongly correlated during the study period ($p < 0.001$, $R = 0.894$). Water temperature was selected as the most important variable as measurements could be taken at the exact place of tagging and it has been shown to effect tigerfish movement.

4.4.2 Morphological data and catching

Two of the 49 tigerfish were not recorded at all in the three days immediately after release. One of these was eaten by a Nile crocodile, while the other disappeared for an unknown reason. The sample of tigerfish therefore comprised of 47 individuals with a mean (± SD) length of 549 ± 55.4 mm FL (median 549 mm, min. 480 mm, max. 760 mm) and mean body mass of 2860 ± 900 g (median 2720 g, min. 1500 g, max. 6011 g). It was assumed that the tigerfish used in this study were adults as males mature at 300-400 mm FL or two years of age and most breeding females mature at lengths exceeding 400 mm FL or approximately four years of age.

The mean (± SD) total fight time was 01:45 ± 01:01 min and the mean total handling time (including fight time) was 09:08 ± 02:21 min (median 09:07 min, min. 06:01 min, max. 14:42 min). The 19 tigerfish monitored in the initial and subsequent periods measured 555 ± 61 mm FL (median 549 mm, min. 483 mm, max. 760 mm) and had a mean body mass of 2961 ± 941 g (median 2940 g, min. 1800 g, max. 6011 g).

4.4.3 Immediate effects

Tigerfish tagged between 21 June and 27 July 2016 (n = 24) had longer movements (mean (± SD) 1930 ± 2557 m) compared with those tagged between 28 August and 22 October 2016 (n = 23, mean (± SD) 640 m ± 1277) (Mann-Whitney U = 118, $p = 0.001$). The total distance moved by tigerfish during the initial three-day tracking decreased with increasing water temperature at tagging and increased with increasing fork length (ANOVA, $F_{(2, 44)} = 9.139$, $p < 0.001$, $R^2 = 0.294$). Neither fight time (ANOVA, $F_{(4, 42)} = 4.58$, $p = 0.511$, $R^2 = 0.304$) nor handling time (ANOVA, $F_{(4, 42)} = 4.58$, $p = 0.764$, $R^2 = 0.304$) had effects on the total distance moved by tigerfish during the initial three-day tracking. Each day during the three-day period after tagging, the tigerfish had significantly more downstream movements (57-62 %) than upstream movements (32-36 %) (Chi square test $\chi^2(2) = 61.574$, $p < 0.001$, Table 4.2). Altogether, during the three-day period 59.6 % (n = 141) of the movements were downstream, 34.8% were upstream, and 5.7% were classified as stationary. The mean (± SD) total distances moved downstream 2303 ± 2786 m (median 968 m, min. 28 m, max. 8783 m) and upstream 1277 ± 1796 m (median 450 m, min. 12 m, max. 7916 m) during the first three-day after tagging were not different (Mann-Whitney U = 1971, $p = 0.685$), and varied between individuals.

Table 4.2: Movement directions of *Hydrocynus vittatus* monitored one to three-days after tagging. Fish that moved < 10 m were classified as stationary.

	Number downstream	Number upstream	Number stationary
Day 1	28 (59.6 %)	17 (36.2 %)	2 (4.2 %)
Day 2	27 (57.4 %)	17 (36.1 %)	3 (6.4 %)
Day 3	29 (61.7 %)	15 (31.9 %)	3 (6.4 %)

The length of the downstream movements of radio tagged tigerfish the first and second day after tagging did not differ significantly (Kruskal-Wallis H test, $X^2_{(1)} = 0.238$, $p = 0.625$), but they were both longer compared with the downstream movements the third day (Kruskal-Wallis H test, $X^2_{(1)} = 9.102$, $p = 0.003$; $X^2_{(1)} = 5.732$, $p = 0.017$, respectively, Figure 4.3). In day one the downstream movements were on average 2534 ± 3338 m (n = 28, median 660 m, min. 19 m, max. 10106 m), on day two 1398 ± 1663 m (n = 27, median 741 m, min. 25 m, max. 3740 m), and on day three 937 ± 1810 m (n = 29, median 69 m, min. 13 m, max. 7139 m, Figure 4.3). However, the length of the upstream movements of radio tagged tigerfish did not differ among the three days monitored after tagging (Kruskal-Wallis H test, $X^2_{(2)} = 1.341$, p = 0.511). On day one the upstream movements were on average 1215 ± 1931 m (n = 17, median 467, min. 44, max. 7917 m), on day two 831± 1056 m (n = 17, median 326, min. 18, max. 3265 m), and on day three 829 ± 1323 m (n = 15, median 301, min. 12, max. 4955 m, Figure 4.4).

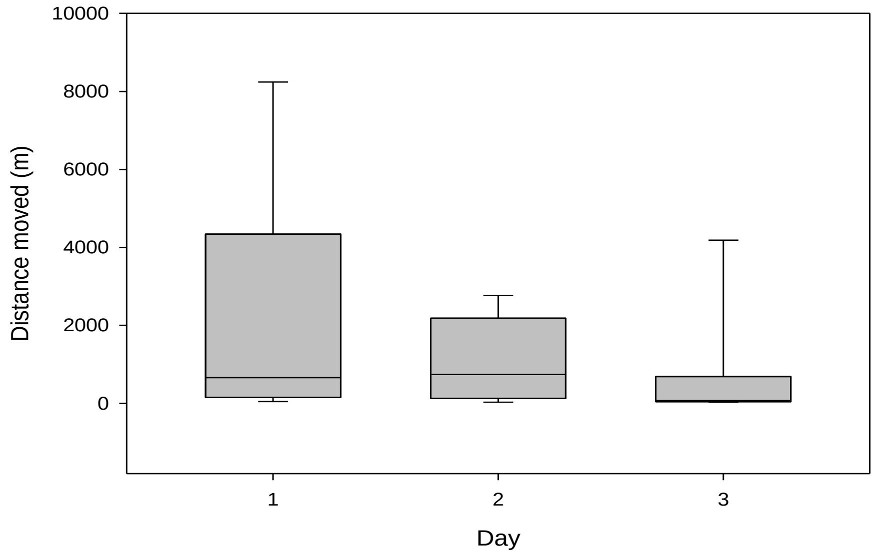

Figure 4.3: Length of the downstream movements of tigerfish during the first three-days after the tigerfish had been tagged in the Kavango River, 2016. (Boxes represent the median and upper and lower quartiles and whiskers represent the minimum and maximum and the variability of the movements).

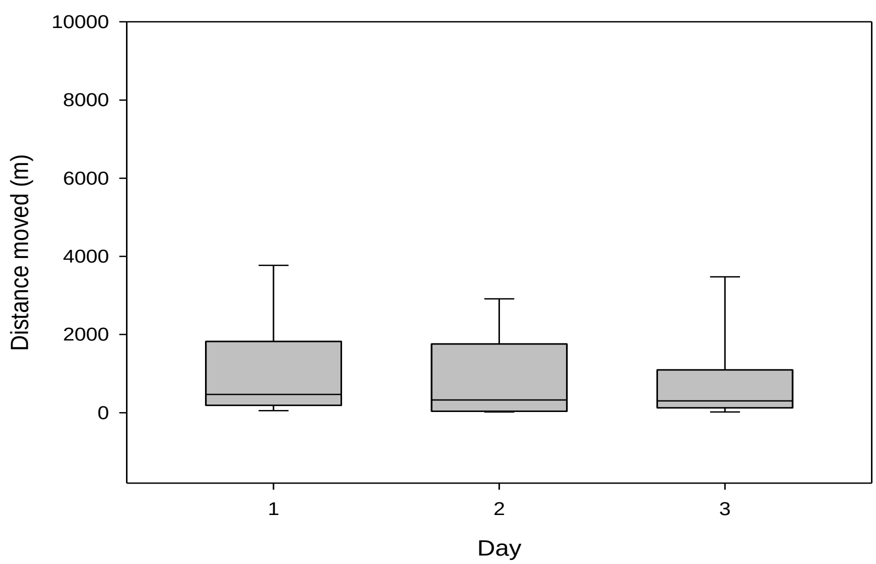

Figure 4.4: Length of the upstream movements of tigerfish during the first three days after the tigerfish had been tagged in the Kavango River, 2016. (Boxes represent the median and upper and lower quartiles and whiskers represent the minimum and maximum and the variability of the movements).

4.4.4 Long-term effects

For the sample of 19 fish monitored, there was no significant difference in distances moved during the seven-day period between tigerfish tagged between 21 and 28 June (n = 9) and 17 and 27 July (n = 10) (ANOVA $F_{(1,17)} = 0.033$, $p = 0.858$).

Similar to the movements of all tagged tigerfish pooled during the immediate three-day period, the 19 tigerfish had more frequent downstream than upstream movements (Chi square test $\chi^2_{(2)} = 26.0$, $p < 0.001$). Out of the 57 movements 58% (n = 33) were downstream movements, 37% (n = 21) were upstream movements and 5% (n = 3) were stationary. However, during the seven-day monitoring, they had similar numbers of up- and downstream movements (Chi square test $\chi^2_{(1)} = 2.2$, $p = 0.138$). Out of the 114 movements 38 % (n = 43) were downstream, 44% (n = 50) were upstream, and 18% (n = 21) were stationary.

The mean distance of both the downstream and upstream movements was significantly further during the first three-day monitoring period than during the later seven days of monitoring (Mann-Whitney U = 438, $p = 0.004$, and U = 348, $p = 0.026$, respectively). Downstream movements during the three-day monitoring (n = 33) were on average 2303 ± 2786 m (median 966 m, min. 28 m, max. 8782 m), while during the seven-day monitoring movements (n = 43) were on average 488 ± 766 m (median 200 m, min. 12 m, max. 4299m) (Figure 4.5). During the three-day period the upstream movements were on average 1276 ± 1795 m (n = 21, median 439 m, min. 12 m, max. 7916 m), while during the 7-days period the upstream movements were on average 905 ± 2365 m (n = 50, median 251 m, min. 13 m, max. 15126 m, Figure 4.6).

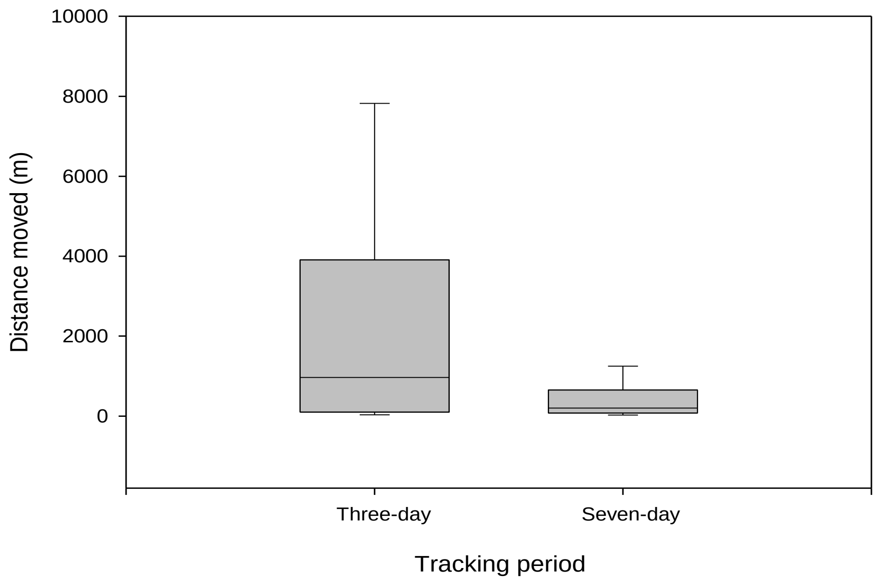

Figure 4.5: Length of the downstream movements of tigerfish during the first three-days after the tigerfish had been tagged and following the second tracking period (seven-days) in the Kavango River, 2016. (Boxes represent the median and upper and lower quartiles and whiskers represent the minimum and maximum and the variability of the movements).

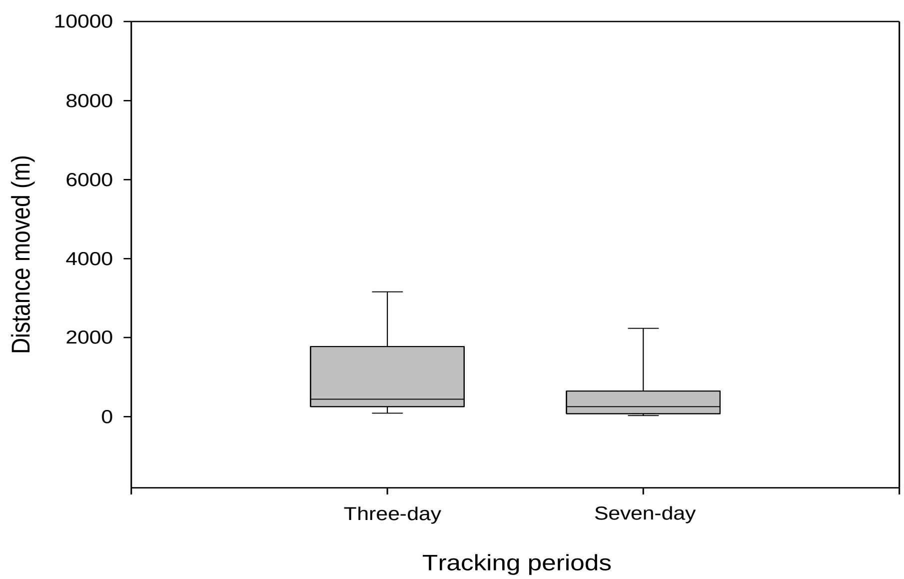

Figure 4.6: Length of the upstream movements of tigerfish during the first three-days after the tigerfish had been tagged and the second tracking period (seven-days) in the Kavango River, 2016. (Boxes represent the median and upper and lower quartiles and whiskers represent the minimum and maximum and the variability of the movements).

4.5 Discussion

4.5.1 Immediate effects

This study found that there was an immediate behavioural effect of radio tagging tigerfish. During the initial three-day monitoring period tigerfish exhibited more frequent and longer downstream movements the first two days after which individuals seemed to move shorter distances. Increased downstream movements immediate after radio tagging have been reported for other freshwater fishes. Havn et al. (2015) observed downstream movements for 72% of *S. salar* during the first four days after being captured and externally radio tagged, presumably associated with stress induced from catch, radio tagging and release. Immediate behavioural responses to tagging was also noted by Mäkinen et al. (2000) for *S. salar* where fish had extensive downstream movements after being caught and radio tagged. Bernard et al. (1999) also found changes in the movement behaviour as 51% of upstream migrant Chinook salmon *Oncorhynchus tshawytscha* moved downstream after being caught, tagged and released, and only resumed upstream migration after 4-5 days presumably as a result from handling and tagging stressors. Bernard et al. (1999) further reported that handling and tagging *O. tshawytscha* resulted in unusual downstream movements compared to split-beam monitored untagged *O. tshawytscha*. While Sundström and Gruber (2002) observed different responses to tagging as juvenile lemon sharks *Negaprion brevirostris* had elevated swimming speed during the first 24 h after being tagged with large, speed sensing tags. Thorstad et al. (2004) documented excessive movements of large cichlids in the Zambezi River, immediately post release which was attributed to a behavioural reaction to induced stress from catch and radio tagging. Smit et al. (2009) suggested that longer angling time increased physiological stress in tigerfish, as significant higher blood lactate concentrations were documented following rod-and-line angling and compared to a control group.

However, no noticeable effects on fish behaviour after radio tagging have also been documented as Thorstad et al. (2000) reported no difference in the swimming performance of adult *S. salar* between fish fitted with external transmitters and untagged controls. While Gray and Haynes (1979) showed that there were no differences in the movements of external radio tagged and gastric implanted tags on *O. tshawytscha* in the Columbia River.

More downstream movements compared with upstream movements observed during the initial three-day period, could have been an immediate effect, related to a combination of stressors from catch, handling and tagging tigerfish. Stress resulting from the tagging procedures may have caused physiological effects that influenced their swimming performance especially during the first two days post-tagging. Significantly lower swimming speed has been observed for externally tagged *S. salar* smolts (Counihan and Frost 1999), rainbow trout *Oncorhynchus mykiss* (Mellas and Haynes 1985) and juvenile white sturgeon *Acipenser transmontanus* (McCleave and Stred 1975) during swimming performance experiments. The decrease in swimming performance was related to an increase in drag resulting from external radio transmitters. Tigerfish may have experienced similar effects from radio tags which may be a reason why movement preference was with the current compared to swimming against the current. The immediate treatment effects are most pronounced during the first two days post release after which tigerfish movements decreased significantly, which could indicate partial recovery or tigerfish may have become accustomed to the extra ballast afforded by the external radio tag.

It is inherently difficult to identify tag effects in the field as untagged fish cannot be tracked and consequently movements of untagged fish are difficult to compare (Frank et al. 2009). The most crucial limitations in linking downstream movements to tagging effects, is the knowledge of downstream and upstream movements pre-tagging. To improve data collection on directional movement after tagging, researchers could increase the number of tagged fish and the frequency and duration of monitoring period. These recommendations is not always feasible due to the associated costs involved with telemetry studies and should be considered as a limitation. Nevertheless, identification of downstream movements as an effect of tagging is important as consequences may include increased likelihood of injury or death, migratory delay, re-exposure to a fisheries and energy expenditure to re-gain lost ground (Frank et al. 2009).

Interestingly, the total distance moved by tigerfish were longer during colder water (16.8 ± 0.6 °C) temperatures compared with movements during the warmer water temperatures (21.1 ± 0.7 °C). However, there were no difference in the total distances moved up- or downstream during the initial three-day period, as the individual variation were large. Freshwater fishes are poikilothermic, and generally tend to move less in winter when their metabolisms slow down (Bramblett and White 2001). Roux (2014) reported that tigerfish move significantly less during colder (< 24.0°C) than during warmer water temperatures (> 25.0°C) in the Olifants River, South Africa. Reduced movement during colder water temperatures have also been reported for externally radio tagged smallmouth yellowfish *Labeobarbus aeneus* in the Vaal River, South Africa (O'Brien et al. 2013). Our study, reported longer movements during colder water temperatures which is in contrast to previous behavioural studies (O'Brien et al. 2012; Roux 2014). This may suggest that tigerfish experienced relatively higher induced stress from the tagging process during colder water temperatures. Water temperature has repeatedly been identified as a significant contributor to stress and mortality in ecothermic aquatic organisms as it may affect the physiological response of exhaustion (Muoneke and Childress 1994; Thorstad et al. 2003).

4.5.2 Long-term effects

For the 19 fish that were monitored immediately after tagging and after 25 to 47 days after they were tagged, the distances of both the downstream and upstream movements were greater during the immediate three-day monitoring period compared with the later seven-day period.

Økland et al. (2005) conducted a behavioural study on tigerfish in the Zambezi River using external radio tags and concluded that tigerfish are well suited for long term radio telemetry studies. Økland et al. (2005) reported mean tigerfish movements of 1447 ± 2289 m SD with, individual means ranging from 17 to 7210 m for tigerfish tracked on average every 4.1 days. This study reported mean downstream movements of 488 ± 766 m and upstream movements of 905 ± 2365 m which are relatively similar to findings by Økland et al. (2005). Interestingly, Økland et al. (2005) found that tigerfish movements longer than 1000 m were 42 % downstream and 58 % upstream. These findings are very similar to the current study, as out of the 114 recorded movements 25-47 days after tagging, 38 % were downstream, 44 % were upstream, and 18 % were stationary. Økland et al. (2005) further showed that 50 % of the monitored tigerfish had consistent site fidelity or residency periods. Stationary movements recorded during this study may have also documented these residency periods and further support that tagging effects are minimal 25 - 47 days after tagging.O'Brien et al. (2012) recorded relatively small home ranges (<750 m) for 58 % of the externally radio tagged tigerfish after they were translocated from Schroda man-made lake into a reservoir in Botswana (Letsibogo man-made lake) within the same catchment. Similarly, Baras et al. 2002 also recorded relatively small home ranges (<3 ha) and *H. brevis* showed consistent site fidelity in the Niger River. The tigerfish movement recorded 25-47 days after tagging are therefore well within the limits of other behavioural studies on tigerfish.

Havn et al. (2015), found that *S. salar* that moved immediately downstream presumably as an effect of radio tagging took a median of 15 days before moving upstream again and 34 days to return to the release site or above. Rogers et al. (2007) have previously suggested that data telemetry studies should give tagged fish time to become accustomed to extra ballast afforded by the radio tag. Knights and Lasee (1996) and Paukert et al. (2001) have reported that activity patterns have been found to be abnormal for at least two weeks following surgery. The current study may have reported similar findings as Havn et al. (2015) where tagging tigerfish probably had a behavioural effect during the initial monitoring period compared to the later monitoring period.

4.6 Conclusions

This study is the first study to document tag-effect from external radio tagging of tigerfish. Results from 47 individuals were tracked for three consecutive days post-release demonstrated that tigerfish exhibited significantly more downstream than upstream movements. The total immediate distance moved did not differ downstream or upstream but, was negatively correlated with water temperature and positively correlated with fish size. Nineteen of these tigerfish were monitored again for seven consecutive days 25 to 47 days after being radio tagged. The comparison between their movements demonstrated that radio tagging tigerfish appeared to have an immediate behavioural effect. The 19 tigerfish also had more downstream than upstream movements but, after approximately three to six weeks the tigerfish had similar numbers of up- and downstream movements. The total distance travelled during the long term experiment were also significantly shorter than immediately after release. This difference in movements of tagged tigerfish between the two tracking periods suggests that radio tagging and/or the associated handling may have an immediate effect on tigerfish behaviour. Further studies are needed, and especially on the physiological effects that tagging may have on tigerfish and the effects from possible environmental variables. The methodology that was evaluated here, i.e. the intermediate and long term consequences of radio tagging tigerfish, is important for studying tigerfishes, and possibly other freshwater fish species, to improve the confidence of behavioural data.

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CHAPTER 5

Are freshwater protected areas suitable for management and conservation of African tigerfish *Hydrocynus vittatus*?

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5.1 Abstract

The purpose of this study was to investigate the area use of African tigerfish *Hydrocynus vittatus* to predict if freshwater protected areas are an effective tool for the management and conservation of this freshwater fish species. Tigerfish (n = 35) in the Kavango River, Namibia, were fitted with external radio-transmitters and manually tracked approximately every twelve days from July-October 2016 to May 2017 for 123 to 246 days. Tigerfish displayed at least two river use patterns. They were either relatively stationary with high site fidelity using less than 33 km of the river, or they used considerably larger areas of the river, up to 397 km upstream and 116 km downstream from their tagging positions. These long distances movements encompassed three countries including Angola, Namibia and Botswana. Twenty-three (66%) of the tigerfish used an area less than the length of the primary study area of 33 km, whereas 12 tigerfish (34%) used a river length larger than the study area. Fourteen (40%) spent more than 80% of the time monitored in this area, and 18 (51%) stayed within the area at least 50% of the monitored time. Based on the area use of the 35 monitored tigerfish a protected river area of at least 10 km, could protect at least 50% of tigerfish for at least 75% of the time. These findings suggest that freshwater protected areas may be an effective tool to sustainably manage tigerfish populations in the Kavango River. Data from this investigation on tigerfish area use may be used to make scientifically sound, evidence-based, fisheries management decisions in order to provide sustainable utilisation of this highly important fish species.

Keywords: freshwater protected area, area use, radio transmitters, tracked, tigerfish, Kavango River

5.2 Introduction

Knowledge of the area use of freshwater fish, e.g. for feeding, spawning, avoidance of unfavourable conditions and colonisation of new habitats, is critical for managers to ensure long-term survival of fish populations (Jungwirth *et al.*, 2000). In Africa, there is scant information on the area use of most freshwater fish species, and this has limited efforts to identify or establish management guidelines (Stiassny, 1996; Økland *et al.*, 2005). This is a cause for concern, among others in southern Africa, where declining tigerfish *Hydrocynus vittatus* (Castelnau 1861) populations have recently been reported (Tweddle *et al.*, 2015; Cooke *et al.*, 2016). The tigerfish is considered an important subsistence (Tweddle *et al.*, 2015; Cooke *et al.*, 2016), commercial (Kenmuir, 1973; Marshall, 1985), recreational (Smit *et al.*, 2009; Cooke *et al.*, 2016), and a keystone species (Winemiller and Jepsen, 1998). Tigerfish populations have declined as a result of pollution (Steyn *et al.*, 1996; Smit *et al.*, 2013; Roux, 2014), erection of migration barriers, and water abstraction activities in rivers (Pott, 1969; Steyn *et al.*, 1996) as well as commercial overfishing (Kenmuir, 1973; Cooke *et al.*, 2016). The decline of tigerfish populations may negatively impact on the local economy (Cooke *et al.*, 2016), food security (Abbott *et al.*, 2015) and change the river food web structures (Winemiller and Jepsen, 1998), which will negatively influence the productivity of the river in the long-term (Cooke and Cowx 2004).

Information on area use of tigerfish has sparsely been reported. Gaiger (1967) and Pienaar (1978) proposed that tigerfish undertake long distance migrations, possibly associated with annual spawning activities and because of a low tolerance for cold water. Badenhuizen (1967) proposed that tigerfish migrate from Lake Kariba to breeding grounds in shallow rivers connected to the lake, while Kenmuir (1973) witnessed shoals of migrating tigerfish in the Sanyati Gorge (Lake Kariba). Økland *et al.* (2005) reported both small and large scale (range 0.09 - 106 km) individual movements for tigerfish in the Zambezi River. Others have also reported relatively small scale individual movements of tigerfish (Baras *et al.*, 2002; O'Brien *et al.*, 2012; Roux 2014). Consequently, large knowledge gaps still exist for tigerfish regarding area use patterns, life history related movements, and possible relationships with hydrological processes.

As a result of declining fisheries, scientists and managers must constantly find alternative management tools that protect, conserve and promote sustainable utilization of freshwater fisheries resources. Although, not as well documented as marine protected areas (MPAs), freshwater protected areas (FPAs) are possibly also effective in achieving the management goals for important freshwater fish species and river ecosystems (Suski and Cooke, 2007; Bower *et al.*, 2015). The aim of our study was to assess the usefulness of FPAs as a management tool for African tigerfish based on the area use of 35 adult radio-tagged tigerfish in the Kavango River in Namibia.

5.3 Materials and methods

5.3.1 Study area

For full catchment description of the Kavango River please refer to Chapter 2 of this thesis. For full study area description please refer to Chapter 4 of this thesis. The primary study area ranged from Popa Falls Game Park downstream to the Botswana border. This section of river had a length of 33 km, with a 100 - 200 m width and a maximum depth of 7 m in the mainstream during the flood season. The study section of river has mostly sandy substrate, with some rocky areas especially the area close to Popa Falls Game Park. This river section also has large nearly stagnant backwaters (2.0 - 3.5 m deep) with reeds along the shore (Hay *et al.* 1996). The mainstream is predominantly clear but, seasonal flooding turns its water muddy and brown. Wildlife is abundant in the study area, especially large herbivores including hippopotamus *Hippopotamus amphibius*, elephant *Loxodonta africana,* buffalo *Syncerus caffer* (Taylor *et al.*, 2017), and also natural predators of tigerfish, including Nile crocodiles *Crocodylus niloticus* and African fish eagles *Haliaeetus vocifer* are present.

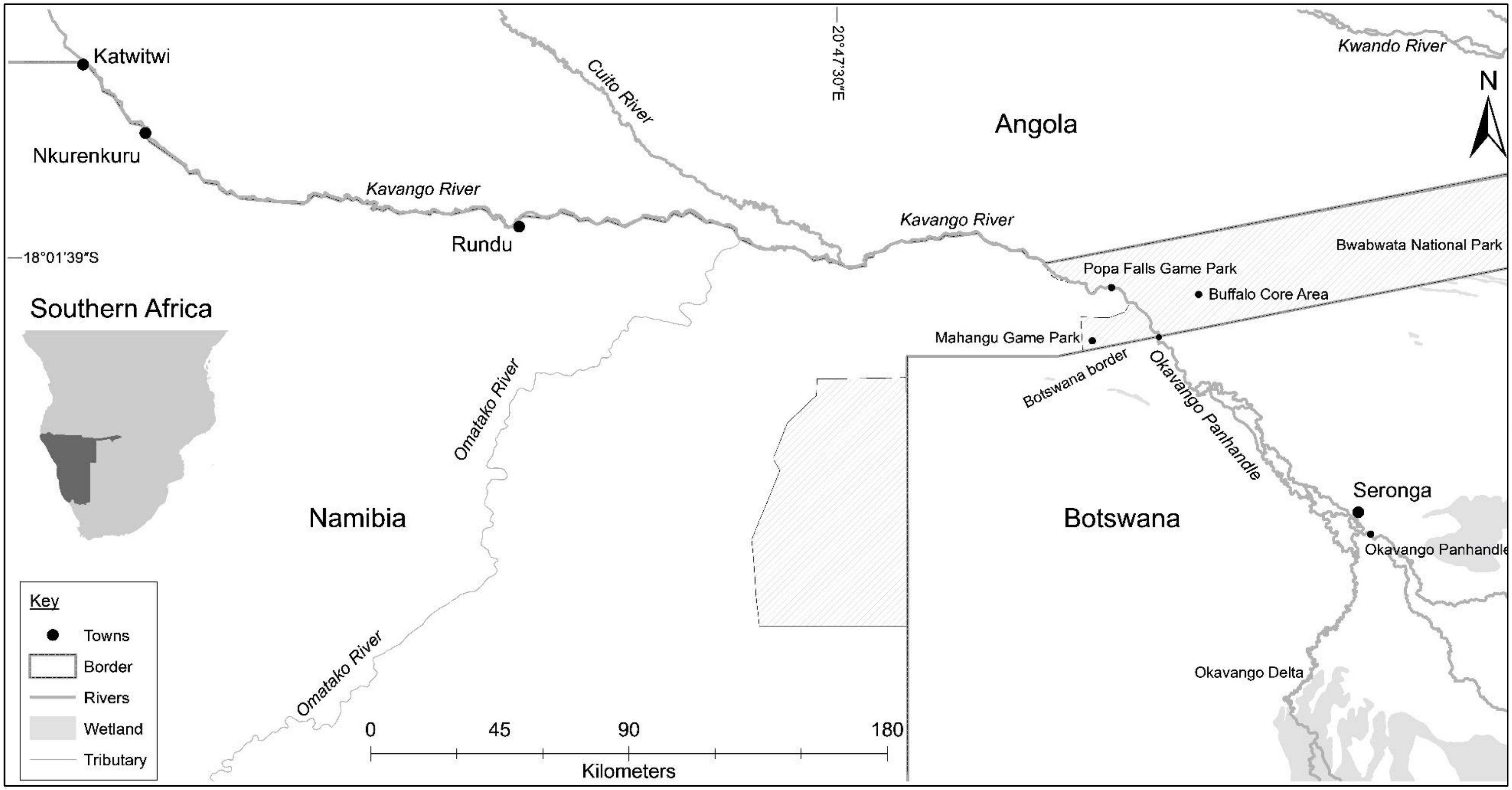

Figure 5.1: The radio tagging experiment of African tigerfish *Hydrocynus vittatus* took place in the Kavango River, Namibia. Tagging was done in the Mahangu Game Park and tracking were carried out predominantly from Popa Falls Game Park to the Botswana border. Additional tracking surveys were conducted from Katwitwi in Namibia downstream to the end of the Okavango Panhandle near Seronga in Botswana.

5.3.2 Fish capture and tagging

To study the area use of tigerfish in the Kavango River, 49 tigerfish were caught by angling from a boat between 21 June and 22 October 2016 (Table 5.1). The tigerfish were placed in a 50 L water filled container into which 2-phenoxy-ethanol, 0.3 ml/L, had been added as anaesthesia (O'Brien *et al.,* 2012). While fish were in an anaesthetized state, external radio transmitters, 16 g in the air and 55 x 20 x 11 mm (Model F2120 Advanced Telemetry Systems, Inc., Isanti, MN, USA), were attached. Weight of radio tags never exceeded 1.5% of fish weight. Stainless steel hypodermic needles were inserted through the musculature below the dorsal fin. Orthopaedic wires (0.65 mm diameter) were threaded through the hypodermic needles and used to firmly secure the tag by twisting and locking the ends of the wire against a plastic back-plate. After tagging, fork length (FL, mm) and total body mass (g) were recorded for each individual fish. All fish were released at their capture site.

In total, fourteen tigerfish were excluded from the area use analyses, which then consisted of 35 individuals (Table 5.1). The reason for this was that 11 tigerfish could not be located up to 22 February 2017 (i.e. to include the proposed spawning in the study period). This might be due to predation, tag failure, the fish being removed from the river, or that they moved out of the total study area from Katwitwi to Seronga. In addition, one tigerfish was caught by a Nile crocodile two days after it was released (FJ witnessed attack and retrieved tag), and two more tigerfish were recaptured by anglers after being tagged, which might influence their behaviour.

Table 5.1: African tigerfish *Hydrocynus vittatus* tagged in the Kavango River, Namibia, from June 2016-August 2017 including tag number (No.), tagging date, fork length (mm), weight (g), total number of positional fixes, monitored period (days) and last tracking date during the study (fish not tracked up to 22 February 2017 are excluded from the table)

No.	Tagging date	Fork length (mm)	Weight (g)	Total number of fixes	Monitored period (days)	Last tracking date
1	21/06/2016	510	1750	33	246	04/06/2017
2	21/06/2016	594	3240	39	246	04/06/2017
3	23/06/2016	535	2240	38	244	04/06/2017
4	23/06/2016	590	3540	19	244	03/06/2017
5	23/06/2016	549	3210	17	244	04/06/2017
6	25/06/2016	558	3270	19	242	04/06/2017
7	25/06/2016	490	1950	20	242	03/06/2017
8	25/06/2016	760	6011	14	242	04/06/2017
9	28/06/2016	603	4220	38	239	07/06/2017
10	28/06/2016	570	3320	23	239	04/06/2017
11	16/07/2016	590	3080	39	221	03/06/2017
12	17/07/2016	525	2400	12	220	04/06/2017
13	17/07/2016	530	2300	39	220	04/06/2017
14	19/07/2016	490	2300	15	218	03/06/2017
15	19/07/2016	610	4008	20	218	04/06/2017
16	19/07/2016	483	1980	39	218	04/06/2017
17	19/07/2016	485	1800	39	218	04/06/2017
18	26/07/2016	575	2990	39	211	04/06/2017
19	27/07/2016	510	2420	37	210	22/02/2017
20	27/07/2016	505	2300	10	210	03/06/2017
21	28/08/2016	615	4200	3	178	04/06/2017
22	02/09/2016	485	2200	6	173	04/06/2017
23	10/09/2016	550	2630	26	165	07/06/2017
24	10/09/2016	615	4640	5	165	04/06/2017
25	28/09/2016	495	2200	25	147	04/06/2017
26	28/09/2016	568	3260	23	147	04/06/2017
27	19/10/2016	580	2390	11	126	04/06/2017
28	19/10/2016	570	3130	22	126	02/05/2017
29	19/10/2016	573	3250	11	126	22/02/2017
30	19/10/2016	490	1900	5	126	02/05/2017
31	20/10/2016	505	1840	15	125	04/06/2017
32	21/10/2016	568	3800	26	124	07/06/2017
33	21/10/2016	615	3860	11	124	07/06/2017
34	22/10/2016	505	2240	6	123	04/06/2017
35	22/10/2016	500	1500	14	123	04/06/2017
36	22/10/2016	530	2720	26	123	04/06/2017
37	22/10/2016	655	3900	26	123	04/06/2017

5.3.3 Tracking

The tigerfish positioning was undertaken during daylight hours, and the tracking was conducted from a boat using a portable receiver (Model R2100 Advanced Telemetry Systems, Inc., Isanti, MN, USA) connected to a 4-element Yagi antenna. Tagged tigerfish were located using signal strength triangulation with a precision of approximately ± 10 m, hence movements less than

10 m were classified as stationary. Tigerfish were tracked approximately every 12 days over the same 33 km stretch of river in the primary study area from Popa Falls Game Park to the Botswana border (Fig. 5.1). To find tigerfish that could not be located in the primary study area, additional tracking was undertaken outside the study area. The additional tracking was important as it could determine the possible fate and total river length used by tigerfish during this study. Additional tracking surveys included, four tracking surveys from Katwitwi to Rundu, six tracking surveys from the Cuito River to Popa Falls Game Park, and two tracking surveys from the Mahangu Game Park lower boundary down to the Panhandle in Botswana (Fig. 5.1).

5.3.4 Water discharge and temperature

Water temperatures were recorded using a HOBO Pro v2 data logger attached to a floating jetty and constantly remained at a depth of 1 m (Onset, Bourne). Logger was programmed to log temperature at 1 h intervals between July 2016 and May 2017. During the study period the mean (± SD) water temperature was 24.3 ± 3.9 °C (median 25.9 °C, range 16.2 - 31.1 °C, Fig. 2). The daily water-discharge data were recorded by the University of Botswana and the Okavango Research Institute, Botswana, at the Mohembo hydrological measuring station. The water discharge was 243 ± 107 m^3/s (median 237 m^3/s, range 82 - 446 m^3/s) from June 2016 to May 2017 (Fig. 2). The study period included the annual flood cycle and monitored tigerfish during sinking, low, rising and high water levels.

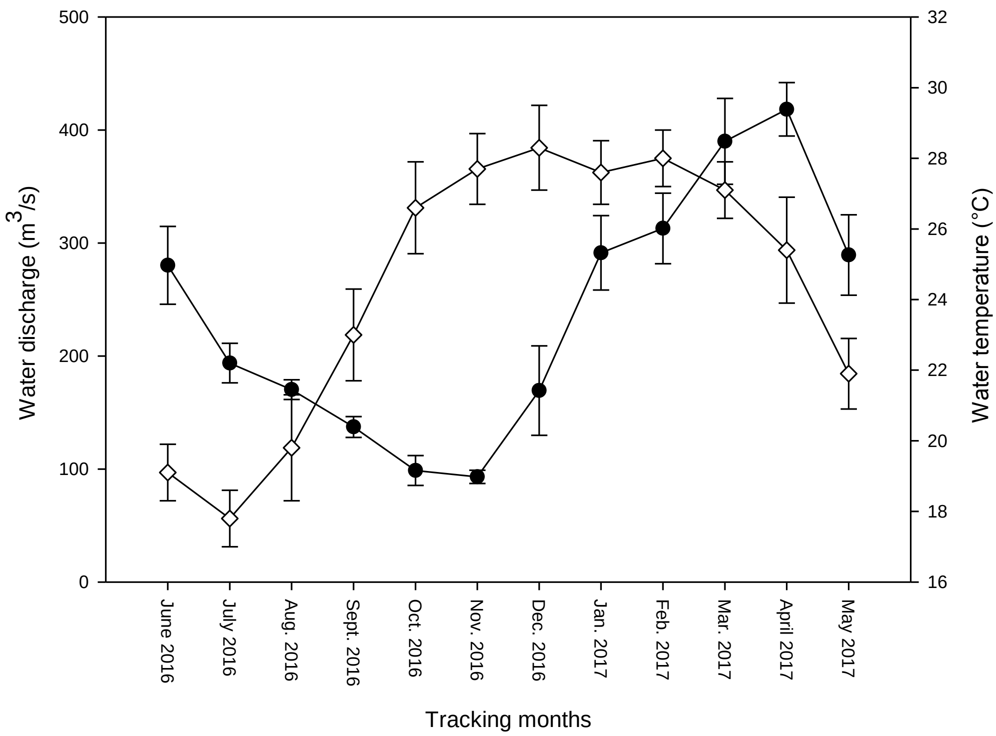

Figure 5.2: The monthly mean ± SD water discharge m^3/s (—●—) and water temperature °C (—◇—) collected during the study period from June 2016 until May 2017

5.3.5 Data analyses

The minimum distance moved for each individual tigerfish was calculated using the 'locate features along routes' tool in ArcMap 10.5 (Geographic Information Systems, Environmental Systems Research Institute, Inc., Redlands, CA, USA). The movement direction (upstream or downstream) was defined as the direction and shortest distance in the river between two spatial tracking points. It is therefore plausible that tigerfish moved further, and the recorded distance was considered a minimum total distance moved. The non-parametric Chi-Square test and Mann-Whitney U test (SPSS 20) were used to test differences between upstream and downstream movements during the tracking period. Total distance moved was Log10 transformed to meet the assumption of normality after testing with Kolmogorov-Smirnov test. A general linear model (ANOVA) was used to test the effect of fish length (FL mm) and number of days monitored on total distance moved, with total distance as the independent variable and tigerfish length and number of days monitored as the dependent variable. The proportion of time that tigerfish spent inside the study area (i.e. Popa Falls Game Park to Botswana border) was calculated as the proportion (%) of the total number of days in relation to the total days each individual was monitored. To exclude possible bias due to tagging effects (Jacobs et al. submitted), the first tracking position fourteen days after tagging was set as the first position of each individual. If an individual was not tracked inside the study area at a tracking survey, it was assumed that the individual had spent half the time since the last tracking survey inside and half of the time outside the study area. The lengths used to predict the proportion of fish that will be protected were selected based on areas over which traditional authorities have direct control over on the Kavango River. These areas range from 2 km for small villages to 5-20 km for larger communities. In addition, to allow for equal possibility of downstream and upstream detection of the fish inside the study area, the distance from the borders of the study area were taken into account when calculating time spent inside the river areas of 2, 5, 15 and 20 km. Hence, the distance from the first position to the ends of the primary study area influenced the number of fish used in this analysis. The model of river length used was based on a minimum of 14 tigerfish.

5.4 Results

5.4.1 Tigerfish morphometrics

The sample of 35 tigerfish used in analyses had a mean (± SD) length of 555 ± 59 mm FL (median 550 mm, range 483 - 760 mm), and mean body mass of 2954 ± 968 g (median 2800 g, range 1500 - 6011 g). It was not possible to sex the tigerfish based on external characteristics.

5.4.2 River length used

The tagged tigerfish were monitored for 123 to 246 days and had at least two area use patterns. They were either relatively stationary with high site fidelity or they used considerably larger areas of the river (Fig. 5.3).

The mean (± SD) minimum river length used by the monitored tigerfish (n = 35) was 47.1 km ± 82.5 (median 7.3 km, range 0.1 – 397.3 km, Fig. 5.3). Of these 35 tigerfish, 23 (66%) individuals were only found in an area less than the primary study area of 33 km from Popa Falls Game Park to the Botswana border, of these individuals 21 (60%) tigerfish used an area considerably smaller than the study area (< 15 km, mean 4.4 km, median 4.2 km, range 0.1 – 92.0 km) (Fig. 5.3). Twelve tigerfish (34%) used a river length larger than the primary study area, of which four individuals moved more than three times the length of the study area (> 99 km, mean 227.1 km, median 198.0 km, range 115.3 – 397.3 km) (Fig. 5.3); with one individual using a minimum upstream river length of 397.3 km. Neither the length of the tracking period (number of days) or fish length (FL) had an effect on the size of the total river length used by tigerfish (days vs area: ANOVA, $F_{(1, 33)}$ = 1.064, p = 0.309, R^2 = 0.010; FL vs area: ANOVA, $F_{(1, 33)}$ = 1.949, p = 0.172, R^2 = 0.060).

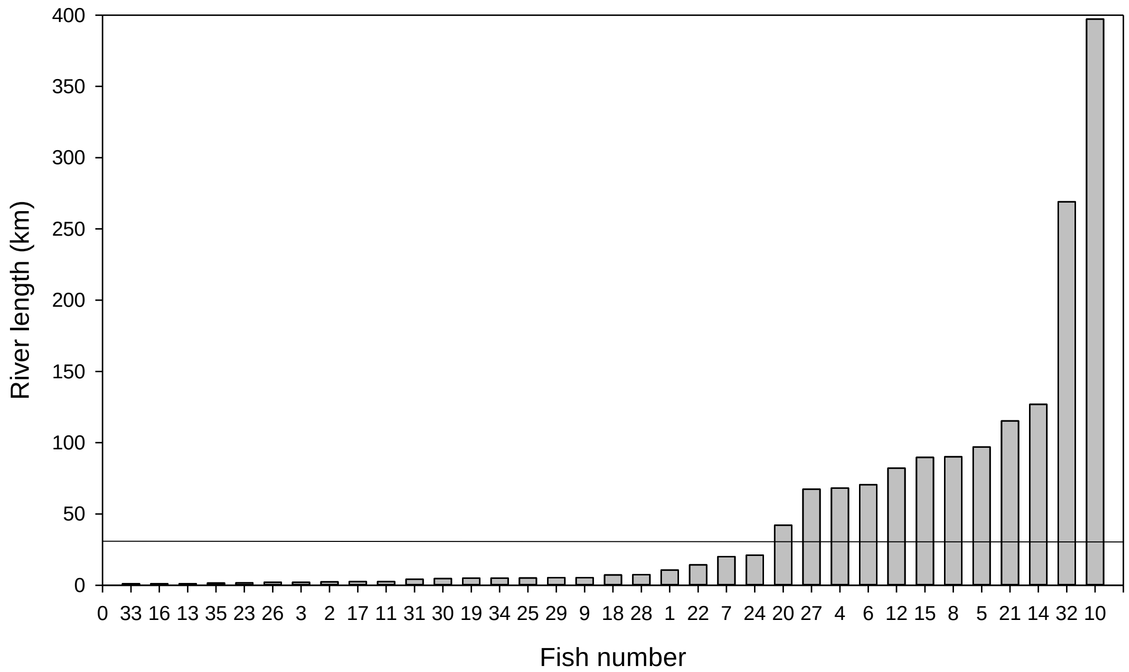

Figure 5.3: The total minimum river length used by individual radio tagged *Hydrocynus vittatus* in the Kavango River, Namibia from June/October 2016 until May 2017. (The horizontal line shows the length of the primary study area).

5.4.3 Area used relative to tagging position

The 35 tagged tigerfish used both upstream and downstream areas from the tagging point (Fig. 5.4). However, fish that used larger areas seemed to either move mostly in an upstream or downstream direction, i.e. had a directional movement. From the tagging positions in the study area tigerfish moved and covered a total river length of 513 km which encompassed three countries including Namibia, Angola and Botswana (Fig. 5.5). None of the monitored tigerfish returned to the primary study area after having left the area.

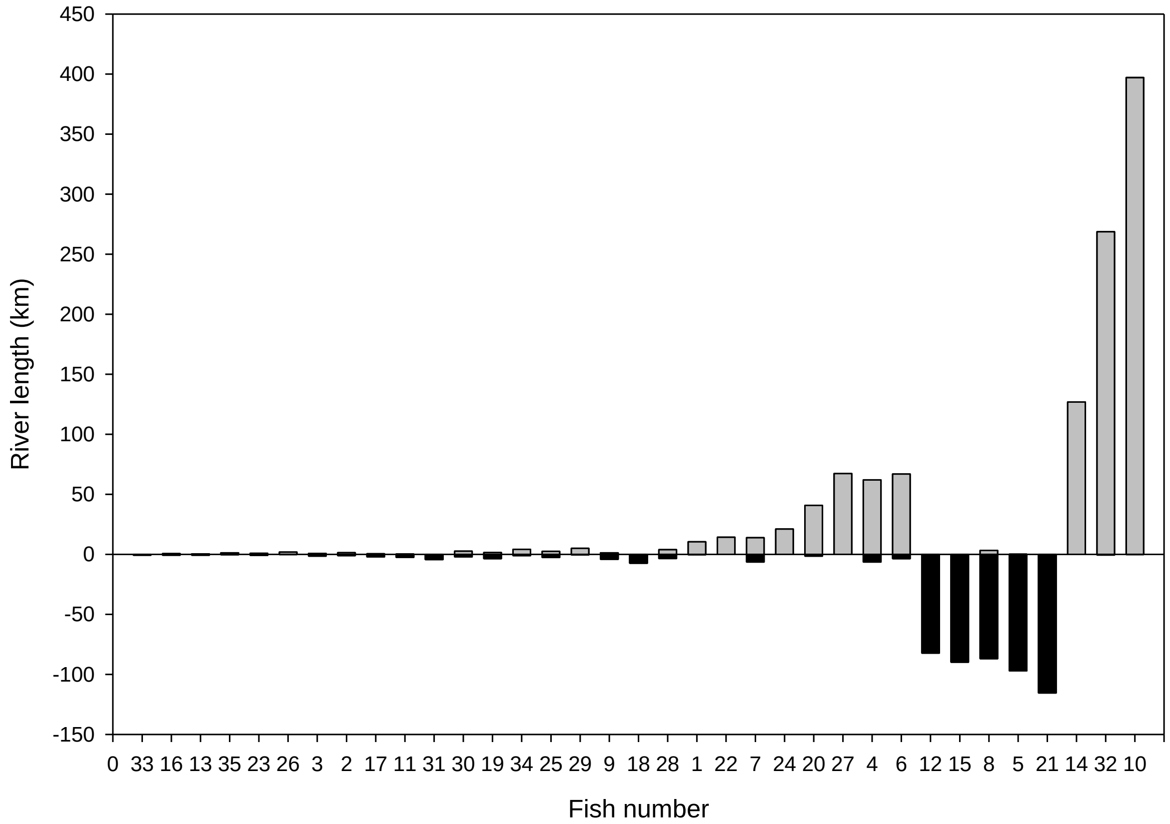

Figure 5.4: Upstream (▭) and downstream (▬) total river length used by *Hydrocynus vittatus* during the radio telemetry study in the Kavango River, Namibia. Tigerfish were tracked from June/October 2016 until May 2017.

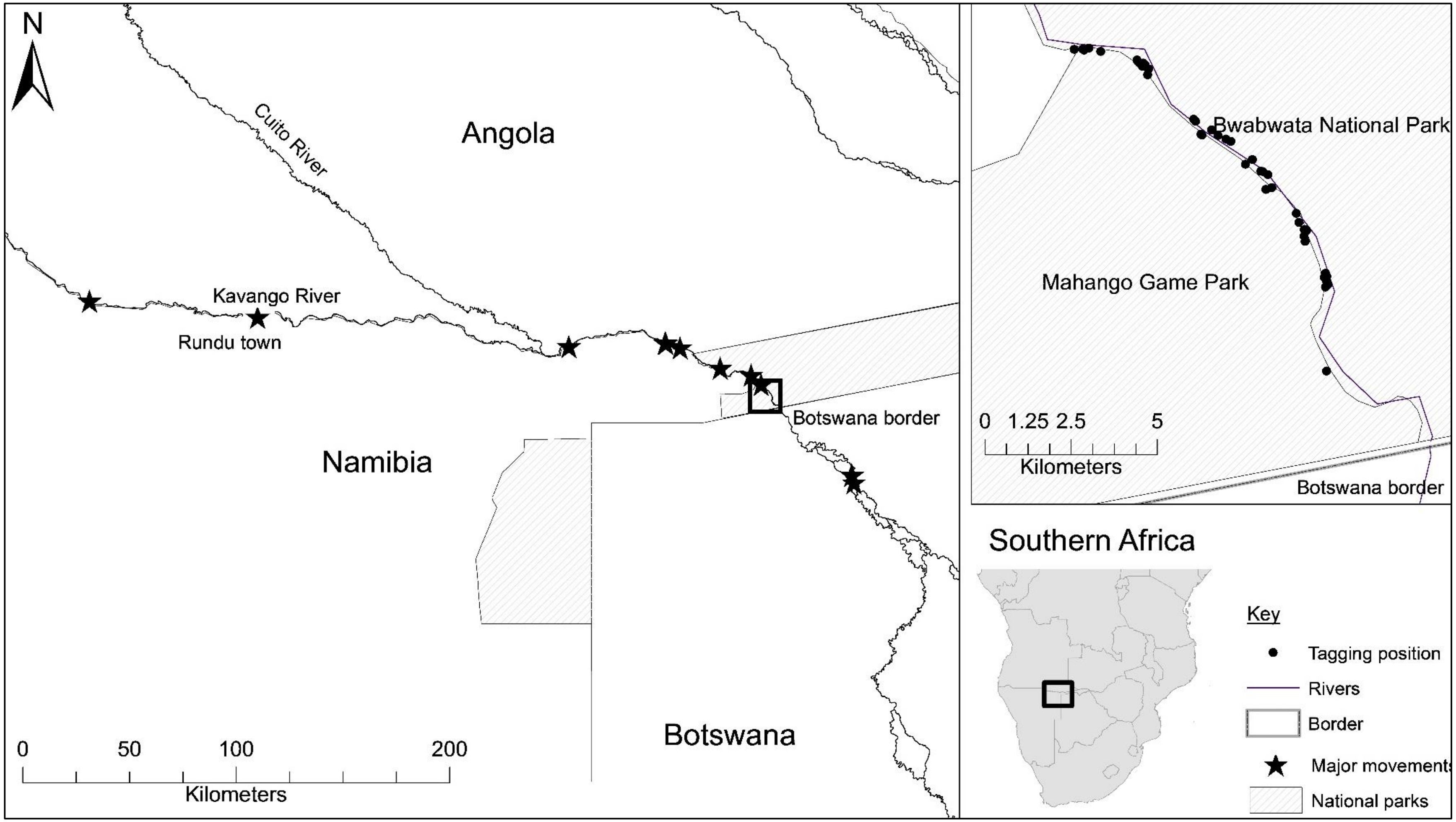

Figure 5.5: The total minimum river length used by individual radio tagged *Hydrocynus vittatus* in the Kavango River, Namibia from June/October 2016 until May 2017. (The insert map shows the tagging positions in the primary study area).

5.4.4 Time spent inside the primary study area

The proportion of time that the tigerfish spent inside the primary study area of 33 km ranged from 0% to 100%. Of the 35 tigerfish monitored, 11 (31%) were never recorded outside the primary study area (Fig. 5.6). Fourteen (40%) spent more than 80% of the time monitored in this area, and 18 (51%) stayed within the area at least 50% of the monitored time (Fig. 5.6).

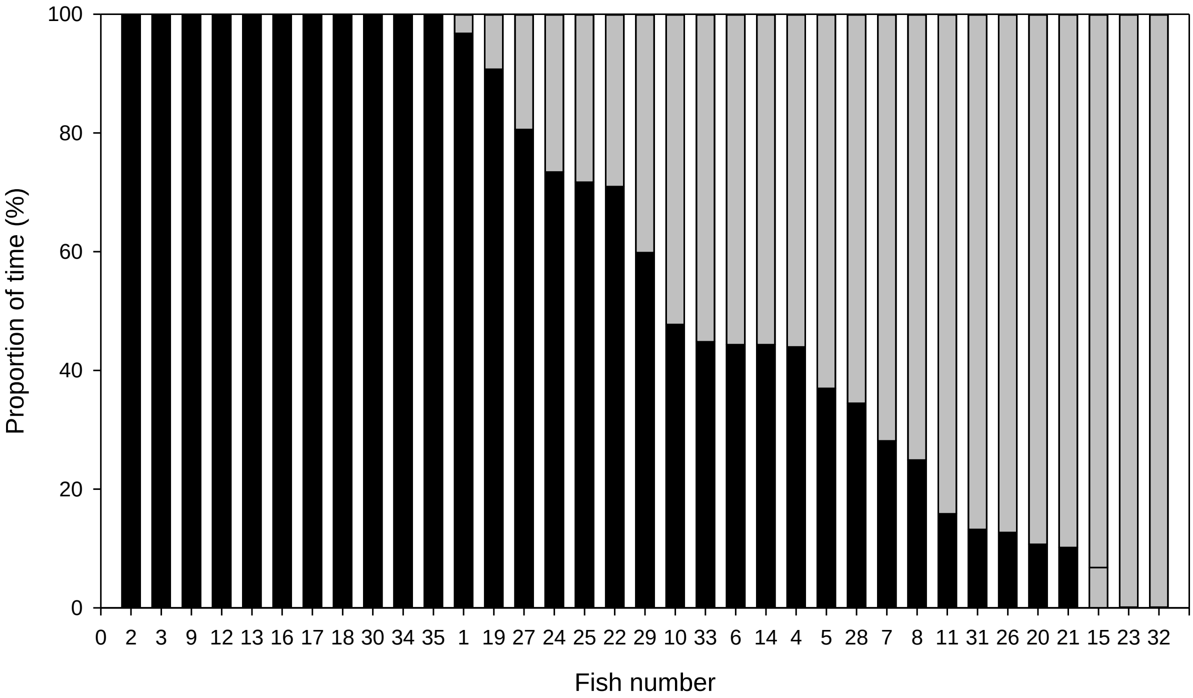

Figure 5.6: The proportion of time (%) the 37 radio tagged *Hydrocynus vittatus* spent inside (▬) or outside (▭) the 33 km study area from Popa Falls Game Park to the Botswana border in the Kavango River, Namibia, during the study period from June/October 2016 until May 2017.

5.4.5 Length of protected area vs area use

To predict the probable conservation effects of a FPA with various lengths, we calculated the time the studied tigerfish spent inside various length of the river. Based on this an allocated area of 10.0 km, 15.0 km and 20.0 km, may protected at least 50% of the monitored tigerfish for at least 75% of the time during the studied period of 126 to 348 days. Areas less than 5 km and 2 km, protected 35% and 26% of the tigerfish, respectively, for at least 75% of the monitored time (Table 5.2).

Table 5.2: Proportion (%) of time spent inside various areas (River length (km)) for *Hydrocynus vittatus* tagged and monitored in the Kavango River, Namibia, from June-October 2016 to May 2017. (Percentage shown with number of individuals in parentheses).

Proportion (%) of time spent inside area	River length (km)				
	2.0	5.0	10.0	15.0	20.0
< 25	59.3 (16)	50.0 (13)	29.2 (7)	15.0 (3)	21.4 (3)
25-50	7.4 (2)	7.7 (2)	8.3 (2)	10.0 (2)	14.3 (2)
50-75	7.4 (2)	7.7 (2)	8.3 (2)	10.0 (2)	7.1 (1)
> 75	25.9 (7)	34.6 (9)	54.2 (13)	65 (13)	57.1 (8)
Number of fish	27	26	24	20	14

5.5 Discussion

5.5.1 Tigerfish river use

The minimum largest river length used by individual tigerfish during this study was 397 km upstream and 116 km downstream from the tagging positions, a total of 513 km, which encompasses Angola, Namibia and Botswana. In the Zambezi River, Namibia, Økland *et al.* (2005) recorded the maximum river length moved by individual tigerfish to be 106 km, when tracking was restricted to Namibia's international border. Roux (2014) recorded shorter individual movements of up to 3.2 km in the Incomati River System. This may suggest that tigerfish river use was previously underestimated as tigerfish can use extensive river lengths. The river use of tigerfish across country borders, both upstream and downstream and between river banks, also highlights the importance of river connectivity, shared fish resources and the need for inter-jurisdictional management across political borders.

River use larger than the primary study area of > 33 km was recorded for approximately half of the monitored tigerfish during our study. Similar to findings by Økland *et al.* (2005) there seems to be substantial individual variation among tigerfish where some have more site fidelity while others move longer distances and use large areas. Of the 35 tigerfish monitored, 31% were never recorded outside the primary study area of 33 km, while 40% spent more than 80% of the monitored time in the study area, and 51% stayed within the study area at least 50% of the monitored time. This may indicate that a portion of the tigerfish population may have strong site fidelity. Økland *et al.* (2005) reported that 50% of the monitored tigerfish in the Zambezi River had consistent site fidelity and relatively small home ranges while others had residency periods after which they moved for long distances to new areas. During a translocation study of tigerfish from the Schroda man-made lake into a reservoir in Botswana (Letsibogo man-made lake) O'Brien *et al*. (2012) recorded relatively small home ranges (< 750 m) for 58% of the externally radio tagged tigerfish while Roux (2014) reported relatively defined home range of approximately 49 km for monitored tigerfish.

Freshwater fish area use is considered being a result of avoidance of unfavourable conditions, optimization of feeding and reproductive success or the colonisation of new habitats (Northcote, 1978; Koehn *et al.*, 2009). Although numerous authors such as Jackson (1961), Bell-Cross (1965), Gaigher (1967), Kenmuir (1973) and Pienaar (1978) have suggested that tigerfish undertake large spawning migrations, such a collective migration was not observed by the fish in this study despite including the proposed spawning time periods. Some tigerfish monitored did use a relatively large (379.3 km) river length but, area use could not be attributed to a general migration pattern such as the well documented long-distance movements of the Salmonids family that undertake yearly spawning migrations, see for example (Trépanier *et al.*, 1996; Gerlier and Roche, 1998; Farrell *et al.*, 2008; Corbett *et al.*, 2012).

Tigerfish are considered potamodromous, which implies they migrate within freshwater habitats for spawning events (Bowmaker, 1973). Various authors including; Jackson (1961); Gaigher (1967); Bowmaker (1973); Kenmuir (1973); Langerman (1980); Winemiller and Kelso-Winemiller (1994) have hypothesised that tigerfish spawning migrations are linked to a combination of physical and chemical factors usually associated with flooding events which inundates nutrient rich floodplains. Merron and Bruton (1988) have suggested that spawning events of tigerfish in the Kavango River takes place prior to annual floods to ensure juveniles have optimum use of flooded areas for both protection and feeding. Jackson (1961) recorded a two-month old juvenile tigerfish in the Okavango as late as early November, which is considered abnormal spawning time for tigerfish. This suggested that the female gonads matured during winter seasons (austral winter) or low flow conditions. This supports findings by Van Zyl (1992) that there may be two breeding cycles for tigerfish which was also mentioned by Kenmuir (1973). It is therefore possible that the relatively longer river use recorded during this study may be related to spawning. However, in our study tigerfish were monitored from June 2016 to May 2017 were all considered mature fish, and we cannot rule out that a smaller proportion of the fish had larger spawning migrations.

It may also be possible that tigerfish, being a long-lived and iteroparous species, do not spawn every year, as documented in other fish species such as walleye *Stizoztedion vitreum* (Johnston and Leggett, 2002), whitefish *Coregonus albula* (Sandlund *et al.*, 1991), and Atlantic salmon *Salmo salar* (Saunders *et al.*, 2006). The possibility that tigerfish may skip spawning events and therefore not migrate every year has not been explored by other authors.

5.5.2 Freshwater protected areas

From the present study, it is predicted that an allocated river area of 10 km, 15 km and 20 km, could protect at least 50% of tigerfish for at least 75% of the time from fishing mortality. Given that the fishing mortality is not too high outside an FPA; a freshwater protected area in the Kavango River that range from approximately 10 km could be considered a management tool that would sustain tigerfish populations in the area.

The development of FPAs with the intention of preserving freshwater aquatic resources in general, has been shown as a useful management tool (Bower *et al.*, 2015). Specifically designed FPAs to protect *Micropterus* spp. during spawning and post spawning periods have been shown to improve catch per unit effort (Sztramko, 1985), and rehabilitation of exploited lake trout *Salvelinus namaycush* (Walbaum 1792) were largely attributed to a no fishing FPA in Lake Superior and Huron (Schram *et al.*, 1995; Reid *et al.*, 2001). In Lake Kariba (Zimbabwe) an FPA had both larger sizes and abundances of several freshwater fish families (Sanyanga *et al.*, 1995).

Hay *et al.* (2000) and Peel (2012) have shown that the Mahangu Game Park had higher catch rates and larger fish compared to other parts of the Kavango River, indicating considerably higher fishing pressure outside the park. For FPAs to be considered effective, understanding of the life history and habitat needs of tigerfish is needed. Although tigerfish move among habitats (Økland *et al.*, 2005), by understanding their life history it is possible to predict which habitats are needed for spawning or feeding during different life stages (Bower *et al.*, 2015). This also includes the protection in possible spawning time periods, and the protection of nursery areas for juveniles (Rosenfeld and Hatfield, 2006). Therefore, the focus of FPAs with regard to migratory species like tigerfish should be to maintain source populations to ensure that populations will persist. Freshwater protected areas do not guarantee against natural variability in fish size and recruitment success which are influenced by numerous internal and external factors including human stressors (e.g. pollution, illegal fishing) (Bower *et al.*, 2015). But, freshwater protected areas can, however, manage or reduce some stressors as fishing mortality to support recruitment and offer habitat and area protection to tigerfish.

5.6 Conclusions

Deciding the size of freshwater protected areas as a tool for conservation and sustainable resource management of tigerfish may depend on factors such as the availability of life history knowledge and the physical attributes of the proposed freshwater system (e.g. lateral and longitudinal connectivity, habitat quality and hydrology). This study showed that 40% of the monitored tigerfish (total n = 35) spent more than 80% of the monitored time in the study area of 33 km, and 51% of the tigerfish stayed within the study area at least 50% of the monitored time. Our study predicted that an allocated area of at least 10 km, could protect at least 50% of tigerfish for at least 75% of the time. These findings suggest that FPAs may be a useful tool to sustainably manage at least a source-population for reproduction and production of juveniles, and therefore, could be considered a viable management tool for tigerfish populations. Data from this investigation on tigerfish area use may be used to make scientifically sound, evidence-based, fisheries management decisions in order to provide sustainable utilisation of this highly important fish species in Namibia.

5.7 Acknowledgements

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CHAPTER 6

6.1 General conclusions

The knowledge gained by measuring the use of space through time by tigerfish is important to understand population and community processes of this species. Understanding these processes can give us insight into their movement patterns, area use, habitat requirements, migration routes and general behavioural aspects, which have profound consequences for their conservation and management. This thesis contributes significantly to the knowledge on aspects of the ecology and conservation of tigerfish. I reviewed the need for management of inland fisheries and then focused on inland fisheries specifically in Namibia in Chapter 1. I then used 17 years of monitoring data from the Namibian sections of the Zambezi and Kavango Rivers to demonstrate that freshwater protected areas contained a higher biomass of tigerfish than fished areas (Chapter 2). These data were used to develop the hypothesis that protected areas may play an important role in sustainable tigerfish management and subsequently developed and used tagging techniques to evaluate the effectiveness of FPAs as a management tool for tigerfish in Chapter 3 to 5.

The development of the radio telemetry techniques consisted of two field experiments. The first was to test whether radio telemetry was necessary by testing relatively cheaper plastic tipped dart tags in a tag retention experiment. Early investigations into mark and recapture techniques for tigerfish in Lake Kariba (Zimbabwe), Olifants, Letaba and Luvuvhu Rivers in South Africa were largely unsuccessful due to the low recapture rates (Langerman 1980, Gagiano 1997, Roux 2005). None of these studies performed tag retention experiments and the little information obtained by recaptured individuals was of little value. This tag retention experiment revealed that PDL plastic tipped dart tags had a 50% tag loss rate at 3.9 months and 100% tag loss after 10 months on tigerfish. The mechanisms for tag loss could not be identified, however, it is suggested that aggressive behaviour might have caused tags to dislodge from behind the ptherygiophores. Tag loss estimates is a vital component of survival estimates that are applied to abundance calculations as part of tigerfish stock assessments. The results from this experiment revealed that PDL plastic tipped dart tags were not retained by tigerfish for a sufficient length of time to make them suitable for long-term studies on tigerfish, radio tagging techniques were required to study movement of tigerfish. The application of this technique, however, first required knowledge of the impacts of radio tagging on the immediate and long-term movement of tigerfish (Chapter 4). Comparing immediate with long-term movements of tagged tigerfish suggested that radio tagging and associated handling had an immediate effect on behaviour for the first two days after tagging, but that this effect became less apparent in the long-term. Hence, radio tagging and subsequent monitoring tigerfish was considered a useful technique to study its area use as long as the behaviour immediately after tagging is not included in the dataset.

Finally (Chapter 5), radio telemetry was used to assess whether FPAs are a suitable management tool for tigerfish in the Kavango River. To test this 35 tigerfish were radio tagged and monitored constantly throughout the study period for 123 to 246 days. The monitored tigerfish displayed at least two river use patterns. They were either relatively stationary with high site fidelity using less than 33 km of the river, or they used considerably larger areas of the river. Twenty-three (66%) of the tigerfish used an area less than the length of the primary study area of 33 km, whereas 12 tigerfish (34%) used a river length larger than the study area. Based on the river length use of the 35 monitored tigerfish a protected river area of at least 10 km, could protect at least 50% of tigerfish for at least 75% of the time. Their river length use recorded during this study indicates that a portion of the tigerfish population may have strong site fidelity, or that the study area had all the necessary life-stage habitats such as spawning, nursery areas, and feeding zones required which should be investigated in future.

This is the first application of radio telemetry to evaluate if FPAs can be a suitable management tool for tigerfish. The number of radio tagged fish was 49, which could be considered relatively few, however, financial constraints play an important part in radio telemetry studies. The importance of formulating relevant research questions should therefore be emphasised. In addition, the tag battery life of radio tags are a significant limiting factor in behavioural studies which highlight the importance of possibly adding fixed monitoring stations and increasing tracking surveys. These are, however, related to the availability of funding.

6.2 Management implications and ecological findings

There are currently two fish protected areas established within the Zambezi River (Kasaya and Sikunga fish protected areas) and one in the Kavango River (Mahangu National Park) but, their effectiveness have not been evaluated. Both the FPAs in the Zambezi River were established as a direct result of declining fisheries within the Namibian section of the Zambezi River while the Mahangu National Park on the Kavango River is mainly a wildlife protected area which by default serve as a FPA. Currently, these areas are assessed annually in a similar fashion as the annual gill net survey to the Zambezi and Kavango Rivers that have been carried out from 1997 by the Ministry of Fisheries and Marine Resources of Namibia. Despite CPUE data being collected most commonly to assess the status of fish stocks, CPUE data alone are not adequate for management decisions. The present study did not manage to identify clear temporal trends even though a database of 17 years was used. One of the major challenges faced when using CPUE data is that it is selective for a component of the fisheries population instead of the total population. The high inter annual variance in the CPUE data provides limited information on the effect of fishing pressure and should therefore, not be used in isolation to assess and manage fisheries communities or ecosystems. It is suggested that these surveys to collect catch data continue, to provide an up to date time series database for each of the studied river systems.

However, it is of vital importance that data collecting methods during these surveys be better standardized to provide accurate information on relative abundance (CPUE), size structure, habitat preferences and biomass of all fish species found within these systems. Gillnet fishing should be supplemented by dedicated research studies to disentangle the effects of environmental factors and possible socio-economic factors that may have an effect on the fisheries.

Although never tested, it has generally been accepted that tigerfish undertake long distance migrations, possibly associated with annual spawning activities and an intolerance for cold water (Badenhuizen 1967, Gaigher 1967, Kenmuir 1973). These migrations has however, not been observed during behavioural studies by Økland et al. (2005), O'Brien et al. (2012), Roux (2014) or during the present study.

Freshwater fish movement can generally be classified in three functional migration categories: (1) to avoid unfavourable environmenatl conditions (e.g. flow, temperature and water quality); (2) to optimize their feeding (e.g. to nutrient rich floodplains), or (3) to optimize resproductive (spawning) success (Northcote 1978, Lucas et al. 2001). Northcote (1978) argued that migratory movements do not necessarily involve large aggregations of fish concentrations but, such movement follow periodicity and occur at specific pathways whereby inevitably, at a certain time and space, there is a concentration of a particular species. Therefore, for fish movements to be generally classified as a migration, a large portion of the particular species, should display synchronised movements, which are relatively larger than its usual home ranges and should be during a specific life cycle stage (Northcote 1978). Tigerfish monitored during the present study were either relatively stationary with high site fidelity using less than 33 km of the river, or they used considerably larger areas of the river up to 379 km upstream and 116 km downstream from their tagging positions. A portion of the tigerfish population seems to restrict their activities to a well-defined area or home range whereas some individuals undertake longer range exploratory movements. These longer exploratory movements, therefore do not conform to the definition of migrations; but rather, suggest dispersal were tigerfish move to find better resources and may occupy this new home range for a defined period (Lucas and Baras 2001). It is therefore possible that large river length use documented in this study, were as a result of dispersion rather than migration. This is supported by the fact that tigerfish used both upstream and downstream areas of the Kavango River and did not follow a clear synchronised movement pattern. This does not imply that tigerfish do not exhibit daily, seasonal or periodic movements associated with resource utilisation in the Kavango River.

The river length use of tigerfish in the Kavango River documented in this study and the relatively similar "non-migration" movement documented by Økland et al. (2005), O'Brien et al. (2012) and Roux (2014) may suggest that tigerfish may not always migrate. This is in contrast to observations from Lake Kariba, a large impoundment where Badenhuizen (1967) and Kenmuir (1973) proposed that tigerfish migrate to breeding grounds in shallow rivers. This may suggest that tigerfish in lentic environments may undertake coordinated spawning movements to lotic environments, if it is available, but succesfull spawning have been confirmed in lentic environments (Roux 2014). Although, no clear migration patterns were identified for tigerfish in comparison to the well-documented migration patterns of *S. salar* that undertake yearly spawning migrations (Farrell et al. 2008, Corbett et al. 2012). The idea that some tigerfish may be migratory and others exhibit residential behaviour is an important management concern. Northcote (1992) have shown that migratory and residential behaviours are important within the same species as it promotes genetic diversity. These behavioural traits are considered highly important in the formulation of conservation and management strategies for salmonids, especially concerning the protection of local stocks and special habitats (Northcote 1992). Similar to tigerfish area use, Brown and Mackay (1995) reported two distinct area use patterns, where cutthroat trout *Oncorhynchus clarki* used the main-stem associated with relatively small area use for spawning and others within the same population emigrated to tributaries and had larger area use in the Ram River, Alberta. This study did not identify specific spawning migrations but, it seems plausible that there is intraspecies variation in tigerfish behaviour and possibly spawning migrations.

The relatively restricted area use documented in this study suggest that a portion of the tigerfish population could be managed locally or regionally in the form of FPAs. In accordance with current widely held views that freshwater fisheries resources are being depleted at unsustainable rates throughout Africa, there is an urgent need for relevant conservation and management strategies (Stiassny 1996, Dudgeon et al. 2006). Freshwater protected areas as a conservation tool for tigerfish and possibly other migratory fish species will depend on many factors, such as species specific information and the specific freshwater system in question (Bower et al. 2015). Establishing freshwater protected areas will furthermore depend on conservation priorities, lateral and longitudinal connectivity of the river system, and probably most importantly, human activities taking place in areas proposed for protection (Bower et al. 2015). Although, research on spawning and seasonal behaviour may still be lacking for tigerfish, information gathered during this study are directly linked to the effective establishment of FPAs for managing tigerfish. Bower et al. (2015) suggested that the most important locations that should be considered for FPA’s are areas where multiple migratory species inhabit the same areas. For example, if certain areas are more likely to support spawning habitat for multiple migratory fish species compared with others, these areas would be more suitable locations for FPA’s. This however, should be the focus of future research.

6.3 Requirement for local and international collaboration

Tigerfish showed largescale river length use both upstream (379 km) and downstream (116 km) in the Kavango River which encompassed three countries including Angola, Botswana and Namibia. This transboundary river length use underscores the need for interjurisdictional management. The Transboundary Fisheries Management Plan for the Okavango Basin is a document that exists between Angola, Botswana and Namibia and exists to create a joint management strategy of the Kavango River. I suggest that this joint management plan should be fully instated to ensure the conservation and sustainable use of the shared tigerfish resources of the Kavango River.

Tigerfish in northern Namibia are an important component of artisanal fisheries where they make a substantial contribution to food security and stimulation of the local economy (Thorstad et al. 2004, Abbott et al. 2015, Tweddle et al. 2015). Because of the value of tigerfish to the ecosystem and local communities, managing exploitation of this species is important (Tweddle et al. 2015, Cooke et al. 2016). The Kavango River is a relatively large river and is connected over a large spatial scale with numerous drivers and many societal interests (McCarthy et al. 2000). Tigerfish are considered high value species and declines as a result of commercialised fisheries have emphasised the need for better management interventions (Tweddle et al. 2015, Cooke et al. 2016).

There are about 30 tourist lodges situated next to the Kavango River in Namibia and Botswana (Fig. 6.1). The majority of these lodges offer recreational fishing for tigerfish and are directly benefiting from healthy tigerfish populations. From this study it is clear that the local populations (e.g. subsistence fisherman) living next to the Kavango River and tourist lodges (e.g. recreational anglers) share the same tigerfish resource. Therefore, the decline in tigerfish populations could cause conflicts between stakeholders of the Kavango River that are often dependent on one another. Increased conflicts between substance fisherman and recreational anglers have occurred in the Zambezi River which was attributed to the declining tigerfish fisheries (Tweddle et al. 2015, Cooke et al. 2016). In addition, tourist lodges offer paid employment for local communities often situated in rural areas were they make an important contribution in the economy (Tweddle et al. 2015, Cooke et al. 2016). The value chain for tigerfish has not been explored for the Kavango River. It is suggested that that socio-economic studies be carried out on the value of tigerfish in the Kavango River before their decline becomes irreversible which will increase conflicts between stakeholders of the Kavango River.

It is important that fisheries managers across international borders reach consensus on how to most effectively manage tigerfish populations, even though there is a lack of information regarding movement (Pracheil et al. 2012). The reasons why tigerfish used relatively large areas in the Kavango River remains unanswered and continual behavioural ecology studies are of utmost importance. Freshwater protected areas may be a viable management tool to sustain local tigerfish populations but, transboundary fisheries management in the Kavango River between Angola, Botswana and Namibia should be seen as a priority focus area.

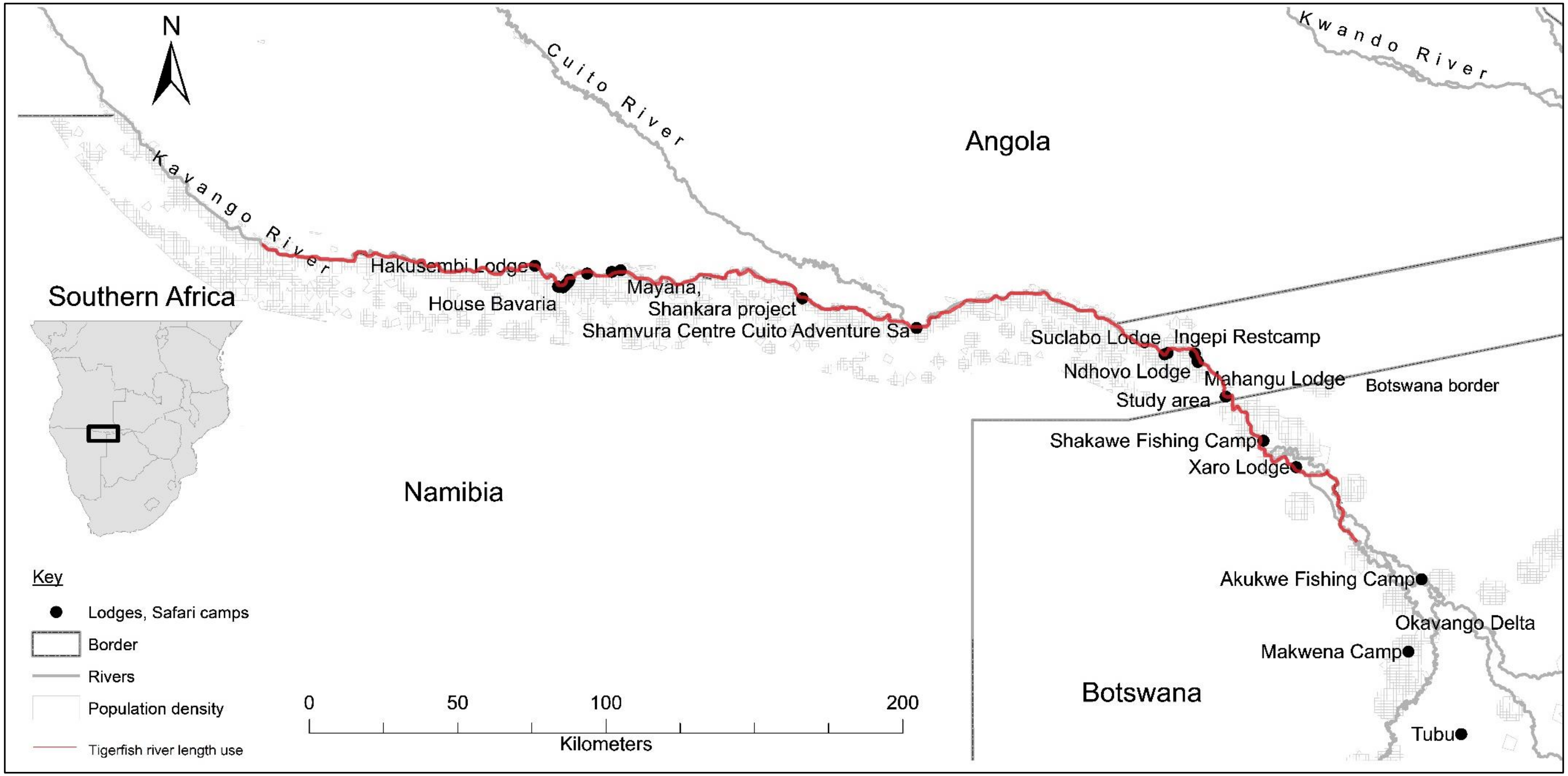

Figure 6.1: Locations of important lodges and safari camps in terms of employment and recreational fishing on the Kavango River and the population density next to the Kavango River. The river length use (red line) of *Hydrocynus vittatus* in the Kavango River during this study.

6.4 Scope for establishing new freshwater protected areas

Understanding the area use of tigerfish is essential for effective conservation planning (Bower et al. 2015). Radio telemetry was used to manually track tigerfish every twelve days from July 2016 to May 2017 in the Kavango River. Although no clear migration patterns were identified during the study, at least two river length use patterns were identified. Approximately, 50% of tigerfish displayed sedentary periods with limited home ranges and high site fidelity whereas others showed large scale area use. This study identified the relative river length use, however, it is important that future research focus on habitat use and life history patterns which is an important consideration for formulating FPA's to ensure survival of the species. It is suggested that an allocated protected area of at least 10 km, could protect at least 50% of tigerfish for at least 75% of the time from fishing mortality. The Namibian Inland Fisheries Resource Act, 2003 (Act No. 1 of 2003), makes provision for the establishment of FPAs, under Section 22 of the Inland Fisheries Resources Act (2003), as follows:

"Section 22. (1) The Minister, on his or her own initiative, or in response to an initiative of any regional council, local authority council or traditional authority, and in consultation with the regional council, local authority council or traditional authority concerned, may by notice in the Gazette declare any area of inland waters as a fisheries reserve if the Minister considers that special measures are necessary:

a) to preserve the aquatic environment;
b) to protect, preserve or rehabilitate the natural environment of fish, related ecosystems including wetlands, lakes, lagoons, nursery and spawning areas, which are essential to maintaining the integrity of an ecosystem, species or assemblages of species;
c) to promote the regeneration of fish stocks;

d) to protect fish resources and their environment from destruction, degradation, pollution and any other adverse impacts through human activities that threaten their health and viability."

6.5 Limitations and recommendations for future research

This study investigated stock status from 17 years of biological survey data, tagging techniques that may be best suited for behavioural studies and the area use of tigerfish. Therefore, extrapolation of conclusions from this study to other freshwater fish species, or even to other populations of the same species in other areas, should be avoided; such claims are not within the scope of this study. Similarly, this study did not include chemical measurements on stress caused by handling and tagging tigerfish, and so the data presented here are mainly observational, preventing any comment on the mechanisms behind the observed trends and area use.

Future research should focus on life histories of tigerfish and aim to elucidating seasonal trends in movement patterns and spawning behaviours, paying special attention to the various environmental drivers that is believed to dictate fish behaviour. The reason why tigerfish spawning has never been documented may be that they were previously considered migratory and therefore, researchers have overlooked the possibility of local spawning events. This should be investigated in the future. In addition to the annual gill net surveys to the Zambezi and Kavango Rivers which are all associated with large seasonal floodplains. It is suggested that annual monitoring should be conducted on the associated floodplains in an effort to gain knowledge on the interactions of the entire ecosystems. During the flood-pulse, water from the main rivers inundates nutrient rich floodplains which supports a rich diversity of aquatic organisms including tigerfish (Merron 1988, Winemiller and Jepsen 1998). The annual flood-pulse plays a major role in the life cycles of aquatic biota which is dictated by the timing of the seasonal floods. Consequently, many tigerfish depend on seasonal colonisation of floodplain habitat, either as possible spawning, feeding or nursery areas for juveniles (Jackson 1961, Winemiller and Jepsen 1998, Winemiller et al. 2015). Numerous studies have suggested that nutrient rich floodplains is of profound importance in the life cycle biology of tigerfish which should be explored to gain knowledge to aid in formulating better management guidelines for tigerfish (Winemiller and Jepsen 1998). Further radio telemetry studies could be performed using two conspecific groups of freshwater fishes, one freshly-wild caught and the other long-term captive, and therefore already accustomed to external radio tags, to determine if behaviour were perhaps influenced by the experimental procedures of radio telemetry. Radio telemetry, although relatively expensive compared to mark-recapture methods using plastic tipped dart tags, seems to be an appropriate tool to study the behavioural ecology of tigerfish. It is therefore suggested that continues behavioural studies be carried out on tigerfish to provide sufficient data on the spatial movement patterns, possible migrations and habitat utilisation of tigerfish in the Kavango River. This information will greatly improve our understanding of the habitat requirements and ecology of tigerfish and help formulate better management guidelines.

6.6 Conclusions

This study contributed to the knowledge of tigerfish in the Kavango River, including identification of population trends, behavioural techniques best suited to study tigerfish and essential river length use. The advantages of FPAs to tigerfish populations in the Kavango River is clearly identified in this study. The continual population and behavioural monitoring are important to generate information regarding population size and movement. These monitoring measures are highly important as it can inform management actions to ensure viable tigerfish populations in the Kavango River. The area use observed during this study showed that approximately half of the tigerfish population can be afforded some protection from FPAs. It is however, not clear if tigerfish restricted to relatively small area use or depends on larger area use. This will imply that river connectivity could play an important part in the life cycle processes of tigerfish in the Kavango River. Further investigations into movements, habitat use and life histories should be carried out to improve conservation and management strategies to mitigate declines in tigerfish populations.

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APPENDIX 6.1

Information poster PDF available for printing in A3 format

THE MOVEMENT OF AFRICAN TIGERFISH IN THE KAVANGO RIVER

Introduction

For decades, northern Namibia, especially the Kavango River and its adjacent floodplains, has been considered an important fishery. In recent years however, the area has faced unprecedented population growth, and a major concern for this system, is the depletion of the natural fish resources. The responsibility to ensure conservation, restoration, protection and sustainable utilization of all inland fisheries resources within Namibia, falls within the strategic objectives of the Ministry of Fisheries and Marine Resources. To achieve these objectives, an understanding of the biology and ecology of various fish populations is of paramount importance.

This study therefore aims to document behaviour, migration and habitat use of the African tigerfish *Hydrocynus vittatus* (Castelnau, 1861).

Importance of this study

The tigerfish is a charismatic species, endemic to African rivers and is considered one of the most important subsistence, recreational and commercial species. Their functional role as top predators in the transfer of energy between eutrophic floodplains and the main river is crucial in maintaining ecosystem functionality. Despite their importance, limited information exist on the movement of tigerfish in the Kavango River.

Materials and methods

- Tigerfish will be captured throughout the Kavango River using a range of techniques
- Each individual fish will be tagged with a highly visible and easily identifiable tag
- Release sites are recorded and movement of radio tagged fish are monitored constantly

Please help us fill in the gaps

- Recapture data is of vital importance for the success of this study
- Tags are imprinted with all the necessary information
- If a marked fish is captured, please record: Date, Tag number and place of capture (GPS if possible)
- Please SMS this information to (+264) 812868168
- If a radio tagged fish is captured please return the fish unharmed to the river
- If a fish carrying a radio tag is not released, please return the tag to Kamutjonga Inland Fisheries Institute (KIFI)

Conclusion

Information gained from this study will greatly improve our understanding of the biology and ecology of this highly important fish species. Future management guidelines will be compiled from the outcomes of this study to ensure the sustainable utilization and conservation of this species in the Kavango River.

UNIVERSITY OF KWAZULU-NATAL INYUVESI YAKWAZULU-NATALI · NINA Norwegian Institute for Nature Research · NCRST · NRF National Research Foundation · SAIAB South African Institute for Aquatic Biodiversity

For any additional information please contact:
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APPENDIX 6.2

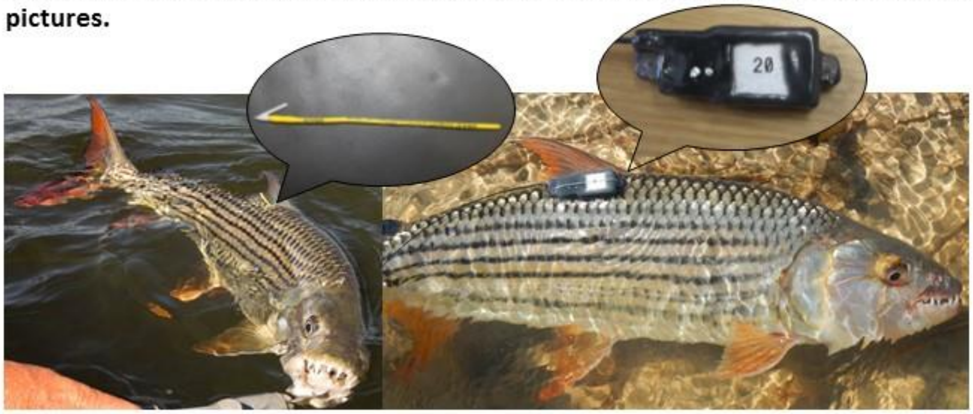
Information poster PDF available for printing in A4 format

IMPORTANT !!!

Report tagged fish

The Ministry of Fisheries and Marine Resources have tagged tigerfish in the Kavango River. The purpose is to study their migration, area and habitat use. **Information from recaptured tagged tigerfish are essential for the success of the study, and important for tigerfish research and management. We therefore rely on good collaboration with the local fishers.**

The tagged fish have an **external electronic tag (5.5 cm long, 2.2 cm wide, 1.1 cm thick, and black) or a bright yellow dart tag just below the dorsal fin. Please see the pictures.**



WHAT TO DO WHEN YOU CATCH A TAGGED FISH:

- Write down the number of the external tag or dart tag
- Write down the place, date, weight and length (Fork length) of the fish
- **NB! IF a fish with an external radio tag is captured, fish must be returned unharmed to the river, after information is recorded**
- REWARD for returned radio tags and information on the fish

Please phone or SMS +264 812868168 or e-mail francoisjacobs.mfmr@gmail.com when you have caught a tagged fish

Thank you for your help!

UNIVERSITY OF KWAZULU-NATAL INYUVESI YAKWAZULU-NATALI

NINA Norwegian Institute for Nature Research

NCRST

NRF National Research Foundation

SAIAB South African Institute for Aquatic Biodiversity

For any additional information please contact:
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APPENDIX 6.4

Information article appeared in Africa's Original Fly-fishing Magazine February/March 2017

GAMEFISH

Article and photos by Francois and Renate Jacobs

The fast and the FURIOUS

SCIENTIFIC PROOF ON WHERE AND HOW TO TARGET TIGERS

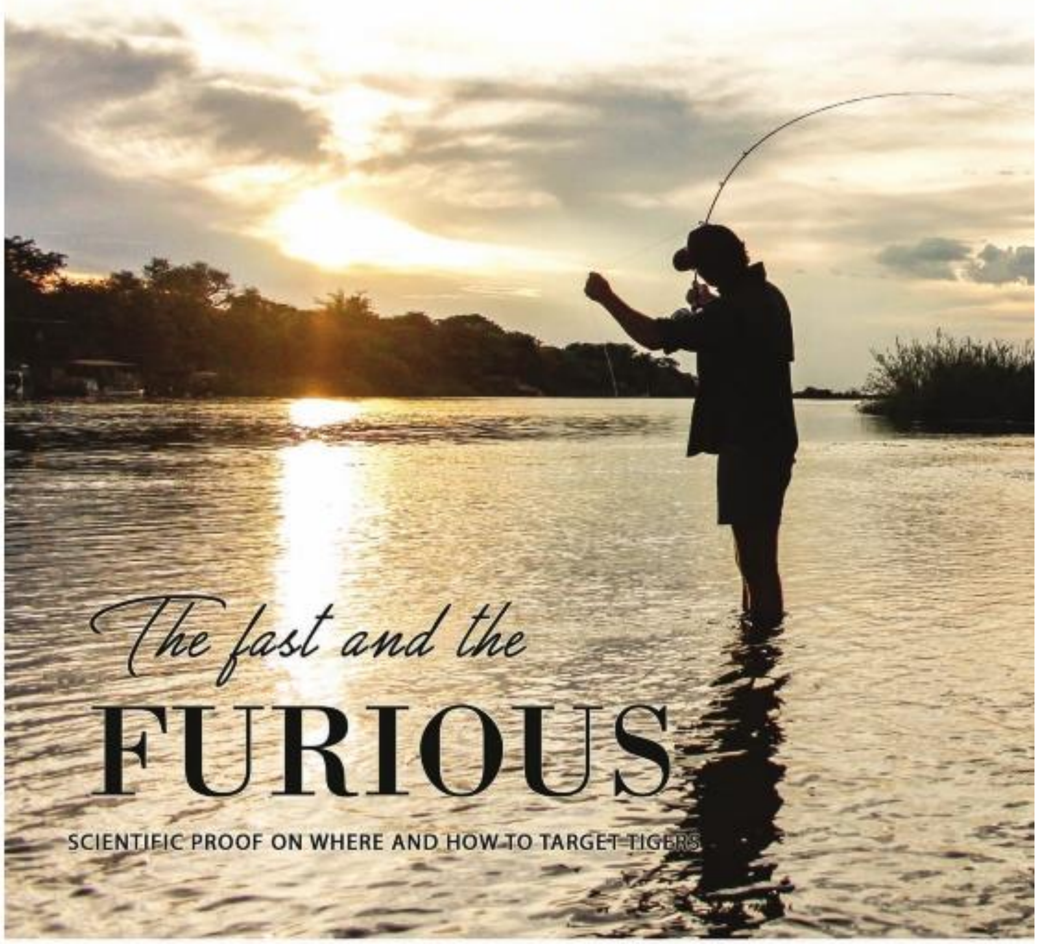
TRANQUILLITY, nature and the movement of the clouds encouraged my mind to drift whilst waiting for the long-anticipated strike. That strike that makes your heart pump volumes of excitement and energy. Suddenly the water exploded with a majestic jump, the flash of a bright red/orange tail and gaping jaws which left me in awe as I stripped in my slack line. Tigerfish wins again!

I battled to figure out what I'd done wrong — I had the best tackle on the market and the sharpest hooks ever made, but still I was losing fish one after the other. I often have to remind myself not to get so disheartened — in some cases rod-breakingly angry — and to accept the fact that I was losing to thousands of years of predatory evolution. If I can give only one piece of advice on targeting this phenomenal species, it's get used to losing — a lot!

The African tigerfish is often said to be one of the premier gamefish species in the world. The best description I have come across thus far was from IJ McCormick dating back to 1949. He stated, "the tigerfish of Africa is the fiercest fish that swims. Let others hold advocate for the mako shark, the barracuda, the piranha of the Amazon, or the bluefish of the Atlantic. To them I say hush, hush".

There's no doubt that the tigerfish deserves its reputation, especially with its impressive dental array and fabled fights coming from all corners of the Dark Continent, but the fact is that this once prolific species is fast becoming one of the most exploited species in southern Africa. Don't be fooled by its rather large range throughout the continent, singular populations in numerous systems are slowly but surely declining. What's even more concerning is that they are the dominant species in many rivers and lakes and their absence will change the entire trophic structure of ecosystems.

This species is my nemesis. I am honoured and privileged to have studied them over large parts of southern Africa and, to be honest, they have many powers over me. I have been in awe at what I have discovered and how resilient our African freshwater fishes can be. There are currently five described tigerfish species all endemic



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to Africa of which *Hydrocynus goliath* in the Congo is the largest, reaching weights of up to 50kg. For the purpose of this article we will focus on the most common tigerfish found in southern Africa — *Hydrocynus vittatus*. The current world record for this species stands at 16.1kg and was caught in Lake Kariba. That is a monster and it will probably hold the record for a very long time to come.

After analysing their populations from a number of large rivers and lakes dating back to the 1960s, I can assure you that any tigerfish around 5kg (fish between 5-8 years of age) can be considered a trophy to be proud of. The bulk of tigerfish populations are usually around 3kg (3-4 years of age).

There is already an impressive amount of literature on how to target tigerfish on fly, so instead of trying to write a how to guide on fishing for tigers, I have decided to provide readers with a little bit of scientific information that may or may not help you catch this highly prized trophy. If nothing else, it might change the way you see this species.

TIGERS AND THEIR ENVIRONMENT

Every person who fishes for tigerfish on a regular basis has probably had some close encounters with the local wildlife such as hippos, crocodiles, elephants, lions and buffalos, which are usually found in close proximity to tiger waters. If you've had the opportunity to experience this, cherish your memories, as the best tiger fishing is in pristine, intact freshwater lakes and rivers which are disappearing faster in Africa than anywhere else on earth. Pollution, habitat modification and unsustainable utilisation of fish resources play a major role in vanishing tigerfish populations. Only a handful of places still exist where decent trophy tigerfish can be caught on a regular basis. Without government intervention and education on the importance of sustainable fishing to local communities, it is a dark future for tigerfish.

That's the truth of it, but for a moment let's move away from the gloomy realities and deal with an even more difficult task ....

Be careful of crocodiles when fishing on sandbars.

SEARCHING FOR TIGERFISH

I am sure this section of my article will draw a lot of criticism, but having tagged well over 1 000 tigerfish in the Okavango River over the past year, their preferred areas have been well documented. Many anglers and guides will swear by structure for tigerfish, but it must be remembered that they are a pelagic species which prefers well oxygenated open water. Yes, you do catch them around structure (for example trees in Lake Kariba), vegetation (like in the Okavango Delta), and around rocky outcrops like in rapids and falls, but they spend most of their time in open water habitats.

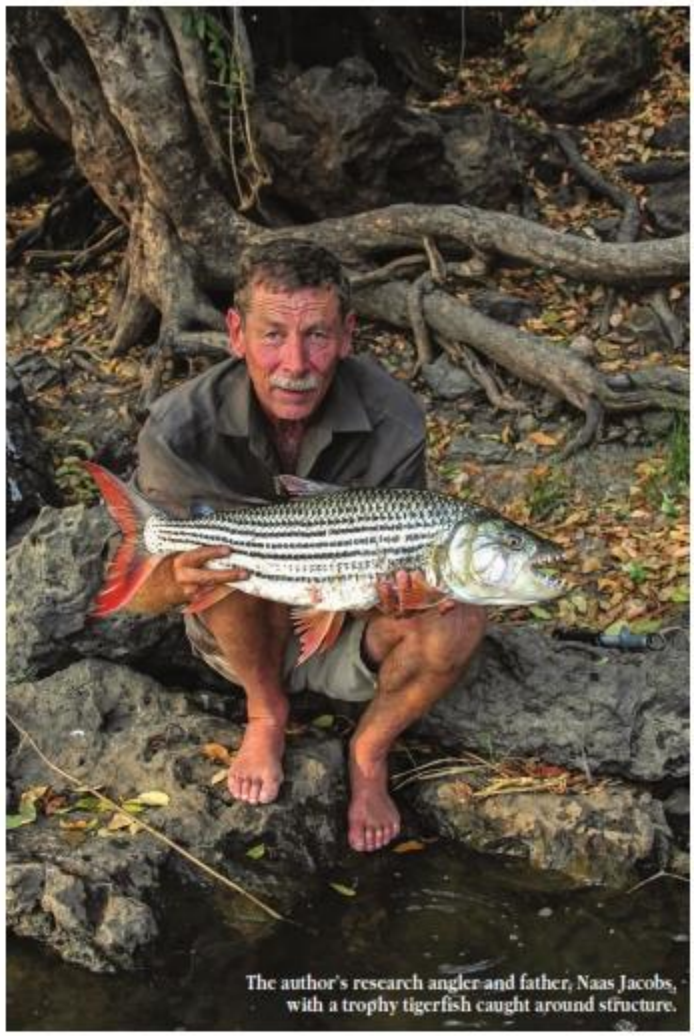
Tigers are not like bream or bass where individual fish search for the best structure and ambush prey from this vantage point; they are actually attracted to structure because of baitfish. If there are no baitfish around the structure, chances are that the tigerfish will not be around either — no matter how beautiful that fallen tree trunk or perfect that rapid looks from the outside. Many anglers waste days on end casting to structures and not catching anything, whereas a better option would have been to drift down the river and working the open water habitats. You'll be surprised at the areas in which you find tigerfish, so don't limit yourself by only looking for structure.

From tagging studies we know that there is a large variation in movement within the same population of tigerfish. For example, we have documented movement of up to 140km upstream within one month of tagging, whereas, some fish show strong territoriality and occupy a home range of less than one kilometre. It is therefore always advisable to start fishing within an area where you have previously had success.

I cannot emphasise enough that tigerfish will occupy areas were food is plentiful. Don't waste time in areas where there are no baitfish. If conditions change, they will vacate an area searching for better feeding grounds, and if you find baitfish, you will find tigers. It's as simple as that.

One of the most overlooked habitats is sandbanks. I am not talking about massive drop offs into deep water, instead I want to turn your attention to those flat sandbanks in the middle of the river that everyone seems to ignore. Tigerfish will often lie on top of sandbanks in water around 1.1m to 1.4m deep. Here, in contrast to their usual behaviour, they do to a certain degree ambush their prey.

The author rewarded for fishing on a flat sandbank.



The author's research angler and father, Naas Jacobs, with a trophy tigerfish caught around structure.

A small but beautiful fish.

Bulldog

Northern churchill

The velocity of the current sometimes increases marginally going over shallower habitats in the middle of the river, and with this change in speed, schools of baitfish are sometimes forced across these sandbanks. Tigerfish will hold their positions behind the slip faces (small depressions) on the sandbanks and shoot out at passing prey. After this attack they mostly occupy the area where they ended up instead of going back to the same position. This means they don't show strong site fidelity.

Although the usual fishing for tigerfish involves stripping as fast as possible, a technique that has really worked well is to cast upstream, much like for salmon fishing, and let your fly drift freely across the sandbank, keeping in direct contact at all times. Be ready, because when a tigerfish takes off in that shallow water it is something you will never forget.

WHEN TO FIND TIGERFISH

Tigerfish are often found in shoals of more or less the same age groups which means you can usually catch a few fish from a single shoal. When you find yourself in this position it is of paramount importance that you take control of your actions.

More often than not the following scenario unfolds: There are two anglers on the boat, you have suddenly run into a shoal of feeding tigers and the strikes are coming thick and fast. Unfortunately, all the fish are lost and the anglers are becoming very frustrated at the strikes they've missed. To make things even worse, angler A is trying his best to outfish angler B and the added sloppy casting, slack line everywhere and extra noise on the boat have spooked the fish as the next couple of casts reveal nothing. Sound familiar?

This is probably the most difficult thing for any angler to do, but if you find yourself in this predicament, try to analyse the situation and work out why the fish are at that specific place. If you don't see any boils, chases or white water from a pack hunting, it means that the fish are feeding in a controlled pattern, possibly on baitfish that are getting washed downstream by small discharge surges within the river. This is the jackpot you have been waiting for.

If this situation presents itself, the best thing is to take turns at casting. Make sure that you put your fly in the right place, keep your line tight and concentrate on the anticipated bite. If you can control the amount of disturbance you make to this area you may well take six or seven fish from the exact same place.

When you have made a couple of casts without any action, sit down, change your fly, drink a bit of water and reminisce about the fish you have just landed. If you give the area a rest for just a couple of minutes, it can bring the feeding back on and you may be rewarded with a couple more fish.

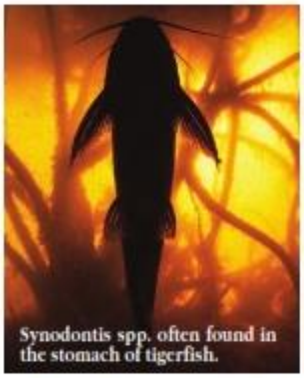
CHOOSING FLIES

Through various studies of prey length relationships we can theoretically work out that the majority of the tigerfish population prefers prey that is less than 40% of its own body length. For example, if the predator (tigerfish) length is about 55cm the maximum prey length will be 22cm. If you'd planned to chuck those big bulky GT flies on the next tiger trip you might be on to something. Although tigers will occasionally eat fish of those sizes, the size of the prey found in their stomachs varies greatly from place to place even within the same river. It helps a lot to keep a close eye on the small baitfish next to the sides — they will give you a good indication of the fly size that will work.

That being said, don't be afraid to experiment with really large flies because one of the species that we frequently find in tigerfish stomachs is from the *Synodontis genus* or squeaker species. Remember that tigerfish will prey on those species they encounter the most, and in the Okavango and Zambezi-Chobe River system that is most likely squeakers. To my knowledge no fly currently exists that resembles anything like these spiny little catfish.

Tigerfish are opportunistic predators and will switch to eating whatever prey is around. For example, they have been documented eating small crocodiles and birds and will gladly take flying insects when the opportunity presents itself. Due to their incredible agility and speed there are very few living organisms (in maximum prey size range) that will be passed up.

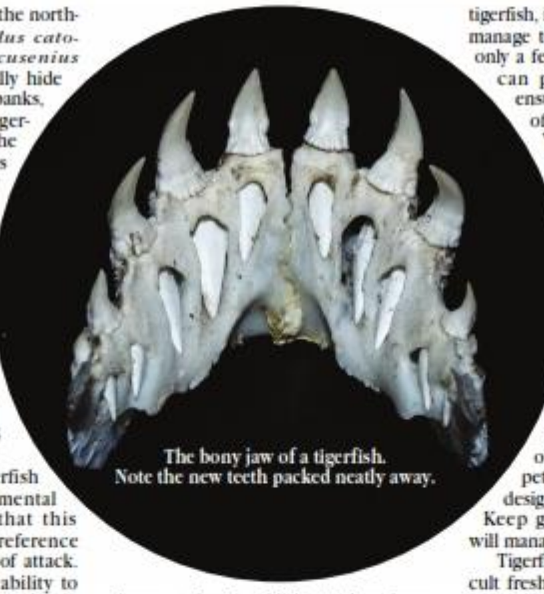
Watch out for these they will attack without hestitation.



Synodontis spp. often found in the stomach of tigerfish.

The best fly for tigerfish in the Okavango River tied by Frikkie Maartens.

Some baitfish species like the northern Churchill (*Petrocephalus catostoma)* and bulldog *(Marcusenius macrolepidotus)* which usually hide between rocks and undercut banks, are a good indication that tigerfish are around. Flies tied in the shape of these two species will certainly improve your chances. If you told me I could only choose one fly, it would be a baitfish pattern — as long as it was purple. Frikkie Maartens from Windhoek supplies my research team with all our flies and I have never come across more robust and perfectly tied flies that work.



The bony jaw of a tigerfish.
Note the new teeth packed neatly away.

WHY ARE SO MANY STRIKES MISSED?

Observing and studying tigerfish predation in a large experimental class aquarium, revealed that this species has absolutely no preference for any particular technique of attack. Its sheer speed gives it the ability to chase down prey and sink its teeth into whatever part comes first, whether it be the head, tail or middle of the fish. If a fish manages to escape the first onslaught the tigerfish will just continue chasing the fish until it catches it. After the prey is immobilised, the tigerfish will simply swallow the fish whole.

If you take a closer look at the design of their teeth, you will notice that they are made for biting and holding. This is the main reason why so many fish are lost during a take. It's simply because the tigerfish crunches down on the fly with its teeth and may never even have the hook properly in its mouth.

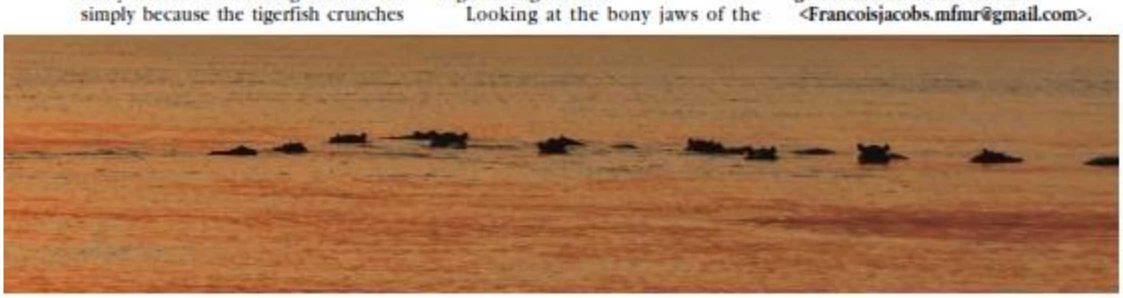
The secret here is not to strike with your rod, but rather give a short strip strike. If the hook manages to find a suitable spot, the fish is on and, if not, the tigerfish will almost certainly attack the fly again, thinking the prey managed to escape. However, this will only happen if the fly is jerked naturally and is not suddenly raised metres by the angler lifting the rod.

Looking at the bony jaws of the tigerfish, it is actually a wonder that we manage to land them at all. There are only a few small spaces where a hook can penetrate deep enough to ensure a fish on the boat, as most of the mouth is impenetrable. With this in mind, it's in your best interests to use the best quality hooks available and make sure you check them at regular intervals. Often during a missed strike the extreme tip of the hook will be bent against a tooth and I can guarantee you the next strike will be spat out due to improper penetration.

So, in conclusion, don't beat yourself up when you are missing one fish after the other, as you are simply competing against an incredibly well designed and well adapted hunter. Keep going — sooner or later you will manage to get one to the boat.

Tigerfish are arguably the most difficult freshwater fish to land on fly and they will win 90% of the time; it's just something you will have to get used to. However, the 10% that you do manage to land — after finger-blistering runs and the sound of teeth crunching down on your fly — will be imprinted on your memory forever.

• Francois Jacobs is the senior fisheries biologist at Kamutjonga Inland Fisheries Institute in Namibia. For further information on their tagging programme contact him via email <Francoisjacobs.mfmr@gmail.com>.



APPENDIX 6.5

Information article appeared in Stywe Lyne/Tight Lines August 2016

NAMIBIA takes pride in freshwater fisheries resources

Text: Francois Jacobs ♦ Photos: Francois and Renate Jacobs

The Ministry of Fisheries and Marine Resources (MFMR) of Namibia, in collaboration with the Norwegian Institute for Nature Research (NINA), has launched one of the largest freshwater fish-tagging programmes in Southern Africa.

Renier Burger, deputy director of inland fisheries and aquaculture, assists in the tagging programme.

Understanding fish behaviour can help us conserve this amazing species. The angler is Naas Jacobs.

The nembwe, an increasingly rare catch in the Kavango River.

To the Western world, gold, uranium, copper and diamonds are arguably the most important resources from Africa. The truth is that inland fisheries are far more valuable than any of these natural resources. With more than 450 000 km² of the African continent covered by water, inland fisheries provide 35% of animal protein intake in Africa and an estimated 2,5 to 4 million people derive subsistence and income from this resource. Unfortunately, there is a steady increase in articles that document the decline and extinction of our freshwater fishes. According to experts, our generation will witness the extinction of many fish species.

The freshwater fisheries sector in the northern perennial rivers of Namibia is considered one of the most important renewable resources in the country. The Zambezi River and surrounding lakes already supported a freshwater fishing industry of around N$9 million in 1996 (N$6 per kg of fish). Today that value is believed to have reached around N$75-100 million (N$20-40 per kg of fish), making fish a valuable commodity. Fishing is so deeply rooted in ritual and political power, especially in the Zambezi region (formerly Caprivi), where a common saying "if you don't fish you are not a Caprivian" is still used today. As more people have become involved in this highly profitable business, productivity has increased rapidly over the past few years. However, the catch per unit effort (CPUE) of subsistence, commercial and recreational fishermen has dropped significantly.

In an effort to improve the sustainable management of Namibia's freshwater fish stocks, the MFMR is carrying out several research projects. The information gained will greatly facilitate decisions on fishing regulation policies and the establishment of fish protected areas (FPAs) in Namibia.

TAGGING PROGRAMME

For the next few years, the MFMR and NINA are committed to a number of freshwater fish behavioural projects. The first of these projects includes a tagging programme in the Kavango River around the Popa Falls/Mahangu area (Divundu).

Long-term marking and recapture study

Capture-recapture methods, using external physical tagging, is one of the most common models for fishery scientists to determine the movement, growth, mortality, survival and recapture probability of fish species. Although this method rarely yields large catch returns, it can provide valuable long-distance migration data. In total an estimated 6 500 fish will receive plastic-tipped dart tags. The main target species include the African tigerfish *Hydrocynus vittatus*, threespot bream *Oreochromis andersonii* and nembwe *Serranochromis robustus*. This study is already underway and this article therefore aims to make the public aware of the process that should be followed when a tagged individual is captured. The MFMR would like to request the public to release all tagged fish back into the river after having recorded the information. The information and the number to which it should be submitted (SMS), are printed on the plastic dart tag.

Step 1

If a dart tag is visible on the fish, please record the following information:

- four-digit tag number, e.g. 0001
- date

Radio-tagged tigerfish.

Dart tag on tigerfish.

Tag applicator in position prior to tagging.

Reviving tigerfish after tagging.

Dart-tagged nembwe.

- place of capture (if possible GPS coordinates)
- if possible, fork length (tigerfish) and total length (bream)

Step 2

SMS this data to (+264) 812 868 168. If the fish is not returned to the river, please remove the tag, record the necessary data and return to:
Kamutjonga Inland Fisheries Institute, PO Box 5147, Divundu, Namibia

RADIO TELEMETRY

The other tagging method that will be used is radio telemetry. This technique provides high-resolution information of selected individuals. In total 60 fish will receive radio transmitters that will be monitored constantly for at least one year. Monitoring will take place manually by boat, on foot and from the air by using light aircraft. After positive identification of the fish's position, a range of environmental and behavioural parameters are recorded.

Radio telemetry is an expensive method and the MFMR requests that all tagged fish are returned to the river. If a fish is taken from the water, please return the radio tag to the address provided above.

The responsibility to ensure conservation, restoration, protection and sustainable utilisation of all inland fisheries resources within Namibia falls within the strategic objectives of the MFMR. To achieve these objectives, an understanding of the biology and ecology of various fish populations is of paramount importance. The MFMR would therefore like to acknowledge the support of the University of KwaZulu-Natal, the South African Institute for Aquatic Biodiversity (SAIAB) and the National Commission on Research Science and Technology (NCRST) of Namibia.