

**THE ROLE OF PROTECTED AREAS IN THE CONSERVATION  
AND MANAGEMENT OF FISHERIES IN THE CHOBE  
DISTRICT OF BOTSWANA**

**A thesis submitted in fulfilment of the requirement for a degree in**

**MASTERS OF SCIENCE**

**of**

**RHODES UNIVERSITY**

**by**

**MODIEGI BAKANE**

**DECEMBER 2016**

Supervisor: Prof. Olaf LF Weyl  
Co-supervisor: Mr. Denis Tweddle

**THE ROLE OF PROTECTED AREAS IN THE CONSERVATION AND  
MANAGEMENT  
OF FISHERIES IN THE CHOBE DISTRICT OF BOTSWANA**

**DECLARATION**

I declare that this thesis is hereby submitted to Rhodes University for a Master of Science in Ichthyology and Fisheries science (Management) and has not been submitted for a degree at any other University. This is my effort; The role of Protected Areas in the Conservation and Management of fisheries in the Chobe district of Botswana and I have not plagiarised anyone's work, ideas, phrases, passages, photographs or illustrations without prior and complete acknowledgment of their authorship.

## ABSTRACT

This study was aimed at better understanding the function of protected areas as a management strategy for the Chobe District fishery in Botswana, by first investigating the relative abundance in fish communities in and outside protected areas and secondly, by performing an assessment of the biology of commercially important large cichlid species viz threespot tilapia *Oreochromis andersonii*, greenhead tilapia *Oreochromis macrochir* and redbreast tilapia *Coptodon rendalli*.

In this study, data and specimens were collected during seasonal surveys between September 2014 and April 2015, using the standard graded fleets of gillnets employed in other programmes in the region, together with D-nets, angling and electro-fishing. The study demonstrated that fish communities in the floodplain ecosystems in the Chobe District of Botswana were representative of the region, containing some 70 species in 14 families. This study also demonstrated that for all the species collected, the mean Catch Per Unit Effort (CPUE) by weight for all the species was significantly higher in protected areas (Kruskal Wallis Test;  $P < 0.05$ ) namely, Zibadianja Lagoon ( $38 \pm 31$  kg/net.night<sup>-1</sup> and Savuti River/marsh  $25 \pm 19$  kg/net.night<sup>-1</sup>) than in the fished Chobe River floodplains CPUE ( $6 \pm 3$  kg/net.night<sup>-1</sup>).

Biological contributions were estimates of longevity, growth and maturity for *O. andersonii*, *O. macrochir* and *C. rendalli*. Age and growth were estimated using sectioned sagittal otoliths. The Von Bertalanffy growth equation from otolith derived length at age was  $L_{t(mm)} = 298 (1 - e^{-0.59(t - 0.98)})$  for *O. andersonii* and  $L_{t(mm)} = 337 (1 - e^{-0.20(t - 2.35)})$  for *C. rendalli*. The results indicated that protected areas enhanced fish longevity, and fish in protected areas were larger and older than those in exploited areas. Maturity estimates for the large cichlids were consistent with other research in the region and the length-at-50% maturity was estimated as 250mm  $L_T$  for *O. andersonii*, 225 mm  $L_T$  for *O. macrochir* and 210 mm  $L_T$  for *C. rendalli*.

Management recommendations are therefore to retain gill net mesh size regulations that ensure that these fish reach maturity and can breed before being harvested and to assess the possibility of increasing the number of protected areas in the district.

## ACKNOWLEDGEMENTS

A sizeable number of individuals and organisations contributed to the success of my study. First, my heartfelt gratitude goes to Prof. Olaf Weyl and Mr. Dennis Tweddle for their unreserved mentorship and supervision provided during my studies. It would be logically absurd to presuppose that the study could have been accomplished without their direction. Many thanks go to Gunda Spingies for proofreading my thesis.

I would like to sincerely thank the Government of the Republic of Botswana, the Ministry of Environment Natural Resources Conservation and Tourism and the Department of Wildlife and National Parks who gave me the chance, opportunity and privilege to read for a Master's Degree. I would also like to thank the Ministry of Environment Natural Resources Conservation and Tourism of Botswana for granting me the permission to conduct my research in the Chobe district of Botswana.

I would like to thank Richard A. Peel and Geraldine C. Taylor for their assistance during my project. Thank you, Richard, for making otolith extraction easy and smooth with the right equipment and thank you Geraldine, with your valuable experience, for making it easy for me to cut and read the otoliths. To custodians and managers of the Selinda Reserve Ng 16, the Joubert family, Derreck and Beverly, Pete and Sharon, George and Emma, the great plains staff, the professional guides who assisted us to load the boat, for accommodating us at CSU and granting us the permission to sample in their area I say thank you. Many thanks go to the Kavimba fishermen at Longara for the fish purchases. I also extend my thanks to the Regional Wildlife Officer, Chobe, Mr. Balisana Marotsi, (R.I.P) and the Research, Statistics and Fisheries personnel at Kasane for their endless support during my data collection.

I also thank my colleagues, the staff at the South African Institute for Aquatic Biodiversity, Department of Ichthyology and Fisheries Science, for welcoming me to South Africa and specifically to Rhodes University. Many international students, friends and contemporaries at Rhodes University, particularly from Mumuni Abdullay from Ghana and Jazman from Malawi deserve my thanks.

## **Table of Contents**

<b>DECLARATION.....</b>	<b>ii</b>
<b>ABSTRACT.....</b>	<b>iii</b>
<b>ACKNOWLEDGEMENTS .....</b>	<b>iv</b>
<b>CHAPTER 1: GENERAL INTRODUCTION.....</b>	<b>1</b>
1.1    Introduction.....	1
1.2    Fisheries .....	2
1.3    Chobe District Fisheries.....	5
1.6 Fisheries Management in Botswana .....	8
1.7 Thesis outline .....	11
<b>CHAPTER 2: STUDY AREA AND FISH BIODIVERSITY IN CHOBE–ZAMBEZI AND KWANDO–LINYANTI RIVER SYSTEMS .....</b>	<b>12</b>
2.1 Introduction.....	12
2.2. Description of the Study area.....	13
2.3 Materials and methods .....	20
2.3 Results.....	30
2.4 Discussion.....	43
<b>CHAPTER 3: EXPERIMENTAL GILLNET CATCHES, COMPOSITION AND RELATIVE ABUNDANCE OF LARGE CICHLIDS SPECIES IN THE CHOBE DISTRICT, BOTSWANA .....</b>	<b>50</b>
3.1 Introduction.....	50
3.2 Material and methods.....	52
3.3 Results.....	53
3.4 Discussion.....	63
<b>CHAPTER 4: AGE AND GROWTH OF THREESpot TILAPIA OREOCHROMIS ANDERSONII, GREENHEAD TILAPIA OREOCHROMIS MACROCHIR AND REDBREAST TILAPIA COPTODON RENDALLI IN THE CHOBE DISTRICT OF BOTSWANA .....</b>	<b>70</b>
4.1 Introduction.....	70
4.2 Materials and methods .....	72
4.3 Results.....	75
4.4 Discussion .....	81
<b>CHAPTER 5: REPRODUCTIVE BIOLOGY OF LARGE CICHLIDS IN THE CHOBE DISTRICT, BOTSWANA.....</b>	<b>84</b>
5.1 Introduction.....	84
5.2 Materials and methods .....	85

5.3 Results.....	88
5.4 Discussion .....	93
<b>CHAPTER 6: CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS.....</b>	<b>98</b>
6.1 Management recommendations .....	99
<b>REFERENCES.....</b>	<b>101</b>

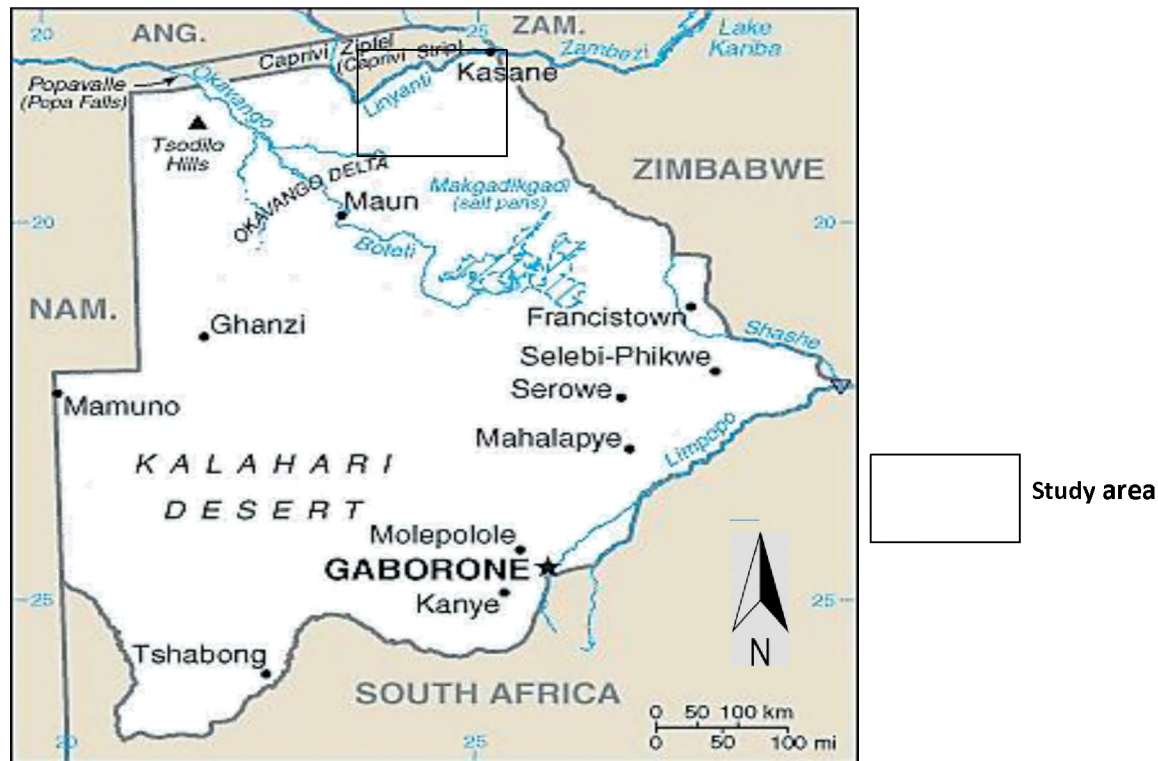
## **CHAPTER 1: GENERAL INTRODUCTION**

### **1.1 Introduction**

Botswana is a landlocked country in southern Africa (Tlou & Campbell, 1983; Jefferis & Nemaorani, 2013), which extends for 581,730 km<sup>2</sup>, is slightly smaller than Texas and slightly larger than France (Government of Botswana, 2001; FAO, 2007). Botswana is bordered on the south-east and south by South Africa, on the north-east by Zimbabwe, Zambia on the north and Namibia on the west and north-west (Tlou & Campbell, 1983) and has an estimated population of 2.1 million people (Botswana Central Statistics, 2011). It is a middle-income country, and is amongst those countries with the highest gross national income at purchasing power parity in Africa (US\$ 14.41 per capita in 2012; FAO, 2007). Botswana's economy is prosperous and dominated by the mining sector which accounts for 40% of all government revenues, and which is one-third of its Gross Domestic Product (GDP). The travel and tourism sector contributed 6.5% to GDP in 2012 (WTT, 2012) and is the second most important contributor to economic growth after diamond mining, which is the pillar for Botswana's economy (Mosetlhi, 2012). However, culturally in Botswana, livestock (cattle and small stock) production and crop production were the principal economic activities (Tlou & Campbell, 1983; Government of Botswana, 2001).

Climatically, Botswana is situated adjacent to the subtropical high pressure belt of the southern hemisphere; as a result of which the country is arid to semi-arid (Botswana National Report, 2012). Botswana's terrain is mostly flat, covered with savanna grasslands and about 84% of the soil is the Kalahari sands (Hitchcock & Smith, 1980; Tlou & Campbell, 1983; Government of Botswana, 2001). There are two main seasons, a hot, (maximum = 44 °C) and wet summer (September to March) and mild but sometimes very cold (can drop below zero) dry winters from April to August. Precipitation is low, erratic, unreliable, unpredictable and regional (Jefferis & Nemaorani, 2013). The mean annual rainfall ranges from 650 mm in the Chobe District to 250 mm in the Kgalagadi District (Hitchcock & Smith, 1980; Merron, 1991). Insolation is very high, and the country receives between 3200–3600hrs of sunshine per year; consequently, evapotranspiration rates are between 1800 mm to 2200 mm annually for surface water (Jefferis & Nemaorani, 2013). Drought

in Botswana is a recurring phenomenon (Jefferis & Nemaorani 2013; Government of Botswana, 2001). The worst years of drought were between 1981/82 to 1986/87 (Jefferis & Nemaorani, 2013).



**Figure 1.1** Map of Botswana showing the study area; source adapted with modifications ([http://www.mapcruzin.com/free-maps-botswana/botswana\\_sm\\_2008.gif](http://www.mapcruzin.com/free-maps-botswana/botswana_sm_2008.gif)).

## 1.2 Fisheries

The fisheries sector in Botswana consists of wild capture fisheries and aquaculture (FAO, 2007; ALCOM, 1996b). While the contribution of the fisheries sector to the national economy is insignificant (0.002% of GDP), (Anon, 1989; FAO, 2007), they are of critical importance to livelihoods for rural development and food security (Halwart et al., 2003; FAO, 2007). This is because fish resources are widely dispersed and easily accessible to marginal and isolated communities, who have no alternative sources of income (Welcomme et al., 2006). Therefore, overfishing and concomitant declines in catch rates pose a threat to food security in these riparian



communities. This is because the rural poor resort to fishing during times when agriculture fails. For example, in Ngamiland, Botswana, in 1996 to 1997, during a cattle eradication exercise due to the contagious cattle lung disease, fish revenues contributed substantially to household earnings (Mosepele & Ngwenya, 2010).

The Okavango Delta is a wetland of international significance (Breen et al., 1997; Ramberg et al., 2006), and this 1000<sup>th</sup> UNESCO World Heritage site (UNESCO, 2014), constitutes the main wild capture fishery, yielding ~ 80% of the national fish catches (Mosepele & Nengu, 2003; FAO, 2007). Fishing activities are typically artisanal, conducted using canoes made from wood (*mokoros*) or fiberglass (FAO, 2007) and the key exploited species in the Delta are Tilapiines cichlids e.g., *Oreochromis andersonii*, *Oreochromis macrochir* and *Coptodon rendalli* (Mosepele, 2000; Mosepele & Kolding, 2003; Mosepele et al., 2003).

The second-largest waterways are the Zambezi-Chobe and Kwando-Linyanti wetland system in the north of Botswana. Historically, the Chobe River floodplains and Lake Liambezi have supported important subsistence and commercial fishing (Merron, 1989a). It has been recorded that in the distant past, yields of more than 1000 tonnes per annum, have been marketed from Lake Liambezi to Zimbabwe and Zambia (Botswana Agricultural Report, 1985). The Chobe system contributes a fraction to the national catch. This is because fishing is not permitted in Chobe National Park, and the bulk of the Lake Liambezi lies in Namibian waters and only about 1% lies in Botswana, therefore very little fishing takes place. The principle species fished are the same as those in the Okavango fishery (FAO, 2003).

The freshwater Lakes Ngami, Xau and Liambezi used to be highly productive, supporting good fishing but dried up as a result of prolonged droughts (Kolding, et al., 2016). However, since the 2010 floods, the lakes have rejuvenated (Bakane pers.obs.). Lake Liambezi for example, was a major fishing area for the Chobe District and Caprivi strip in the 1970s prior to its desiccation in 1985 (Botswana Agricultural Report, 1985; Gumbo, 2010; Simasiku, 2014). However, in 1985, Lake Liambezi dried out and fishermen had limited fishing grounds. This prompted Fisheries in Botswana to assess alternative fishing grounds which were later established in Linyanti near the Zibadianja Lagoon. These unconventional fishing grounds, identified at Linyanti swamps, were

largely for the Satau and the Parakarungu Fishing Cooperative designated for commercial fishing. The cooperative has since collapsed because of poor governance and management in the author's opinion. However, in 2014 the cooperative resuscitated, although now as an association called Chobe Fresh and Dry Fishermen's Association.

However, there has been conflicts between the commercial fishermen and concessioners managing the area, which led to the eviction of fishermen from this fishing ground on 28 October 2012. In the initial stages of the conflict, the Concessionaires insisted that their leases did not permit commercial fishing (use of factory made gillnet to catch fish) although they could permit subsistence fishing. The other reasons brought forward were that fishers pollute the area, block tourists' routes (the area is a photographic concession) and there was suspicion of poaching on a subsistence level. Fisherman's resistance rested on the premise that they also have access and user rights into the Concessions. Elsewhere fishing conflicts have been recorded between artisanal and commercial fishers (Pauly, 1979). For example, in Okavango, the impasse was between commercial fishermen and tour operators (Setshwalo, 2007; Mosepele & Ngwenya, 2010), where tour operators called for a moratorium on fishing in lagoons and on basket fishery in floodplains. These tour operators based their argument on a tourism policy that granted them exclusive user rights (Government of Botswana, Tourism policy, 1990). Mosepele et al. 2003 contended that commercial fishermen and recreational fishers compete for the same trophy market sized fish and that a lack of defined user, access and well-defined property rights (Mosepele et al., 2015) instigates conflicts while Yasmi et al. (2006) argued that the impasse arises when there are varied interests of people in a particular resource.

The other areas with fishery potential are major dams in south-eastern Botswana; Gaborone, Shashe, Bokaa, Letsibogo, and, recently, Dikgatlhong, Thune and Lotsane (FAO, 2007; DWNP unpublished monitoring surveys). Aquaculture development in Botswana is still in its embryonic stage. When fully developed, it is a key sector for job creation and ensuring food security. Its history dates to the 1980s and 1990s when Aquaculture for Local Community Development (ALCOM) under the auspices of the FAO sought to address the region's poor and undernourished rural populations by promoting fish production (ALCOM, 1996b). In an endeavour to promote aquaculture, Botswana, under the National Development Plan 9 (NDP 9), funded and established

a state hatchery in Mmadinare near Letsibogo Dam to diversify the economy, enhance rural livelihood and to supply fingerlings to aspirant aquaculturalists (Davis, 2011).

### **1.3 Chobe District Fisheries**

Fishing is a traditional activity of high significance in Chobe and the Ngamiland Districts of Botswana. The early traditional fishing activities of the indigenous people in the Okavango and Lake Ngami have been described by Andersson (1967) and Tlou (1985). For instance, the River San poisoned the lagoons with rubber hedge (*Euphorbia tiriculla*), spear fished and used funnel-shaped traps. They were later followed by the Zambezian people, the Bayei, who introduced traditional nets and weirs made of plant materials (Tlou, 1985). In the Chobe District the Basubia (Veekuhane) of Chobe also used traditionally crafted nets (*Lukuku*) and traps for fishing (Shamukuni, 1972). Fish was, and is, an important part of the diet of the Basubia, not only as a source of protein but a source of perceived intelligence because it is locally believed that one who eats fish, especially its head, becomes intelligent (Shamukuni, 1972). Commercial fishing is catching fish with factory made gillnets (Botswana fish Protection Regulations 2008). Based on the number of commercial fishing licenses issued, there are about 120 commercial fishermen in the Chobe District of Botswana (DWNP unpublished data, 2008–2014); however, the Chobe Frame survey, conducted in 2008 recorded a total of 319 fishermen (van der Waal et al., 2008, unpublished).

The frame survey is a complete census and inventory of the number of landing sites, fishermen, fishing vessels, gear by type and size as well as the processing and marketing strategies of the fish resources (Cowx et al., 2003). Frame surveys are important because they provide the fisheries managers, stakeholders and researchers with information on the composition, magnitude of fishermen's crafts and gear to guide the development and management of the fisheries. This knowledge also helps in the assessment of socio-economic factors in the community (FAO, 2002).

Last conducted in 2008 in Chobe District of Botswana, the frame survey revealed that the fishermen were aged between 11 and 99 years old and that there was higher involvement among men (71%) than women (29%) in wild capture fisheries (van der Waal et al., 2008 unpublished). This agrees with the findings by Mosepele (2001) who reported more males (56%) than females

(44%) in the fishery of the Okavango Delta. Salas and Gaertner (2004) claimed that social and cultural factors such as gender, age, income and ethnicity shape access to fishing and the methods and gears employed. This is true for fisheries in Botswana where, if women are involved, they fish with traditional gears such as basket, bottles, line and hook and are involved in the gutting and selling of the fish (FAO, 2007; Gumbo, 2010; Bakane pers.obs.). The Basubia tribe comprised most the fishers (74%) followed by the Basarwa 5%, Bayei 4%, Bambukushu 4%, Kalanga 3%, Lozi 4%, and the remaining (6%) are other Botswana tribes (Batawana, Bangwato, Banajwa, Badereku and foreign nationals such as the Shona, Ndebele and Tonga). Eighty-eight fishing craft were recorded where the universally used craft were mekoro (84%), followed by 7% fibre glass and 2% aluminium vessels.

In the Chobe Frame survey of 2008, 844 set of fishing gear were recorded. Hook and line comprised the major fishing gear, (used by 69% of the interviewees) followed by gillnets (28%), bottles traps (2%) and the other gears (1%) such as mosquito bed nets, hand picks, traps and baskets. In the Chobe District of Botswana and in the Zambezi Region of Namibia, one unique subsistence gear for harvesting small fish (e.g. *B. lateralis* and *M. acutidens*) is the use of bottle traps (Bakane pers.obs.).

#### **1.4 Fish surveys**

Pioneering studies in the Chobe Region in the 1800s concentrated on fish collections. For example, in the 1890's Emil Holub, the Austrian, collected *Sargochromis giardi* in Chobe River (Bell-Cross & Jubb, 1976). After him, the Vernay-Lang Kalahari expedition followed in 1930 (Fowler, 1935a) in the Chobe River near Kasane. This was followed by the Bernard Carp expedition in 1952 in Kwando River (Jubb, 1958). They were succeeded by the Lake Liambezi fish collection for the Queen Victoria Museum, Zimbabwe, in 1961. Later a study on the effects of *Salvania molesta* on fishes at Shaile (Linyanti) was conducted by Fox and Watt (1976). Since then, studies in the region were published by van der Waal (1976, 1980 a, b), 1984, 1985, 1990, 1991) and Skelton in the Caprivi, (1976), Skelton et al. (1985), Skelton and van der Waal (1984), who reviewed the early history of fish collections in the Chobe Region. They were followed by Merron (1989a) who conducted surveys in Kwando, Selinda spillway and Chobe River between September 1985 and December 1986 and recorded 53 species. He found that the ichthyofauna assemblage in this region

resembled Okavango Delta species. In the same year (1985) a recreational fishing competition was staged at Kasane in the Chobe River and 172 fish (nine species) were captured (Merron & Sehemo, 1987).

More recently, Hay et al. (1996, 1999, 2000, 2002, 2003), Tweddle (2009, 2010), Tweddle et al. (2003, 2009, 2010, 2011, 2015), Tweddle and Hay (2011) conducted studies in Namibian waters shared by Botswana and Namibia and partly in Okavango. Numerous studies have concentrated in the Okavango Delta (e.g., Merron, 1991; 1993a); Merron & Bruton, (1984a, b, 1988, 1995); Kgathi et al. (2005); Mmopelwa et al. (2005), Mosepele (2000, 2001); Mosepele et al. (2003, 2005, 2009); Mosepele & Ngwenya (2010); Bokhutlo (2011) but not on the Chobe-Linyanti and Zambezi wetland of Botswana. By 2000 a holistic approach into fisheries research emerged, such as utilisation of modern technologies such as telemetry studies by Hay et al. (2003). Co-management is promoted due to the recognition of conflicts between riparian states and the transboundary nature of fisheries resources (Tweddle & Hay, 2011). In-depth studies of Lake Liambezi fishes and fisheries were later undertaken by Peel (2012) who focused on large cichlids biology, and later Simasiku (2014) assessed the fishery of the Lake, and Peel et al. (2016) described the ecology, fishes and fisheries of the Lake.

## **1.5 Overfishing**

In the Okavango Delta, the potential annual fish yield was projected to be between 5 000 and 8 000 tonnes in 2003 (FAO, 2003). The previous research showed that there was abundance of fish that, to some extent, it was unexploited (ARDC, 2001; FAO, 2007). There were, therefore, no signs of overfishing of the main fish stocks in the Okavango Delta (Mosepele & Kolding, 2003). For example, Kgathi et al. (2005) demonstrated that CPUE data remained stable between 1996 and 2002. However, of recent, in the southern part of the Okavango, a fishing ban was imposed in Lake Ngami and Lake Xau during the 2015 fishing season (Weekend Post, 2 March 2015). The closure was not based on any scientific data because no comprehensive study had been conducted on Lake Ngami fishery after flow resurgence in 2007. The main issue was that, there was a lucrative market in Zambia and the Democratic Republic of the Congo, where large quantities of fish were exported (e.g., in a single trip a fisher could export 6000 fish). This kind of harvesting was seen as unsustainable, hence the ban of fishing in the lakes. There were also environmental concerns such

as pollution and unhygienic conditions as a result of the influx of people (estimated at up to a 1000), including foreigners who camped around the lake and had no ablution blocks (Weekend Post, 2 March 2015). However, one should be cautious in future because fishing effort levels are increasing as more people venture into fishing, and with the introduction of monofilament nets, fishing is becoming unsustainable. For example, in the Chobe River floodplains, which are part of the Caprivi floodplains, there are signs of overfishing evident in a decrease in catch rates of larger cichlids. This has been attributed to the fishing pressure caused by the replacement of multifilament nets by the more efficient monofilament gillnets (Simasiku, 2014; Tweddle et al., 2015).

## **1.6 Fisheries Management in Botswana**

Fisheries management in Botswana is the role of the Fisheries Division (FD) under the Department of Wildlife and National Parks (DWNP) in the Ministry of Environment, Natural Resources Conservation and Tourism. The division used to be managed by the Ministry of Agriculture under the National Policy on Agricultural Development (1991). The core mandate of DWNP is to conserve the fish and wildlife of Botswana in consultation with local, regional and international stakeholders and Fisheries Division oversees conservation, management and sustainable utilisation of Botswana's fish stocks in man-made dams, and natural rivers as well as aquaculture development. The legal instruments for fisheries management are the Fish Protection Act of 1975, Fish Regulations of 2008 and in the case of fisheries in the protected area (such as where Chobe River traverses the Chobe National Park), the Wildlife and National Parks Act of 1992 takes precedence. However, plans are underway to incorporate the Fish Regulations and Act into the Botswana Wildlife and National Parks Act of 1992. However, besides this Acts there is no national fisheries policy to guide fisheries management (Mosepele & Mosepele, 2005).

The Fisheries management approaches in Chobe District of Botswana include effort regulations, fishing closed season, co-management and licensing. However, the fisheries resources in the Zambezi-Chobe and Kwando-Linyanti wetland system are complex to manage because they are a shared transboundary resource between the countries. For example, there are multi-stakeholders with divergent mandates, laws and even diverse land uses such as National Parks adjacent to communal areas and Conservancies. However, the wetland falls within the Kavango Zambezi

Transfrontier Conservation Area (KAZA TFCA), which was formed with the understanding that, adjacent ecosystems are interdependent, thus the need to cooperate as riparian countries and to eliminate physical impediments to wildlife including fish and birds that transverse boundaries.

Effort regulation is one of the most implemented control methods (Tweddle, 2009). For all major dams in Botswana, effort regulation is performed by restricting the number of fishermen per dam (e.g., a quota of about three to four fishermen per dam), while commercial fishermen are prohibited from using a panel of more than 150 m length of gillnet (Botswana Fish Protection Regulations, 2008). These regulations reduce the effort and controls the amount of catch hence minimising chances of overfishing. Mosquito nets are prohibited to protect juveniles fish and recruitment into fishery. Coupled with these, is the issuing of fishing permits by the Department of Wildlife and National Parks under the licensing unit in Botswana. This ensures that fishermen import the acceptable gillnets mesh sizes (Botswana Fish Protection Regulations, 2008).

A closed fishing season is a method to protect the fish communities during their reproductive phase to ensure successful recruitment and reduce fish mortalities (Bhukaswan, 1980; Bedding & Rettig, 1984). Closed seasons are implemented mainly to protect the species over the spawning season or to limit catch effort (Gullard, 1974). For example, in Malawi, fishing closed season commences on 1 November to the end of December to protect Chambo (*Oreochromis* “nyasalapia” spp) during their spawning (Donda & Njaya, 2007). In Botswana, fishing closed season was strategically initiated to protect spawning fish; as most of the species spawn in summer (van der Waal, 1985; Peel, 2012). The closed season runs from the first of January to the end of February each year. This is a compromise between the fishery management and the fishermen. This is because during the wet season for Botswana, the majority of fishers leave fishing as it overlaps with ploughing, hence releasing pressure from the fisheries (Mosepele, 2001; Ngwenya et al., 2012). This has also been observed in Lake Liambezi where fishermen return to villages in spring to plant crops and resume fishing after the rains (van der Waal, 1980). Zambia's fish closed season is synchronised with Botswana's close season except that Zambia's moratorium runs from 1 December to the end of February, and similarly for Namibia fish closed season is from 1 December to end of February. The country however, rarely enforces the moratorium, with the except during the outbreak of epizootic ulcerative syndrome when the fishery was closed from 21 December 2006 to 28 February

2007 (Tweddle, 2009). Local fishermen acknowledged significantly improved catches experienced in 2007 after the floods as a result of the moratorium (Tweddle, 2009). Coupled with these are closed areas meant to regulate fishing efforts by designating a geographical location as a closed area for fishing (Bedding & Rettig, 1984). For example, in Botswana, any form of fishing is prohibited inside protected areas such as in National Parks and Game Reserves (Wildlife and National Parks Act, 1992; Fish Protection Regulations, 2008). This ensures the protection of fish stock and these stocks recolonise adjacent areas (Bedding & Rettig, 1984).

Minimum length restriction has not been implemented in Botswana fisheries. The main purpose is to prohibit fishers from harvesting immature fish of designated length size, so that they can mature and spawn at least once before exploitation. In Botswana, it is prohibited to use mesh sizes less than 4 inches (100 mm), while in Namibia it is permissible to use 3 inches (76 mm) which might capture immature fish (Inland Act MFMR, 2003). In Malawi, based on fish size at maturity information, minimum size restriction is implemented to protect young fish to enable them to mature prior to harvesting (Donda & Njaya, 2007). For management purposes, in heavily exploited areas such as Zambezi and Chobe rivers, the vulnerability of large cichlids to overharvesting could be reduced by using minimum length limits to delay entry of year classes into the fishery (Payne et al., 1990). By allowing the fish to mature, they will contribute to future spawning stocks and increase in catches (Burr, 1991).

The Shared Resources Management project (SRM) on the Zambezi and Chobe Rivers in the Eastern Caprivi has been initiated in collaboration with neighbouring countries to formulate research methodologies and acquire skills to ensure consistency of survey methodologies, and to develop working relationships between stakeholders on both sides of the river (Naesje et al., 2002, 2003). Several NAMBOT (Namibia and Botswana) joint security meetings have been held twice yearly by various departments to combat and address fisheries and wildlife crimes, and to educate and consult with riparian communities living along Chobe-Linyanti-Kwando and the Zambezi Region of Namibia.



## 1.7 Thesis outline

Management of any natural resources should be based on sound scientific knowledge of the biology of the target species (Bokhutlo, 2011). The aim of the study is to better understand the function of protected areas as a management strategy for the large cichlids Threespot tilapia *Oreochromis andersonii*, Greenhead tilapia *Oreochromis macrochir* and Redbreast tilapia *Coptodon rendalli* fishery in Botswana. These species are the most preferred and targeted by fisherman (Mosepele, 2000).

The thesis is comprised of five chapters. After the general introduction (Chapter 1), Chapter 2 describes the study area and its fish biodiversity. In Chapter 3, experimental gillnet surveys are used to assess whether commercially important large cichlids are more or less abundant in exploited areas. In Chapter 4, the age and growth of large cichlids are explored to test whether the exploited areas have older large-bodied fish and to assess regional variations in growth rates between these populations and a population assessed by Peel et al. (2016). In Chapter 5, the reproduction of the three species was assessed to determine the length at 50% maturity of large cichlids in the Chobe District and to show how it differs from that in the Zambezi, Kwando and Okavango Rivers and whether the minimum mesh size recommended by Peel (2012) from the Zambezi region (Namibia) would be appropriate for the Chobe District. Finally, Chapter 6, includes the general discussion and management recommendations for Chobe fishery with particular reference to the large cichlids in Botswana.

## **CHAPTER 2: STUDY AREA AND FISH BIODIVERSITY IN CHOBE–ZAMBEZI AND KWANDO–LINYANTI RIVER SYSTEMS**

### **2.1 Introduction**

For fisheries managers to effectively conserve and manage fishing, an understanding of the fishery in the region to promote sustainable utilisation is required. The Zambezi–Chobe and Kwando–Linyanti wetland system straddles Botswana and Namibia. The Chobe River borders the Northern part of the Chobe National Park, forming the international boundary between Botswana and the Zambezi Region of Namibia (Child, 1986). The Chobe National Park, is Botswana's second largest (11,700 km<sup>2</sup>) park and it provides critical habitat for the largest elephant (*Loxodonta africana*) population in Africa, and is a host to other wildlife species (Fox & Alexander, 2015). The study area has different microhabitats such as marshes, waterways, riverine forests, dry woodlands, floodplains and savanna grasslands essential for fish and wildlife biodiversity.

Foundational studies in the Chobe Region in the 1800s concentrated on fish collections when naturalist-explorers made expeditions into southern Africa to collect plant and animal specimens (Skelton, 2001). These early works, focused on description of species rather than on the biology and the ecology of species. For example, in 1853 Charles John Andersson explored Lake Ngami in Botswana and described finny fishes like perch (probably tilapias) and barbels. More examples of early works, and the gradual development up to the current freshwater scientific research were described in chapter One. Several studies have been conducted on the Namibian waters (Chobe River) shared by Botswana and Namibia. The current study therefore focuses on the less studied habitats in Botswana which include the Zibadianja Lagoon, Savuti River and marsh and the Seboba rapids. The results will complement current research on Lake Liambezi and the main stream rivers in the Zambezi–Chobe and Kwando–Linyanti River systems.

The Botswana Department of Wildlife and National Parks (Fisheries section) surveys were conducted from late 2006, after an outbreak of epizootic ulcerative syndrome (EUS). These experimental data were collected in the Chobe River every two months and in the Kwando-

Linyanti wetlands every October or November by Botswana fisheries officers based in Kasane. The data were collected primarily to understand the causative agent of EUS and to recommend preventative measures for further spread. Consequently, these data were also used to assess the fish stocks and compile the fish inventory for Chobe fish. These data have not been published, therefore, this is the first attempt to publish a comprehensive checklist for the Chobe district of Botswana.

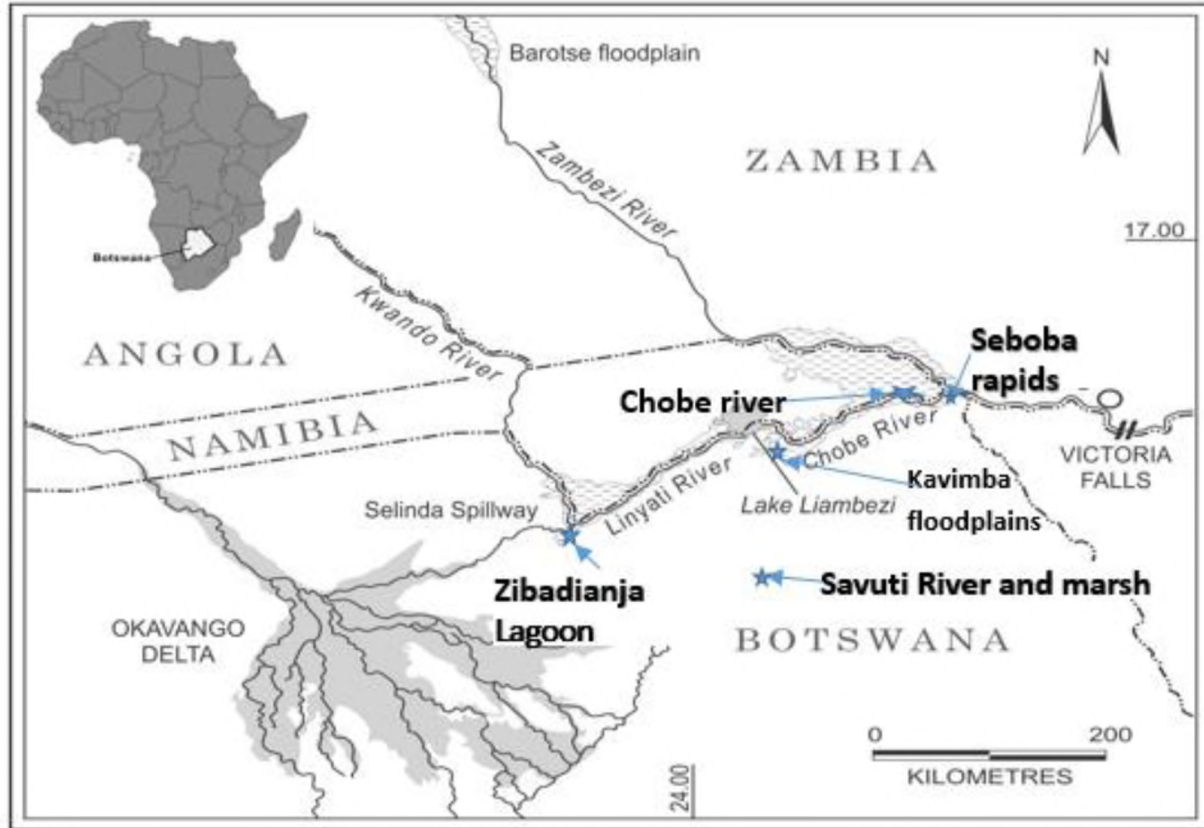
### **Aims and Objectives**

The primary aim of this chapter was to describe the habitats of and to undertake fish biodiversity survey for the less explored parts of the aquatic ecosystem of the Chobe District of Botswana. To do this, surveys were conducted in the Sebola rapids of the Chobe river, Chobe river and Kavimba floodplains, Savuti River and marsh, and Zibadianja Lagoon on the Kwando–Linyanti River system. This chapter is intended to be a qualitative assessment of the fish and habitat of these four localities and to provide a species checklist of the Chobe district of Botswana.

## **2.2. Description of the Study area**

### **Sampling sites**

Sampling was conducted in Zibadianja Lagoon, both in deep and shallow habitats, the Savuti River main channel and marsh, the Chobe River and Kavimba floodplains, side channel, backwater, and Sebola rapids (Figure 2.1). These habitats are representative of the Zambezi–Chobe, Kwando–Linyanti and Savuti rivers.



**Figure 2.1.** The study area showing major rivers and sampled areas in Northern Botswana. Source: Weyl, produced with permission. The position of the various water bodies sampled indicated by blue stars

Chobe River receives water from local precipitation and from the Zambezi River. When the Zambezi is in high flood, it causes the Chobe River to backflow feeding the Kavimba floodplains and Lake Liambezi (Figure 2.2). Lake Liambezi is fed by the Bukalo channel and Linyanti River. The Linyanti River is fed by the Kwando River and Selinda spillway. The Zibadianja Lagoon receives water from the Kwando River and the Okavango through the spillway. The Zibadianja Lagoon feeds the Savuti River and marsh, which ends at the Mababe depression where water from the Mababe River through the Khwai River from the Okavango ends. Ultimately, in high floods, the whole river system connects. The Selinda spillway connects the Kwando–Linyanti to the Okavango Delta, and the Zambezi River via Lake Liambezi to the Chobe River (van der Waal & Skelton, 1984; Merron, 1989a; Deloitte & Touche, 1992) during extremely high floods.

## Chobe River and Kavimba Floodplains

The Chobe River, which forms the international border between Botswana and Namibia, connects to the Kwando-Linyanti river system via Lake Liambezi (Mpho, 2002). Basically, it is an extension of Lake Liambezi in the west along the Botswana border to the Zambezi River at Impalila Island (Peel, 2012). The river consists of the narrow channel near Lake Liambezi, which rapidly becomes an extensive shallow floodplain north of Kachikau, Kavimba, Mabele and above the border town of Ngoma (Peel, 2012). The water depth of the Chobe River varies. For example, at Ngoma Bridge it can reach 1.8–2.0 m, at Kasane towards the Zambezi it reaches 5.1 m, while at the Game Lodge it reaches 2.6 m in April (Cronberg et al., 1995). The chemical composition of the Chobe River seems to be like that of the Zambezi at Kariba inflow (Cronberg et al., 1995).

## Hydrology

The flow of the Chobe alternates depending on the prevailing hydrological cycle (van der Waal, 1980). It is predicted that during the years of high floods the Chobe River can change direction at least three times a year. In August to January it flows eastwards towards the Zambezi and from February–March it flows westwards towards Lake Liambezi. This is common when the Zambezi is in high flood, it reverses the Chobe creating a backflow inundating the Chobe/Linyanti floodplains on the south–west of the Zambezi (Tweddle, 2010). Then in April–June it flows eastwards again as a result of the drainage of the floodplains after the Zambezi recession (van der Waal, 1980).

The Chobe River has deep, fast-flowing and well oxygenated water near the town of Kasane towards the Zambezi River (Cronberg et al., 1995). The rocky substrate is found near Chobe Game lodge, Savanna lodge and towards the Ngoma Bridge. The substrate attracts the presence of invertebrates such as crabs, damselflies and dragonflies (Bakane pers. obs.). The river possesses sandy substrate, as well as clay substrate around Sedudu Island. The Island can be completely covered by water during high floods. The Chobe River has marginal vegetation mainly reeds *Phragmites mauritianus*, water chestnuts *trapa* and bulrushes with *Papyrus* *Cyperus papyrus* and hippo grass *Vossia cuspidata*. Most of the backwaters at Chobe savanna and Sedudu are covered with waterlilies *Nymphaea nouchali*. The Kariba weed *Salvania molesta* has been

removed by biological control using weevils *Cyrtobagous salviniae* (Deloitte & Touche, 1992; Kurugundla et al., 2010) and only a few patches were observed especially during the inflow between December 2014 and April 2015 (Bakane pers. obs.). The Chobe River has higher phytoplankton biomass (0.05–0.86 mg/l) compared to Kwando-Linyanti (Cronberg et al., 1995). It is dominated by blue-green algae *Microcystic aeruginosa* and the diatoms *Aulacoseira* and *Cyclotella* (Balon & Coche, 1974; Davies, 1986).

## **Land Use**

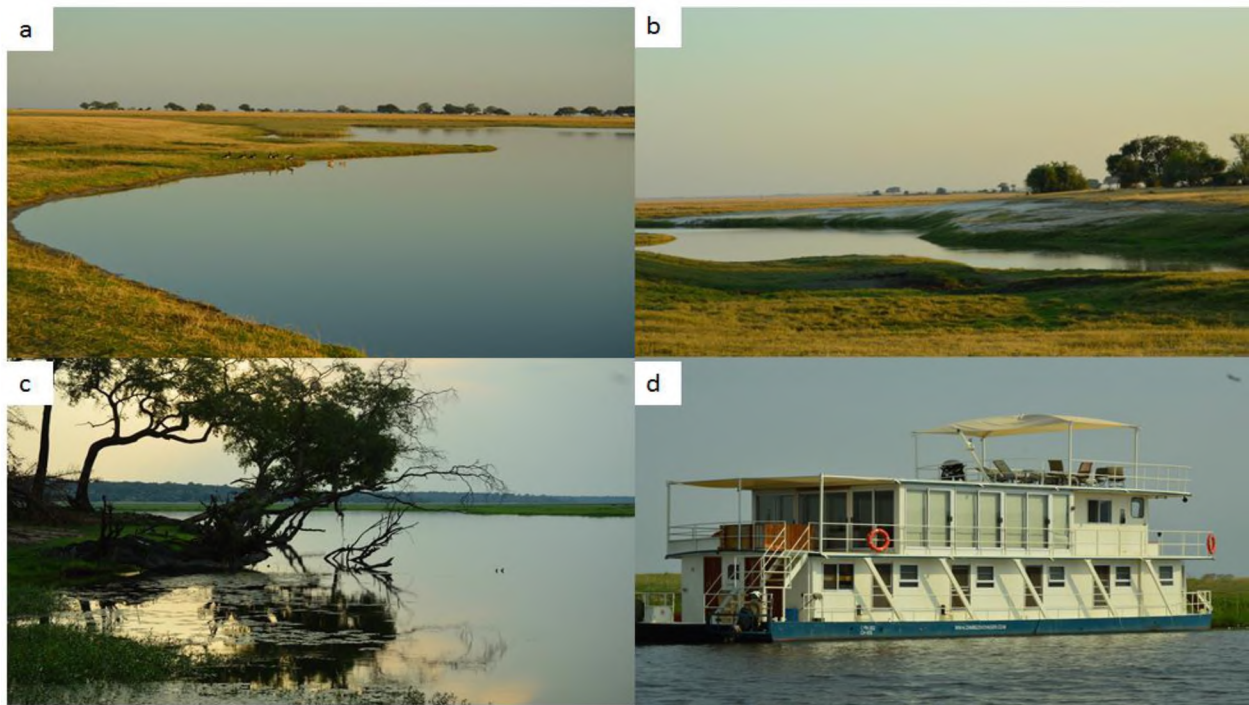
Chobe River is part of Chobe National Park. The park is rich in biodiversity (Mosetlhi, 2012) hence a tourist destination. The natural resource base of the Chobe makes the district the second most popular tourism destination in Botswana after the Okavango. Annual visitors to Chobe National Park increased from 60, 000 in 1995 to more than 110, 000 in 2004 (Fox & Alexander, 2015) especially during dry season when a large aggregation of wildlife flock to the riverfront (Chase, 2012). A wealth of animal life is associated with riverine forests, the reed bed and river banks. Figure 2.2 summarises some of the habitats in Chobe River. Some species are resident while a range of others migrate seasonally between the wetland and adjacent savannas (Mosetlhi, 2012).

The Chobe River rises in the northern Angolan highlands and travels a great distance before it reaches Botswana. The Chobe River traverses the Chobe National Park and, therefore, fishing is prohibited except on the Namibian side of the same river. Tourists visit Chobe National Park and enjoy morning and afternoon game drives and boat river cruises where thousands of elephants, ungulates, birds, predators, reptiles and fish are seen (Mosetlhi, 2012).

## **Fish Fauna of Chobe River**

The fish fauna of the Chobe river is like that of Okavango Delta and upper Zambezi river, because of periodic inter linking of these river basin (Merron 1989a). Earlier surveys by Merron (1989a) in Kwando, Selinda spillway and Chobe River between September 1985 and December 1986 and recorded 53 fish species. An analysis of fish catches during the 1985 Chobe fishing competition revealed nine species which were common to both gillnet and recreational catches (Merron & Sehemo, 1987). These were *Hydrocynus vittatus*, *Clarias gariepinus*, *Clarias ngamensis*,

*Synodontis* spp, *Oreochromis andersonii*, *Oreochromis macrochir*, *Sargochromis giardi*, *Serranochromis robustus jallae* and *Coptodon rendalli*. The Chobe River fisheries such as *Hydrocynus vittatus*, *Opsaridium zambenzense*, *Micralestes acutidens*, *Labeo lunatus* and *Mastacembelus frenatus* are highly mobile and rheophilic species preferring fast-flowing waters (Merron, 1989a). The presence of *Hydrocynus vittatus* and *Labeo cylindricus* indicate a more riverine habitat (Merron, 1989a). Species such as spiny eel *Mastacembelus vanderwaal*, catfish *Clariallabes platyprosopos* are also present and restricted to rapid habitat (Tweddle et al., 2004). Most specimens collected during the fishing competition were threespot tilapia which contributed 66% of the catches. The largest *O. andersonii* weighed 2.3kg, the largest *H. vittatus* was 2.2 kg and the largest *C. gariepinus* weighed 6.8 kg.



**Figure 2.2.** (a) Backwaters in the Chobe river, (b) isolated pools at Kabulabula in the Chobe River, (c) the Chobe river main channel, (d) boat such as speed boats, fishing boats and house boats are used by tourists for cruising and game viewing along the Chobe River. Photos by Bakane M.



## Sampling station

The Zambezi-Chobe river system was sampled at Sedudu 1: S17° 45.452, E025° 08.039, Sedudu 2: S17°49.526, E025° 07.252, Sedudu 3: S17° 49.930, E025° 06.037, Chobe savanna S17°49.645 E 025° 02.569 and fish purchases were made at Kavimba floodplains S18° 05.874 E025° 02.569. Figure 2.3 summaries the four sampled habitats in the Chobe river.



**Figure 2.3.** Four sampling stations in the Chobe River between September 2014 and April 2015. Source; Google earth maps.

## Seboba Nature and Recreational Park (rapids)

Seboba (S17.781195, E025.168688) or Chihuha, in local Sisubiya and Sivuva in Lozi, means a place of rapids.



## **Hydrology**

The rapids date to the late quaternary era when the Chobe River formed as an extension of the Kwando–Linyanti system to occupy a channel previously abandoned by the Zambezi River (Deloitte & Touche, 1992). During the flooding of Zambezi-Chobe in February–May the water covers the rocks and creates rapids and riffles (Bakane pers.obs). The Zambezi floods may delay and may reach Chobe River at the end of March or arrive as early as February. After flood recession, isolated pools with stagnant water remain as habitat for some fish species. The habitats in and around the Sebola rapids are variable. They include fast–flowing current over the rocks and well oxygenated water, clear water with sandy or rocky substrate as well as marginal vegetation (Bakane pers. obs.).

## **Land Use**

The Sebola Nature and Recreational Park is under the management of Botswana Tourism Organization and Commissioners Kop Conservation Trust which have gone into partnership to develop Sebola Nature and Recreational Park (Botswana tourism organisation pers. comm.).

The Sebola Nature and Recreational Park offers tourism activities such as walking trails where a 2-km network of walking trails has been erected on an elevated platform with looks out points fitted with benches for relaxation and bird watching. There are two self-catering picnic sites, a traditional village with four huts and or structures depicting the Basubia, Banamibia, Basarwa and Batawana culture in Chobe regarding their sleeping places, kitchens, food storage and family areas. Lastly, it has a multipurpose performance arena, where guests are provided with cultural entertainment through traditional song, dance and poetry from all over Botswana.

The rapids are an important bird area. Slaty egret, African finfoot, long crested eagle and the African skimmer; rock pratincole have been seen during low flood waters. Open bill stork normally nest in the trees at Sebola rapids in August and September, however, sometimes young boys around Kasane stone the birds and their nests to get the chicks for baiting fish (Bakane pers.obs.).

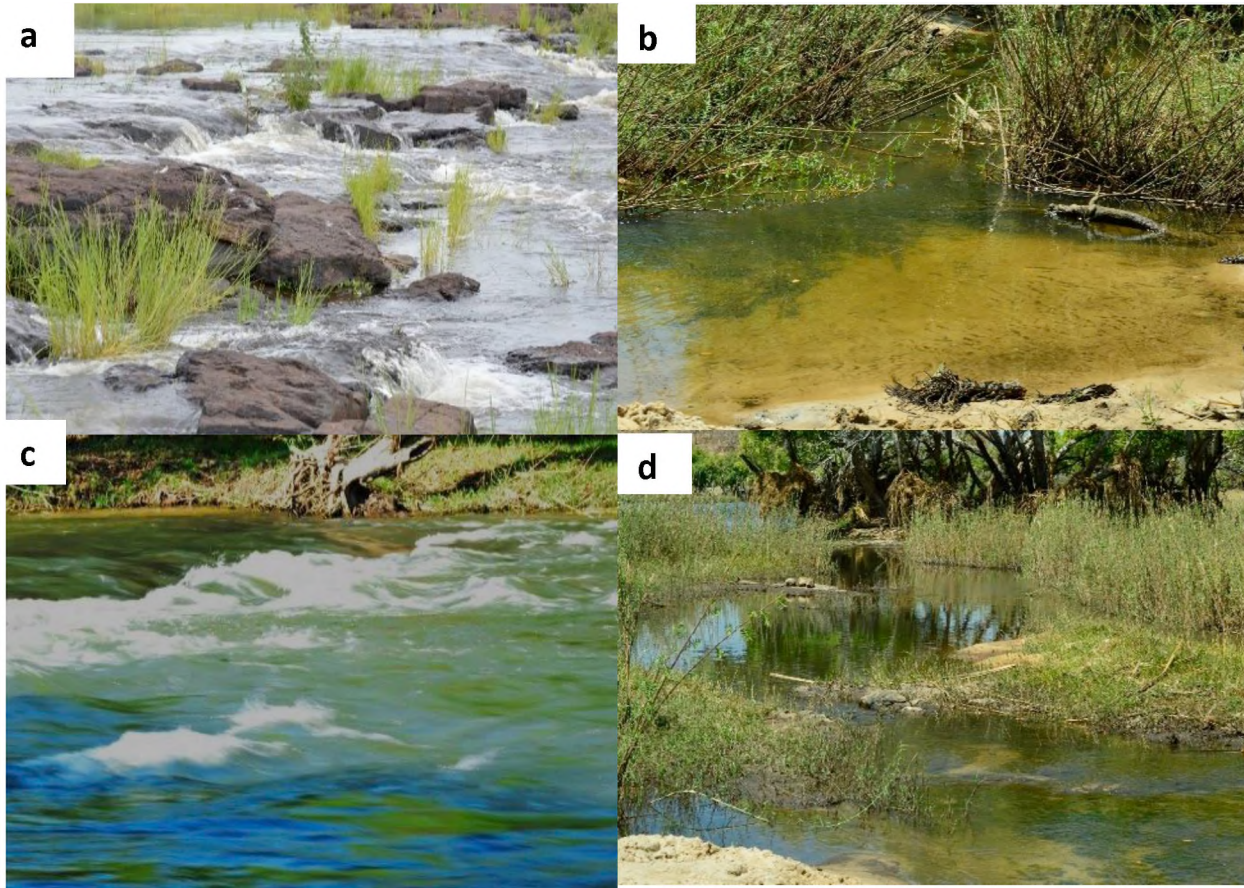
## **Fish fauna of the Seboba rapids**

The Seboba rapids are rarely sampled as special paraphernalia (shocking apparatus and or rotenone) are required but are not available for most institutions. The relative abundance of fish fauna varies prior to and after flooding (Bakane pers.obs.). During high floods (February–May), when the water runs through the rapids, fish are dispersed and fishers use traditional gear such as traps and spears for fishing. However, after the water recedes, the fish present are predominately rock dwellers. The fish species associated with these rapids include *Clarillable platyprosops*, *Mastacembelus frenatus* and *Mastacembelus vanderwaali*, *Labeo cylindricus*, *Amphilius uranoscopus*, *Enteromius condingtonii*, *Synodontis* spp, *Hippopotamyrus szaboi*, *Opsaridium zambenzense*, *Enteromius eutamia* and *Chiloglanis* species (van der Waal, 2009).

## **2.3 Materials and methods**

### **Electrofishing**

To assess the fish population of Seboba rapids electro fishing was conducted by wading through the rapids. A Sumus 725g back pack electro fisher was used attached to a 12V battery with settings for electrofishing standardised at three milliseconds and frequency 80 Hz. After each pass fish caught were placed in a bucket with water and another pass conducted. The shocker was effective as water has good conductivity. Two scoop-nets were used to collect stunned fish from the shocker. The rapids, although rocky, had sandy substrate in some areas. Figure 2.4 illustrate the habitats and figure 2.5 the electro-fished habitats of Seboba rapids.



**Figure 2.4.** (a) the Seboba rapids are inside the Seboba Nature & Recreational Park– during the flooding of Zambezi-Chobe in February–May the water covers the rocks and creates riffles, (b) clear water with sandy substrate, (c) fast–flowing current over the rocks is well oxygenated, (d) after the floods, isolated pools of stagnant water remain as habitat for some fish species. Photos by Bakane M.



**Figure 2.5.** Sampled habitats in the Seboba Rapids in Chobe River, Kasane in September 2014. Source; Google earth maps.

### **The Kwando-Linyanti River system**

The Kwando River originates from southern eastern Angola (Merron, 1989a). It enters Botswana at longitude  $23^{\circ} 17' .855'$  and latitude  $17^{\circ} 59' .942$ . The Kwando in Botswana falls in the Controlled Hunting area (CHAs) in NG 14. The NG14 covers an area of  $2,325 \text{ km}^2$ .

There is no clear-cut line between the Kwando and Linyanti Rivers and therefore referred as the Kwando-Linyanti system to illustrate their hydrological connection. The Linyanti falls within controlled hunting area (CHA) NG 15. The NG 15 covers an area of  $1,250 \text{ km}^2$ . As Kwando flows into the Sajawa, it becomes the Linyanti and there is variation in flora. The Linyanti River flows along the fault scarp and creates small seasonal floodplains but is mainly characterised by swamps, which gives the Linyanti swamps (Merron, 1989; Deloitte & Touche, 1992). The Selinda spillway connects Kwando-Linyanti to the Okavango Delta, and ultimately Zambezi River via Lake Liambezi to the Chobe River (Merron, 1989; Deloitte & Touche, 1992) during extremely high floods (e.g., in 2008/09 and 2009/2010) (Kurungundla & Mpho, 2003; Kurugundla et al., 2010).

## **Zibadianja Lagoon /Madiba complex**

Zibadianja lies within the Selinda Reserve in a controlled hunting area (CHA) NG 16. This area covers 1,350 km<sup>2</sup>. Zibadianja in the local Subia language means a *lagoon for red lechwe Kobus leche*. The semi-amphibious red lechwe migrate into and out of the Islands following water levels. Their seasonal aggregation on shallow grazing lawns act as a nutrient pump by retrieving nutrients over a wide area and concentrating them on the grazing lawn (Huchzermeyer, 2013) by defecating and foraging on the island which enriches the water (Mosepele et al., 2009). The lagoon is situated on the south of the Kwando-Linyanti Rivers. The lagoon is approximately 2.67 km<sup>2</sup>.

## **Hydrology**

The region receives local precipitation between November and March (Mpho, 2002) and receives water from Kwando-Linyanti via the Dumatau channels but outflows from Okavango Delta during high floods may reach the lagoon via Selinda spillway (Deloitte & Touche 1992). The Dumatau Lagoon is connected to Zibadianja Lagoon (Kurungundla et al., 2010). The peak of flooding in the Kwando River is in winter around June/July, but because of the meandering course of the river and the presence of aquatic reeds *Phragmites mauritianus* and *Cyperus papyrus* margins water reaches the Zibadianja Lagoon in August (Merron, 1989a). Welcomme et al. (2006) reported that the flow of the river is determined by the general geomorphological character of the river, the shape and size of the river channel. The water depth of Kwando-Linyanti Rivers can reach 2–3 m in April (Davies, 1986). The chemical composition of the Kwando-Linyanti River indicate that the water has higher ionic content, lower pH. and higher sulphate concentrations than the Okavango (Cronberg et al., 1995). Kwando-Linyanti is characterised by few phytoplankton species and low total biomass (0.02–0.32mg/l). *Cryptomonas*, *Cyclotella* and *Synedra* dominate this area (Cronberg et al., 1995).

Zibadianja Lagoon exhibits slow-flowing, turbid water with marginal vegetation and submerged macrophytes. Reduced water velocity allows the establishment of aquatic plants (algae and macrophytes) (Rolls et al., 2012) which results in high macroinvertebrates abundance (Shostell & Williams, 2007). The Zibadianja Lagoon houses hippopotami, large populations of fish, flora and fauna.



## Land Use

The lagoon is a major tourist attraction for photography and game viewing in the Kwando-Linyanti system. The lagoon lies in the concession area NG 16, for Linyanti exploration and the Great Plains (Kurugundla et al., 2010). There is minimal fishing; predominantly catch and release and subsistence fishing overseen by resident professional guides in the concession normally on Sunday afternoons (Bakane pers. obs.).

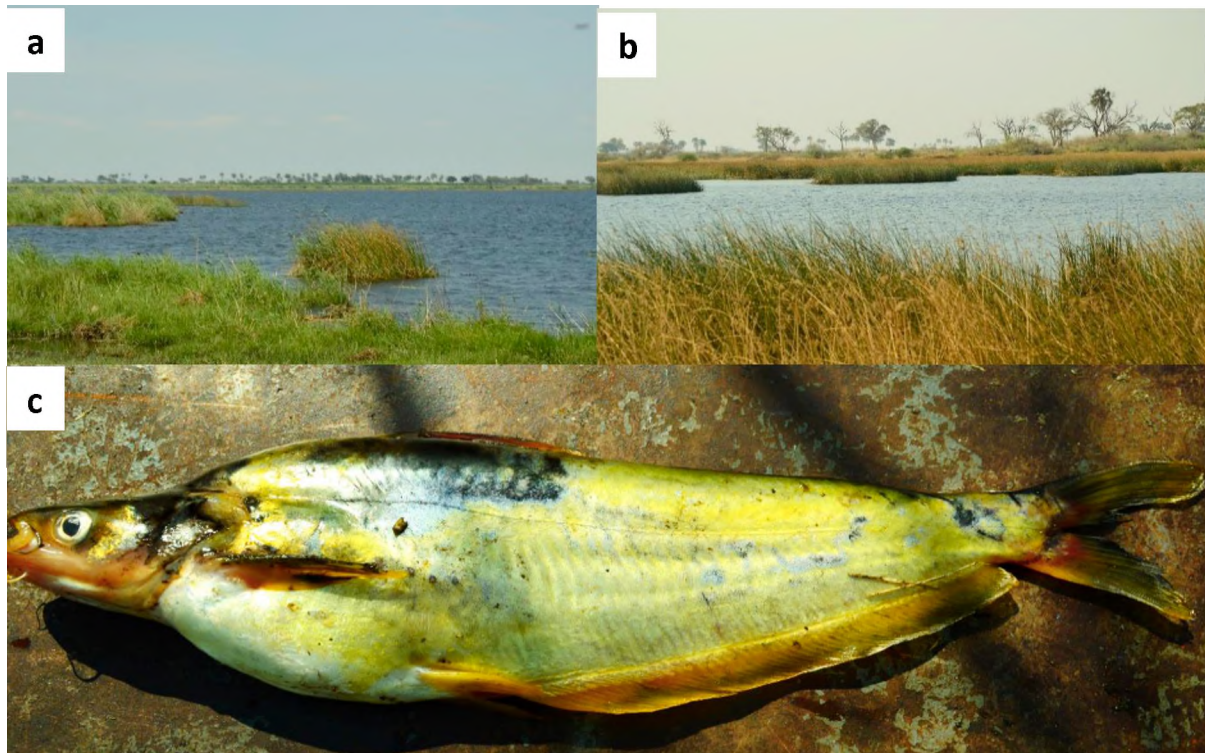
## Fish fauna of Zibadianja Lagoon

The ichthyofauna of Zibadianja Lagoon near the Selinda spillway, were first described by Merron (1989a), who characterised them as sedentary species. The fish population was dominated by *Oreochromis andersonii* (19%), *Serranochromis angusticeps* (12%), *Serranochromis robustus* (5%), *Sargochromis giardi* (11%), *Clarias gariepinus* (23%), *Clarias ngamensis* (12%), *Schilbe intermedius* (5%), *Mormyrus lacerda* (3%) and *Hepsetus cuvieri* (2%). Zibadianja provided a CPUE of 30 kg per gillnet fleet (Merron, 1989a).

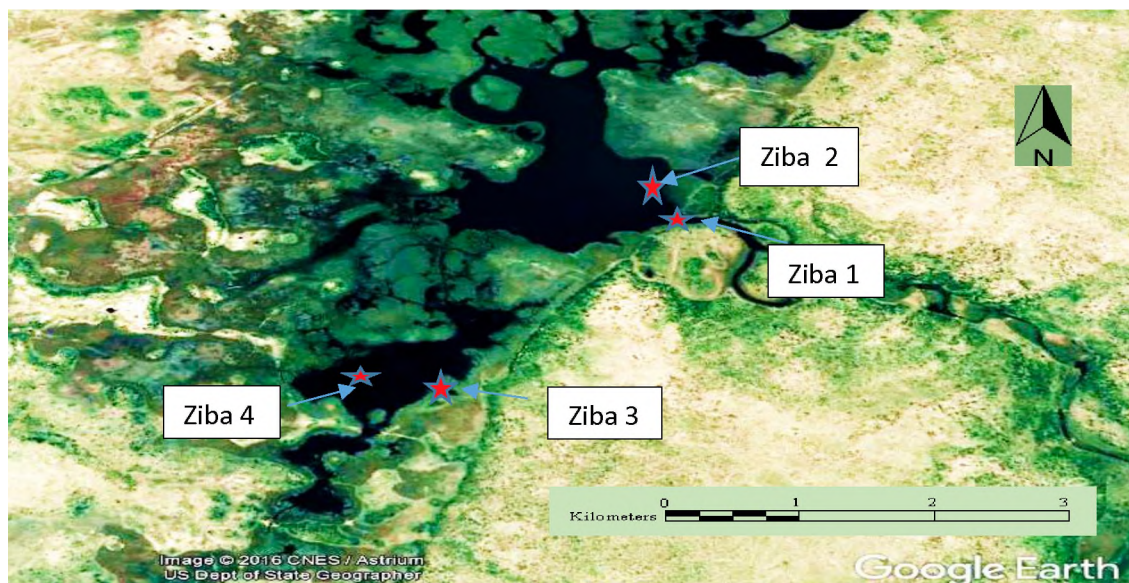
In 2003, Zibadianja Lagoon dried up (Kurugundla et al., 2010). This impacted negatively on the tourism sector and biodiversity in the concession. After investigation, it was revealed that, vegetation and the increase in sediments blocked the supplying channels to Zibadianja Lagoon. The channels were unblocked and the hydrology was restored (Kurugundla et al., 2010). Figure 2.6 summaries the habitats and Figure 2.7 the sampled habitats in the Zibadianja lagoon.

## Sampling stations

Zibadianja Lagoon (S18°3439.4, E023° 3227.3) was sampled at four sites to cover both deep and shallower habitats at the periphery of the lagoon Ziba 1: S 18° 34.435, E 023° 32.416, Ziba 2: S 18° 34.754, E023° 32.176, Ziba 3: S18° 36.538, E023° 30.631, Ziba 4: S18° 36.432, E 023° 30.848.



**Figure 2.6.** (a) Zibadianja lagoon, (b) shallow lagoon with macrophytes, (c) *Schilbe intermedius* was the dominant species by number and weight in the lagoons (this study). Photos by Bakane M.



**Figure 2.7.** Sampled habitats in Zibadianja Lagoon between September 2014 and April 2015. Source; Google earth maps.

## **Savuti River and Marsh**

Savuti marsh (alluvial fan) is an oval shaped fossil Lake bed in the Mababe depression (Shaw, 1984). Savuti River is an outflow from Zibadianja Lagoon (Deloitte & Touche, 1992). Topographically the area is flat but there are dolomitic rocks of Gubatsa hills formed millions of years ago as a result of volcanic movements. Savuti marsh is situated on the eastern side of the Kwando-Linyanti River and marks the end of 60–70 km of the Savuti channel, which conveys water to Mababe depression from the Linyanti swamps (Shaw, 1984).

## **Hydrology**

Savuti is characterised by small streams with marginal vegetation and deep hippo pools in the main channel. The water gradient is low and the system is not highly erosive (Deloitte & Touche, 1992). The substratum is sandy and muddy. From October to March high water in the Linyanti swamps flows through the Savuti channel that breaches the sand ridge. Savuti is characterised by episodic flows which may be attributed to climatic changes such as poor rainfall and tectonic movements along the Linyanti Chobe fault lines, as well as sedimentation and or vegetation dynamics at its source (Deloitte & Touche, 1992). For example, it dried up in the 1900s. After a long period (50 years) the flow began in 1957 (Deloitte & Touche, 1992). In the 1980s it dried up again until flow resurgence in 2008 after 28 years. By 2010, the water had reached the Savuti marsh. During extreme high floods in the Okavango Delta, water escapes via Magwegqana (Selinda spillway) into the Linyanti swamps to reach the Savuti marsh. Water from the Okavango also reaches Mababe through Khwai River to Mababe River ultimately reaching the Mababe depression.



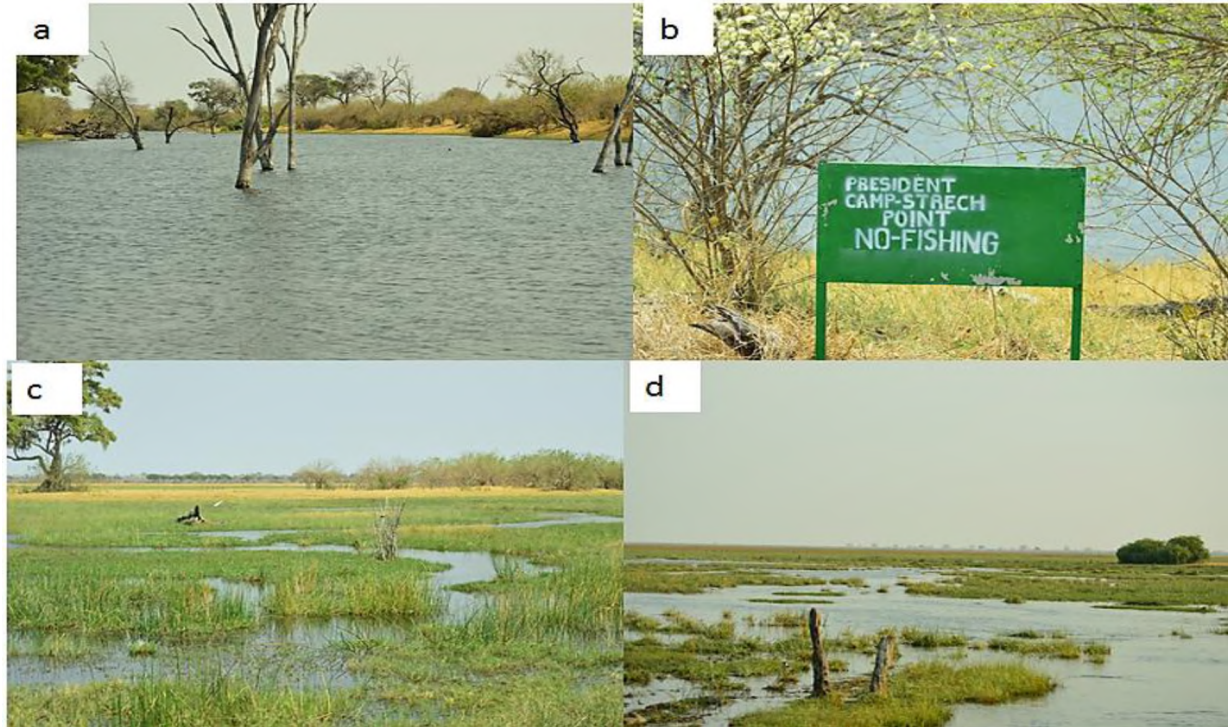
## **Fish fauna of Savuti**

There has never been any research conducted on Savuti Ichthyofauna. However, the Fisheries Division in Kasane pioneered a monitoring programme in 2010 when flow resurgence resumed. These data (DWNP surveys, 2010–2012) revealed 29 fish species which are closely linked to the Kwando-Linyanti species from which the Savuti originated. As the Savuti marsh and river dried up, recolonisation comes from fish surviving in the Kwando–Linyanti Rivers when the Savuti River commences flowing.

## **Land Use**

The Savuti marsh covers 5000 km<sup>2</sup> south of the Chobe National Park, which was established in 1967. It is a tourist destination. The marsh is open grassland covered by nutritious Couch grass *Cynodon dactylon* (Deloitte & Touche, 1992), and attracts large herds of herbivores and subsequently predators such as lions, hyenas and leopards. Large herds of zebras, elephants and buffaloes are resident but migrate seasonally. The Savuti marsh resembles a floodplain/delta environment.

The marshy vegetation, which acts as a floodplain is important for fish as spawning ground, nursery grounds; and refuge against predators (Welcomme, 1979, 1985). The detritus and large biomass of invertebrates in the floodplains enhances the rapid growth rate of juvenile fish, which can then avoid predation pressure once they leave the floodplains to return to the main channel (Ribeiro et al., 2004; Crain et al., 2004). The main channel has stumps of dead trees in the main channel which providing macroinvertebrates and habitat. The Savuti marsh has reputed annual migration of zebras and predators (UNESCO, 2010). Figure 2.8 summaries the Savuti river and marsh habitats and Figure 2.9 shows the sampled habitats.



**Figure 2.8.** (a) Savuti River main channel (deep hippo pool), the stumps of dead trees along the main channel are a testament to being dry for 28 years, (b) park signage prohibits fishing in the park at Savuti, fishing is not compatible with national park activities, (c) savuti marsh with small side channels, (d) some channels are wide in Savuti but still marshy-the marshy area and vegetated area has slow water velocity and cichlids nest in this area (Bakane pers. obs.). Photos by Bakane M.

### Sampling station

The Savuti River and Marsh was sampled at Rhino Vlei: S 18° 38.302, E024° 05.021, Savuti 2: S 18° 35.041, E024° 05.021, Motsebi Island S18° 37.391, E024° 04.320 and President's Camp S18° 36.522, E024° 04.724.



**Figure 2.9.** Sampled habitat in Savuti River and marsh between September 2014 and April 2015. Map by Simmon, (2012).

### Materials and methods

Biodiversity surveys were conducted between September 2014 and April 2015. Sampling gear included experimental gillnets of stretch mesh sizes (12, 16, 22, 28, 35, 45, 57, 73, 93, 118 150 mm), and a long-handled D-net. Conventional angling and an electro-fisher were employed depending on the area and habitat (Table 2.1). In addition, some specimens were purchased from fishermen, but these were primarily intended to supplement biological samples (Chapter 4). Upon capture, fish were identified to species level and measured to the nearest mm ( $L_T$ ).

**TABLE 2.1.** Gears used and habitat sampled in Chobe district between September 2014 and April 2015

Method	Seboba Rapids	Chobe River floodplains	Savuti River Marsh	Zibadianja Lagoon
Experimental gillnets	x	✓	✓	✓
Commercial nets	x	✓	✓	✓
Electrofishing	✓	x	x	x
D-Netting	x	x	x	✓
Line & Hook	x	x	✓	✓

### **Experimental gillnets**

Multifilament maroon research gillnets, comprising 11 panels (12, 16, 22, 28, 35, 45, 57, 73, 93, 118 and 150 mm) were used. The nets were set overnight, generally between 1700 hrs–1900 hrs. in the evenings (night setting) and retrieved between 0600 hrs–0800 hrs. in the mornings. The nets were set parallel to the shore in diverse habitats including marsh, lagoon, backwaters, main channel and floodplains. On retrieval fish were removed, identified using Skelton (2001), measured using a ruler to the nearest mm total length ( $L_T$ ) and weighed collectively to the nearest (g).

### **Electro fishing**

Electrofishing was conducted at Sebobas rapids in Kasane. A SAMUS 725g back pack electro fisher attached to a 12v battery with settings for electrofishing standardised at three milliseconds and frequency 80 Hz. Fish were actively collected while electrofishing various habitats, and all fish samples were placed in a bucket for later identification and measurement.

### **Scoop net and D-net**

A Scoop net and a D-net were mainly used in shallow vegetated water at the Zibadianja Lagoon, during the biodiversity survey in September 2014, in the littoral zones of Zibadianja Lagoon where aquatic macrophytes and hippopotami made gillnet sampling impractical.

### **Angling**

Angling was used to supplement samples collected with other gears in the Zibadianja Lagoon, and Savuti River. Bait was mainly earth worms or a piece of chicken.

## **2.3 Results**

A total of 8836 fish representing 54 species and 12 families were identified from the sampled habitat (Table 2.2). The investigated habitat yielded variable species richness and abundance (see Chapter 3) between stations and between the habitats of lagoon, main channel, flood plain, backwaters and rapids. In the current chapter, the increase of species as compared to sampled specimen in chapter 3, reflected the diversity of habitats sampled and the combined utilisation of various sampling gear rather than just experimental gillnets. The Cyprinidae family was the most

speciose with 18 species (Table 2.2), and the second most speciose family was Cichlidae with 13 species. Two families, Anabantidae and Mastacembelidae, were not recorded in this study. A common haplochromine cichlid, *Serranochromis robustus jallae*, was also not recorded. The most widely spread species were *Brycinus lateralis*, *Pharyngochromis acuticeps*, *Pseudocrenilabrus philander*, *Schilbe intermedius*, *Tilapia sparrmanii* and *Marcusenius altisambesi* but they varied in abundance in different areas. These results were not in agreement with the distribution of these species as recorded by Merron (1989a) who did not record *B. lateralis*, as ubiquitous in a checklist of Kwando River, Selinda Magwegqana spillway, Lake Liambezi and the Chobe rivers. Table 2.3 shows the updated checklist of the fish fauna in the Chobe District using the current survey and historical data.

**TABLE 2.2.** A Checklist of fish fauna in the Chobe district sampled between September 2014 and April 2015. Tick (✓) represents the habitat the species was recorded in and (x) shows an absence of the species from the current survey.

Species	Seboba Rapids	Zibadianja Lagoon	Savuti River/marsh	Chobe River
<b>Family Mormyridae (Mormyrids)</b>				
<i>Hippotamyrus szaboi</i>	✓	x	✓	✓
<i>Cyphomyrus cubangoensis</i>	✓	x	✓	✓
<i>Mormyrus lacerda</i>	x	✓	✓	✓
<i>Petrocephalus longicapitis</i>	x	✓	x	✓
<i>Marcusenius altisambesi</i>	✓	✓	✓	✓
<i>Pollimyrus marianne</i>	✓	x	x	x
<i>Pollimyrus castelnaui</i>	✓	x	x	x
<i>Pollimyrus cuandoensis</i>	x	✓	x	x
<b>Family Cyprinidae (Cyprinids)</b>				
<i>Enteromius spp</i>	x	x	x	✓
<i>Enteromius poechii</i>	✓	x	✓	✓
<i>Enteromius radiatus</i>	x	x	x	✓
<i>Enteromius thamalakanensis</i>	✓	x	x	x
<i>Enteromius unitaeniatus</i>	✓	✓	x	x
<i>Labeo cylindricus</i>	✓	x	x	✓
<i>Labeo lunatus</i>	x	x	x	✓
<i>Opsaridium zambenzense</i>	✓	x	x	x
<i>Enteromius afrovernayi</i>	✓	x	x	x
<i>Enteromius barnardi</i>	x	✓	x	x
<i>Enteromius bifrenatus</i>	✓	x	x	✓
<i>Enteromius eutaenia</i>	✓	x	x	x
<i>Enteromius fasciolatus</i>	✓	x	x	x
<i>Enteromius haasianus</i>	x	✓	x	x
<i>Enteromius multilineatus</i>	✓	x	x	x
<i>Enteromius kerstenii</i>	✓	x	x	x
<i>Enteromius paludinosus</i>	x	✓	✓	✓
<i>Coptostomabarbus wittei</i>	x	✓	x	x
<b>Family Distichodontidae (Citharine)</b>				
<i>Nannocharax multifaciatius</i>	✓	x	x	x
<b>Family Characidae (characids)</b>				
<i>Brycinus lateralis</i>	x	✓	✓	✓
<i>Hydrocymus vittatus</i>	x	✓	✓	✓
<i>Micralestes acutidens</i>	✓	x	x	✓

**TABLE 2.2 continued**

**Hepsetidae**

*Hepsetus cuvieri* x ✓ ✓ ✓

**Claroteidae**

*Parauchenoglanis ngamensis* ✓ x x ✓

**Family Amphiliidae (Mountain catfishes)**

*Amphilius uranoscopus* ✓ x x x

**Family Schilbeidae (Butter catfishes)**

*Schilbe intermedius* ✓ ✓ ✓ ✓

**Clariidae**

*Clarias gariepinus* x ✓ ✓ ✓

*Clarias ngamensis* x ✓ ✓ x

**Family Mochokidae**

*Synodontis spp* ✓ x x ✓

*Synodontis nigromaculatus* x x x ✓

**Family Poeciliidae**

*Micropanchax johnstonii* ✓ x x x

*Micropanchax katengae* ✓ x x X

*Micropanchax hutereaui* x ✓ x x

**Family Cichlidae**

*Oreochromis andersonii* x ✓ ✓ ✓

*Oreochromis macrochir* x ✓ ✓ ✓

*Pseudocrenilabrus philander* ✓ ✓ ✓ ✓

*Sargochromis carlottae* x ✓ x ✓

*Sargochromis giardi* x ✓ ✓ ✓

*Serranochromis angusticeps* x ✓ ✓ x

*Serranochromis altus* x ✓ ✓ x

*Serranochromis macrocephalus* x ✓ ✓ ✓

*Serranochromis thumbergi* x ✓ ✓ x

*Pharyngochromis acuticeps* ✓ ✓ ✓ ✓

*Sargochromis condingtonii* x ✓ ✓ ✓

*Coptodon rendalli* x ✓ ✓ ✓

*Tilapia sparrmanii* ✓ ✓ ✓ ✓

**Total species 28 29 24 31**

**TABLE 2.3.** Updated Checklist of fish fauna in the Chobe district using current surveys September 2014 and April 2015, historical data from Tweddle et al. (2004) and Department of Wildlife and National Parks surveys (2006–2012).

<b>Family Mormyridae</b>	<b>Family Amphiliidae (Mountain catfishes)</b>
<i>Hippotamyrus szaboi</i>	<i>Amphilius uranoscopus</i>
<i>Cyphomyrus cubangoensis</i>	<i>Zaireichthys</i> sp ‘pallid’
<i>Mormyrus lacerda</i>	<i>Zaireichthys</i> sp ‘dorae’
<i>Petrocephalus longicapitis</i>	<b>Family Schilbeidae (Butter catfishes)</b>
<i>Marcusenius altisambesi</i>	<i>Schilbe intermedius</i>
<i>Pollimyrus marianne</i>	<b>Clariidae</b>
<i>Pollimyrus castelnaui</i>	<i>Clarias gariepinus</i>
<i>Pollimyrus cuandoensis</i>	<i>Clarias ngamensis</i>
<b>Family Cyprinidae (Cyprinids)</b>	<i>Clarias stappersii</i>
<i>Enteromius spp</i>	<i>Clarias liocephalus</i>
<i>Enteromius poechii</i>	<i>Clarias theodora</i>
<i>Enteromius radiatus</i>	<i>Clariallabes platyprosops</i>
<i>Enteromius thamalakaniensis</i>	<b>Family Mochokidae</b>
<i>Enteromius unitaeniatus</i>	<i>Synodontis</i> spp x6
<i>Labeo cylindricus</i>	<i>Synodontis nigromaculatus</i>
<i>Labeo lunatus</i>	<b>Family Poeciliidae</b>
<i>Opsaridium zambezense</i>	<i>Micropachax johnstonii</i>
<i>Enteromius afrovernavi</i>	<i>Micropachax katengae</i>
<i>Enteromius barnardi</i>	<i>Micropachax hutereaui</i>
<i>Enteromius bifrenatus</i>	<b>Family Cichlidae</b>
<i>Enteromius barotseensis</i>	<i>Hemichromis elongatus</i>
<i>Enteromius eutaenia</i>	<i>Oreochromis andersonii</i>
<i>Enteromius fasciolatus</i>	<i>Oreochromis macrochir</i>
<i>Enteromius haasianus</i>	<i>Pseudocrenilabrus philander</i>
<i>Enteromius multilineatus</i>	<i>Sargochromis carlottae</i>
<i>Enteromius kerstenii</i>	<i>Sargochromis giardi</i>
<i>Enteromius paludinosus</i>	<i>Serranochromis angusticeps</i>
<i>Coptostomabarbus wittei</i>	<i>Serranochromis altus</i>
<b>Family Distichodontidae (Citharine)</b>	<i>Serranochromis macrocephalus</i>
<i>Nannocharax multifaciatius</i>	<i>Serranochromis robustus jallae</i>
<i>Nannocharax machodoi</i>	<i>Serranochromis thumbergi</i>
<i>Nannocharax macropterus</i>	<i>Pharyngochromis acuticeps</i>
<b>Family Characidae (Characids)</b>	<i>Sargochromis condingtonii</i>
<i>Brycinus lateralis</i>	<i>Coptodon rendalli</i>
<i>Hydrocynus vittatus</i>	<i>Tilapia sparrmanii</i>
<i>Micralestes acutidens</i>	<i>Tilapia ruweti</i>
<i>Rhabdalestes maunensis</i>	<b>Mastacembelidae</b>
<b>Hepsetidae</b>	<i>Mastacembelus vanderwaali</i>
<i>Hepsetus cuvieri</i>	<i>Mastacembelus frenatus</i>
<b>Claroteidae</b>	
<i>Parauchenoglanis ngamensis</i>	



## Seboba rapids

A total of 336 fish, representing nine families and 28 species, were sampled at Seboba rapids in Kasane during low water levels in September 2014. The results are summarised in Table 2.4. As the rapids were sampled by electrofishing, which is more selective for smaller species than the gill nets used in the other habitats, the results from this locality are not directly comparable to those from the other sites. They are, however, included as they are illustrative of the diversity of fishes in the Chobe district.

**Table 2.4.** A checklist of Seboba Rapids ichthyofauna in Kasane sampled with an electrofisher in September 2014.

Species (this study)	(%N; N=336)
<i>Pollimyrus marianne</i>	14
<i>Hippopotamyrus szaboi</i>	4.2
<i>Cyphomyrus cubangoensis</i>	0.3
<i>Marcusenius altisambesi</i>	0.3
<i>Pollimyrus castelnaui</i>	0.6
<i>Enteromius eutaenia</i>	3.3
<i>Enteromius poechii</i>	1.8
<i>Enteromius thamalakanensis</i>	0.9
<i>Enteromius afrovernayi</i>	0.3
<i>Enteromius kerstenii</i>	0.3
<i>Enteromius multilineatus</i>	0.3
<i>Enteromius bifrenatus</i>	2.7
<i>Labeo cylindricus</i>	9.8
<i>Opsaridium zambezense</i>	5.3
<i>Enteromius bifrenatus</i>	2.7
<i>Enteromius fasciolatus</i>	5.1
<i>Nannocharax multifaciatatus</i>	6.8
<i>Micralestes acutidens</i>	13
<i>Parauchenoglanis ngamensis</i>	0.3
<i>Synodontis</i> spp	3.6
<i>Amphilius uranoscopus</i>	0.3
<i>Schilbe intermedius</i>	5.9
<i>Chiloglanis</i> spp	3.0
<i>Micropanchax johnstonii</i>	3.9
<i>Micropanchax katengae</i>	3.0
<i>Pharyngochromis acuticeps</i>	6.3
<i>Pseudocrenilabrus philander</i>	2.7
<i>Tilapia sparrmanii</i>	2.1

## Chobe River and Kavimba floodplains

The total surveys in Chobe River and Kavimba floodplains yielded 2337 fish, weighing 134 kg, of which (94%) were sampled using an experimental multifilament research net, while (5%) were from fishermen's commercial nets. They represented nine families and 31 species (see Chapter 3). Table 2.5 summaries the fish fauna and counts in experimental nets (this study).

Kavimba floodplains yielded 117 fish of which *Oreochromis andersonii* comprised 68%, *Oreochromis macrochir* 26%, and *Coptodon rendalli* 6%. *Oreochromis andersonii* was abundant in the Kavimba floodplains. Species that were not recorded in this study but recorded in Department of Wildlife and National Parks (DWNP) surveys (2006–2012) were *Enteromius fasciolatus*, *Enteromius unitaeniatus*, *Clarias ngamensis*, *Serranochromis robustus jallae*, *Serranochromis altus*, *Serranochromis angusticeps*, *Sargochromis greenwood* and *Tilapia ruweti*. Both DWNP surveys (2006-2012) and current study shows similarity in the dominance of *Hydrocynus vittatus*, *Clarias gariepinus*, *Schilbe intermedius*, *Synodontis* and *Synodontis nigromaculatus* in the Chobe river main channel.

**TABLE 2.5.** Chobe River fish fauna in experimental gillnets and sampled habitats between September 2014 and April 2015

Current study	Main channel (%N; N=513)	Side channel (%N; N=529)	Back waters (%N; N=1178)
<i>Hippopotamyrus szaboi</i>	0.2	0.2	0.1
<i>Cyphomyrus cubangoensis</i>	1.2	0.4	1.0
<i>Mormyrus lacerda</i>	-	-	0.3
<i>Marcusenius altisambesi</i>	9.7	7.0	9.0
<i>Petrocephalus longicapitis</i>	13	10	-
<i>Enteromius species</i>	-	0.2	-
<i>Enteromius paludinosus</i>	4.1	16	4.2
<i>Enteromius bifrenatus</i>	-	-	0.8
<i>Enteromius radiatus</i>	20	4.0	12
<i>Enteromius poechii</i>	1.2	2.0	0.9

**Table 2.5 continued**

<i>Labeo lunatus</i>	0.6	0.9	0.6
<i>Labeo cylindricus</i>	-	-	0.9
<i>Hydrocynus vittatus</i>	15	7.0	11
<i>Micralestes acutidens</i>	0.1	13	3.0
<i>Brycinus lateralis</i>	5.5	7.0	35
<i>Hepsetus cuvieri</i>	-	-	0.08
<i>Clarias gariepinus</i>	0.6	0	0.4
<i>Parauchenoglanis</i>	-	0.9	0.3
<i>ngamensis</i>			
<i>Schilbe intermedius</i>	8.8	19	6.0
<i>Synodontis nigromaculatas</i>	2.0	2.3	1.0
<i>Synodontis spp</i>	8.0	9.0	6.5
<i>Oreochromis andersonii</i>	-	0.1	0.2
<i>Oreochromis macrochir</i>	0.2	-	0.2
<i>Pharyngogromis acuticeps</i>	6.0	1.3	2.4
<i>Pseudocrenilabrus</i>	-	0.4	0.9
<i>philander</i>			
<i>Sargochromis carlottae</i>	0.2	-	0.3
<i>Sargochromis</i>	0.4	0.9	0.2
<i>contringtonii</i>			
<i>Sargochromis giardi</i>	0.2	-	-
<i>Serranochromis</i>	1.0	0.8	0.7
<i>macrocephalus</i>			
<i>Coptodon rendalli</i>	0.2	-	-
<i>Tilapia sparrmanii</i>	0.6	-	0.5

---

## Zibadianja Lagoon

In the Kwando-Linyanti system at Zibadianja Lagoon a total of 3230 fish representing seven families and 29 species were sampled, of which 91.6% were sampled using a multifilament experimental research net, 5.1% using a fisherman's commercial net, 1.8% from hook and line and 1.4% from a D-net.

Experimental gillnets yielded 2960 fish. Most fish (72%) inhabited deeper zones of the Zibadianja Lagoon, while 28% inhabited a shallower habitat of the lagoon which are the peripheries of the lagoon with aquatic macrophyte beds. *Schilbe intermedius* (42%), *Marcusenius altisambesi* (18%) and *Brycinus lateralis* (25%) were dominant in the deeper habitat of Zibadianja. Other species that inhabited the deep habitat of Zibadianja lagoon were *Sargochromis giardi* (0.4%), and *Pharyngochromis acuticeps* (2%), whereas, the shallower habitats of the lagoon were inhabited by *B. lateralis* (25%), *M. altisambesi* (20%) and *S. intermedius* (30%). Cichlidae species were also notable in the shallower lagoon e.g., *Pharyngochromis acuticeps* (6%), *Serranochromis angusticeps* (1.9%), *O. andersonii* (1.4%) and *Sargochromis contringtonii* (1.4%). Other species were *C. gariepinus* (2.6%), *Enteromius barnardi* (2.4%), *Petrocephalus longicapitis* (1.9%) and *Hepsetus cuvieri* (3%).

In the commercial nets, 165 fish were captured of which 39% inhabited deep zones of Zibadianja lagoon while 61% came from more shallower water habitats of the lagoon. The deeper habitats of the lagoon were inhabited by *C. gariepinus* (22%), *S. giardi* (13%), *C. ngamensis* (5%), *O. andersonii* (11%), *O. macrochir* (11%), *M. lacerda* (9.3%), *C. rendalli* (6.3%), *S. angusticeps* (7.8%), *H. vittatus* (1.6%), *H. cuvieri* (1.6%) and *S. intermedius* (1.6%). Shallower water habitats were the peripheries of the lagoon and more like the floodplains. Of the shallower water habitats, *C. gariepinus* (43%) dominated, followed by *O. andersonii* (15%), *O. macrochir* (8.9%), *C. rendalli* (8.9%), *C. ngamensis* (8.9%), *S. intermedius* (6.9%), *S. angusticeps* (5.9%), *S. macrocephalus* (3%), *S. giardi* (0.9%), *S. condingtonii* (0.9%) and *S. thumbergi* (0.9%). Species that were not recorded in the shallow zones of the lagoon but were recorded in the deep zones of the lagoon were *M. lacerda* and *H. vittatus*.

A D-net, that was used in the littoral vegetated zone at Zibadianja Lagoon, yielded 46 fish in total representing four families and nine species. For example, *Micropanchax hutereaui* were numerically abundant (32.6%), followed by *B. lateralis* (15%), *Pseudocrenilabrus philander* (13%), *Coptostomabarbus wittei* (10.9%), *Enteromius barnardi* (8.7%), *Enteromius haasianus* (8.7%), *Tilapia sparrmanii* (2%) and *C. rendalli* (2%).

A total of 59 fishes representing four species in one family (Cichlidae), were sampled using line and hook sizes 2.0 and 2.5. Line and hook did not add to the species diversity as the same species were sampled as in the experimental gillnets. Therefore, the findings indicate that angling can be very selective. The *C. rendalli* was numerically abundant (88%) captured by this gear, followed by *O. andersonii* (5.1%), *O. macrochir* and *Sargochromis condingtonii* (3.4%) respectively.

Additional data to compile the species list was from DWNP surveys (2006–2012), which recorded the presence of *Serranochromis robustus jallae*, *Tilapia ruweti*, *Labeo lunatus*, *Enteromius bifrenatus*, *Enteromius fasciolatus*, *Clarias stappersii*, *Clarias theodora* and *Synodontis* spp. Merron (1989a) used rotenone ichthyocide on the vegetated pools and reed beds of Kwando and Zibadianja lagoon in December 1986. The species recorded in that study that were not recorded in this study (2014–2016) were *Micralestes acutidens* and *Opsaridium zambezense*. Species that were recorded in this study but not recorded in DWNP surveys (2006–2012) were *Hydrocymus vittatus*, *Coptostomabarbus wittei*, *Micropanchax hutereaui* and *Enteromius haasianus*. The species checklist and counts (this study) in the Zibadianja lagoon catchment are summarised in Table 2.6

**TABLE 2.6.** Species checklist for Zibadianja Lagoon based on surveys 2014/15

Current study	Deep lagoon (%N; N=2127)	Shallow lagoon (%N; N=833)
<i>Marcusenius altisambesi</i>	18	2.0
<i>Mormyrus lacerda</i>	0.1	-
<i>Petrocephalus longicapitis</i>	3.0	-
<i>Enteromius barnardi</i>	3.1	0.6
<i>Enteromius unitaeniatus</i>	0.7	1.0
<i>Enteromius paludinosus</i>	0.2	-
<i>Clarias gariepinus</i>	2.4	3.0
<i>Clarias ngamensis</i>	1.0	1.2
<i>Brycinus lateralis</i>	25	25
<i>Hydrocynus vittatus</i>	0.4	-
<i>Hepsetus cuvieri</i>	0.9	3.0
<i>Schilbe intermedius</i>	42	30
<i>Oreochromis andersonii</i>	0.2	1.4
<i>Oreochromis macrochir</i>	0.2	0.5
<i>Pharyngogomus acuticeps</i>	2.0	6.0
<i>Pseudocrenilabrus philander</i>	0.1	0.6
<i>Serranochromis altus</i>	0.1	0.5
<i>Serranochromis angusticeps</i>	0.2	1.9
<i>Sargochromis carlottae</i>	-	0.2
<i>Sargochromis contringtonii</i>	-	1.4
<i>Sargochromis giardi</i>	0.4	0.2
<i>Serranochromis thumbergi</i>	0.05	-
<i>Serranochromis macrocephalus</i>	0.1	0.7
<i>Coptodon rendalli</i>	0.4	1.0
<i>Tilapia sparrmanii</i>	0.2	2.0

## Savuti River and Marsh

In total Savuti River and marsh yielded 2933 fish, weighing 458 kg, of which 96% were caught using experimental multifilament research nets, 3.6% fishermen's commercial nets and 0.55% were hook and line caught. All these represented seven families and 24 species. Species that were recorded at Zibadianja lagoon but not recorded at Savuti River were *Enteromius unitaeniatus*, *Enteromius barnardi*, *Sargochromis carlottae*, *Coptostomabarbus wittei*, *Micropanchax hutereaui* and *Enteromius haasianus*.

Experimental surveys yielded 2812 fish. Most species were riverine species (57%) while 31% inhabited President Camp (deep hippo pool) and only 5% were captured in the marshy habitat. *Marcusenius altisambesi* (57%) and *Schilbe intermedius* (24%) dominated in the deep hippo pool (President Camp). *Enteromius paludinosus* (30%), *Brycinus lateralis* (30%) and *Marcusenius altisambesi* (29%) were numerically abundant in the main channel. Species that dominated in the marshy areas with muddy substrate were *Clarias gariepinus* (43%) and *Clarias ngamensis* (13%), while sandy substrate vegetated areas were inhabited by cichlids *Oreochromis andersonii* (4.2%) *Oreochromis macrochir* (6.2%), *Pseudocrenilabrus philander* (2.1%) and *Tilapia sparrmanii* (2.1%).

Species that were recorded by DWNP surveys (2010–2012) but were not recorded in the current study in Savuti River/marsh were *Serranochromis robustus jallae*, *Enteromius* spp., *Enteromius barnardi*, *Enteromius eutaenia* and *Enteromius unitaeniatus*. Table 2.7 summaries the fish fauna and counts in experimental nets (this study).

**TABLE 2.7.** Savuti River and marsh fish fauna sampled between September 2014 and April 2015

Species	President Camp (%N; N=861)	Main channel (%N; N=1601)	Marsh (%N; N=142)
<i>Mormyrus lacerda</i>	-	0.1	-
<i>Hippopotamyrus szaboi</i>	-	0.06	-
<i>Cyphomyrus cubangoensis</i>	-	0.2	-
<i>Marcusenius altisambesi</i>	57	29	2.1
<i>Enteromius paludinosus</i>	0.6	30	18
<i>Enteromius poechii</i>	4.4	2.0	5.0
<i>Brycinus lateralis</i>	0.1	30	-
<i>Hydrocymus vittatus</i>	0.1	0.2	-
<i>Hepsetus cuvieri</i>	1.2	0.1	-
<i>Schilbe intermedius</i>	24	4.0	1.4
<i>Clarias gariepinus</i>	9.1	1.9	13
<i>Clarias ngamensis</i>	0.8	0.4	4.2
<i>Oreochromis andersonii</i>	0.8	1.3	6.3
<i>Oreochromis macrochir</i>	0.7	0.2	0.7
<i>Pharyngogromis acuticeps</i>	0.2	0.3	2.1
<i>Pseudocrenilabrus philander</i>	-	0.3	-
<i>Serranochromis altus</i>	-	0.1	-
<i>Serranochromis angusticeps</i>	-	0.1	1.4
<i>Serranochromis thumbergi</i>	0.1	-	1.4
<i>Serranochromis macrocephalus</i>	0.6	0.5	-
<i>Sargochromis giardi</i>	-	0.1	-
<i>Sargochromis contringtonii</i>	-	0.1	-
<i>Coptodon rendalli</i>	-	0.3	-
<i>Tilapia sparrmanii</i>	-	0.3	-



## 2.4 Discussion

### Checklist of species

The fish sampled from different environments in this study represent those of the Chobe district in general, with variation in species assemblage and distribution being mainly attributable to varied sampling methods and the availability of preferred habitat. In the current study, taxonomic biodiversity was represented by 54 species and 12 families (Table 2.2). This was lower than the total checklist of the adjacent the catchment; > 80 species from the Namibian section of the Zambezi and Chobe Rivers (Tweddle, 2009); 71 species from the Okavango Delta (Tweddle et al., 2003; Ramberg et al., 2006), and about 98 species from the Upper Zambezi River (Tweddle et al., 2004). It was, however, higher than that from the previous DWNP unpublished surveys (2006–2012) which have recorded 50 species using experimental nets. In this study, there were no alien species recorded during the surveys. The surveys allowed to produce an updated species checklist using currently collected and historical data (Table 2.3). The total species list for the Chobe district is therefore 70 species and 14 families.

In the current study, there was variation in species richness. The Chobe River was most species rich (31 species) followed by Zibadianja Lagoon (29 species), Seboba rapids (26 species) and Savuti River (24 species) (Table 2.2). In the current study, some species were not recorded in their preferred habitat despite being known to exist historically. Notable species absent were *Ctenopoma multispine*, *Microtenepoma intermedium*, *Serranochromis robustus jallae*, *Tilapia ruweti*, *Hemichromis elongatus*, *mastacembelus vanderwaali*, *mastacembelus frenatus*, *Rhabdalestes maunensis*, *Enteromius barotseensis*, *Nannocharax machodoi*, *Nannocharax macropterus*, *Clariallabes platyprosopos* and *Clarias liocephalus*. This may be attributable to the relatively low sample size resulting from the short duration of this study as well as sampling gear selectivity.

Several factors may influence species richness, including predation (Moyle & Vondracek, 1985), competition (Ross et al., 1985) water chemistry, flow regime and temperature (Oberdorff et al., 1995). In the current study, the variation was attributed to Chobe River being more diverse with regard to flows, substrate and depth, than Zibadianja Lagoon and the Savuti River. In addition, the use of electrofishing made the results from Seboba rapids incomparable with those from other sites. For these reasons these are discussed separately.

## Seboba rapids

Fish of rapids are habitat specialists (Roberts & Stewards, 1976) and are generally sedentary species (Welcomme et al., 2006). According, to Hay et al. (2000), they are more vulnerable to habitat disruption than species that exhibit habitat generalism. Although some species were ubiquitous, (*Brycinus lateralis*, *Pharyngochromis acuticeps*, *Pseudocrenilabrus philander*, *Schilbe intermedius*, *Tilapia sparrmanii* and *Marcusenius altisambesi*), the ichthyofauna of Seboba rapids varied substantially from the riverine species in the Chobe main channel, Zibadianja Lagoon and Savuti main channel. This is consistent with suggestions made by Zaret and Rand (1971) who contended that fish tend to specialise on a specific habitat. For example, *Nannocharax multifaciatatus* and *Enteromius kerstenii* (with a single specimen) were only found at the Seboba rapids habitat. Therefore, altering and destruction of these habitats poses a threat to fish, and subsequent loss of fish biodiversity (Kahn, 1997). For instance, it has been observed that damming Zambezi River into Lake Kariba led to the decline in the *Opsaridium zambezense* population and almost extinction (Kenmiur, 1984; Timberlake & Childes, 2004). This shows how a current living species may be disrupted by lacustrine habitats.

In the Seboba rapids in this study *O. zambezense* was restricted to pools with sandy substrate surrounding the Seboba rapids. This distribution concurs with Bell-Cross and Jubb (1976), who recorded this species around the rocky pools of water. The highly abundant species at Seboba rapids were *Pollimyrus marianne* (14%) followed by *Micralestes acutidens* (13%), while dominant families were Cyprinidae (31%) followed by Mormyridae (9.2%). Mormyridae such as *P. marianne* could be susceptible to electrofishing because of its emission of electronic pulses (Kramer et al., 2003). Mormyridae may not only be abundant but also the most speciose family of the rapid habitat. In the Seboba rapids, in the Chobe, 11 Cyprinidae species and five Mormyridae species were recorded. This is similar to findings elsewhere. For example, in Zaire River, Mormyridae (19 species) and Cyprinidae (19 species) were the most speciose families in rapid habitats (Roberts & Stewart, 1976). *Micralestes acutidens* also prefers fast flowing water, as was evident in this study, and from Upper Lukulu River below the Kupandalupili falls (Huchzermeyer, 2013). However, in dry seasons, *M. acutidens* may be found downstream of the sand banks, where the current stirs up sediments, liberating food particles (Bell-Cross & Jubb, 1976). This is where they may be preyed on by smaller tigerfish (Bell-Cross & Jubb, 1976). Species peculiar to the

Seboba rapids were *M. katengae*, *E. afrovernayi*, *E. kerstenii*, *E. thamalakanensis*, *Zaireichthys pallidus*, *Chiloglanis* species, *N. multifaciatius*, *O. zambenzense*, *P. castelnaui* and *P. marianne*.

In rapids habitats, adaptation plays an important role in fish behaviour. For instance, according to Keenleyside (1991), rock dwellers may utilise rock openings as a defence mechanism to avoid predation and for privacy, to spawn without intrusion. Eggs of *Amphilius uranoscopus* are laid under stones, and the larvae swim with the same wriggling motion as tadpoles (Jackson, 1961). They have morphological modifications for life in the rapids (Roberts & Stewart, 1976; Welcomme et al., 2006). *Amphilius uranoscopus* have numerous backward-pointing spines positioned on the leading edges of their paired fins. In some Amphillidae spp, the pectoral and pelvic fins are broad, and form a feeble sucking disc to help the fish cling to the rocks in swift streams (Cutler et al., 2016; Jackson, 1961). These act as adhesion pads and enable the fish to sit in fast open waters and climb rock surfaces by sticking on with their pectoral and pelvic fins (Timberlake & Childes, 2004).

*Chiloglanis* species were also sampled in Seboba rapids. The mouth of *Chiloglanis* forms a sucking disc that allows the fish to hold onto rocks in fast currents and to scale vertical waterfalls (Timberlake & Childes, 2004). Disc mouths may also be an adaptation to forage on the rocks as some are rheophilic algae scrapers, or filter feeders (Welcomme et al., 2006; Cutler et al., 2016). This observation agrees with Braga et al. (1998) who reported that morphologically, the Loricariids species in Atlantic rainforest streams possessed dorsoventrally flattened bodies, sucker-like mouths and comb-like tooth plates that enable the fish to scrape attached algae and diatoms from the substrate.

Some species avoid light as well as strong current by delving deeply into interstices offered by jumbled piles of rocks (Roberts & Stewart, 1976). They may be light in colour as a major adaptation to reflect the sun's rays, have small eyes superficial in position or reduced in size, which may be partially or completely covered over by skin or they may be completely without eyes (van der Waal & Skelton, 1984). The Chobe sand catlet *Zaireichthys pallidus* is known to inhabit fine sand and stay buried with only its eyes exposed (Skelton, 1993, 2001). It blends very well with the sand colour and this may also be some form of adaptation.

Some rock dwellers are well adapted to living in rocky habitats because oxygen levels are constantly high because of water aeration by the rocks and the fast current. This may explain why van der Waal (2009) recorded *H. vittatus* in the Popa rapids in the Okavango River. Although there is a fast-well-oxygenated current, *H. vittatus* was not recorded at Sebobá rapids. This may be because its flooding is seasonal and rapids are shallower and may block fish movement, which could limit its distribution. Several studies have recorded rapids as barriers against fish species. For example, in the region, the Victoria Falls, Kafue Gorge and Kariba dam form barriers to the migration of freshwater eels, anguillidae, and limit their distribution (Jackson, 1961).

The abundance of *Pollimyrus marianne* around Sebobá rapids is due to the fact that this species lives in cover under rocks or in bankside vegetation out of the current (Kramer et al., 2003). *Pollimyrus marianne* is restricted to the Sebobá rapids, while *Pollimyrus cuandoensis* inhabits, the Kwando-Linyanti River system, and the *Pollimyrus castelnaui* is distributed in the Okavango (Kramer et al., 2003). Cichlids that were recorded at the rapids were the small cichlids such as *Tilapia sparrmanii*, *Pseudocrenilabrus philander* and *Pharyngochromis acuticeps*. This distribution is not consistent with reports by van der Waal (2009), who recorded *H. vittatus*, *C. rendalli* and *S. robustus* at the Popa rapids in the Okavango River of Namibia. The difference in species may be attributed to the depth of the rapids. Elsewhere in the Zaire River, cichlids have been recorded in rapids. However, these exhibited exceptionally elongated morphological adaptation (Roberts & Stewards, 1976).

The two *Mastacembelus* (*frenatus* and *vanderwaal*) were not recorded at Sebobá rapids during this study, despite *M. vanderwaal* having been recorded in the same habitat before (Tweddle et al., 2004). *Mastacembelus* spp. inhabit diverse aquatic habitat, and Cutler et al. (2016) have reported rheophilic mastacembelids being able to wedge themselves into rocky crevices to withstand strong currents. Their absence may have been as a result of the relatively low sampling effort or inability of the gear to extract these fish from rock crevices.

### **Lagoons and marginal floodplains**

In marginal floodplain areas, new inundation enhances habitat complexity (Welcomme, 1979; Bass, 1992). This is because during flooding there is the creation of more complex habitats as new

littoral zones opens up, fragmented channels reconnect (Balcome & Arthington, 2009) and floodplains are inundated (Merron & Bruton, 1988). During these periods, water temperatures and conductivity are low, while water depth, velocity and dissolved oxygen are greater (Winemiller & Jepsen, 1998). Floodwater recession in turn reduces the availability of aquatic habitats, and increases fish densities and the biotic interactions (Zaret & Rand, 1971), thereby changing biotic composition, and trophic structure of fish communities (Roll et al., 2012).

In the Kwando-Linyanti river system, a slightly greater species richness (24 species) was recorded using experimental nets set in deeper habitat, than in the shallow habitat (23 species) of Zibadianja Lagoon. This agrees with Sheldon (1968), who suggested that fish partitioned water columns so that deeper zones habitat supported more diverse faunas, as observed in Owego Creek in Tiago and Tompkins counties in New York in the United States. In contrast, commercial, more selective gillnets caught more species in shallow waters. While some species (*S. intermedius*, *B. lateralis* and *M. altisambesi*) were ubiquitous and generalist, inhabiting both deep and shallower zones of the Lagoon, as has been described by other studies in the region ( Hay et al., 2002; Naesje et al., 2004), some (e.g., *Serranochromis giardi*, *Petrocephalus longicapitis*, *Serranochromis thumbergi*, *Mormyrus lacerda* and *Hydrocynus vittatus* were sampled only from deep zones and others *Coptostomabarbus wittei*, *Microparchax hutereaui* and *Enteromius haasianus* were sampled from shallow, vegetated zones.

Habitat partitioning is common in many fish species, such as in cichlids (Skelton, 2001). Lagoons and shallow habitats are also a preferred spawning habitat for many cichlids, including *C. rendalli*, *O. andersonii* and *Serranochromis altus*, because the shallow water habitat with high temperatures optimises juvenile growth (Ward & Stanford, 1995). Most juvenile cichlids seek refuge in shallower, vegetated microhabitat to avoid predation (Reebs, 2008). Similarly, *Hepsetus cuvieri* (an aggressive apex predator) uses aquatic vegetation habitats for concealment to ambush prey (Moriarty, 1983; Merron et al., 1990; Merron, 1991, 1993; Abilhoa et al., 2011), and for attachments to its bubble foam nest, that protects eggs and larvae from predators and direct intense tropical heat (Bruton, 1990). This may explain why Winemiller and Kelso-Winemiller (1994) recorded 98% of *H. cuvieri* in lagoons, while in lacustrine Lake Kariba, it inhabited muddy waters with a variety of vegetation (Kenmiur, 1984; Sanyanga & Feresu, 1994).

According, to Mosepele, (1990), *Hydrocynus vittatus* is a key indicator of main channel and open water species. This further concurs with Ramberg et al. (2006), who argued that Alestidae and Cyprinidae are fast swimmers that are adapted to open and midwater. In Chobe River, for example, *H. vittatus* was abundant and; prominently sampled from the main channel. Studies in Okavango (Merron & Bruton, 1988; Merron, 1991; Mosepele, 1990) and Zambezi River (Winemiller & Kelso Winemiller, 1994) made similar observations. Hay et al. (2002) observed a trend in the utilisation of side channels, backwaters and floodplains by *H. vittatus* during rising waters in Zambezi River. This agrees with the current study where it was sampled from backwaters connected to the main channel in the Chobe River.

In the current study, higher abundance of *H. vittatus* was observed and a lower abundance of *H. cuvieri* in Chobe River, while in Zibadianja Lagoon and Savuti River there was a higher abundance of *H. cuvieri* than *H. vittatus*. Typically, *H. vittatus* are rare in the Kwando–Linyanti and Savuti river systems. Historically, only one specimen has been recorded in Savuti River at President Camp in the main channel (DWNP surveys, 2010–2012; unpublished). This might be due to habitat preference.

According, to Jackson (1961), *H. vittatus* is not found in small streams except seasonally for spawning, nor in swampy marshes except where there is a large swamp-channel or another flow of well-aerated water. Owing to intermittent seasonal episodic flows in Savuti River, *H. vittatus* may not be able to establish themselves and those specimens that are present are likely to be occasional migrants attempting to take advantage of expanding food and habitat resources (Galacatos et al., 2004). This is because water permanency, depth and flow are primary requirements for distribution and abundance of this species (Merron, 1991). Therefore, habitat preference plays a crucial role in their distribution, with *H. vittatus* preferring open fast-flowing oxygenated water (Skelton, 2001; Mosepele et al., 2009), while *H. cuvieri* prefers vegetated habitats (Skelton, 2001).

Habitat type also influenced taxa distribution in this study. For example, both *Labeo lunatus* and *cylindricus* had limited distribution and were only sampled from rocky substrate habitats of Chobe River. In addition, *L. cylindricus* was recorded solely in backwaters with gravel substratum

whereas *L. lunatus* was recorded in both main channel, backwater and side channels. In Lake Liambezi, *L. cylindricus* was not found due to an absence of riverine habitat (Peel, 2012).

### **Large cichlids**

The results of this survey demonstrated that the large, commercially important cichlids *Oreochromis andersonii*, *Oreochromis macrochir* and *Coptodon rendalli*, make up only a small proportion of the fish fauna. This was particularly true for the Chobe River, where large cichlids were rare. This is most likely as a result of high fishing pressure (see Tweddle et al., 2015). Current results, therefore, contrast with those of Merron (1989a) who reported *O. andersonii* as dominating the fish community in the Chobe River. During this survey, large tilapiines were generally only sampled from the more protected lagoon, Savuti River and backwater systems, where exploitation pressure was low.

To develop a better understanding of the potential impact of exploitation on these fishes, the next chapter will focus on quantitative comparisons of diversity and relative abundance using data from the standardised gill net fleet.

## **CHAPTER 3: EXPERIMENTAL GILLNET CATCHES, COMPOSITION AND RELATIVE ABUNDANCE OF LARGE CICHLIDS SPECIES IN THE CHOBE DISTRICT, BOTSWANA**

### **3.1 Introduction**

Inland water fisheries in Africa are threatened by human activities such as pollution, water diversion and by, eutrophication, invasive species and over-exploitation (Sala et al., 2000; Dudgeon et al., 2005). In the Zambezi basin, overfishing through the use of more efficient monofilament nets and the use of destructive fishing methods such as seining netting with mosquito netting (Tweddle et al., 2015) has resulted in depletion of large, high value species such as the large cichlids Threespot Tilapia *Oreochromis andersonii*, Greenhead Tilapia *Oreochromis macrochir* and Redbreast Tilapia *Coptodon rendalli* (Tweddle et al., 2015). These large cichlids are favoured by fishers because they generally command higher market prices than small species (Weyl et al., 2010; Tweddle et al., 2015). As a result, these commercially important large cichlids are the dominant group of fish sold in formal markets, e.g., at Katima Mulilo fish market in Namibia (van der Waal et al., 2011). Reduced catch rates for these species are therefore a cause for concern, as there are examples of complete collapse of some fisheries in the region (Banda et al., 2005; Weyl et al., 2010). In Malawi, for example, the collapse of the once valuable Chambo *Oreochromis* “nyasalapia spp” stocks in Lakes Malombe and Malawi was as a consequence of an unsustainable fishing effort, non-compliance with fishing regulations and the use of the illegal gear which denuded juvenile habitat (Banda et al., 2005).

Inland fisheries in developing countries in Africa, Asia and South America are typically artisanal fisheries characterised by a large number of participants, using multiple gear to harvest multiple-species assemblage (Allan et al., 2005). As a result, fishers often adapt to overfishing by switching to smaller, more abundant, but less valuable species as the larger more valuable species are depleted (Christensen & Pauly, 1998; Ward et al., 2001; Welcomme, 2001). In Kenya for example, fishers adapt to declining catches of high value species by increasing effort, changing gear and changing location (Muthiga & Kawala, 2010). Such behaviour enables fishermen to maintain the quantity of fish harvested but not the value (Marshall, 2016). By changing species composition



from larger, slower growing species to smaller, faster growing species (Fenberg & Roy, 2008), high exploitation levels are also capable of transforming an originally stable, mature and efficient ecosystem into an immature and stressed system (Garcia et al., 2003).

Understanding and mitigating these impacts is therefore important not only for ensuring sustainable utilisation, but also for preserving the ecosystem integrity, which in turn secures the livelihoods of the people dependent on the resource. Typical interventions include reduced fishing effort, gear restriction, closed seasons and protected areas (FAO, 1995; Banda et al., 2005; Beets & Manuel, 2007; Kaur, 2012; Wallace et al., 2015).

In Botswana, 17% of the land surface area is designated as National Parks and Game Reserves and a further 21% is designated as Wildlife Management Areas (Government of Botswana, 1975; IUCN, 1987a). Elsewhere protected areas play an important role in fisheries management, research, single species conservation and habitat protection (Gardner & Struthers, 2012). There are many examples of the benefits of protected areas in fisheries management, e.g., arresting and possibly reversing the global and local decline in fish populations and productivity by protecting critical breeding, nursery and feeding habitats (Kenchiton et al., 2003) and increased abundance and spawning biomass (Bohnsack, 1998). In South Africa for example, Marine Protected Areas (MPAs) typically contain fish of large size and higher abundance than adjacent fished areas (Cowley et al., 2002), while in Kenya, species' richness was significantly higher in a Marine Reserve than beyond reserve boundaries (Cote et al., 2001). As a result, no-take Marine Protected Areas are recognised as an important strategy for slow growing species with limited distribution as well as for stock rebuilding of overexploited species (Cowley et al., 2002). The role and potential importance of protected areas in fisheries management, in freshwaters is, however, not well researched.

This chapter is the first assessment of the diversity and relative abundance of the fish inside and outside protected areas in the Chobe/Zambezi region of Botswana. This assessment is based on gillnet surveys conducted at sites representing a heavily exploited area (Chobe River near the Town of Kasane); a less exploited area (Zibadianja Lagoon) and a protected area, Savuti River and marsh. Species composition, diversity and relative abundance derived from these surveys were used to test the overall hypothesis that exploitation reduces species diversity and resulted in the depletion of large bodied fish. The specific hypotheses tested were (1) diversity in exploited areas

was lower than in protected areas; and (2) CPUE for large bodied cichlid species was lower in exploited areas than in lightly exploited areas, and protected areas.

### **3.2 Material and methods**

The study site is described in detail in Chapter Two. Gillnet surveys were conducted once a month for four months, with four night settings for each of the three river systems between September 2014 and April 2015 using 11 multifilament gill net fleets, and each comprising of eleven 10 m panels of 2 m deep panels with stretched mesh sizes of 12, 16, 22, 28, 35, 45, 57, 73, 93, 118 and 150 mm. The nets were set overnight for approximately 12 hours (set at 1700 hrs. and 1900 hrs. and retrieved in the mornings between 0600 hrs. and 0800 hrs.). All fish sampled were identified to species level using Skelton (2001), and counted and weighed to the nearest gram. As the sampling effort was equal between months, all subsequent analyses are conducted on grouped data.

#### **Fish diversity and species composition**

To describe the fish community sampled in experimental gillnets and to provide qualitative description of catches in the different areas, gillnet catches were first described by calculating the percentage of the total number (%N), percentage of the total biomass (%W) and the frequency of occurrence (%F) of each species in the total number of net settings (Kolding, 1998). Subsequently, an Index of the Relative Importance (IRI) was calculated using the equation  $IRI = (\%N + \%W) \times \%F$  and the IRI for each species was expressed as a percentage of all species at each site.

To test the hypothesis that fish diversity in exploited areas was lower than in protected areas, a Principal Component Analysis (PCA) was conducted using the software package PRIMER (Clarke & Warwick, 1994; Clarke & Gorley, 2006). PCA uses ordination to highlight similarity and dissimilarity. Areas with similarity are grouped closer to one another while areas with dissimilarity are far apart (Clarke & Warwick, 1994). Fish diversity at each site was estimated using the Shannon and Shannon -Wiener index of diversity. The Shannon -Wiener index of diversity ( $H'$ ) is a measure of species richness, weighed by their abundances or evenness and calculated as:  $H' = -\sum p_i \ln p_i$ , where  $p_i$  is the proportion of individuals found in the  $i$ th species (Magurran, 1988). The Shannon Index ( $J'$ ) assumes that individuals are randomly sampled from an indefinitely large

population; and that all species are represented in the sample, that was calculated as  $J' = H'/H_{\max}$ , where  $H' = -\sum p_i \ln p_i$ , where  $S$  is the total number of species in a community (Richness).  $J'$  assumes the value between 0 and 1, a value of 1 meaning all species are equally abundant in the area.

### **Comparison Catch per Unit effort (CPUE)**

Catch per unit effort (CPUE) was used to test the hypothesis that relative abundance of large cichlids was higher in protected areas than fished areas. To do this, CPUE was first calculated as;  $CPUE_i = C_i/E_i$ , where  $C_i$  is the catch of the species ( $i$ ) (in either numbers or weight) and  $E_i$  is the effort expended to obtain  $i$ . CPUE was standardised as number.net night<sup>-1</sup> and Kg.net nights (Kolding, 1998). For comparative purposes, CPUE was compared for the total catch, and for large, exploited cichlid species *O. andersonii*, *O. macrochir* and *C. rendalli* individually. Exploratory analysis revealed that data did not conform to the conditions of parametric tests analysis and therefore, the non-parametric Kruskal-Wallis test was used for statistical comparison. The Tukey tests for pairwise Multiple Comparison Procedures were used as a post-hoc test to isolate the differences between the sites.

## **3.3 Results**

### **Fish diversity**

Surveys yielded a total of 7992 fish weighing 1095 kg and comprised of nine families and 37 species. Ordination plots reveal that the fish fauna of Chobe River is distinct from the Zibadianja Lagoon and the Savuti River, whereas Savuti and Zibadianja overlap in species and abundance (Figure 3.1).

## Catch composition

### Chobe River and Floodplain

In experimental gillnet catches, a total of 2220 fish weighing 97 kg and comprising nine families and 31 species were sampled in 16 nights (Table 3.1). The most numerous species was *Brycinus lateralis* (21.7%), followed by *Enteromius radiatus* (11.9%) and *Hydrocynus vittatus* (10.9%). *H. vittatus* contributed the most weight (43.8%), followed by *Schilbe intermedius* (12.9%) and *Clarias gariepinus* (11.4%) respectively. The five most important species accounting for 74% IRI were *H. vittatus* (30%), *S. intermedius* (13.2%), *B. lateralis* (12.8%), *Synodontis* species (10.1%) excluding *S. nigromaculatus*, and *E. radiatus* (7.8%). *Clarias ngamensis* was not recorded in Chobe River during this study.

**TABLE 3.1** Experimental gillnet catch composition in percentage numbers (%NO), percentage weight (%WT) and percentage frequency of occurrence (%FO) and percentage index of relative importance (%IRI) of all species sampled in Chobe River between September 2014 and April 2015 in Chobe district, Botswana.

<b>SPECIES</b>	<b>%NO</b>	<b>%WT</b>	<b>%FO</b>	<b>IRI</b>	<b>%IRI</b>	<b>RANKING</b>
<i>Hydrocynus vittatus</i>	10.9	43.8	87.5	4786	30.0	1
<i>Schilbe intermedius</i>	9.59	12.9	93.8	2110	13.2	2
<i>Brycinus lateralis</i>	21.7	3.49	81.3	2044	12.8	3
<i>Synodontis spp</i>	7.43	8.77	100	1621	10.1	4
<i>Enteromius radiatus</i>	11.9	0.47	100	1241	7.77	5
<i>Marcusenius altisambesi</i>	8.56	4.58	93.8	1231	7.70	6
<i>Enteromius paludinosus</i>	7.03	0.29	93.8	686	4.30	7
<i>Petrocephalus longicapitis</i>	8.06	0.85	75.0	669	4.19	8
<i>Clarias gariepinus</i>	0.36	11.4	31.8	368	2.30	9
<i>Synodontis nigromaculatus</i>	1.62	2.84	62.5	279	1.75	10
<i>Pharyngochromis acuticeps</i>	2.93	0.78	68.8	255	1.59	11
<i>Serranochromis macrocephalus</i>	0.77	2.38	50.0	157	0.98	12
<i>Micralestes acutidens</i>	4.59	0.11	31.3	147	0.92	13
<i>Labeo lunatus</i>	0.50	1.93	43.8	106	0.66	14
<i>Cyphomyrus cubangoensis</i>	0.90	0.76	50.0	83.2	0.52	15
<i>Enteromius poechii</i>	1.17	0.31	50.0	74.2	0.46	16
<i>Sargochromis condingtonii</i>	0.23	0.83	25.0	26.3	0.16	17
<i>Mormyrus lacerda</i>	0.14	1.6	12.5	21.7	0.14	18
<i>Tilapia sparrmanii</i>	0.41	0.24	31.3	20.1	0.13	19
<i>Sargochromis carlottae</i>	0.23	0.56	25.0	19.6	0.12	20
<i>Oreochromis andersonii</i>	0.14	0.37	18.8	9.41	0.06	21
<i>Parauchenoglanis ngamensis</i>	0.18	0.36	12.5	6.79	0.04	22
<i>Oreochromis macrochir</i>	0.14	0.20	18.8	6.29	0.04	23
<i>Hippopotamyrus szaboi</i>	0.14	0.01	18.8	2.71	0.02	24
<i>Pseudocrenilabrus philander</i>	0.14	0.01	12.5	1.86	0.01	25
<i>Sargochromis giardi</i>	0.05	0.06	6.25	0.67	0.00	26
<i>Hepsetus cuvieri</i>	0.05	0.05	6.25	0.56	0.00	27
<i>Labeo cylindricus</i>	0.05	0.03	6.25	0.50	0.00	28
<i>Coptodon rendalli</i>	0.05	0.00	6.25	0.29	0.00	29
<i>Enteromius spp</i>	0.05	0.00	6.25	0.29	0.00	30
<i>Enteromius bifrenatus</i>	0.05	0.00	6.25	0.29	0.00	31

## Zibadianja Lagoon

In experimental gillnet catches, a total of 2960 fish weighing 599 kg and comprising of seven families and 25 species were sampled in 16 nights (Table 3.2). The most numerous species according, to %IRI was *S. intermedius* (39%) in Zibadianja, followed by *B. lateralis* (25%) and thirdly *M. altisambesi* (18.3%). *Schilbe intermedius* contributed the most weight (46.8%). The five most important species contributing to 92.7% IRI were *S. intermedius* (47.2%), *M. altisambesi* (16.2%), *B. lateralis* (14.2%), *C. gariepinus* (13%) and *C. ngamensis* (2.1%).

**TABLE 3.2.** Experimental gillnet catch composition in percentage numbers (%NO), percentage weight (%W) and percentage frequency of occurrence (%FO) and percentage index of relative importance (%IRI) of all species sampled in Zibadianja Lagoon sampled between September 2014 and April 2015 in Chobe District, Botswana.

SPECIES	%NO	%WT	%FO	IRI	%IRI	RANKING
<i>Schilbe intermedius</i>	39.0	46.8	100	8575	47.2	1
<i>Marcusenius altisambesi</i>	18.3	15.3	87.5	2942	16.2	2
<i>Brycinus lateralis</i>	25.0	0.8	100	2576	14.2	3
<i>Clarias gariepinus</i>	2.60	22.5	93.8	2355	13.0	4
<i>Clarias ngamensis</i>	1.08	4.52	68.8	385	2.12	5
<i>Hepsetus cuvieri</i>	1.42	2.14	87.5	311	1.71	6
<i>Pharyngochromis acuticeps</i>	2.91	0.2	93.8	291	1.60	7
<i>Enteromius barnardi</i>	2.36	0.02	56.3	134	0.74	8
<i>Oreochromis andersonii</i>	0.57	1.11	62.5	105	0.58	9
<i>Serranochromis angusticeps</i>	0.71	1.33	50.0	102	0.56	10
<i>Coptodon rendalli</i>	0.57	0.76	62.5	83.3	0.46	11
<i>Petrocephalus longicapitis</i>	1.86	0.01	43.8	81.6	0.45	12
<i>Sargochromis giardi</i>	0.34	0.97	31.3	40.9	0.23	13
<i>Hydrocymus vittatus</i>	0.27	1.1	25.0	34.4	0.19	14
<i>Oreochromis macrochir</i>	0.30	0.44	43.8	32.6	0.18	15
<i>Sargochromis condingtonii</i>	0.41	0.54	25.0	23.5	0.13	16
<i>Tilapia sparrmanii</i>	0.61	0.04	31.3	20.3	0.11	17
<i>Serranochromis macrocephalus</i>	0.24	0.21	37.5	16.9	0.09	18
<i>Enteromius paludinosus</i>	0.44	0.01	31.3	14.1	0.08	19
<i>Serranochromis altus</i>	0.17	0.63	12.5	9.97	0.05	20
<i>Mormyrus lacerda</i>	0.07	0.36	12.5	5.30	0.03	21
<i>Pseudocrenilabrus philander</i>	0.24	0.00	18.8	4.52	0.02	22
<i>Enteromius unitaeniatus</i>	0.47	0.01	6.25	3.02	0.02	23
<i>Sargochromis carlottae</i>	0.07	0.06	12.5	1.60	0.01	24
<i>Serranochromis thumbergi</i>	0.03	0.10	6.25	0.85	0.00	25

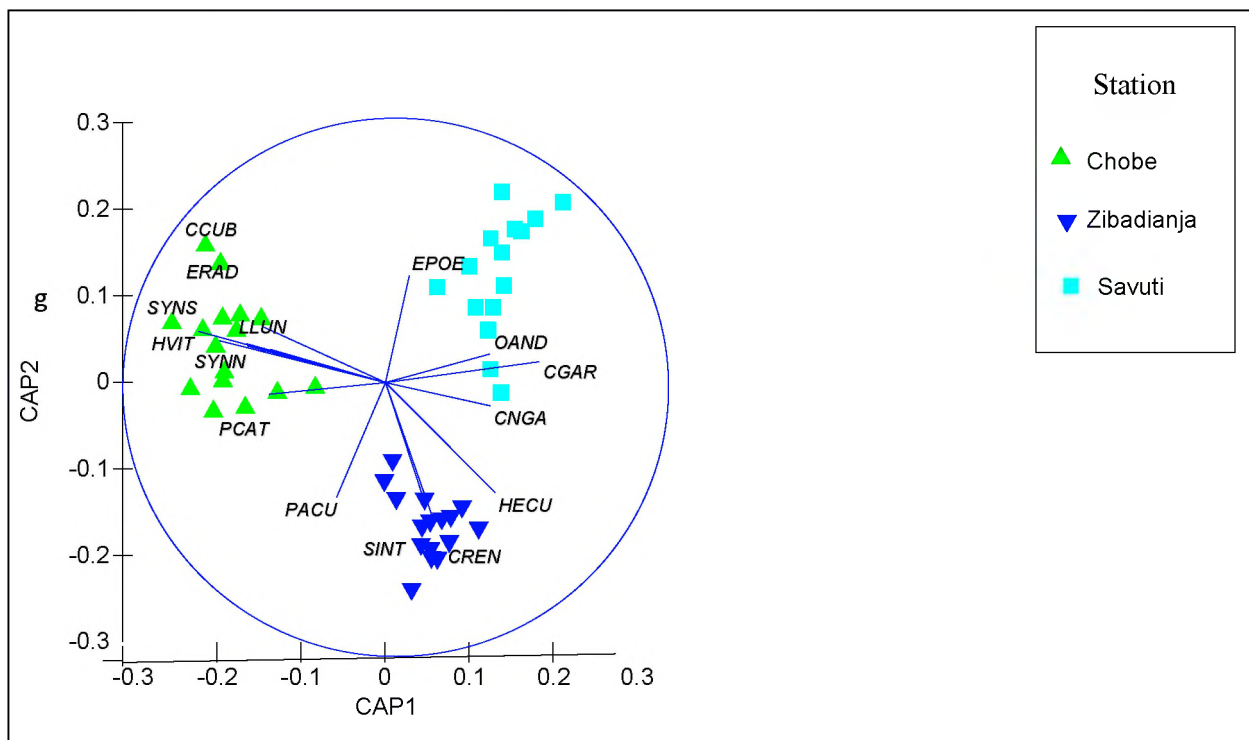
## Savuti Marsh

In experimental gillnet catches, a total of 2812 fish weighing 399 kg and comprising seven families and 24 species were sampled in 16 nights (Table 3.3). Cichlids were well represented (50%). The most numerous species was Momyridae *M. altisambesi* (37.7%) while *C. gariepinus* contributed the bulk of the weight (54.4%). The five most important species accounting for 90.5% IRI were *C. gariepinus* (39.5%), *M. altisambesi* (30.2%), *S. intermedius* (8.42%), *E. paludinosus* (6.7%) and *B. lateralis* (5.7%).

**TABLE 3.3.** Experimental gillnet catch composition in percentage numbers (%NO), percentage weight (%WT) and percentage frequency of occurrence (%FO) and percentage index of relative importance (%IRI) of all species sampled in Savuti River and marsh between September 2014 and April 2015 in Chobe District, Botswana.

SPECIES	%NO	%WT	%FO	IRI	%IRI	RANKING
<i>Clarias gariepinus</i>	7.11	54.4	100	6147	39.5	1
<i>Marcusenius altisambesi</i>	37.7	20.1	81.3	4699	30.2	2
<i>Schilbe intermedius</i>	10.2	5.88	81.3	1310	8.42	3
<i>Enteromius paludinosus</i>	18.1	0.32	56.3	1034	6.65	4
<i>Brycinus lateralis</i>	17.2	0.61	50.0	891	5.73	5
<i>Clarias ngamensis</i>	1.46	5.55	50.0	350	2.25	6
<i>Oreochromis andersonii</i>	1.28	3.17	68.8	306	1.97	7
<i>Hepsetus cuvieri</i>	0.60	4.01	56.3	260	1.67	8
<i>Enteromius poechii</i>	2.81	0.37	75.0	239	1.53	9
<i>Oreochromis macrochir</i>	1.14	2.34	56.3	195	1.26	10
<i>Serranochromis macrocephalus</i>	0.57	0.63	50.0	59.8	0.38	11
<i>Hydrocynus vittatus</i>	0.14	0.76	18.8	16.9	0.11	12
<i>Tilapia sparrmanii</i>	0.39	0.10	25.0	12.3	0.08	13
<i>Pharyngochromis acuticeps</i>	0.36	0.10	25.0	11.5	0.07	14
<i>Serranochromis altus</i>	0.11	0.66	12.5	9.53	0.06	15
<i>Sargochromis condingtonii</i>	0.14	0.15	18.8	5.42	0.03	16
<i>Serranochromis angusticeps</i>	0.07	0.27	12.5	4.32	0.03	17
<i>Pseudocrenilabrus philander</i>	0.25	0.01	12.5	3.18	0.02	18
<i>Coptodon rendalli</i>	0.07	0.18	12.5	3.08	0.02	19
<i>Serranochromis thumbergi</i>	0.04	0.16	6.25	1.25	0.01	20
<i>Cyphomyrus cubangoensis</i>	0.11	0.06	6.25	1.05	0.01	21
<i>Sargochromis giardi</i>	0.04	0.12	6.25	0.99	0.01	22
<i>Mormyrus lacerda</i>	0.04	0.08	6.25	0.72	0.00	23
<i>Hippopotamyrus szaboi</i>	0.04	0.00	6.25	0.22	0.00	24

Ordination plots revealed that the fish fauna of the Chobe River is distinct from that of Zibadianja Lagoon and Savuti river and marsh. The PCA revealed that the communities of the three sampling areas can be grouped into three distinct species assemblages (Figure 3.1). The Chobe River was distinguished by *Petrocephalus* spp, *Enteromius radiatus*, *Hydrocynus vittatus* and *Cyphomyrus cubangoensis*. Species characteristic to the Chobe River were *Labeo cylindricus*, *Labeo lunatus*, *Parauchenoglanis ngamensis*, *Synodontis* species and *Enteromius bifrenatus*. The fish community in Zibadianja Lagoon was distinguished by the abundance of *Schilbe intermedius*, *Coptodon rendalli*, *Hepsetus cuveiri* and *Pharyngochromis acuticeps*. The Savuti River fish community was characterised by the presence of *Enteromius poechii*, *Oreochromis andersonii*, *Clarias gariepinus* and *Clarias ngamensis*.



**Figure 3.1.** Fish assemblage structure of experimental gillnets using PCA showing distinctive diversity between Chobe River, Zibadianja Lagoon and Savuti River sampled between September 2014 and April 2015 in Chobe District, Botswana. OAND= *Oreochromis andersonii*, CGAR= *Clarias gariepinus*, CNGA= *Clarias ngamensis*, HECU= *Hepsetus cuvieri*, CREN= *Coptodon rendalli*, EPOE= *Enteromius poechii*, ERAD= *Enteromius radiatus*, HVIT= *Hydrocynus vittatus*, PACU= *Pharyngochromis acuticeps*, LLUN= *Labeo lunatus*, PCAT= *Petrocephalus longicapitis*, CCUB= *Cyphomyrus szaboi*, SYNN= *Synodontis nigromaculatus*, SYNS= *Synodontis* spp.



## Species richness and diversity

The Shannon-Wiener diversity ( $H'$ ) and evenness ( $J'$ ) indices for the three localities are summarised in Table 3.4. The result did not support the hypothesis that fish diversity in exploited areas was lower than in protected areas. The Chobe River and associated floodplains was the richest (31 species), followed by Zibadianja Lagoon (25 species), and the Savuti River and marsh (24 species). The most species-rich family at every station was Cichlidae with 13 species in the Zibadianja, 12 species in the Savuti River, and ten species in the Chobe River. The Cyprinidae family was the second most species-rich with seven species in the Chobe River, three species in Zibadianja Lagoon and two species in the Savuti River.

The Shannon-Wiener diversity ( $H'$ ) revealed higher species diversity and evenness at Chobe river ( $H'2.46$ ;  $J' 0.72$ ), even though not significantly higher (Kruskal Wallis Test;  $p>0.05$ ) than Savuti River and marsh ( $H' 1.84$ ;  $J' 0.58$ ) and the least diverse being Zibadianja Lagoon ( $H'1.79$ ;  $J'0.56$ ).

**TABLE 3.4.** Shannon-Wiener diversity ( $H'$ ) and evenness ( $J'$ ) indices for the three stations

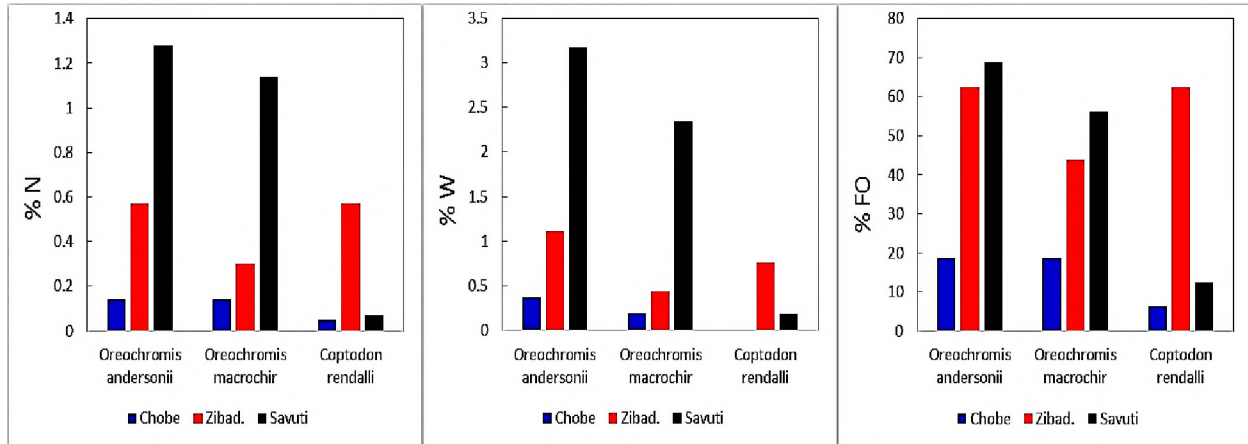
Indices	Chobe River	Zibadianja Lagoon	Savuti River & Marsh
$H'$	2.46	1.79	1.84
$J'$	0.72	0.56	0.58

## Relative abundance

### Comparison between three economically important large cichlids

Comparisons between % NO, %WT and %FO of the three large cichlids *O. andersonii*, *O. macrochir* and *C. rendalli* are shown in Figure 3.2. In all cases, the three-species occurred in the fewest catch samples and contributed less to the total number and biomass of the catch in exploited areas than in the protected areas. This observation supports the hypothesis that these large cichlids contribute more to the species composition in protected areas and are more abundant in protected

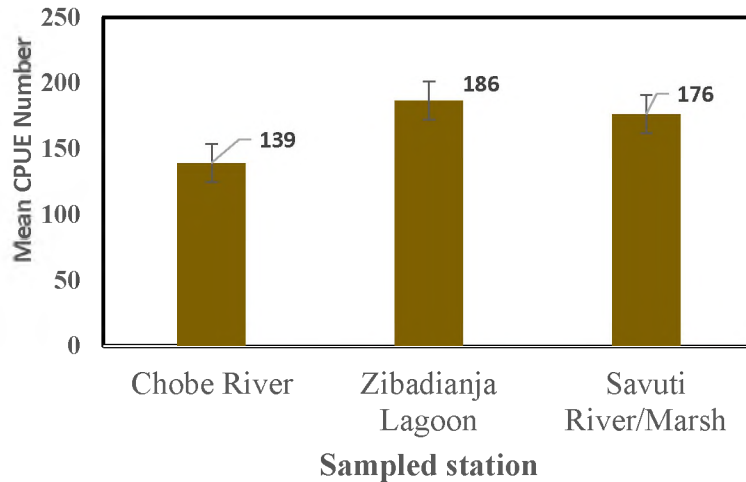
areas than in exploited areas. This hypothesis was subsequently tested on the basis of Catch Per Unit Effort.



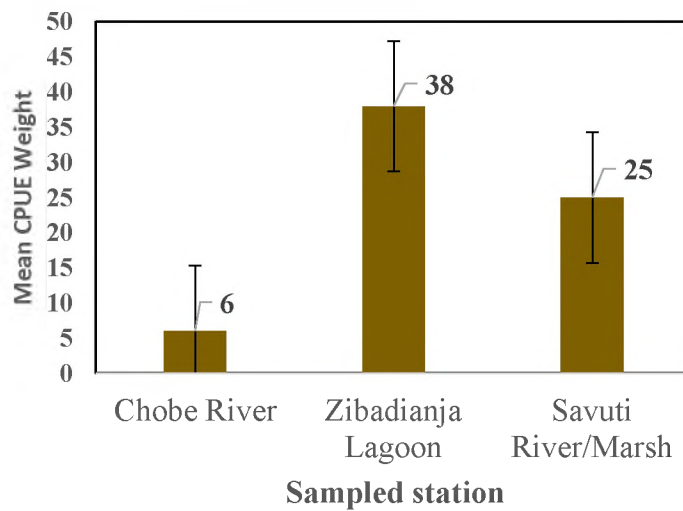
**Figure 3.2.** Comparison between three river systems showing variation in %NO, %WT and %FO for three large important cichlids

The mean Catch Per Unit Effort (CPUE) by numbers for cumulative catches for all species did not differ significantly between the three areas (Kruskal Wallis Test;  $p > 0.05$ ) and the mean ( $\pm$ standard deviation) was  $139 \pm 70$  fish/net. night<sup>-1</sup> at the Chobe River;  $186 \pm 135$  fish/net. night<sup>-1</sup> at Zibadianja Lagoon and  $176 \pm 147$  fish/net. night<sup>-1</sup> at Savuti River (Figure 3.3). As a result, the hypothesis that fish were generally more abundant in protected areas was rejected.

Mean CPUE by weight for cumulative catches for all species did not differ significantly between two protected areas (Kruskal Wallis Test;  $P < 0.05$ ) Zibadianja Lagoon ( $38 \pm 31$  kg/net.night<sup>-1</sup> and Savuti River/Marsh  $25 \pm 19$  kg/net.night<sup>-1</sup>) but both were significantly higher than the CPUE for experimental gillnets set at exploited Chobe River CPUE ( $6 \pm 3$  kg/net.night<sup>-1</sup>), (Figure 3.4). When compared with equal numerical CPUE significantly higher biomass supported the hypothesis that fish in protected areas were generally larger than those outside protected areas.



**Figure 3.3.** Mean CPUE (Number)  $\pm$  S.D fish/net/ night and (weight)  $\pm$  S. D kg/net. night<sup>-1</sup>) between stations sampled between September 2014 and April 2015 in Chobe district, Botswana



**Figure 3.4.** Mean CPUE (weight)  $\pm$  S.D kg/net/ night) between stations sampled between September 2014 and April 2015 in Chobe district, Botswana

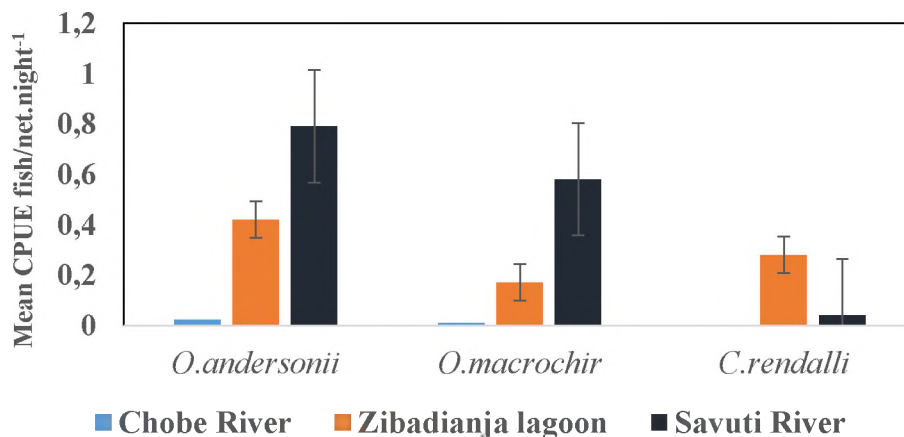
### Mean CPUE for economically important large cichlids in experimental gillnets

Analyses of the mean CPUE for large economically important cichlids generally supported the hypothesis that these fish were more abundant, and CPUE higher, in protected areas than non-

protected areas (Figure 3.5). The CPUE for the experimental net set in Chobe River consistently yielded the lowest CPUE; (Kruskal-Wallis: Turkey test  $p < 0.05$ ). The mean CPUE of *Oreochromis andersonii* was highest in the Savuti River ( $0.8 \pm 0.8$  kg/net.night<sup>-1</sup>), followed by Zibadianja Lagoon ( $0.4 \pm 0.5$  kg/net.night<sup>-1</sup>) and the Chobe River ( $0.002 \pm 0.0$  kg/net.night<sup>-1</sup>).

The mean CPUE for *Oreochromis macrochir* also differed significantly between river systems (ANOVA:  $P < 0.05$ ) being higher in Savuti River ( $0.6 \pm 1.2$  kg/net.night<sup>-1</sup>) and Zibadianja Lagoon ( $0.2 \pm 0.2$  kg/net.night<sup>-1</sup>) than in the Chobe River ( $0.01 \pm 0.02$  kg/net.night<sup>-1</sup>).

The mean CPUE for *Coptodon rendalli* was significantly higher (ANOVA:  $P < 0.001$ ) at Zibadianja Lagoon ( $0.3 \pm 0.3$  kg/net.night<sup>-1</sup>) than in the Savuti River ( $0.04 \pm 0.12$  kg/net.night<sup>-1</sup>) and in the Chobe River ( $0.0001 \pm 0.005$  kg/net.night<sup>-1</sup>).



**Figure 3.5.** Experimental gillnet CPUE by weight for *Oreochromis andersonii*, *Oreochromis macrochir* and *Coptodon rendalli* in the Chobe River, Savuti River and the Zibadianja Lagoon in Chobe district, Botswana sampled between September 2014 and April 2015.

### **3.4 Discussion**

#### **Fish assemblage structure**

Species diversity and richness in exploited areas were higher than the diversity and richness in protected areas, therefore the hypothesis that exploitation reduces species diversity was rejected. However, species diversity and richness may differ due to habitat difference and not necessarily due to protected areas. Furthermore, the assemblage structure shows minimal alteration, which may be attributable to variation in fish habitat and hydrological variability rather than exploitation. Fish distribution and abundance are affected by the fragmentation and alteration of habitat (Kiraly et al., 2014). For example, resident fish movements are impeded by dams, river capture, bridges and rapids, resulting in changes to fish assemblage structure through isolation and restriction of access to habitats essential to fish at different life stages (Porto et al., 1999). Historically, the Chobe River and Linyanti River may have been one river system but separated due to river capture caused by faulting (Moore, 1999; Moore & Larkin, 2001; Moore et al., 2007). This also concurs with the notion that Kwando–Linyanti, Zambezi–Chobe and the Okavango are in periodic confluence during high floods, allowing immigration of species to occur (van der Waal, 1980; Curtis et al., 1998; Varias et al., 2008). The presence of common fish species across different rivers is evidence of interconnection and early links between drainages (Skelton, 1993; Moore et al., 2007). For example, the distribution of *Hydrocymus vittatus* in the Zambezi system illustrates the complex geomorphological history of the Zambezi system (Tweddle, 2010). This is because *H. vittatus* is believed to have originated in the Congo Basin, but entered the Upper Zambezi via the Kasai/Upper Zambezi river capture (Moore et al., 2007).

#### **Species richness and diversity**

Species richness and diversity varied between river systems, with Chobe River being the most species-rich (31 species), followed by Zibadianja Lagoon (25 species) and Savuti River (24 species). The close diversity and richness of the Zibadianja Lagoon and Savuti River species shows their hydrological connection.

There is a relationship between habitat size and number of species globally (Smith, 1981). This explains why narrow, shallower streams like Savuti River and marsh have lower species diversity and richness than large, diverse and more structurally complex habitats such as the Zambezi-Chobe

and Kwando-Linyanti river systems. Furthermore, intermittent flows in Savuti may generate low species richness (Oberdorff et al., 1995). Species richness is strongly related to basin size, (Welcomme, 1985) and patterns of variation in richness of assemblages are influenced by longitudinal position in a water shed, by regional diversity and by size of local habitat. This explains why Peel (2012) recorded higher diversity in river systems (Kwando and Zambezi) than in Lake Liambezi. Subsequent study by Simasiku (2014) also recorded higher diversity in the Kavango floodplain (24 species), than the 18 species in Lake Liambezi.

Experimental gillnet DWNP data (2006–2012) recorded 50 species in the Chobe River excluding the rapids, 37 species at Kwando-Linyanti excluding Zibadianja Lagoon and 29 species at the Savuti River and marsh. Therefore, long term monitoring reveals more species rich than the current study hence time factors could have limited this study. At Kwando-Linyanti diverse habitat (floodplain, main channel, side channel) were sampled over six years whereas during this study Zibadianja lagoon alone was sampled, and this could have limited the diversity and species richness found. For instance, species such as *Enteromius fasciolatus*, *C. stappersii* and *S. robustus* were abundant during the DWNP surveys (2006–2012) were found to be absent in this study.

The most speciose family in the three sampled habitats were the Cichlidae, while Cyprinidae was the second most speciose family. The higher diversity of cichlids has been recorded by several authors in the Okavango Delta (Siziba et al., 2011) and in Lake Liambezi (van der Waal, 1980; Peel, 2012; Simasiku, 2014). The current study, therefore, agrees with studies by Hay et al. (2002); Naesje et al. (2004) who both recorded Cyprinidae and Cichlidae being the most diversified families in the Kwando and Kunene Rivers respectively. The current study, for example, indicates that Zibadianja Lagoon has 13 species of cichlids, Savuti River and marsh has 12 species and Chobe River ten cichlid species. Naesje et al. (2004) recorded 14 species of the Cichlidae family at Kwando in Namibia which is comparable with species recorded at Zibadianja Lagoon.

Overfishing and fishing pressure is known to alter species composition (Garcia et al., 2003). For example, in Lake Malawi/Nyasa, Tweddle and Turner (1977), attested to changes in species' composition and a decline in diversity as a result of the introduction of trawl fishery in 1968. In this study, the hypothesis that fish species diversity and richness was lower in fished areas than unfished areas, was, however, not supported. This was likely because the fishery focusses on large

species, which were lower in abundance but not absent from the more intensely fished Chobe River.

### **Catch composition**

The catch composition varied between river systems. According, to Balcombe and Arthington (2009), variation in fish composition can be as a result of the interplay of colonisation, extinction, competition, predation, changes to habitat structure and food resources in the river systems. For example, the current study reflected an abundance of predators in the catch composition, e.g., *Hydrocynus vittatus*, *Schilbe intermedius* and *Clarias gariepinus*. Predation is one of the key biological forces structuring abundance, recruitment, species composition, diversity and prey behaviour (Ceccarelli & Ayling, 2010). Therefore, their loss or removal alters the functioning of an ecosystem (Ward et al., 2001), resulting in tropic downgrading of the ecosystem (Ceccarelli & Ayling, 2010). In Kenya for instance, increased fishing intensity resulted in reduced sea urchin predators, hence a population explosion of sea urchins (Tuda & Omar, 2012). In turn the high abundance of sea urchins led to scraping of the coral reefs, reducing their diversity and complexity (McClanahan, 1994). In Chobe River, excluding the rapids and Kavimba floodplains, *H. vittatus* dominated the catch composition, whereas in Zibadianja Lagoon *S. intermedius* dominated catch composition and in Savuti *C. gariepinus* dominated catch the composition. The dominance of predators has also been recorded in the Okavango Delta (Merron, 1991; Mosepele, 2011; Bokhutlo, 2011). This dominance of predators in tropical fish assemblages is attributed to the ample food supply of aquatic invertebrate (Welcomme, 1979). This is because macroinvertebrate density is often associated with stagnant or slow water velocity (Rolls et al., 2012).

The relatively high abundance of *H. vittatus* and Clariid catfishes in the Chobe District could be attributed to several factors. For example, both species are not prime targeted species by commercial fishermen. The *H. vittatus* is highly mobile and appears less vulnerable to fishing pressure than territorial cichlids because it ranges over large distances and has high fecundity (Merron, 1991; Tweddle et al., 2015). For example, a large female may have up to 780 000 ova (Skelton, 2001). Their high abundance is attributable to high prey density and a species-rich ecosystem (Ceccarelli & Ayling, 2010). By way of example, in Lake Kariba, the expansion of the Kapenta population led to a high abundance of *H. vittatus* (Kenmiur, 1984). This is because predators concentrate their efforts in regions of higher prey density (Hassell, 1978; Cowie &

Krebs, 1979). High abundance of *H. vittatus* is also correlated to habitat and mesohabitats. For example, Merron (1991) postulated that water permanency, depth and flow are some of the major ecological factors limiting the distribution of *H. vittatus* and, therefore, the perennial Chobe River is favourable to this species. Although restricted to Chobe River, during high inundations between March and May, their distribution stretches as far as Kavimba floodplains (Bakane pers. obs.). These findings are consistent with Merron (1985) who recorded *H. vittatus* as an apex predator in the Chobe River floodplains. *H. vittatus* is an important species for angling in Chobe district (Bakane pers. obs.).

The two-small species, *Brycinus lateralis* and *Enteromius radiatus* were numerically highly abundant in Chobe River as prey for predacious species and were third and fifth according to %IRI. Similarly, Simasiku (2014) found Alestidae, mainly *Rhabdalestes maunensis* and *B. lateralis*, also relatively abundant in Lake Liambezi, while (Peel et al., 2016) in a recent study reported overwhelming dominance (CPUE=441 fish net<sup>-1</sup> night<sup>-1</sup>) of *B. lateralis* in the same lake. The DWNP data (2006–2012) indicated an absence of *H. vittatus* in Kwando-Linyanti and Savuti River and they have never been thought to be present in that system. Peel (2012) and Simasiku (2014) also recorded absence of this species in Lake Liambezi. This is because during DWNP surveys (2006–2012), Zibadianja Lagoon was not sampled. Only the floodplains and the main channel were sampled. During this study, *H. vittatus* was sampled in the Zibadianja Lagoon and the Savuti River, albeit rarely %FO<sub>≤</sub> Savuti 18.8 % and Zibadianja 25%. Historically, Merron (1989a) recorded its high abundance in the Kwando River, where it dominated the ichthyofauna (69%) of the total biomass. One could then argue that the presence of *H. vittatus* in Zibadianja Lagoon results from immigration from the Kwando side rather than the Chobe River. For example, a subsequent study by Naesje et al. (2004) at Kwando River in Namibia attested to it being the most important species according, to % IRI. Merron (1991) and Merron & Bruton (1988) observed that although *H. vittatus* is mostly a main channel species, it inhabits large lagoons (ox-bow lakes and lagoons) connected to the main channel, which could explain its presence in Zibadianja Lagoon. The permanent connection of the Zibadianja Lagoon to the main channel implies that during seasonal immigration, *H. vittatus* exerts predation pressure on the lagoon (Welcomme, 1985).

*Schilbe intermedius* dominated the Zibadianja Lagoon and its peripheries, especially at the mouth of the Savuti channel that branches from the Zibadianja Lagoon. Its dominance has been recorded



by DWNP Surveys (2006–2012) at Kwando-Linyanti, Bokhutlo (2011) in Okavango by Mosepele et al. (2011) in four lagoons in Okavango Delta, Peel (2012) in Lake Liambezi and Hay et al. (2008), Hay et al. (2000) in Kunene and Kavango respectively. The high abundance of *S. intermedius* in Zibadianja Lagoon may be linked to the lower abundance of *H. vittatus*. Peel (2012) observed that under lower predation pressure from *H. vittatus*, *S. intermedius* or *H. cuvieri* may occupy the vacant niche while Petry et al. (2003) contended that opportunistic fish species in Upper Parana floodplains perform exceptionally well in lagoons. This may explain in part, the abundance of *S. intermedius* in Zibadianja Lagoon in this study. However, the high level of abundance and dominance of *S. intermedius* may be attributed to its high fecundity (135000 eggs for a 221mm fish) (Montcho et al., 2011).

*Clarias gariepinus* dominated catch in the Savuti River and marsh with 100% FO. This is because as the Savuti River is subjected to episodic flows, and the only species that survives are catfishes. Catfishes are adapted to endure habitat desiccation (Ward & Stanford, 1995). They survive by burrowing into the mud and undergoing aestivation during desiccation, as in Lake Liambezi, Chad and Lake Chilwa (Merron, 1989a; Furse et al., 1979; Lancaster, 1979). This explains why catfishes are among the pioneer species to repopulate the rivers during flood resurgence. As a survival strategy during the drawdown periods catfishes in the Okavango hunt in packs when flood waters arrive (Bokhutlo, 2011).

The large important cichlids are the main target species for commercial, subsistence and recreational fishing in the Chobe District than the predators, and therefore depletion by fishing is the most noticeable for these species. Commercial fishermen regard predators as less value species and as bycatch because they do not command a better price in the market as large cichlids. Catfishes are often discarded (Bakane pers. obs.) as evidenced also in the Okavango Delta (Bokhutlo, 2011). However, predatory species such as *H. vittatus* are important for recreational fishermen, and are often released after capture with only a few large specimens kept for mounting as trophies (Hay & van der Waal, 2009).

### **Relative abundance**

The results of the Catch Per Unit Effort (CPUE) comparison supported the hypothesis that fish communities in protected areas contained larger fish than the exploited areas. This was particularly

evident when comparing the relative abundance of large high-value cichlids in, the exploited Chobe River to the less exploited Zibadianja Lagoon and to the unexploited Savuti marsh. This study, therefore, indicated that large high-value cichlids are in constant decline because of the effects of anthropogenic and environmental perturbations, and these can result in the complete collapse of the fishery as evidenced in the Chambo stocks of Lake Malombe and Malawi fishery (Banda et al., 2005).

Previous studies in the region have recorded a lower mean CPUE of large cichlids outside protected areas (e.g., Hay et al., 2000; Hay & van der Waal., 2009). This is attributed to the intense exploitation and removal of large important cichlids, agreeing with Peel et al. (2012) who reported that outside the protected areas in a lagoon environment of Luambimba River on the Barotse floodplain, experimental gillnet catches yielded no adult specimens of any economically important large cichlids. Prior to the current study, extremely low catches of large high value cichlids in the Zambezi and Chobe River were also recorded by Hay and van der Waal (2009). Research elsewhere shows similar declines in large-bodied cichlid species in the Kafue flats floodplains, Lake Kariba, Zambezi, Chobe floodplains and Central Barotse floodplains (Tweddle et al., 2015).

The results of higher CPUE from protected areas are consistent with observations from marine environments. For example, Cowley et al. (2002), recorded that CPUE was higher in Tsitsikamma National Park than in open access areas. Several factors are thought to have contributed to the observed decline. Hay and van der Waal (2009), for example, contended that large high value cichlids are susceptible to fishing pressure outside protected areas because of their behaviour, as schooling, nesting, spawning behaviour and a slow growth rate making them vulnerable to capture. This concurs with Merron (1991) who contended that the biology of cichlids such as low fecundity, makes them susceptible to exploitation. This further agrees with Adams et al. (1997) who argued that species which possess aggregative behaviour, sedentarity and territoriality are vulnerable to exploitation. Regarding behaviour, tilapiines *O. andersonii*, *O. macrochir* and *C. rendalli* are generally territorial and defend their nests, form schools and exhibit shorter migrations relative to other species (van der Waal, 1985; Thorstad et al., 2007). Hay and van der Waal (2009), observed that in the Zambezi Region, *O. andersonii* and *O. macrochir* were susceptible to drag netting during the spawning season, when these species aggregate in shallow habitats and floodplains to construct nests.

The relatively large movements observed in *O. andersonii* may, on the one hand allow for recolonisation and replenishment of the exploited population from less exploited neighbouring populations (Naesje et al., 2003). On the other hand, the shorter observed home ranges of *O. macrochir* could make it more susceptible to exploitation and less likely to replenish from protected areas (Thorstad et al., 2007). Moreover, fishermen's preference for high-value cichlids makes harvesting very selective and innovative for cichlids resulting in more targeted pressure (Hay & van der Waal, 2009). Tweddle et al. (2015) pointed out that the introduction of monofilament gillnets from 2000, replacing multifilament gillnets, has further increased the effort per fishermen without increasing the overall net length. In Botswana, these gillnets are imported from Zambian dealers at a low cost (Bakane pers. obs.). It is clear, therefore, that if these resources remain unmanaged, they will consequently collapse as a result of intense exploitation by fishermen as they race to harvest fish in an open access system (Hardin, 1968; Symes & Cream, 1995).

Protected areas have several benefits. For example, they may enhance fisheries in adjacent areas via spillover effects by increasing larval export into neighbouring non-reserve areas and adult fish biomass (Roberts & Polunin, 1991; Rowley, 1994; Cote et al., 2001). The National Parks, Game Reserve and Concessions in Botswana may therefore fulfill an important role in fisheries management.

## **CHAPTER 4: AGE AND GROWTH OF THREESpot TILAPIA *OREOCHROMIS ANDERSONII*, GREENHEAD TILAPIA *OREOCHROMIS MACROCHIR* AND REDBREAST TILAPIA *COPTODON RENDALLI* IN THE CHOBE DISTRICT OF BOTSWANA**

### **4.1 Introduction**

Knowledge of the age and growth rate of commercially important species is essential for fisheries conservation, management and sustainable utilisation (Beamish & McFarlane, 1987; Jones, 1992) because knowledge of age and growth, aids in an improved understanding of factors affecting the recruitment process, while in adult fish populations, it helps to determine the effects of fishing on stocks, efficacy of fisheries management policies, life history events and maximum sustainable yields (Jones, 1992).

Factors that influence fish metabolic rates (temperature, reproduction and spawning) are reflected in the growth of calcified structures such as scales, opercular bone and otoliths as alternating opaque and hyaline growth zones (Campana & Neilson, 1985; Jones, 1992). These growth zones can be used to determine age which, when correlated with length, can be used to determine growth rate (Welcomme, 1979; Hecht, 1980a, b; Weyl & Hecht, 1998; Jones, 1992). Age and growth of economically important cichlids has been investigated using mostly scales (Dudley, 1974; Kapetsky, 1974; van der Waal, 1985) and sectioned otoliths (Weyl & Hecht, 1998; Booth et al., 1995; Booth & Merron, 1996; Peel, 2012). Sectioned otoliths are the preferred microstructures to age fish because scales tend to underestimate longevity and thus overestimating growth (Hecht, 1980a; Carlender, 1987; Jones, 1992; Campana & Thorrold, 2001). In the Lumphepe-Nwanezi impoundment in South Africa for example, Hecht (1980), working on Mozambique tilapia *Oreochromis mossambicus* reported that scales hampered age and growth estimation as a result of the deposition of false checks (Le Roux, 1961; Bruton & Allanson, 1974) and the tendency of fish scales to be re-absorbed during starvation and spawning (Hecht, 1980).

In tropical and subtropical waters, the period of annulus formation in cichlids varies (Weyl & Hecht, 1998). For example, in Lake Chicamba formation of a single opaque band in the otolith of *Coptodon rendalli* occurred in July and August, which corresponded with the end of winter, low

temperatures and drawdown periods (Weyl & Hecht, 1998). In the Okavango Delta, Botswana and the Kafue floodplain, Zambia, annulus formation in *Oreochromis andersonii* occurred in summer which coincided with a reduction in somatic metabolic rate resulting from reproductive activities (Kaspersky, 1974; Booth et al., 1995). Similarly, Peel et al. (2016) reported that in the Upper Zambezi, the highest proportion of otoliths with opaque margins for *O. andersonii*, *O. macrochir* and *C. rendalli* were observed in summer between October and December, but the edge analysis indicated that they were deposited in winter between June and September when water temperatures were lowest at 17 °C.

Tropical floodplain fish are characterised as having fast and seasonal growth (Merron & Bruton, 1988). Their growth rates also vary between populations due to environmental variability between localities (Merron, 1991). For example, Peel (2012) reported that in the Upper Zambezi growth the rate of *O. andersonii*, *O. macrochir* and *C. rendalli* varied considerably between the river systems. In his study, the growth rates for these commercially important cichlids were rapid in exploited systems, i.e., Zambezi River and Lake Liambezi as opposed to the non-exploited Kwando River. This is because in exploited systems, fishing reduces fish densities and therefore reduces the density dependent competition, which results in increased quality of diets and increased growth, while in non-exploited systems there are higher fish densities and inter and intraspecific competition that results in a reduction in the quality of diets and reduced growth rates (Jackson et al., 2001). Therefore, it is important to assess the difference in growth in different localities.

The objective of this chapter was to determine the age and growth of *O. andersonii*, *O. macrochir* and *C. rendalli* samples using otoliths to assess regional variations in growth rates between these populations and population assessed by Peel et al. (2016). In addition, age data was also used for differences in longevity between protected and non-protected areas.

## 4.2 Materials and methods

### General sampling

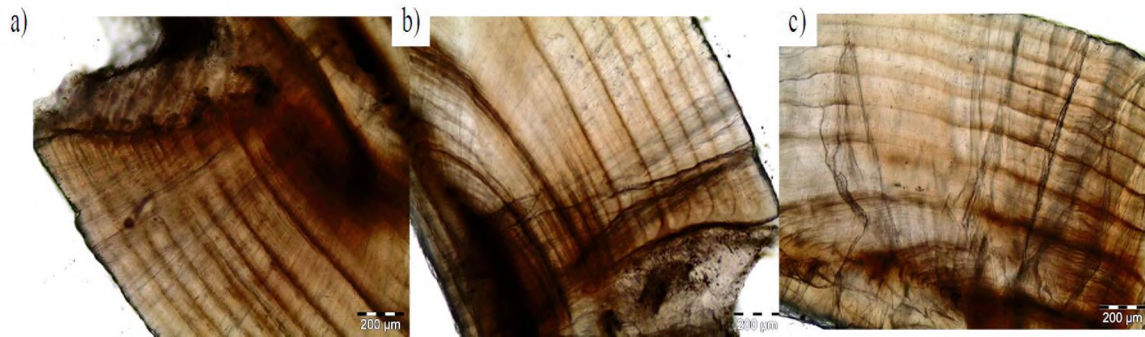
Biological data for commercially important large cichlids were collected between September 2014 and April 2015 using multifilament gillnets fleets and each comprising eleven 10 m panels of 2 m deep panels with stretched mesh sizes of 12, 16, 22, 28, 35, 45, 57, 73, 93, 118 and 150 mm), a 75-m long monofilament commercial net of mesh size 115 mm, a D-net on littoral zones, angling and purchases from commercial fishermen. All fish sampled were identified to species level (using Skelton 2001), measured to the nearest mm total length ( $L_T$ ), weighed (to nearest g), dissected, sexed and sagittal otoliths were removed, cleaned of membranous and blood tissue, dried and stored in cross-referenced Eppendorf tubes (date, species, number, locality) for later analysis.

### Otolith preparation

Otoliths were embedded in clear polyester casting resin prior to sectioning with a double-bladed diamond edged saw at Rhodes University Department of Ichthyology and Fisheries Science general laboratory, using the procedure outlined by Weyl and Hecht (1998). Rectangular moulds were filled halfway with resin mixture then dried. Otoliths were mounted sulcul side down, then covered with a second layer of resin and dried again. Once dry, they were transversely sectioned through the nucleus with a doubled-bladed diamond-edged saw at 0.3–0.4 mm thickness. Sections were labelled and mounted on microscope slides using a DPX mountant.

Otoliths were read using a compound dissecting microscope under transmitted light at various magnification (10–40  $\times$ ) to view the annual rings as outlined in Winker et al. (2010 a, b). To avoid disruptive high error rates in obtaining an estimation of precision, an experienced primary reader was assigned to age the first 50 otoliths, by reading opaque zones from the nucleus to the edge of the otolith. The second and third reader estimated the age of the 426 otoliths, and if two readings coincided, they were accepted but if they varied by >2 increments or 10%, then the otolith was re-read or mean aged. If it could not be assigned an age it was discarded as unreadable. Otoliths were read with no reference to fish length, weight, date of capture or area sampled. Photomicrographs of sectioned sagittal otoliths of (oldest fish) were obtained using a Zeiss light Microscope at

Rhodes University Zoology Department using transmitted light under various magnifications (Fig 4.1, a, b, c).



**Figure 4.1 a, b, c.** Photomicrograph of sagittal otolith sections showing the translucent and opaque growth zones in the otoliths of (a) an eight-year-old 290 mm  $L_T$  female *Oreochromis andersonii* from Savuti River, (b) an eight-year-old 279 mm  $L_T$  female *Oreochromis andersonii* from Zibadianja Lagoon and (c) an eight-year-old 278 mm  $L_T$  male *Coptodon rendalli* from Savuti River in Chobe district, Botswana sampled between September 2014 and April 2015.

### Precision and Accuracy

Accuracy denotes relevance of method and structure (Svedang et al., 1998), while precision is the reproducibility of a given structure, irrespective of whether those measurements (age readings) are accurate (Campana, 2001). Both accuracy and precision are necessary in age estimation to ensure reliable and reproducible results in fish biology (Svedang et al., 1998; Beamish & Fournier, 1981).

The growth zone for the three large cichlids was validated by Peel et al. (2016) who showed that in this region in a similar environments one growth increment represented one year of growth. Thus, all growth analyses in this chapter were performed under the assumption that one growth increment (one translucent and one opaque zone) represents one year of growth.

Precision was estimated using the average percent error (APE) and coefficient of variation (CV) methods (Chang, 1982) because they are age dependent and allow for comparisons among species and population (Hoxmeier et al., 2001). An average percent error (APE) (Beamish & Fournier, 1981) was calculated as

$$APE_j(\%) = 100 \times \frac{1}{R} \sum_{i=1}^R \frac{|X_{ij} - X_j|}{X_j}$$

Where  $X_{ij}$  is the  $i$ th age determination of the  $j$ th fish,  $X_j$  is the mean age estimate of the  $j$ th fish and  $R$  is the number of times each fish is aged. When averaged across many fish it becomes the index of average percent error (Campana, 2001). Chang (1982) suggested that standard deviation be substituted for the absolute deviation from the mean age (Campana, 2001).

Coefficient of variation (CV) is the ratio of standard deviation over the mean (Campana, 2001). CV between the age estimates was calculated as

$$CV_j(\%) = 100 \times \frac{\sqrt{\frac{\sum_{i=1}^R (X_{ij} - X_j)^2}{R-1}}}{X_j}$$

### Growth modeling

Where appropriate, Von Bertalanffy growth curves were fitted to  $L_t$  length at age data for combined sexes and stations for Commercially important cichlids using the three-parameter Von Bertalanffy growth model (VBGF) of the form:

$$L_t = L_{\infty} (1 - \exp(-k(t - t_0)))$$

Where  $L_t$  is the length (mm  $L_T$ ) at age  $t$  (years),  $L_{\infty}$  is the predicted asymptotic length,  $K$  is the Brody co-efficient ( $\text{year}^{-1}$ ) (Ricker, 1975) and  $t_0$  is the theoretical age (years) at zero length. Least square regression and solver were employed in Microsoft Excel. Owing to the rarity and near-vulnerability status of cichlids in the region there was insufficient data for reasonable Von Bertalanffy growth model fits for all systems due to the lack of young fish.

Parameters were estimated by minimising the negative log likelihood of the form

$$-LL = n \ln(\hat{\sigma})$$

Where  $\hat{\sigma}$  is the maximum likelihood estimate of the model standard deviation, as described as:

$$\hat{\sigma} = \sqrt{\frac{\sum_i (L_i - \hat{L}_i)^2}{n}}$$



Where  $L_i$  is the observed length at age,  $\hat{L}_i$  is the predicted length at age and  $n$  is the total number of observations. Standard deviation of the model parameters was estimated using parametric bootstrap resampling (Efron, 1982) with 1000 iterations.

### **Growth comparisons**

Populations with different growth parameters may have similar growth performances due to the interaction and dependence of  $K$  and  $L_\infty$ . Phi-prime (Pauly & Munro, 1984) was used for comparisons between the populations of *O. andersonii* and *C. rendalli*.

Phi-prime was described by the equation of the form:  $\phi' = 2\log L_\infty + \log K_L$

where  $L_\infty$  is the predicted asymptotic length and  $K$  the Brody growth co-efficient from the VBGF model.

### **Comparisons of longevity**

In some cases, sample sizes were too small to allow for direct comparisons for VBGF parameters for all populations. As a result, comparisons between closed and non-protected areas were based on mean age, mean length and mean length at age. A Kruskal-Wallis test was used for comparisons. A significance level ( $p=0.05$ ) was used. An all pair-wise Multiple comparison test (Dunn's Method) was used to isolate difference.

## **4.3 Results**

### **Ageing precision**

Of the 426 otoliths collected from *O. andersonii*, *O. macrochir* and *C. rendalli* only one otolith was rejected as unreadable. Data on the precision of estimates are presented in Table 4.1. Precision varied between species and with age. For example, greater precision was observed to increase with age for *O. andersonii* and *C. rendalli* while it decreased with age in *O. macrochir*. At ages  $>4$  precision was generally good (APE=3.7–9.7) (CV 13.5–29.9) but poorest at age  $<4$  e.g., at age 1 (APE=21.1–28.6).

**TABLE 4.1.** Average percent error (APE), coefficient of variation (CV) between otoliths readings of *Oreochromis andersonii*, *Oreochromis macrochir* and *Coptodon rendalli* sampled in Chobe Kavimba floodplains, Zibadianja Lagoon and Savuti River and marsh between September 2014 and April 2015.

Species	0	1	2	3	4	>4	APE	CV	N
<i>O. andersonii</i>	88.9	21.1	23.1	22.4	11.0	9.7	15.4	29.9	201
<i>O. macrochir</i>	0	13.7	2.1	8.7	2.4	3.5	5.5	10.7	112
<i>C. rendalli</i>	0	28.6	7.2	6.0	7.1	3.7	5.9	13.5	115

### Longevity

Comparative longevity for *O. andersonii*, *O. macrochir* and *C. rendalli* are summarised in Table 4.2. The results support the hypothesis that fish in protected areas grow to older ages than fish in fished areas. Mean age for the three-species differed significantly between habitats (Dunn's Method,  $p < 0.05$ ) with fish in protected areas consistently being older than those in fished habitats. *O. andersonii* in the Chobe Kavimba floodplains were younger by  $2.4 \pm 1.6$  years than those in Savuti River ( $= 4.3 \pm 1.8$  years) and Zibadianja Lagoon ( $= 5.3 \pm 1.6$  years). *O. macrochir* were older in the Zibadianja Lagoon  $5.0 \pm 1.4$  years and the Savuti River ( $= 3.9 \pm 1.4$  years) than in the Chobe River ( $= 1.2 \pm 0.9$  years). *C. rendalli* mean age was significantly higher (Dunn's Method,  $p < 0.05$ ) in the Savuti River  $5.1 \pm 1.9$  years than Zibadianja Lagoon  $4.4 \pm 2.02$  years and least at Chobe River/Kavimba  $2.3 \pm 2.7$  years.

**TABLE 4.2.** Maximum and mean age  $\pm$  standard deviation for *Oreochromis andersonii*, *Oreochromis macrochir* and *Coptodon rendalli* sampled at Chobe/Kavimba, Savuti River and Zibadianja Lagoon in Botswana between September 2014 and April 2015

Species	Chobe/Kavimba		Zibadianja		Savuti	
	Max.	Mean age	Max.	Mean age	Max.	Mean age
<i>O. andersonii</i>	6	$2.4 \pm 1.6$	8	$5.3 \pm 1.6$	8	$4.3 \pm 1.8$
<i>O. macrochir</i>	4	$1.2 \pm 0.9$	7	$5.0 \pm 1.4$	7	$3.9 \pm 1.4$
<i>C. rendalli</i>	7	$2.3 \pm 2.7$	8	$4.4 \pm 2.02$	8	$5.1 \pm 1.9$

## Growth

Sufficient samples for a reasonable fit of the Von Bertalanffy growth model (VBGF) were only available for *O. andersonii* at Savuti River and *Coptodon rendalli* at Zibadianja Lagoon. Parameter estimates for VBGF for *O. andersonii* and *C. rendalli* are summarised in Table 4.3.

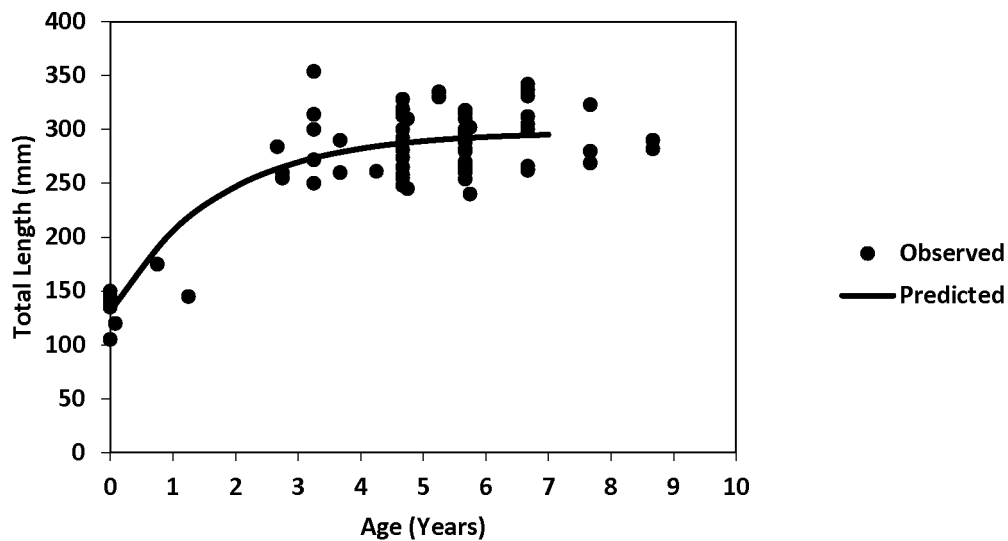
The  $L_t$  age for *O. andersonii* in Savuti River was best described as  $L_t(\text{mm}) = 297.72 (1 - e^{-0.59(t-0.98)})$  (Figure 4.2). For *C. rendalli* in Zibadianja Lagoon  $L_t$  was best described as  $L_t(\text{mm}) = 336.5 (1 - e^{-0.20(t-2.35)})$  (Figure 4.3). In both cases, the VBGF parameter  $t_0$  were negative for *O. andersonii* ( $-0.98 \pm 0.10$  years) and *C. rendalli* ( $-2.35 \pm 0.51$  years), which reflects limited data for small and young fish. Initially, growth rate for *O. andersonii* was rapid, with asymptotic length reached after three years. The asymptotic length was slightly later for *C. rendalli* in Zibadianja Lagoon. Table 4.4 shows observed mean lengths at age ( $\pm$ standard deviation) at Savuti River for *Oreochromis andersonii* and *Coptodon rendalli* at the Zibadianja Lagoon sampled during this study.

**TABLE 4.3.** Parameter estimates and standard deviations (S.D) of combined sexes and stations fitted using the von Bertalanffy growth model for *Oreochromis andersonii* in the Savuti River and marsh and *Coptodon rendalli* sampled in the Zibadianja Lagoon in Botswana between September 2014 and April 2015

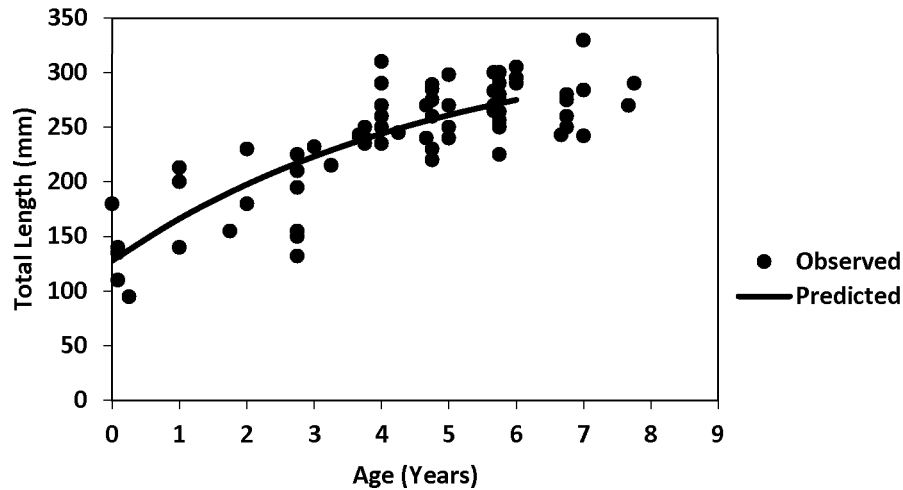
Parameter	$L_{\infty}$ ( $\pm$ S. D)	K (S.D)	$t_0$ ( $\pm$ S. D)	$\phi''$
<i>O. andersonii</i>	297.72 (15.42)	0.59 (0.04)	-0.98 (0.10)	4.72
<i>C. rendalli</i>	336.5 (15.22)	0.20 (0.21)	-2.35 (0.51)	2.36

**TABLE 4.4.** Observed mean lengths at age ( $\pm$ standard deviation) at Savuti River for *Oreochromis andersonii* and *Coptodon rendalli* at Zibadianja Lagoon sampled between September 2014 and April 2015

Age years	<i>O. andersonii</i> (Savuti River/marsh) $L_T \pm S. D$	<i>C. rendalli</i> (Zibadianja Lagoon) $L_T \pm S. D$
0	131.4 $\pm$ 9.1	127.7 $\pm$ 17.2
1+	205.6 $\pm$ 8.0	166.1 $\pm$ 11.5
2+	246.6 $\pm$ 7.6	197.4 $\pm$ 11.4
3+	269.4 $\pm$ 6.3	243.9 $\pm$ 5.1
4+	282.0 $\pm$ 4.7	243.9 $\pm$ 5.1
5+	289.0 $\pm$ 3.5	261.0 $\pm$ 4.2
6+	292.9 $\pm$ 3.8	274.8 $\pm$ 5.7
7+	295.1 $\pm$ 5.2	281.4 $\pm$ 3.8



**Figure 4.2.** Von Bertalanffy growth curve for *Oreochromis andersonii* at Savuti River/marsh in the Chobe district, Botswana, sampled between September 2014 and April 2015. The  $L_t$  at age was described by the von Bertalanffy growth equation as  $L_t(\text{mm}) = 297.72 (1 - e^{-0.59(t-0.98)})$  ( $n=78$ ).



**Figure 4.3.** Von Bertalanffy growth curve for *Coptodon rendalli* at Zibadianja Lagoon in Chobe district, Botswana, sampled September 2014 and April 2015. The  $L_t$  at age was described by the von Bertalanffy growth equation as  $L_t(\text{mm}) = 336.5 (1 - e^{-0.20(t-2.35)})$  ( $n=82$ ).

### Comparison of growth performance between the species

Growth performance was best in *O. andersonii* ( $\phi' = 4.72$ ) compared to *C. rendalli* ( $\phi' = 2.36$ ). The growth performance of *O. andersonii* in the Savuti River was higher than growth performance recorded by (Peel, 2012) at Kavango River ( $\phi' = 4.60$ ) and Lake Liambezi ( $\phi' = 4.60$ ).

When comparing the growth performance of *C. rendalli* in the Zibadianja Lagoon ( $\phi' = 2.36$ ) with other studies (Table 4.5), the growth performance was less than the growth performance of *C. rendalli* in the Kwando River ( $\phi' = 4.35$ ) (Peel, 2012), Lake Chicamba ( $\phi' = 4.35$ ) (Weyl & Hecht, 1998), Lake Liambezi ( $\phi' = 4.34$ ) (van der Waal, 1985) and Lake Kariba ( $\phi' = 4.34$ ) (Kolding et al., 1992). Sex ratio may influence the growth rates; therefore, the difference may also be due to skewed sex ratios.

**TABLE 4.5.** Calculated length-at-age, Von Bertalanffy growth parameters and calculated phi-prime ( $\phi'$ ) (Pauly & Munro, 1984) for combined *Oreochromis andersonii*, and *Coptodon rendalli* in Southern Africa water bodies based on published data. The data was standardised to standard length. Equation  $SL\text{ (mm)} = -2.29 + 0.797 L_T\text{ (mm)}$  (Weyl & Hecht, 1998) was used for *Coptodon rendalli* and equation  $SL\text{ (mm)} = -1.67 + 0.8035 L_T\text{ (mm)}$  (Kapetsky, 1974) was used for *Oreochromis andersonii*; Others were adopted from Peel (2012).

Species/Locality	Length (mm SL)-at-age (years)					Growth performance		
	1	2	3	4	5	L	K	$\phi'$
<b><i>O. andersonii</i></b>								
Savuti River <sup>1</sup>	164	196	215	125	231	298	0.59	4.72
Kavango River <sup>2</sup>	136	187	232	270	303	493	0.163	4.60
Kwando River <sup>2</sup>	104	155	191	217	236	284	0.329	4.42
Lake Liambezi <sup>2</sup>	168	205	241	277	312	8223	0.005	5.53
Zambezi River <sup>2</sup>	149	195	241	287	332	8145	0.006	5.60
Kafue River	108	152	188	218	243	366	0.186	4.40
Lake Liambezi	171	221	259	287	308	370	0.291	4.60
Okavango Delta <sup>4</sup>	146	172	193	209	222	267	0.247	4.25
<b><i>C. rendalli</i></b>								
Zibadianja Lagoon <sup>1</sup>	130	155	192	192	205	337	0.20	2.36
Kavango River <sup>2</sup>	124	171	208	236	258	327	0.267	4.46
Kwando River <sup>2</sup>	101	145	177	200	216	257	0.337	4.35
Lake Liambezi <sup>2</sup>	163	196	209	213	215	217	0.966	4.66
Zambezi River <sup>2</sup>	131	192	225	244	255	268	0.584	4.62
Lake Liambezi <sup>4</sup>	119	157	183	201	214	240	0.380	4.34
Lake Kariba <sup>5</sup>	72	114	151	183	211	387	0.145	4.34
Lake Chicamba <sup>6</sup>	132	158	172	180	184	188	0.636	4.35

<sup>1</sup>Present study - Savuti River and Zibadianja Lagoon in Chobe District

<sup>2</sup>Peel, 2012 - Kavango, Kwando, Lake Liambezi and Zambezi Rivers, Namibia

<sup>3</sup>Booth et al., 1995 - Okavango Delta

<sup>4</sup>Kapetsky, 1974 - Kafue floodplain, Zambia

<sup>5</sup>Van der Waal, 1985 - Lake Liambezi, Namibia

<sup>6</sup>Kolding et al., 1992 - Lake Kariba, Zimbabwe

<sup>7</sup>Weyl and Hecht, 1998 - Lake, Mozambique

## 4.4 Discussion

This chapter has demonstrated that the cichlids were easily aged using otoliths which facilitated the comparison of growth rates between populations and the comparison of the mean and maximum age between the sampled regions. Assessment of the growth zone in sectioned otoliths demonstrated that for all species growth zones were visible and easily readable without the necessity of enhancing visibility by burning as outlined by other authors (Booth et al., 1995; Booth & Merron, 1996; Peel, 2012). Ageing precision was comparable to other studies in the region, with APE and CV being either lower or comparable to values previously obtained for *O. andersonii*, *O. macrochir* and *C. rendalli* (Peel, 2012; Peel et al., 2016).

### Comparison of growth performance between the species

Growth performance was better in *O. andersonii* ( $\phi' = 4.72$ ) than *C. rendalli* ( $\phi' = 2.36$ ) while *O. macrochir* was excluded because it could not fit in the growth model. The growth performance of *O. andersonii* in the Savuti River was higher than growth performance recorded by Peel (2012) at Kavango River ( $\phi' = 4.60$ ) and Lake Liambezi ( $\phi' = 4.60$ ). The variation in growth performance of the *Oreochromis* species within and between the regions may be attributed to the differences in the production of the systems such as variation in nutrient cycling and levels. For instance, the Savuti River and marsh is shallower (some areas 0.5 m) and more productive due to grass litter and herbivore droppings than Zibadianja Lagoon. When comparing the two large cichlids, *O. andersonii* is hardier which means it is superior in growth rates and maximum length than *C. rendalli*, which may relate to the variation in growth performance between the two species (Silva, 2005). For example, under experimental conditions in aquaculture ponds in Mansa Zambia, the growth of *O. andersonii* proved to be superior to *C. rendalli* (Banda, 1993).

When comparing the growth performance of *C. rendalli* in the Zibadianja Lagoon ( $\phi' = 2.36$ ) with other studies, the growth performance was less than the growth performance of *C. rendalli* in the Kwando River ( $\phi' = 4.35$ ) (Peel, 2012), Lake Chicamba ( $\phi' = 4.35$ ) (Weyl & Hecht, 1998), Lake Liambezi ( $\phi' = 4.34$ ) (van der Waal, 1985) and Lake Kariba ( $\phi' = 4.34$ ) (Kolding et al., 1992). These

may indicate that Zibadianja Lagoon may be decreasing in productivity or generally poor in nutrients.

Longevity observed in the entire distribution of the Chobe large cichlid species in this study was less than the longevity observed in previous studies in the region. For example, in the current study *C. rendalli*'s longevity was eight years whereas Peel (2012) recorded 13 years of the same species in Kwando River. These age disparities may be a result of environmental factors and human induced factors. Protected areas (unexploited areas) enhanced longevity. This explains why, in this study, longevity for *O. andersonii* reached eight years in the protected areas of Zibadianja Lagoon and Savuti Rivers respectively as opposed to the six years in the Chobe River and floodplains.

In a more stable environment, fish exhibit extended longevity. For example, in the Okavango Delta longevity of *O. andersonii* reached 13+ years (Booth et al., 1995), while in the Kavango and Kwando *O. andersonii* reached a maximum age of 12 years (Peel, 2012). Similarly, Peel (2012) recorded a maximum age of 13 years for *O. macrochir* in the Kwando River, while in the Okavango Delta, a maximum of 11 years was reported for *O. macrochir* (Booth & Merron, 1995). The extended longevity in these systems is enhanced by the spatial structure of the Okavango Delta because some areas of the Delta are inaccessible to commercial and subsistence fishermen (Bokhutlo, 2011), hence fishes may be safer from exploitation. Moreover, the delta is more variable in size and has diverse habitats (FAO, 2007), and therefore, the fish population may have a longer life span compared to the Chobe district rivers system. In the Kavango and Kwando River system, the longer life span is also attributed to pristine unexploited fisheries.

Exploited areas in the Chobe District in this study exhibited diminished fish longevity. For example, both the Chobe Kavimba floodplains (this study) and Zambezi River (Peel, 2012) recorded a maximum age of six years. This is may be because both the Zambezi River and Chobe Kavimba floodplains are subjected to heavy commercial and subsistence exploitation, hence a relatively diminished longevity of large cichlids. These results agree with studies by Garcia et al. (2003) who contended that overfishing modifies fish age and size structure. In Venezuelan Rivers in South America, commercially important *Cichla* spp were negatively affected by fishing pressure. This was evidenced in a rare capturing of *Cichla temensis*. The captured *Cichla*



*orinocensis* exhibited a young age (0-year-old), and there was a reduction in the body size of *Cichla temensis* due to size selective sport fishing and illegal net fishing (Jepsen et al., 1999).

Overall, the results of this study support the hypothesis that growth rates of fish differ within and between the regions, and that protected areas are inhabited by larger fish with extended life expectancies. The Chobe Kavimba floodplains had a significantly lower mean age for the three large cichlids than the two protected areas. This is attributed to fishing pressure in the Chobe River (Tweddle et al., 2015). This observation supports the findings by Russ, (1991) who reported that the natural age and size structure of fish become distorted under fishing pressure. This is because commercial and subsistence fishermen selectively harvest large-bodied and older members of stock leaving young smaller fish (Policansky, 1993; Chambers & Tripple, 1997). This is likely to have impact on the population as selective removal of large, older, more fecund fish, will result in lower fish stock egg production because the large, older, fish are the primary spawning broodstock (Pauly, 1979). The remaining young fish result in poor reproductive potential as they may produce fewer eggs and lower quality gametes (Pauly, 1979; Chambers & Tripple, 1997; Ward et al., 2001).

The protected areas, therefore, facilitate the development of a natural, extended age structure of target species, maintain genetic variability, increase recruitment and prevent deleterious evolutionary changes from the effects of fishing pressure (Selgeby, 2000; Roberts et al., 2005). There is also an increase in mean age and sizes of the individuals due to the *reserve effect* (Francour, 1989). For example, Cowley et al. (2002), attested to a higher catch per unit effort, mean age and mean individual size in Tsitsikama National Park than in open access areas of the south-eastern cape in South Africa. Although the Savuti is a protected area, the hydrology is capricious. This contributes to major mortality of riverine species during the times of drought, which leads to relatively lower mean age when compared to Zibadianja Lagoon (Davey et al., 2006). Fish that recolonises the Savuti River after drought, comes from the Zibadianja Lagoon. In conclusion, fishes in protected areas lived longer than fishes in open areas. Therefore, protected areas are essential for enhancing the longevity of large cichlids in the Chobe district.

## CHAPTER 5: REPRODUCTIVE BIOLOGY OF LARGE CICHLIDS IN THE CHOBE DISTRICT, BOTSWANA

### 5.1 Introduction

The determination of reproductive periodicity and the proper estimation of size at first maturity in fish is essential for fisheries management (Karna & Panda, 2011). This is because knowledge of the breeding season can inform the design of closed seasons to allow for the protection of fish species during the spawning season. It also enables the setting of the minimum legal harvesting sizes larger than the length at maturity, which allows the fish to breed at least once before being harvested thereby reduces the risk of recruitment of overfishing (Donaldson & Donaldson, 1992; Welcomme, 2001; Kolding et al., 2015).

Tilapiine cichlids have progressive breeding habits which are not dependent on stimuli such as flood pulse, but on temperature and day length (Fryer & Iles, 1972; Welcomme, 2001). Spawning occurs in summer and usually with a prolonged spawning period lasting all the warmer months (Fryer & Iles, 1972; van der Waal, 1985; Weyl & Hecht, 1998). Even though they appear to breed throughout the warmer months, there is often a peak in spawning activity synchronised with the onset of the rainy season and the floodplain inundations (Trewavas, 1983, Weyl & Hecht, 1998; Beveridge & McAndrew, 2000). In sub-tropical regions, the flooding of rivers and inundation of floodplains coincides with rising temperatures that favours and enhances juvenile fish growth by providing an abundance of food and vegetation cover as refuge to hide from predators (Welcomme, 1985; Wootton, 1990; Skelton, 1993). During the colder winter season (June–August) in the sub-tropical regions, cichlids are generally reproductively inactive (Ellender et al., 2008).

Length at maturity for large cichlids in the Zambezi Region (Namibia) was previously determined by Peel (2012) who demonstrated that length at maturity for *Oreochromis andersonii* and *Coptodon rendalli* did not differ significantly from each other in the four sampling areas, while in *Oreochromis macrochir*, the length at maturity differed significantly between the systems with Zambezi River specimens, having a significantly larger length at maturity than those in the Kwando River. He concluded that these similarities in length at maturity in the Zambezi Region

implied that the environmental variables that influence length at maturity were similar in each system. This also meant that, for management purposes, a single mesh size of 3.5'' inches (86 mm) was recommended for the entire system.

The biogeophysical environment can, however, influence the size and age at first maturity (Alm, 1959; Weyl & Hecht, 1998). For instance, population increase of fish due to the drying of rivers and floodplains results in less food availability, competition for food resources and thus leads to decrease in size at maturity (Karna & Panda, 2011). In Lake Sibaya in South Africa, early maturity of *Oreochromis mossambicus* was attributed to the abiotically harsher environmental conditions of the Lake (Bruton, 1979). Length at maturity is therefore essential in making fisheries management decision. Therefore, it is imperative that fisheries regulations such as minimum sizes are set according to length at maturity.

As the reproductive seasonality of cichlids is well researched, the aim of this chapter was to test the length at 50% maturity of large cichlids in the Chobe district and show how it differs from that the in Zambezi, Kwando and Okavango Rivers, and whether the minimum mesh size recommended by Peel (2012) from the Zambezi Region (Namibia) would be appropriate for the Chobe district.

## **5.2 Materials and methods**

### **General sampling**

Samples of *O. andersonii*, *O. macrochir* and *C. rendalli* were collected during the spawning season between September 2014 and April 2015 using multifilament gill nets fleets as described in Chapter 3. Because there was low abundance of study species in experimental nets, samples were supplemented by; purchasing samples from Chobe Kavimba floodplains, using a 75 m long 115 mm mesh size commercial gillnet and angling at the Zibadianja Lagoon and Savuti River.

All fish sampled were identified to species level using Skelton (2001), measured to the nearest mm total length  $L_T$ , counted, and weighed to the nearest gram.

Fish were then dissected and sexed. The gonads for both sexes were classified into five reproductive stages of maturity following the Microscopic criteria after Weyl and Hecht, (1998)

(Table 5.1). Fish were considered mature if they were assigned a gonadal development stage from 3–5 (developing, ripe or spent). Stages of maturity from 1–2 were considered juveniles or immature.

**TABLE 5.1.** Microscopic criteria used to determine reproductive stages of maturity of males and females in *Oreochromis andersonii*, *Oreochromis macrochir* and *Coptodon rendalli* (Weyl & Hecht, 1998)

Stages	Gonad appearance
1. Juvenile	Gonads as a thin translucent strip. Unable to determine sex macroscopically
2. Resting	Sex distinguishable. Ovaries white or yellowish. Oocytes macroscopically distinguishable. Testes appear as thin white bands.
3. Developing	Ovaries enlarged, Oocytes readily visible and yellow. Testes broadened, distended and cream in colour
4. Ripe	Oocytes of maximum size, dull yellow in colour in <i>O. andersonii</i> and dark olive green in <i>C. rendalli</i> . Testes white and swollen to maximum size.
5. Spent	Ovaries flaccid with irregular oocyte size. Testes reduced in size and dirty grey in colour.

### Length–Weight Relationship

The Length–Weight Relationship was estimated using the formula  $W=aL^b$  (Anderson & Newman, 1996) where W is observed Weight in (g), L is observed total length ( $L_T$ ) in (mm), a' and b' are model parameters.

### Condition factor

Condition factor (K) is a measure of the condition of a fish (Ricker, 1975). Bagenal and Tesch (1978) hypothesised that heavier fish of a particular length are in a better physiological condition. Therefore, condition factor is a useful index in monitoring feeding intensity, breeding season, growth rate, age, physiological state, relative robustness and general well-being of intra and inter populations (Oni et al., 1983; Dan-Kishiya, 2013). To make comparisons between mean condition

factor between the systems and species, the Fulton condition factor (K) was calculated for each population, whereby,

$$K = W \times \frac{10^5}{TL^3}$$

In the above formula, K= is the condition factor, W= is the wet weight of fish in grams and  $L_T$ = is the Total length of fish in cm (Ricker, 1975; Froese, 2006).

### **Length at 50% maturity ( $L_{m50}$ )**

Unfortunately, sample sizes were too small to calculate sex-specific length at maturity. As a result, males and females were grouped for analysis. Length at maturity was expressed as the proportion of mature fish in each 10 mm  $L_T$  size class. Length-at-50% maturity ( $L_{m50}$ ) was estimated by fitting these data into a two-parameter logistic model form:  $\psi_L = \frac{1}{1 + \exp^{-(L - L_{m50})/\delta}}$  where  $\psi_L$  is the predicted proportion of mature fish at length  $L$  and  $\delta$  the width of the logistic ogive (King, 1995).

### **Length maturity at age and maximum gillnet selectivity**

The length maturity at age for *O. andersonii*, *O. macrochir* and *C. rendalli* were derived from length at 50% maturity in this study. Predicted length class at maximum selectivity for different gillnet selectivity curves for large cichlids were adopted from Peel (2012) who used the same experimental gillnet as in this study for sampling large cichlids.

### **Sex ratio**

Chi-square was used to test for unity between the females and the male population of *O. andersonii*, *O. macrochir* and *C. rendalli* in all the systems (Greenwood & Nikulin, 1996), whereby

$$\chi_c^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

Where  $c'$  is the degrees of freedom,  $O'$  is observed value and  $E'$  is expected value.

### 5.3 Results

The total sample comprised 201 *Oreochromis andersonii* (105–400 mm  $L_T$ ), 108 *Oreochromis macrochir* (110–300 mm  $L_T$ ) and 117 *Coptodon rendalli* (70–355 mm  $L_T$ ).

#### Length and weight

The Length-weight relationship for the three large cichlids is summarised in Table 5.2. The length-weight relationship for *O. andersonii* was defined by relation  $W(g) = 0.0008 L_T(mm)^{2.3037}$  while *O. macrochir* was defined by the relation  $W(g) = 0.00002 L_T(mm)^{2.9529}$ , whereas the *C. rendalli* was defined by  $W(g) = 0.00004 L_T(mm)^{2.8931}$ .

**TABLE 5.2.** Morphometric relationships for (Combined sexes) of *Oreochromis andersonii*, *Oreochromis macrochir* and *Coptodon rendalli* from Chobe Kavimba floodplains, Zibadianja Lagoon and Savuti River (WT=weight and  $L_T$ =total length).

Species	Relationship	$r^2$	n
<i>Oreochromis andersonii</i>	$W(g) = 0.0008 L_T(mm)^{2.3037}$	0.9073	201
<i>Oreochromis macrochir</i>	$W(g) = 0.00002 L_T(mm)^{2.9529}$	0.9279	108
<i>Coptodon rendalli</i>	$W(g) = 0.00004 L_T(mm)^{2.8931}$	0.8997	117

#### Mean condition factor

Mean condition factor differed significantly between systems (Zibadianja vs Savuti, Zibadianja vs Chobe) (Dunn's Method;  $p < 0.05$ ) and between species, but did not differ significantly between the Savuti and Chobe Rivers. Mean condition factor between the systems and between the species is summarised in Table 5.3. In *O. andersonii* mean K-value was significantly higher (Dunn's Method;  $p < 0.05$ ) in the Zibadianja Lagoon ( $K = 1.8 \pm 0.3$ ), followed by Savuti River ( $K = 1.7 \pm 0.3$ ) and lastly by Chobe Kavimba floodplains ( $K = 1.6 \pm 0.2$ ). There was no significant difference (Dunn's Method,  $p > 0.05$ ) between the mean condition factor for *O. andersonii* in Chobe Kavimba

floodplains and the Savuti River. The mean condition factor for *C. rendalli* was significantly higher (Mann-Whitney Rank sum test;  $p < 0.001$ ) in the Zibadianja Lagoon ( $K = 2.22 \pm 0.67$ ) than in the Savuti River ( $K = 1.68 \pm 0.24$ ). For *O. macrochir* mean K-value was significantly higher in the Savuti River ( $K = 2.18 \pm 0.83$ ) and in the Zibadianja Lagoon ( $K = 2.13 \pm 0.17$ ) than in the Chobe River ( $K = 1.83 \pm 0.13$ ).

**TABLE 5.3.** Mean Condition factor between the systems and between the species *Oreochromis andersonii*, *Oreochromis macrochir* and *Coptodon rendalli* from Chobe River and Kavimba floodplains, Zibadianja Lagoon and Savuti River and Marsh sampled between September 2014 and April 2015

Species	No.	Area	Mean K	S. D
<i>Oreochromis andersonii</i>	81	Chobe/Kavimba	1.6	0.2
<i>Oreochromis andersonii</i>	41	Zibadianja Lagoon	1.8	0.3
<i>Oreochromis andersonii</i>	69	Savuti River and Marsh	1.7	0.3
<i>Coptodon rendalli</i>	69	Zibadianja Lagoon	2.2	0.7
<i>Coptodon rendalli</i>	30	Savuti River and Marsh	1.7	0.2
<i>Oreochromis macrochir</i>	31	Chobe/Kavimba	1.8	0.1
<i>Oreochromis macrochir</i>	28	Zibadianja Lagoon	2.1	0.2
<i>Oreochromis macrochir</i>	42	Savuti River and Marsh	2.2	0.8

## Reproduction

### Sex ratio

The sex ratio of *O. andersonii*, *O. macrochir* and *C. rendalli* are summarised in Table 5.4. The sex ratio of the three-species differed between the stations. However, the sex ratio of *O. andersonii* and *O. macrochir* did not differ significantly between the river systems ( $P > 0.05$ ), whereas the sex ratio of *C. rendalli* were significantly skewed ( $P < 0.05$ ) towards males in all the river systems.

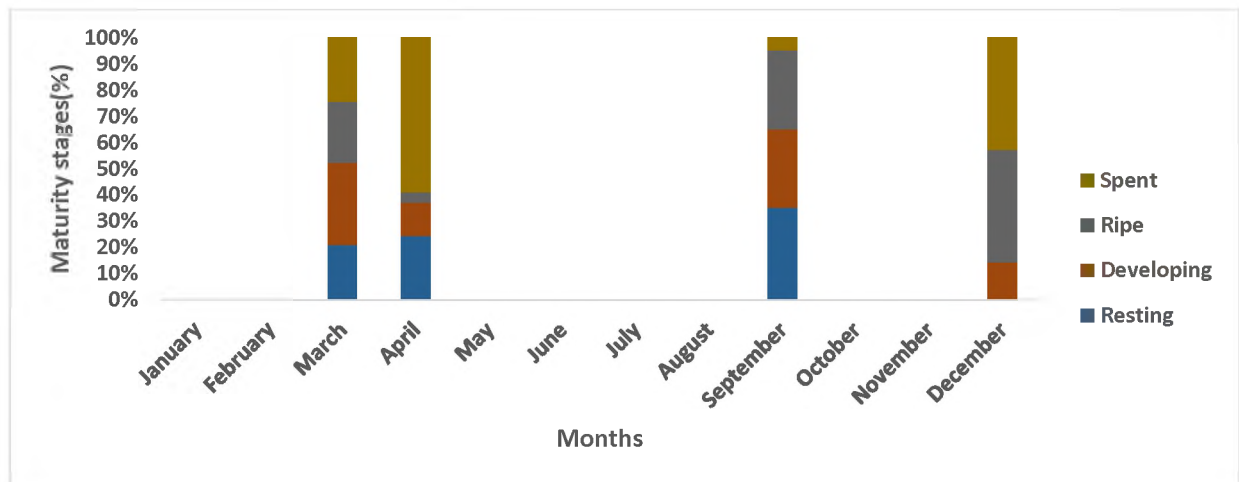
**TABLE 5.4.** Sex ratio and  $\chi^2$  test statistics (df=1) of mature *Oreochromis andersonii*, *Oreochromis macrochir* and *Coptodon rendalli* sampled in the Chobe Kavimba floodplains, Zibadianja Lagoon and Savuti River and Marsh in Botswana between September 2014 and April 2015

Species	N	Sex ratio F: M	Collective	p
<i>O. andersonii</i>				
Chobe Kavimba	79	1:1.3	93:95	>0.05
Zibadianja	41	1:1.3		
Savuti	68	1:1.1		
<i>O. macrochir</i>				
Chobe Kavimba	49	1:0.4	58:58	>0.05
Zibadianja	28	1:1.5		
Savuti	47	1:0.6		
<i>C. rendalli</i>				
Chobe Kavimba	8	1:3.0	77:30	<0.05
Zibadianja	69	1:2.3		
Savuti	30	1:3.3		

## Maturity

A preliminary assessment of reproductive activity showed that developing, ripe and spent stages were present in the population during between September 2014 and April 2015 (Figure 5.1). In September, 30% of specimens were ripe and by December 43% were in a spent condition. This indicates that the peak spawning season was between September and December. By April, 60% of mature fish were spent while 24% were resting and very few (4%) were ripe. Data for all the months were therefore used for the subsequent in assessment of maturity.

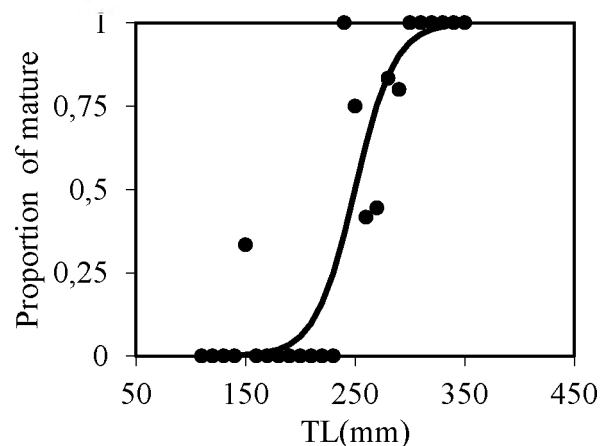




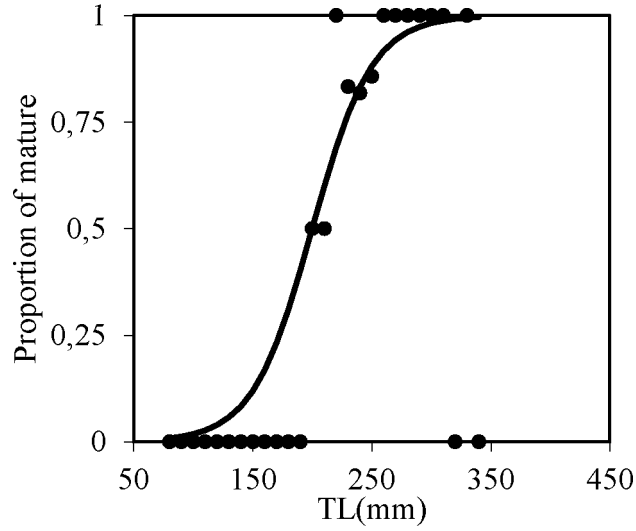
**Figure 5.1.** Reproductive seasonality for all three large cichlids in Chobe District sampled between September 2014 and April 2015

### Length at 50% maturity

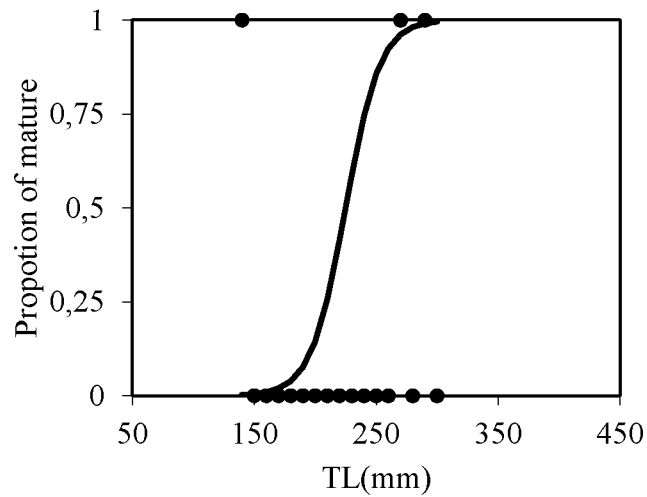
Length at 50% maturity for *O. andersonii* in the Savuti River was 250 mm  $L_T$  ( $\delta_L = 18 \text{ mm}^{-1} L_T$ ) (Figure 5.2). For *C. rendalli* at Zibadianja Lagoon it was 210 mm  $L_T$  ( $\delta_L = 25 \text{ mm}^{-1} L_T$ ) (Figure 5.3) and length at 50% maturity for *O. macrochir* in the Savuti River was 225 mm  $L_T$  ( $\delta_L = 14 \text{ mm}^{-1} L_T$ ) (Figure 5.4).



**Figure 5.2.** Logistic ogives fitted to the proportion of reproductively active *O. andersonii* for Savuti River and marsh in the Chobe district, Botswana, sampled between September 2014 and April 2015, (n=78).



**Figure 5.3.** Logistic ogives fitted to the proportion of reproductively active *Coptodon rendalli* for Zibadianja Lagoon in the Chobe district, Botswana, sampled between September 2014 and April 2015, (n=82).



**Figure 5.4.** Logistic ogives fitted to the proportion of reproductively active *Oreochromis macrochir* for Savuti River in the Chobe district, Botswana sampled between September 2014 and April 2015, (n=47).

### Length maturity at age and maximum gillnet selectivity

The length at maturity for *O. andersonii* (250 mm  $L_T$ ), *O. macrochir* (225 mm  $L_T$ ) and *C. rendalli* (210 mm  $L_T$ ) correspond to 93 mm mesh size and maturity at two years. Table 5.5 summarises the length maturity at age and Table 5.6 shows predicted length class at maximum selectivity for different gillnet selectivity curves for the large cichlids in Chobe District.

**TABLE 5.5.** Length maturity at age and corresponding mesh size for the Chobe district, Botswana large cichlids sampled between September 2014 and April 2015.

Species	Length at maturity	Corresponding mesh size	Corresponding year
<i>O. andersonii</i>	250 mm $L_T$	93 mm	2
<i>O. macrochir</i>	225 mm $L_T$	93 mm	2
<i>C. rendalli</i>	210 mm $L_T$	93 mm	2

**TABLE 5.6.** Predicted length class at maximum selectivity for different gillnet selectivity curves for *Oreochromis andersonii*, *Oreochromis macrochir* and *Coptodon rendalli* (Adapted from Peel, 2012).

Species	Mesh size					
	45 mm	57 mm	73 mm	93 mm	118 mm	150 mm
<i>O. andersonii</i>	-	160	200	260	330	420
<i>O. macrochir</i>	-	-	190	240	300	-
<i>C. rendalli</i>	120	160	200	250	-	-

### 5.4 Discussion

The results of this study support the hypothesis that length at maturity differed slightly between *O. andersonii*, *O. macrochir* and *C. rendalli*. Studies in the reproductive life history of tilapiine cichlids have reported variation in size at first sexual maturity (Fryer & Iles, 1972; van der Waal, 1985; Kolding, 1993). This is attributable to the prevailing environmental conditions experienced by the fish population. For example, in the Okavango Delta, Merron and Bruton (1988) observed that *O. andersonii* in small floodplains connected to lagoons were stunted in comparison to fish in stable permanent water of the panhandle and large ox bow lake. This agrees with the findings in the Lower Shire River floodplain in Malawi where *Oreochromis mossambicus*

matured at a smaller size due to fishing pressure and a hydrologically unstable environment (Chimatiro, 2004). However, the length at maturity in the Chobe district was comparable to a study on large cichlids conducted by Peel (2012) in the Zambezi region (Namibia), which shares the waters with the Chobe River.

The results show that the length at 50% maturity for male and female *O. andersonii* in the Savuti River was slightly higher (250 mm  $L_T$ ) than the length at 50% maturity for *O. macrochir* in the Savuti River, and *C. rendalli* (210 mm  $L_T$ ) in the Zibadianja Lagoon. The results for *O. andersonii* concur with other studies in the region. For example, Trewavas (1983) reported that length at 50% maturity ( $L_m$ ) for *O. andersonii* was 24.4 cm in the Zambezi River, while Peel (2012) reported a 254 mm  $L_T$  in Lake Liambezi in the Zambezi region. These findings were also consistent with length at 50% maturity (25–27cm) reported by Hay (2003) in the Kwando River. However, these lengths at 50% maturity were slightly higher than maturity length for *O. andersonii* reported in the Okavango Delta (105–55 mm), Zambezi (240 mm  $L_T$ ) and Kavango Rivers (238 mm  $L_T$ ) (Merron, 1991; Peel, 2012). These variations may be accounted for by the ecological opportunities provided by each system and the availability of food and habitat needed for growth (Abdul, 2009; Merron, 1991). Greater length at 50% maturity has been associated with favourable environmental conditions and shorter length at maturity has been associated with harsher, less favourable conditions (James & Bruton, 1992).

The length at 50% maturity for *O. macrochir* in the Savuti River (225 mm  $L_T$ ) was comparable to the 230 mm  $L_T$  and 221 mm  $L_T$  reported at Lake Liambezi, but slightly greater than the 215 mm  $L_T$  reported in the Kwando River (van der Waal, 1985; Peel, 2012). However, the length at maturity for *O. macrochir* in the Zambezi River was higher (254 mm  $L_T$ ) than the length at maturity in the Savuti River (225 mm  $L_T$ ). The greater length at maturity in the Zambezi River is inconsistent with the assertion that under fishing pressure, fish species mature early to enable them to reproduce rapidly in the variable environment (Booth & Merron, 1996; Chimatiro, 2004).

Length at 50% maturity for *C. rendalli* in the Zibadianja Lagoon was smaller (210 mm  $L_T$ ) when compared to the 218 mm  $L_T$  of *C. rendalli* in males but comparable to the 205 mm in females at Lake Chicamba in Mozambique (Weyl & Hecht, 1998). These maturity lengths were higher than the lengths at 50% maturity recorded in Lake Liambezi (109 mm SL), Kavango (195 mm  $L_T$ ), and

in Kwando (203 mm  $L_T$ ) (van der Waal, 1985; Peel, 2012). The results for *O. andersonii* and *C. rendalli* indicate that, despite the interlinking of these river systems during high inundations, species inhabiting these systems matures at different lengths owing to differences in environmental factors. Differences may also be due to genetic differences between the three species. For example, *O. andersonii* grows larger (400 mm  $L_T$ ) than *O. macrochir* (300 mm  $L_T$ ) and *C. rendalli* (355 mm  $L_T$ ) as was observed in the current study.

### **Length-weight relationship**

In fish, weight is the function of length (Weatherly & Gill, 1987). In this study, the regression coefficient (b-values) for *O. andersonii*, *O. macrochir* and *C. rendalli* ranged from 2.3-2.9 signifying the negative allometric growth among all the three species (Gayanilo & Pauly, 1997). Other distant previous studies, have also recorded negative allometric growth in tilapias. For example, king reported negative allometric growth in tilapia mariae in lake Umuoseriche in Nigeria.

### **Condition factor**

The results of this study support the hypothesis that fish condition factor varies according to waterbody and region. In the current study, the mean condition factor between the river system was  $>1$  with mean K-values ranging from 1.62–2.22. This signifies good physiological fish conditions (Le Cren, 1951).

Condition factors for the three large cichlids in the Chobe district varied between stations. These variations in condition factor from one locality to the other may be due to various combined factors. In tropical and sub-tropical river systems, these variations may be influenced by both biotic and abiotic factors (Anene, 2005), such as ecological conditions, variation in productivity of the river system, seasonality, environmental parameters, state of gonadal development, availability of food and feeding regime (Le Cren, 1951; Oni et al., 1983; Ogidiaka & Esenowo, 2015).

The results of this study also show that sex ratios across the study species were skewed towards males. This is because males tend to show territorial aggressive behaviour, and are therefore more vulnerable to exploitation, especially to angling, as was the case in this study (Turner &

Huntingford, 1987). The other factors that contributed to the ratios may have been segregation during spawning, gear selectivity and sample site (Admassu, 1994).

The results of this study show that large cichlids in the Chobe district reproduce in summer from September to March. This was revealed by the presence of mature gonads in the samples from September to March. These findings agree with previous studies conducted in the region (Merron, 1989a; van der Waal, 1985; Peel, 2012). These were also consistent with findings at Lake Chicamba in Mozambique, where reproductive activity of cichlids was confined to summer from September to May, when mean temperatures were more than 24 °C (Weyl & Hecht, 1998).

### **Recommended mesh size and closed season**

This study shows that length at 50% maturity of *O. andersonii*, *O. macrochir* and *C. rendalli* in Chobe district were comparable to those reported by Peel (2012) in the Zambezi Region (Namibia). In the Chobe district, the length at maturity for *O. andersonii*, *O. macrochir* and *C. rendalli* corresponded to a 93-mm mesh size, at which all these species are mature. The legal minimum mesh size in the Chobe district is 4 inches (100 mm). This mesh size should be maintained as is, because it allows large cichlids to mature and breed before being harvested. However, in the Zambezi region (Namibia), the length at maturity for some specimen (*O. macrochir* and *C. rendalli* at Kavango), corresponded to a 73-mm mesh size (Peel, 2012). This length at maturity was lower and implies that these species may be being harvested before maturation. This is because the minimum legal mesh size in Namibia is 3'' inches (76 mm) (Namibian, Inland Act MFMR, 2003). Therefore, Peel (2012) recommended a mesh size of 89 mm so that this species could mature and breed before being harvested. This, then, implies that the mesh sizes of 3.5 (89 mm) recommended by Peel (2012) and the current 4 inches (100 mm) used by commercial fishermen in Botswana are compatible. These mesh size can be applied in both countries, as large cichlids in these areas mature at about the same size, and these mesh sizes will allow large cichlids to mature and breed at least once before being harvested.

This study has also revealed that the spawning of large cichlids in the Chobe district (Botswana) occurs in summer from September to March. This corresponds with the spawning season for large cichlids in the Zambezi region (Namibia). Therefore, Botswana's fish closed season from 31 December to the end of February could be extended to Namibia. This will ensure that the fish

population is protected in both countries during the reproduction phase and recovery phase to ensure successful recruitment and to reduce of fish mortality (Bhukaswan, 1980). This will further reduce resource conflicts among these riparian communities.

The subsistence and commercial fishing season for Botswana spans from the 1 March to 31 December each year (Fish Regulations, 2008). However, the current study shows that some cichlid species still spawn in March, especially in the Kavimba floodplains. Therefore, the current fishing moratorium from December 31 to the end of February should be amended to include March. The overall management recommendations are summarised in Chapter 6.

## **CHAPTER 6: CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS**

Inland fishing remains an essential source of food, nutrition, income and livelihoods for millions of people around the world (FAO, 2016). Despite this significant role in global food security and livelihoods, fishing pressure has diminished the productive capacity of many inland fisheries (FAO, 2016). In the entire Zambezi river system and its tributaries, for example, almost all fisheries have experienced severe declines in catch rates (Tweddle et al., 2015). This has been attributed to increased efforts through commercialisation of the fishing and the introduction of more efficient monofilament gillnets, coupled with the use of destructive fishing methods (Tweddle et al., 2015). In many fisheries, this has resulted in loss of the larger and more valuable fish species (Weyl et al., 2004b, 2005b, 2010). The results of the current study demonstrate that the evidence of depletion of larger and older fish in the exploited areas of the Chobe River floodplain, can be added to previous evidence of overfishing in all parts of the Upper Zambezi River, including the Barotse floodplain, Lake Liambezi and the Kafue flats floodplains (Tweddle et al., 2015).

Owing to the global concern over declining fish stocks, FAO has set a code of conduct for responsible fisheries to be used as a global reference for sustainable fisheries (Cochrane, 2002; FAO, 2016). One of the suggested fundamental principles of fisheries management states that the biological production of fish stock is the function of the size of stock and of the ecological environment, which can be influenced by natural or anthropogenic factors (Cochrane, 2002). Therefore, to guard against the collapse of fisheries, there is need to understand not only the biology, life history and distribution of target species, but also exploitation factors when developing strategies to ensure effective conservation and management (King, 1995).

This study has helped to enhance the understanding of the fisheries of the floodplain in the Chobe region. The study demonstrates that fish communities in the floodplain ecosystems in the Chobe district were representative of the region, containing some 70 species in 14 families (Chapter 2). Fishing pressure in the Chobe River did not affect fish diversity and richness. Surveys in Chapter 2, for example, demonstrated that the highly-exploited Chobe River had greater species diversity and richness (31 species) than areas with lower (Zibadianja Lagoon (,25 species) and no (Savuti River (,24 species) exploitation. However, areas with lower or no exploitation contained more fish



than exploited areas (Chapter 3). Mean catch per unit effort (CPUE) by weight was significantly higher in the protected Zibadianja Lagoon ( $\text{CPUE}=38 \pm 31 \text{ kg/net.night}^{-1}$ ) and Savuti River ( $\text{CPUE} = 25 \pm 19 \text{ kg/net.night}^{-1}$ ) than in the exploited Chobe River ( $\text{CPUE} = 6 \pm 3 \text{ kg/net.night}^{-1}$ ) (Chapter 3).

This study also showed that large cichlids were easily aged using otoliths, which facilitated the comparison of growth rates between populations and the comparison of the mean and maximum age between the sampled regions (Chapter 4). This study showed that in areas with low or no fishing pressure, the mean age of large cichlids e.g., *Oreochromis andersonii*, in protected Zibadianja Lagoon ( $5.3 \pm 1.6$  years) and Savuti River ( $4.3 \pm 1.8$  years) were significantly higher than in exploited Chobe River ( $2.4 \pm 1.6$  years).

## 6.1 Management recommendations

The results of this study demonstrate that areas with low or no fishing pressure, which contain fish that represent the diversity of the region and occur at a high abundance and at large sizes and old ages, act as refugia and help in recolonising adjacent overfished areas through the spillover effect (Roberts & Polunin, 1991; Russ & Alcala, 1996; McClanahan & Mangi, 2000). This is important because adult fish are the primary brooding stock and their removal reduces the spawner biomass, which can result in recruitment overfishing (Berkeley et al., 2004a). Therefore, it is important to establish more protected areas for fisheries management in the region. In Namibian waters, there are two existing fish reserves (Sikunga and Kasaya channels) established by Namibian conservancies along the Zambezi and Chobe Rivers to act as refuges for mature fish during drawdown events when the fishing pressure is high (Tweddle & Hay, 2011; Peel, 2012). On the opposite side of the Chobe River in Botswana waters there is Chobe National Park, where fishing is prohibited. These areas will therefore both serve towards the management of Chobe fisheries. Although important, these two fish protection areas may not be sufficient as refuge, spawning, growth and recruitment habitats for species that are exploited throughout the Upper Zambezi Region. Therefore, since the Chobe River on Botswana waters is a National Park, it is recommended that more adjacent areas on the Namibia waters should be established as fish reserves. This should be done considering fish range, migration and movements.

The legal minimum size of mesh is a control measure instituted to protect juveniles, to give them time to grow to an economically useful size before they are harvested, or in the case of the sub adults, protection from exploitation until they are large and mature enough to spawn. In this way, the size of the spawning stock can be protected. Current Botswana gillnet mesh size of 4 inch (100 mm), the regulation of importing gillnets and prohibition of mosquito nets use, are meant to ensure that there is sustainable harvesting of mature fish (Botswana Fish Regulations, 2008). As was demonstrated in Chapter 5, the length at maturity of large cichlids in Chobe district Botswana, were consistent with those estimated in Namibia by (van der Waal, (1985) and Peel, (2012).

Even though floodplain fishery is characterised by multi-gear and multi-species, the harvesting strategy for large cichlids should be based in length at maturity. This implies that *O. andersonii* should not be harvested before 250 mm  $L_T$ , *O. macrochir* before 225 mm  $L_T$  and *C. rendalli* before 210 mm  $L_T$  (Chapter 5). This is to ensure that the fish reach maturity and can breed before being harvested. Based on the length at maturity from this study with gillnet selectivity, and the maturity of these species in Namibia (van der Waal, 1985; Peel, 2012), the stretched mesh sizes of 3.5 inches (89 mm) recommended by Peel (2012) in Namibia and the current 4-inch (100 mm) mesh used by commercial fishermen in Botswana are suitable for exploiting the three main target species at lengths larger than maturity.

This study also demonstrated that the large cichlids spawning seasons were comparable (September to March) between the Chobe district (Botswana) and the Zambezi Region (Namibia). It is therefore, recommended that the fish closed season be synchronised over the period December 1 to March 31 to simplify fish management in the region.

## REFERENCES

- Abilhoa, V., Braga, R. R., Bornatowski, H and Vitule, J. R. S. (2011). Fishes of the Atlantic Rain Forest streams: ecological patterns and conservation, p. 259–282, In: O. Grillo and G. Venora (eds.). Changing diversity in changing environmental. Rijeka: InTech.
- Abdul, W. O. (2009). Stock assessment of tilapia zilli in the freshwater ecotype of Ogun estuary, Ogun state Nigeria. PhD, thesis, University of Agriculture, Abeokuta, Nigeria p.189.
- Admassu, D. (1994). Maturity, fecundity, brood size and sex-ratio of Tilapia (*Oreochromis niloticus*) in Lake Awassa. SINET: *Ethiopian Journal of Science* **17**, 53-69.
- Allan, J. D., Abell, Z., Revenga, C., Taylor, B.W., Welcome, R. L., & Winemiller, K. O. (2005). Overfishing of Inland Waters. *Bioscience* **55**, 1041-1051.
- Alm, J. D. (1959). Connection between maturity, size and age in fishes. Report of the institute of Freshwater Research. Drottingholm **40**, 1-145.
- Andersson, C. J. (1976). Lake Ngami or explorations and discovery during four years of wondering in the wilds of south western Africa (facsimile 2<sup>nd</sup> ed.). London: Hurst and Blackett.
- Anderson R. O. & Newman R. M. (1996). Length, Weight, and Associated Structural Indices, p.447-481. In: Murphy B. E. and Willis D.W. (eds.) *Fisheries Techniques*, second edition. American Fisheries Society.
- Anon, (1989). SADC Country situational report, regional fisheries survey, Botswana manuscript.
- Applied Development Research Consultants (ADRC). (2001). A Report on the socio ecological survey of the Okavango Basin, Gaborone, Kalahari Conservation Society.
- Aquaculture for Local Development and Utilisation of small water bodies in southern Africa (ALCOM). (1996b). Joint evaluation by recipient countries, donor Government and FAO.
- Bagenal, T. B., & Tesch, A. T. (1978). Condition and growth patterns in freshwater habitats. Oxford: Blackwell Scientific Publications.

- Balcome, S. R. & Arthington, A. H. (2009). Temporal changes in fish abundance in response to hydrological variability in a dryland floodplain river. *Marine and freshwater Research* **60**, 146–159.
- Balon, E. K. & Coche, A. G. (eds.). (1974), *Lake Kariba: A man-made tropical ecosystem in Central Africa, Monographiae Biologicae* 24, The Hague: Dr. W. Junk Publisher. p. 766.
- Banda, K. P. (1993). Fingerling production and stocking of tilapias. report of the Workshop of Improved Fish Farming Practices and Extension Services for Zambia. Mansa. Zambia, p.15–18.
- Banda, M., Jamu, D., Njaya, F., Makuliwa, M., & Maluwa, A. (eds.) (2005). The Chambo restoration strategic plan. World fish Center Conference Proceedings, Penang, Malaysia.
- Bass, D. (1992). Colonisation and succession of benthic macroinvertebrates in Arcadia Lake, a south-central USA reservoir. *Hydrobiologia* **242**, 123–131.
- Beamish, R. J. & Fournier, D. A. (1981). A method for comparing the precision of a set of age determinations. *Canadian Journal of Fisheries and Aquatic Sciences* **38**, 982–983.
- Beamish, R. J. & McFarlane, G. A. (1987). Current trends in age determination methodology. In: R.C. Summerfelt, & G.E. Hall. (eds.). *The Age and growth of fish*. pp 15-42. Ames, IA, Iowa state University Press.
- Beddington, J. R. & Rettig, R. B. (1984). Approaches to 1984 the regulation of fishing effort. FAO Fisheries Technical Paper (243) p. 39.
- Beets, J. & Manuel, M. (2007). Temporal and seasonal closures used in fisheries management: a review with application to Hawaii: Hawaii Department of Marine Science, University of Hawaii-Hilo.
- Bell-Cross, G. & Jubb, R. A. (1976). *Fishes of Rhodesia*. National Museum, Salisbury, Rhodesia. Salisburg, vii+268p.
- Berkeley, S. A., Hixon, M. A., Larson, R. J., Love, M. S. (2004a). Fisheries sustainability via protection of age structure and spatial distribution of fish populations. *Fisheries* **29**, 24–32.

- Beveridge, M. C. M. and McAndrew, B. J. (2000). Tilapias: Biology and exploitation. London. Fish and Fisheries series: Kluwer Academic Publishers.
- Bhukaswan, T., (1980). Management of Asian reservoir fisheries. FAO Fisheries Technical Paper, (207) p. 69.
- Bohnsack, S. A. (1998). Application of Marine Reserve to reef fisheries Management. *Australian Journal of Ecology* **23**, 298–304.
- Bokhutlo, T. (2011). Life History and stock Assessment of *Clarias Gariepinus* in the Okavango Delta, Botswana. Msc thesis, Rhodes University, Grahamstown, South Africa.
- Booth, A. J. & Merron, G. S. (1996). The age and growth of the green head tilapia *Oreochromis macrochir* (Pisces: Cichlidae) from the Okavango Delta, Botswana. *Hydrobiology* **321**, 29–34.
- Booth, A. J., Merron., G. S., & Buxton, C. D. (1995). The growth of *Oreochromis andersonii* (Pisces: Cichlidae) from Okavango Delta, Botswana, and a comparison of the scale and otolith methods of ageing. *Environmental Biology of Fishes* **43**, 171–178.
- Botswana Agricultural Report. (1985). Fish-food for the future. Animal Production Division. Annual Report. Ministry of Agriculture, Botswana.
- Botswana Central statistics, (2011). Preliminary results of the 2011 Population and Housing Census p.1–8.
- Botswana National Report for United Nations Conference on Sustainable Development RIO+20 Conference. (2012). Seaname Conservation Consultancy (Pty) Ltd p.1–46.
- Braga, M. I., Castro, G., Hooten, A., Mackinnon, K., Rees, C., & Whitten, T. (1998). Integrating freshwater Biodiversity Conservation with development: some lessons. Natural Habitats and Ecosystems Management Series Paper No.61. The World Bank. Washington, D. C.
- Breen, C. M, Quinn, N. W. & Mander, J. J. (eds.). (1997). Wetlands conservation and management in Southern Africa: Challenges and opportunities. Harare: IUCN.

- Bruton M. N. (1979a). The fishes of Lake Sibaya. In: B. R. Allanson, (eds.). Lake Sibaya. *Monographiae Biologicae*, The Hague: W. Junk Publishers **36**, 162–245.
- Bruton, M. N. & Allanson, B. R. (1974). The growth of *Tilapia mossambicus* (Peters: Cichlidae) in Lake Sibaya, South Africa. *Journal of Fish Biology* **6**, 701–715.
- Burr, J. M. (1991). Length limit regulations as applied to Alaskan lake trout fisheries, a synthesis of available data with recommendations. Alaska Department of Fish and Game. Fishery Manuscript No.91-5 p.1–52.
- Campana, S. E. (2001). Accuracy, Precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology* **59**, 197–242.
- Campana, S. E. & Neilson, J. D. (1985). Microstructure of Otoliths. *Canadian Journal of Fisheries and Aquatic Science* **42**, 1014–1031.
- Campana, S. E. & Thorrold, S. R. (2001). Otoliths, increments and elements: key to a comprehensive understanding of fish populations? *Canadian Journal of Fish Aquatic Science* **58**, 30–38.
- Carlender, K. D. (1987). A history of scale age and growth studies in Northern America fresh water fish. In: R. C. Summerfelt., G. E. Hall, (eds.). Age and growth of fish. Ames, IA Ioma State University press p. 3–14.
- Ceccarelli, D. & Ayling, T. (2010). Role, Importance and vulnerability of top predators on Great Barrier Reef. Australian Government-Great Barrier Reef Marine Park Authority, No.105 p.150.
- Chambers, R. C. & Trippel, E. A. (1997). Early life history and recruitment in fish populations, London: Chapman and Hall
- Chang, W. Y. B. (1982). Statistical method for evaluating the reproducibility of age determination. *Canadian Journal of Fisheries and Aquatic Sciences* **39**, 1208–1210.

- Chase, M. (2012). Dry season fixed-wing aerial survey of elephants and wildlife in northern Botswana. Report for elephants without borders p.1–94.
- Child, G. (1968). An ecological survey of northern Botswana. FAO Report T. A 2563. Rome, Italy.
- Chimatiro, S. K. (2004). The biophysical dynamics of the lower Shire River floodplain fisheries in Malawi. PhD thesis, Rhodes University p.1–271.
- Christensen, V. & Pauly, D. (1998). Changes in models of aquatic ecosystems approaching carrying capacity. *Ecological Applications* **8**, S104–S109.
- Clarke, K. R. & Warwick, R. M. (1994). Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. Plymouth Marine Laboratory, Plymouth, USA.
- Clarke, K. R. & Gorley, R.N. (2006). PRIMER v6: User manual/Tutorial. Plymouth, UK: PRIMER Ltd p.190.
- Cochrane, K. L. (ed.). (2002). A fishery manager's guidebook. Management measures and their application. FAO Fisheries Technical Paper No. 424. Rome, FAO p. 231.
- Cote, I. M., Mosqueira, I., & Reynolds, J. D. (2001). Effects of marine reserve characteristics on the protection of fish populations: A meta-analysis. *Journal of Fish Biology* **59**, 178–189.
- Cowie, R. J. & Krebs, J. R. (1979). Optimal foraging in patchy environments. p.183–205. In: Anderson, R. M, Turner, B. D. & Taylor, L. R.(eds.). British Ecological Society Symposium on Population Dynamics, Oxford: Blackwell Scientific.
- Cowley, P. D., Brouwer, S. L., & Tilney, R. L. (2002). The role of Tsitsikamma National Park in the management of four shore-angling fish along the Southeastern cape coast of South Africa. *South African Journal of Marine Science* **24**, 27–36.
- Cowx, I. G., Knaap, M., Van Der, Muhoozi, L. I. & Othina, A. (2003). Improving fishery catch statistics for Lake Victoria, *aquatic health and management* **6**, 299–310.
- Crain, P., Whitener, K. & Moyle, P. (2004). Use of a restored Central California floodplain by larvae of native and alien fishes. American Fisheries Society Symposium p.39: In F. Feyrer., L.R. Brown., J. J. Orsi, (eds.). Early Life history of Fishes in the San Francisco

- Estuary and watershed. American Fisheries Society Symposium, Bethesda, Maryland 125–140.
- Cronberg, G., Gieske, A., Martin, E., Prince Nengu, J., Stenstrom, I. M. (1995). Hydrological studies of the Okavango Delta and the Kwando/Linyanti/Chobe River, Botswana, surface water quality analysis. *Botswana Notes and Records* **27**, 151–226.
- Curtis, B., Roberts, K. S., Griffin, M., Bethune, S., Hay, C. J. and Kolberg, H. (1998). Species richness and Conservation of Namibian freshwater macro-invertebrates, fish and amphibians. *Biodiversity and Conservation* **7**, 447–466.
- Cutler, J., Apse, C., Cavelier, T., Fermon, Y., Mvé-Beh, J. H., Paiz, M. C., Sidlauskas, B., and Sullivan, J. P. (2016). Fish Biodiversity Assessment of the Rapids of Mboundou Badouma and Doumé Ramsar Site and Surrounding Areas in Gabon. The Nature Conservancy, Arlington, VA. p.1–70.
- Dan-Kishiya, A. S. (2013). Length-weight relationship and Condition factor of five species from a tropical water supply reservoir in Abuja, Nigeria. *American Journal of Research communication* **1**, 175–187.
- Davey, A. J. H., Kelly, D. J. & Biggs, B. J. F. (2006). Refuge use strategies of stream fishes in response to extreme flows. *Journal of Fish Biology* **69**, 1047–1059.
- Davies, B. R. (1986). The Zambezi system. p. 225–288. In: B. R., Davies, & K. F. Walker, (eds.). The Ecology of river systems. Dordrecht, The Netherlands: W. Junk, Publishers.
- Davis, J. (2011). Botswana aquaculture development strategy. ACP Fish II Coordination Unit Service Contract n° CU/PE1/MZ/10/004, SOGES S.p.A. consortium p.1–109.
- Davis, J. L. D. (2000). Spatial and seasonal patterns of habitat partitioning in a guild of southern California tide pool fishes. *Marine Ecology Progress series* **196**, 253–268.
- Deloitte & Touche. (1992). Chobe National Park: Management plan two volumes. Department of Wildlife and National Parks Management Consultants, Gaborone, Botswana.
- Department of Wildlife and National Parks Fisheries surveys 2006–2012. Unpublished.



- Department of Wildlife and National Parks Fisheries surveys 2010–2012. Unpublished.
- Donaldson, W. E. & Donaldson W. K. (1992). A review of the history and justification for size limits in Alaskan king, Tanner, and snow crab fisheries. *Fishery Research Bulletin* **92**, 1–33.
- Donda, S. & Njaya, F. (2007). Fisheries Co-Management in Malawi: An analysis of the underlying policy process, Food security and poverty alleviation through improved valuation and Governance of River Fisheries in Africa. World Fish Centre. Africa & West Africa programme, Cairo. Egypt **16**, 1–40.
- Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D.J., Leveque, C., Naiman, R. J., Prieur-Richard, A.H., Soto, D., Stiassny, M. L. J., & Sullivan. C. A. (2005). Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological reviews* **81**, 163–182.
- Dudley, R. G. (1974). Growth of tilapia of the Kafue floodplain, Zambia: predicted effects of the Kafue Gorge Dam. *Transactions of the American Fisheries Society* **103**, 281–291.
- Efron, B. (1982). Nonparametric estimates of standard error: the jack-knife, the bootstrap and other methods. *Biometrika* **68**, 589–599.
- Ellender, B. R., Weyl, O. L. F., Shanyegange, M. K., & Cowley, P. D. (2008). Juvenile population dynamics of *Oreochromis mossambicus* in an intermittently open estuary at the limit of its natural distribution. *African Zoology* **43**, 277–283.
- FAO GIEWS, (1999). Food supply situation and crop prospects in Sub Saharan Africa. Africa Report No.3, Botswana.
- FAO, (1977). Symposium on River and Floodplains Fisheries in Africa, Bujumbura, Burundi.
- FAO, (1995). The code of conduct for responsible fisheries. Rome, Italy.
- FAO, (2002). Sample-based fishery surveys. Rome, Italy.
- FAO, (2003). Fisheries Management, Technical guidelines for responsible fisheries. UN, Rome.

- FAO, (2007). Republic of Botswana, Fishery country profile. Botswana.
- FAO, (2016). The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all. Rome p. 200.
- Fenberg, P. B. & Roy, K. (2008). Ecological and evolutionary consequences of size-selective harvesting: how much do we know? *Molecular Ecology* **17**, 209–220.
- Fowler, H. W. (1935a). Scientific results of the Vernay-Lang Kalahari Expedition, March to September 1930. *Annals of Transvaal Museum* **16**, 251–293.
- Fox, J. T., & Alexander, K. A. (2015) Spatiotemporal Variation and the Role of Wildlife in Seasonal Water Quality Declines in the Chobe River, Botswana. *PloS ONE* 10 (10).
- Fox, P. J. & Watt, E. H. (1976). Some effects of *Salvania molesta* on fish population in the Linyanti River. unpublished report, Botswana Fisheries unit.
- Francour, P. (1989). Les peuplements ichthyologiques de la Reserve de Scandola: influence de la reserve integrale. *Travaux scientifiques Parc national regional reserve naturel Corse, Fr.* **21**, 33–93.
- Froese, R. (2006). Cube law, condition factor and weight-length relationships: history, meta-analysis and recommendations. *Journal of Applied Ichthyology* **22**, 241–253.
- Fryer, G. & Iles, T. D. (1972). The cichlid fishes of the great lakes of Africa. Oliver & Boyd, Edinburgh p. 641.
- Furse, M. T., Kirk, R. C., Morgan, P. R., & Tweddle, D. (1979). Fishes: Distribution and Biology in relation to change, in Lake Chilwa: studies of changes in a tropical ecosystem, Kalk, M., McLachlan, A. J. and Howard-Williams, C (eds.). *Monographiae Biologicae* **35**, 175–208.
- Galacatos, R., Barriga-Salazar and Stewart, D. J. (2004). Seasonal and habitat influences on fish communities within the lower Yasuni River Basin of Ecuadorian Amazon. *Environmental Biology of Fishes*. Kluwer Academic publishers. Netherlands **71**, 33–51.

- Gayanilo, F. C, Pauly D. (1997). FAO International Centre for Living Aquatic Resource Management (ICLARM) stock assessment tools (FISAT), references manual. FAO Computerized information series(Fisheries), No.8, Rome, FAO p. 262.
- Garcia, S. M., Zerbi, A., Aliaume, C., Do chi. T. & Lasserre, G. (2003). The ecosystem approach to Fisheries; Issues, terminology, principles, institutional foundations, implementation and outlook. Fisheries Technical paper. No. 443. Rome, FAO p.71.
- Gardner, J. P. A. & Struthers, C. D. (2012). Comparisons among survey methodologies to test for abundance and size of a highly-targeted fish species. *Journal of Fish Biology* **82**, 242–262.
- GOM (1999). Resource Report. (1999). Fisheries Department, Government of Malawi.
- Government of Botswana. (1975). National policy on Tribal Grazing Land. Gaborone: Government Printer.
- Government of Botswana. (1990). Tourism policy. Gaborone: Government Printer.
- Government of Botswana. (1991), National policy on Agricultural Development. Gaborone: Government printing & publishing services.
- Government of Botswana. (1992). Wildlife Conservation and National Parks Act, Gaborone: Government Printer.
- Government of Botswana. (2001). Botswana National Atlas. Gaborone: Department of Surveys and Mapping.
- Government of Botswana. (2008). Fish Protection Regulations. Gaborone: Government Printing and Publishing Services.
- Greenwood, P. E., & Nikulin, M. S. (1996). A guide to chi-square testing. New York: Wiley and sons.
- Gulland, J. A. (1974). Guidelines for fishery management. Rome, FAO, IOFC/DEV/74/36 p. 84.

- Gumbo, G. B. (2010). Economic and social change in the communities of the wetlands of Chobe and Ngamiland, with special reference to the period since 1960. PhD. thesis. University of Cape Town. South Africa p. 1–275.
- Gupta, A. C. (2012). Conservation's complexities: A study of livelihoods and people-park relations around Chobe National Park, Botswana. PhD. thesis, University of California, Berkeley p. 103.
- Halwart, M., Funge-Smith, S. & Moehl, J. (2003). The role of aquaculture in rural development, in FAO Fisheries Circular No. 886 (Revision 2), FAO, Rome, Italy p. 1–12.
- Hay, C. J. (1991). The distribution of fish in the Fish River, Namibia. In: R. E. Simmons, C.J., Brown, & Griffin, M. (eds.). Status and Conservation of wetland in Namibia. *Madoqua* **17**, 211–215.
- Hay, C. J. (1993). The distribution of freshwater fish in Namibia. Unpublished Msc. thesis. Rand Afrikaans University, Johannesburg.
- Hay, C. J., Naesje, T. F., Breistein, J., Harsaker, K., Kolding, J., Sandlund, O. T., Van Zyl, B. (2000). Fish populations, gillnet selectivity and artisanal fishery in the Okavango River, Namibia. NINA-NIKU project report **10**, 1–105.
- Hay, C. J., Naesje, T. F., Kaprika, S., Koekemoer, J., Strand, R., Thorstand, E. B. and Harsaker, K. (2002). Fish populations, gillnet catches and net selectivity in the Zambezi and Chobe Rivers, Namibia from 1997 to 2000. NINA-NIKU project report **17**, 1–88.
- Hay, C. J., Naesje, T. F., Strand, R., Purvis, J., Thorstad, E. B., Abbott, J. and Nickanor, N. (2003). Shared Resources Management on the Zambezi/Chobe systems in Northeast Namibia: Current Practices and Future Opportunities River Fisheries study: February 2002-February 2003. Ministry of Fisheries and Marine Resources, Windhoek, Namibia p. 52.
- Hay, C. J. & van der Waal, B. C. W. (2009). Analysis of historic research data for the Caprivi Region. Report for the Namibian Nature Foundation p. 75.
- Hay, C. J., Van Zyl, & Steyn, G. J. (1996). A quantitative assessment of the biotic integrity of the Okavango River, Namibia based on fish. *Water South Africa* **22**, 263–84.

- Hay, C. J., Van Zyl., van der Bank., Ferreira, F. H., Steyn, G. J. (1999). The distribution of freshwater fish in Namibia. *Cimbebasia* **15**, 41–63.
- Hardin, G., (1968). The tragedy of the commons. American association of advancement of science, **162**, 1243–1248.
- Hassell, M. P. (1978). The dynamic of anthropod predator-prey systems. Princeton, New Jersey. United States of America: Princeton University Press.
- Hecht, T. (1980). The value of otoliths in fresh water fisheries biology and taxonomy. University of the North, Pietersburg. Series A 19 p.17.
- Hecht, T. (1980a). A Comparison of the otolith and scale methods of ageing, and the growth of *Sarotherodon mossambicus* (Pisces: Cichlidae) in a Venda impoundment (Southern Africa). *South African Journal of Zoology* **15**, 222–228.
- Hecht, T. (1980b). Age, growth, reproduction and mortality of the Butter catfish *Eutropius depressirostris* (Schilbeidae: Pisces) in the Luphephe-Nwanedzi impoundment. Venda (South Africa). *Journal of Limnological Society of Southern Africa* **6**, 39–45.
- Hitchcock, R. R., & Smith, R. (1980). Settlement in Botswana; Historical development of a human landscape, National Museum, Gaborone, Botswana. Heinemann Educational Books Ltd. Botswana society p. 401.
- Hoxmeier, J. H., Aday, D. D. & Wahl, D. H. (2001). Factors influencing precision of age estimation from scales and otoliths of Bluegills in Illinois reservoirs. *North American Journal of Fisheries Management* **21**, 374–380.
- Huchzermeyer, C. F. (2013). Fish and fisheries of Bangweulu wetlands, Zambia. Msc thesis. Rhodes University, South Africa p.1–171.
- Huchzermeyer, D. A., & van der Waal, B. C. W. (2012). Epizootic ulcerative syndrome: Exotic Fish disease threatens Africa`s aquatic ecosystems. *Journal of the South African Veterinary Association* **83**, 2004.
- Huntingford, F. & Turner, A. (1987). Animal Conflict. London: Chapman and Hall.

- Hutchings, J. A. & Myers, R. A. (1993). Effect of Age on the seasonality of maturation and spawning of Atlantic Cod *Gadus morhua* in the Northwest Atlantic. *Canadian Journal of Fisheries and Aquatic Sciences* **50**, 2468–2474.
- Inland Fisheries Resource Act, (2003) No.1 of 2003. Ministry of Fisheries and Marine Resources, Namibia.
- International Union for Conservation of Nature (IUCN), (1987a). IUCN directory of Afrotropical protected areas. IUCN, Gland, Switzerland and Cambridge, UK, p. 963–966.
- Jackson, D. A., Peres-Neto, P. R. & Olden, J. D. (2001). What controls who is where in freshwater fish communities-the roles of biotic, abiotic and spatial factors. *Canadian Journal of Fisheries and Aquatic Sciences* **589**, 157–170.
- Jackson, P. B. N. (1961). The impact of predation, especially by tigerfish (*Hydrocynus vittatus* castelnaui, 1861) on African freshwater fishes. *Journal of Zoology* **136**, 603–622.
- James, N. P. E. & Bruton, N. M. (1992). Alternative life history traits associated with the reproduction of *Oreochromis mossambicus* (Pisces: Cichlidae) in small water bodies of the eastern Cape, South Africa. *Environmental Biology of Fisheries* **34**, 379–392.
- Jefferis, K. & Nemaorani, T. (2013). Botswana Country Overview, Capital Resources (Pty). Limited.
- Jepsen, D. B., Winemiller, K. O., Taphorn, D. C. & Rodriguez Olarte, D. (1999). Age structure and growth of peacock cichlids from rivers and reservoirs of Venezuela. *Journal of Fish Biology* **55**, 433–450.
- Jones, C. M. (1992). Development and application of the otoliths technique. p.1–11. In: D. K. Stevenson & S. E. Campana (eds.). Otolith microstructure analysis. *Canadian Special Publication and Fisheries Aquatic Sciences* **117**, p.126.
- Jubb, R. A. (1958d). A preliminary report on the collections of freshwater fishes made by the Bernard Carp Expedition to the Caprivi Strip, 1949, the Lower Sabie River, 1950 and to Barotseland, 1952, *Occasional Paper, National Museum of Southern Rhodesia* **3**, 177–189.

- Jubb, R. A. (1967). Freshwater Fishes of Southern Africa. Cape Town. Gothic printing company Limited.
- Jubb, R. A., & Gaigher, I. G. (1971). Checklist of fishes of Botswana. *Arnoldia Rhodesia* ,5,1–22.
- Kahn, S. (1997). The Economic approach to environmental and natural resource, Harcourt. New York: Brace College Publishers.
- Kapetsky, J. M. (1974). The Kafue River floodplain: an example of Pre-impoundment potential for fish production. In E. K. Balon & A. G. Coche (Eds.), Lake Kariba: A man-made tropical ecosystem in central Africa (p. 497–523). Dr. W. Junk Publishers, The Hague.
- Karna, K. S. & Panda, S. (2011). Growth estimation and length at maturity of a commercially important species i.e. *Daysciaena albida* (Boroga) in Chilika Lagoon, India. *European Journal of Experimental Biology* **1**, 84–91.
- Kaur, R. C. (2012). Are closed areas solution for fisheries management? Maritime Institute of Malaysia Sea Views, No.3, p.1–10.
- Keenleyside, M. H. A. (1991). Cichlid Fishes: Behavior, Ecology. Chapman and Hall, London.
- Kenchington, R., Ward, T. & Hegerl, E. (2003). The Benefits of Marine Protected Areas. Report. Department of Environment and Heritage p.1–38.
- Kenmiur, D. H. S. (1984). Fish population changes in the Sanyati Basin, Lake Kariba, Zimbabwe, *South African Journal of Zoology* **19**, 194–209.
- Kgathi, D. L., Mmopelwa, G. & Mosepele, K. (2005). Natural Resource Assessment in the Okavango Delta, Botswana; Case studies of some key Resources, Natural Resource Forum **29**, 70–81.
- King, M. (1995). Fisheries Biology, Assessment and Management. Oxford: Fishing News Books, Blackwell Science Ltd.
- King, R. P. (1991). The biology of *Tilapia mariae* Boulenger 1899 (Perciformes: Cichlidae) in a Nigeria Rainforest stream. PhD. thesis, Department of Zoology, University of Port Harcourt, Nigeria. xiv+237p.

- Kiraly, I. A., Coghlan, S. M., Zydlewski, J., Hayes, D. (2014). An assessment of fish assemblage structure in a large river. *River Research and Applications* **31**, 301–312.
- Kleynhans, C. J. (1997). Threatened Fishes of the World: *Chiloglanis emarginatus* (Jubb & LeRoux, 1969) (Mochokidae). *Environmental Biology of Fishes* **49**, 206.
- Kolding, J. (1993). Population dynamics and life history styles of Nile Tilapia, *Oreochromis niloticus*, in Ferguson's Gulf, Lake Turkana, Kenya. *Environmental Biology of Fishes* **37**, 25–46.
- Kolding, J. (1998). PASGEAR: A Database Package for Experimental Fishery Data from Passive Gears: An Introductory Manual. Bergen: Department of Fisheries and Marine Biology, University of Bergen, High Technology Centre.
- Kolding, J., Tirasin, E. M., & Karengi, L. (1992). Growth, mortality, maturity and length-weight parameters of fishes in Lake Kariba, Africa. *INAGA, ICLARM Quarterly* **15**, 39–41.
- Kolding, J., van Zwieten, P., Martin, F., & Poulain, F. (2016). Fisheries in the drylands of sub-Saharan Africa 'fish come with the rain'' Building resilience for the fisheries-dependent livelihoods to enhance food security and nutrition in drylands. Aquaculture Circular No.118. Rome, Italy p.1–64.
- Kramer, B., van der Bank, F. H., Wink, M., Flint, N. & Sauer-Gurth, H. (2003). Evidence for parapatric speciation in the mormyrid fish, *Pollimyrus castelnaui* (Boulenger, 1911), from the Okavango-Upper Zambezi River Systems: *P. marianne* sp. nov. defined by electric organ discharges, morphology and genetics. *Environmental Biology of Fishes* **77**, 47–70.
- Kurugundla, C. N. & Mpho, M. (2003). Hydrological phenomenon of Zibadianja Lagoon Kwando-Linyanti system: Department of Water Affairs. Gaborone, Botswana.
- Kurugundla, C. N., Dikgola, K., Kalaote, K., Mpho, M. (2010). Restoration and rehabilitation of Zibadianja Lagoon in Kwando-Linyanti River system in Botswana. Botswana Society. *Botswana notes and records* **42**, 79–89.



- Lancaster, N. (1979). The changes in the lake level. In: M. Kalk., A.J. McLachlan., & C. Howard-Williams, (eds.). Lake Chilwa: studies of change in a tropical ecosystem, *Monographiae*, **35**, 59–78.
- Le Cren, E. D. (1951). Length-weight relationship and seasonal cycle on gonad and condition on the Perch (*Perca fluviatilis*) *Journal of Animal Ecology* **20**, 201–219.
- Le Roux, P. J. (1961). Growth of *Tilapia mossambicus* Peters in some Transvaal impoundment. *Hydrobiologia* **18**, 165–175.
- Magurran, A. E. (1988). Ecological diversity and its measurement, Princeton: Princeton University Press.
- Marshall, B. E. (2016). Inland fisheries of tropical Africa. p.349. In: J. F, Graig, Freshwater Fisheries Ecology (eds.). Chichester: John Wiley & Sons, Ltd.
- Mazunder, S. K., Das, S. K., Ghaffar, M. A., Rahman, M. N., Majunder, M. K., Basak, L. R. (2016). Role of Co-management in wetland productivity: a case study from Hail haor in Bangladesh. *AACL Bioflux* **9**, 466–482.
- McClanahan, T. R. (1994). Kenyan coral reef lagoon fish; effects of fishing, substrate complexity and sea urchins. *Coral reefs* **13**, 231–241.
- McClanahan, T. R. & Mangi, S. (2000). Spillover of exploitable fishes from a marine park and its effects on adjacent fishery. *Ecological Applications* **10**, 1792–1805.
- McLachlan, S. M. (1971). The rate of nutrient release from grass and dung following immersion in Lake water. *Hydrobiologia* **37**, 521–530.
- McPhee, D. P., Leadbitter, D. & Skilleter, G. A. (2002). Swallowing the bait: Is Recreational fishing in Australia ecologically sustainable? *Pacific Conservation Biology* **8**, 40–51.
- Merron, G. S. (1989a). A checklist of the fishes of the Kwando River, Selinda (Magwegqana) Spillway, Lake Liambezi and Chobe River systems with notes on their Biology and distributions. *Botswana notes and records* **21**, 135–151.

- Merron, G. S. (1989b). The Development of a sustainable yield strategy for the fish resource of the Okavango delta, Botswana. Project proposal to USAID p.17.
- Merron, G. S. (1991). The Ecology and Management of the fishes of Okavango Delta, Botswana, with particular reference to the role of seasonal floods. PhD. thesis, Rhodes University, Grahamstown, South Africa p. 171.
- Merron G. S. (1993a). The Diversity, Distribution and Abundance of the Fishes in the Moremi Wildlife Reserve, Okavango Delta Botswana, *South African Journal of Wildlife Reserve*, **23**, 112–115.
- Merron, G. S. (1993b). Pack hunting in two species of catfish *Clarias gariepinus* and *Clarias ngamensis*, in the Okavango Delta, Botswana. *Journal of fish Biology* **43**, 575–584.
- Merron, G. S. & Bruton, M.N. (1984a). Report on the October-November 1983 expedition to the Okavango Delta. Botswana. J. L. B Smith Institute of Ichthyology, Investigation report No 8, p. 21.
- Merron, G. S. & Bruton, M. N. (1984b). Report on the June–July 1984 expedition to the Okavango Delta. Botswana. J. L. B Smith Institute of Ichthyology, Investigation report No.8, p. 21. Unpublished.
- Merron, G. S. & Bruton, M. N. (1988). The ecology and Management of the fishes of the Okavango Delta, Botswana, with special reference to the role of seasonal floods. J.LB. Smith Institute of Ichthyology, Grahamstown, South Africa. Investigational Report No. 29. p. 291.
- Merron, G. S. & Bruton, M. N. (1995). Community ecology and conservation of the fishes of the Okavango Delta, Botswana. *Environmental Biology of Fishes* **43**, 109–119.
- Merron, G. S. & Sehemo, T. (1987). Analysis of fish catches during Chobe Fishing competition Botswana Notes and Records **19**, 91–94.
- Merron, G. S., Holden, K. A. & Bruton, M. N. (1990). The reproductive biology and early development of the African pike, *Hepsetus odoe*, in the Okavango delta, Botswana. *Environmental Biology of Fishes* **28**, 215–235.

- Mmopelwa, G., Segametsi, R. & Mosepele, K. (2005a). Cost benefit analysis of commercial fishing in Shakawe, Ngamiland, *Botswana Notes and Records* **37**, 11–19.
- Montcho, S. A., Chikou, A., Laleye, P. A. & Linsenmair, K. E. (2011). Population structure and reproductive Biology of *Schilbe intermedius* in the Penjari River Benin, *African Journal of Aquatic Science* **36**, 2.
- Moore, A. E. (1999). A reappraisal of epeirogenic flexure axes in Southern Africa. *South African Journal of Geology* **102**, 363–376.
- Moore, A. E., & Larkin, P. A. (2001). Drainage evolution in South-central Africa since the breakup of Gondwana. *South African Journal of Geology* **104**, 47–68.
- Moore, A. E., Cotterill, F. P. D., Main, M. P. L., Williams, H. B. (2007). Chapter 15: The Zambezi River. In: A. Gupta, (eds.). Large Rivers, p. 311–332. Chichester, England: John Wiley and sons, Ltd.
- Moriarty, C. (1983). The African pike, *Hepsetus odoe*. The Nigerian Field **47**, 212–222.
- Mosepele, K. (2000). Preliminary length based stock assessment of the main exploited stocks of the Okavango delta fishery. MPhil. Thesis, University of Bergen, Norway p.139.
- Mosepele, K. (2001). Preliminary description of the Okavango delta fishery. Gaborone, Botswana. Fisheries section. Ministry of Agriculture p.132.
- Mosepele, K., Basimane, O., Mosepele, B., Thethela, B. (2005). Using population parameters to separate fish stocks in the Okavango delta fishery, Botswana: a preliminary assessment. *Botswana Notes and Records* **37**, 292–305.
- Mosepele, K. & Kolding, J. (2003). Fish stock assessment in the Okavango Delta: Preliminary results from a length-based analysis. p.363–390. In: T. Bernard., K. Mosepele., L. Ramberg, (eds.). Environmental Monitoring of Tropical and Subtropical Wetlands. Maun (Botswana): Harry Oppenheimer Okavango Research Center. Okavango Report Series No. 1.

- Mosepele, K., & Mosepele, B. (2005). Spatial and temporal variability in fishery and fish community structure in the Okavango Delta, Botswana: Implications towards fisheries management. *Botswana Notes and Records* **37**, 280–291.
- Mosepele, K., Mmopelwa, G., Kgathi, D.L., Setswalo, O. and Mosepele, B. (2015). Conflict Resolution and Management between Local Fishers and Tour Operators in the Okavango Delta's Panhandle, Botswana. *Natural Resources* **6**, 312-324. <http://dx.doi.org/10.4236/nr.2015.64028>
- Mosepele, K., Mmopelwa, T.G., Mosepele, B., (2003). Characterisation and monitoring of the Okavango Delta artisanal fishery. In: Bernard, T., Mosepele, K., Ramberg, L. (Eds.) Proceedings of the Environmental Monitoring of Tropical and Subtropical Wetlands Conference, 4–8 December 2002. Harry Oppenheimer Okavango Research Centre, University of Botswana, Maun, Botswana.
- Mosepele, K., Moyle, P. B., Merron, G.S., Purkey, D. R., Mosepele, B. (2009). Fish, floods, and ecosystem engineers: aquatic conservation in the Okavango Delta, Botswana. *BioScience* **59**, 53–64.
- Mosepele, K. & Nengu, S. (2003). Growth, Mortality and length–weight parameters of selected fishes of the Okavango Delta, Botswana. ACP-EU Fisheries Research Report **14**, 67–74.
- Mosepele, K. & Ngwenya, B. N. (2010). Socio-economic survey of commercial fishing in the Okavango delta. Gaborone, Bay Publishing.
- Mosetlhi, B. (2012). The Influence of Chobe National Park on People's Livelihoods and Conservation Behaviors. PhD. dissertation, University of Florida, Gainesville, Florida, USA p.1–220.
- Moyle, P. B. & Vondracek, B. (1985). Persistence and structure of fish assemblage in a small California Stream. *Ecology* **66**, 1–13.
- Mpho, M. (2002). Kwando–Savuti–Linyanti River System and its effect on Zibadianja Lagoon, 19 March 2002, Department of water affairs. Gaborone, Botswana.

- Muthiga, N. A., & Kawala, J. (2010). Progress Towards Conservation Science of Marine Protected Areas in Kenya; An annotated Bibliography. WIOMSA. Book series.
- Naesje, T. F., Hay, C. J., Nicknor, N., Koemoer, J. H., Strand, R., & Thorstad, E. B. (2004). Fish populations, gillnets catch and gillnet selectivity in the Kwando River, Namibia-NINA Project Report 27 p.64.
- Naesje, T. F., Thorstad, E. B., Hay, C. J., Chanda, B. & Okland, F. (2003). Movement and habitat utilisation of threespot in the Upper Zambezi River NINA project Report No.23.
- Ngwenya, B. N, Mosepele, K, Magole, L (2012) A case for gender equity in governance of the Okavango Delta fisheries in Botswana. *Natural Resources Forum* **36**, 109 –122.
- Oberdorff, T., Guegan, J. F. & Hgueny, B. (1995). Global scale patterns of fish species richness in rivers. *Ecography* **18**, 345–352.
- Ogidiaka, E. & Esenowo, I. K. (2015). Length weight relationship and condition factors of *Tilapia zilli* (Perciformes: Cichlidae) in Warri River, Southern Nigeria. *International Journal of Fisheries and Aquatic studies* **2**, 359–361.
- Oni, S. K., Olayemi, J. Y., & Adegboye, J. D. (1983). Comparative physiology of three ecologically distinct freshwater fishes, *Alestes nurse* Ruppell, *Synodontis schall* Bloch and *S. Schneider* and *Tilapia zilli* Gervais. *Journal of fish Biology* **22**, 105–109.
- Pauly, D. (1979). Theory and management of tropical multispecies stocks: a review, with emphasis on Southeast Asian demersal fisheries. ICLARM Studies and Reviews 1 p. 35.
- Pauly, D. & Munro, J. L. (1984). Once more on the comparison of growth in fish and invertebrates. *ICLARM, Fishbyte* **2**, 21.
- Payne, N. R., Korver, R.M., MacLennan, D. S., Nepszy, S. J., Shuter, B. J., Stewart, T. J. & Thomas, E. R. (1990). The harvest potential and dynamics of Lake trout populations in Ontario. Lake trout Synthesis, Ontario Ministry of Natural Resources, Toronto p. 72.
- Peel, R. A. (2012). The biology and abundance of three cichlid species from Kavango and Caprivi Regions, Namibia, Msc thesis, University of Namibia, Namibia p. 1–148.

- Peel, R. A., Tweddle, D., Simasiku, E. K., & Weyl, O. L. F. (2016). Ecology, fish, fishery of Lake Liambezi, a recently refilled floodplain lake in the Zambezi Region, Namibia. *African Journal of Aquatic Science* **40**, 1–8.
- Petry, A. C., Agostinho, A. A. & Gomes, L. C. (2003a). Fish assemblages of tropical floodplain lagoons: exploring the role of connectivity in a dry year. *Neotropical Ichthyology* **1**, 111–119.
- Policansky, D. (1993). Fishing as a cause of evolution in fishes. In: T. K. Stokes, J. M. McGlade, & R. Law, (eds.). The exploitation of evolving resources. Berlin, Germany: Springer–Verlag.
- Polunin, N. V. C. (2002). Marine Protected Areas, Fish and Fisheries. P 293–318. In: P.J.B. Hart, & A. D. Reynolds, (eds.) Handbook of Fish and Fisheries. Oxford, London: Blackwell Science.
- Porto, L. M., McLaughlin, R. L., & Noakes, D. L. G., (1999). Low-head barrier dams restrict the movement of fishes in two Lake Ontario streams. *North American Journal of Fisheries Management* **19**, 1028–1036.
- Potter, E. C. E. & Pawson, M. G. (1991). Gillnetting. Laboratory leaflet 69:5. Ministry of Agriculture, Fisheries and Food Directorate of Fisheries Research. Laboratory leaflet, Ministry of Agriculture Fisheries and Food, Directorate of Fisheries Research. Lowestoft, UK (69) p. 34.
- Ramberg, L., Hancock, P., Lindholm, M., Meyer, T., Ringrose, S., Silva, J., Van As J, Vanderpost, C. (2006). Species diversity in the Okavango delta, Botswana. *Aquatic Sciences* **68**, 310–337.
- Reeb, G. S. (2008). How fish try to avoid predators. Universite de Moncton, Canada p. 1–12.
- Ribeiro, F., Crain, P. K. & Moyle, P. B. (2004). Variation in condition factor and growth in young-of-year fishes in floodplain and riverine habitats of the Cosumnes River, California. *Hydrobiologia* **527**, 77–84.

- Ricker, W. E. (1975). Computation and interpretation of biological statistics of fish population. *Bulletin of the Fisheries Research Board of Canada* **191**, 1–382.
- Roberts, C. M. & Polunin, N. V. (1991). Are Marine Reserves effects in Management of reef fisheries? *Reviews in Fish Biology and Fisheries* **1**, 65–91.
- Roberts, T. R. & Stewart, D. J. (1976). Rapids fishes of Zaire or Congo River. *Bulletin Museum of Comparative Zoology* **147**, 239–317.
- Robertson, A. I. & Crook, D. A. (1999). Relationship between riverine fish and woody debris: implications for lowland rivers. *Marine and Freshwater Research* **50**, 941–953.
- Rolls, R. J., Leigh, C. & Sheldon, F. (2012). Mechanistic effects of low-flow hydrology on riverine ecosystem: ecological principles and consequences of alteration. *Freshwater Science* **31**, 1163–1186.
- Ross, S. T., Matthews, W. J. & Echelle, A. A. (1985). Persistence of stream fish assemblage; effects of Environmental change. *American Naturalist* **126**, 24–40.
- Rowley, R. J. (1994). Marine reserves in fisheries management, aquatic conservation. *Marine and Freshwater Ecosystems* **4**, 233–254.
- Russ, G. R. (1991). Coral reef fisheries; effects and yields. p. 601–635. In: P. F. Sale (eds.). The ecology of fishes on Coral reefs, New York, USA Academic Press.
- Russ, G. R. & Alcala, A. C. (1996). Do marine reserves export adult fish biomass? Evidence from Apo Island, central Philippines. *Marine Ecological Progress Series* **132**, 1–9.
- Salas, D. & Gaertner, D. (2004). The behavioural dynamics of fishes, management Implications. *Fish and Fisheries* **5**, 153–167.
- Sala, O. E., Chapin, I. F. S., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., Huber Sanwald, E., Huenneke, L. F., Jackson, R. B., Kinzig, A., Leemans, R., Lodge, D. H, Mooney, H. A., Oosterheld, Leroy, M., Poff, N., Sykes, M. T., Walker, B. H., Walker. M., Wall, D. H. (2000). Global biodiversity scenarios for the year 2100. *Science* **287**, 1770–1774.

- Sanyanga, R. A. & Feresu, F. (1994), First catches of the African pike *Hepsetus odoe* (Bloch, 1974) (Pisces: Hepsetidae) in Lake Kariba, Zimbabwe. *Revue d'Hydrobiologie Tropicale*, **27**, 39–42.
- Sato, T. (1994). Active accumulation of spawning substrate: a determinant of extreme polygyny in a shell-brooding cichlid fish. *Animal Behavior* **48**, 669–678.
- Selgeby, D. H. (2000). Longevity and resilience of Chesapeake Bay striped bass. ICES, *Journal of Marine Science* **57**, 808–815.
- Setswalo, O. (2007). Conflicts and conflict resolution between local fishermen and Tour operators in the upper panhandle of the Okavango Delta, Botswana. Diploma thesis, Botswana Wildlife Training Institute, Maun, Botswana p. 29.
- Shamukuni, D. M. (1972). The Basubia. Botswana notes and records **4**, 161–184.
- Shaw, P. A. (1984). A Historical note on the outflows of the Okavango delta system, *Botswana notes and records* **16**, 127–130.
- Sheldon, A. L. (1968). Species diversity and longitudinal succession in stream fishes. *Ecology* **49**, 193–198.
- Shostell, J. M. & Williams, B. S. (2007). Habitat complexity as a determinant of benthic macroinvertebrates community structure in Cypress tree reservoirs. *Hydrobiologia* **575**, 389–399.
- Silva, E. J. (2005). Planning and Management for sustainable development of inland aquaculture in Angola. Institute of Development of artisanal fisheries and aquaculture(IPA), Ministry of fisheries Rua Jose Tuca 36/38 Luanda, Angola.
- Simasiku, E. K. (2014). Assessment of the Lake Liambezi fishery, Zambezi Region, Namibia. Msc thesis, Rhodes University p. 154.
- Siziba, N., Chimbari, M. J., Mosepele, K., & Masundire, H. (2011). Spatial and Temporal variations in densities of small fishes across different temporary floodplains types lower



- Okavango Delta, Botswana. Okavango Research Institute, University of Botswana p. 1–177.
- Skelton, P. H. (1976). A new species of *mastacembelus* (Pisces, mastercembelidae) from the upper Zambezi River, with a discussion of the taxonomy of the genus from this system. *Annals of the cape Provincial Museums (Natural History)* **11**, 103–116.
- Skelton, P. H. (1993). A complete Guide to the freshwater fishes of Southern Africa, Johannesburg, RSA, Halfway House: Southern Book Publishers.
- Skelton, P. H. (2001). A complete guide to the freshwater fishes of Southern Africa. Cape Town (South Africa): Struik Publishers.
- Skelton, P. H., Bruton, M. N., Merron, G. S. & van der Waal, B. W. C. (1985). The fishes of the Okavango Delta drainage system in Angola, Southwest Africa (Now Namibia) and Botswana. Taxonomy and Distribution. Grahamstown, South Africa, J.L.B. Smith Institute of Ichthyology, *Ichthyological Bulletin* **50**, p. 21.
- Smith, G. R. (1981). Effects of habitat size on species richness and adult body size of desert fishes. In: R. J. Naiman, and D. L. Soltz, (eds.), ``Fishes in North American deserts``, p.125–171., New York: Wiley.
- Svedang, H., Wickstrom, H., Reizenstein, M., Holmgren, K. & Florenius, P. (1998). Accuracy and precision in eel age estimation, using otoliths of known and unknown age. *Journal of Fish Biology* **53**, 456–464.
- Symes, D. & Cream, K. (1995). Privatisation of the commons: the introduction of individual transferable quotas in developed fisheries. *Geforum* **26**, 175–185.
- Thorstad, E. B., Hay, C. J., Okland, F., Nickanor, N., & Naesje, T. F. (2007). Spatial behaviour & management of Greenhead tilapia *Oreochromis macrochir* in Zambezi River, Namibia-NINA Report 287, p. 26.
- Timberlake, J. R. & Childes, S. L. (2004). Biodiversity of the Four Corners Area: Technical Reviews Vol 2. (Chapter 5–15). Occasional Publications in Biodiversity No. 15. Biodiversity Foundation for Africa, Bulawayo, Zambezi Society, Harare, Zimbabwe.

- Tlou, T. (1985). A history of Ngamiland, 1750–1906; The formation of the African State, Gaborone, Botswana: Macmillan.
- Tlou, T. & Campbell, A. (1983). History of Botswana. Gaborone; Macmillan Botswana publishing Co (Pty) Ltd.
- Trewavas, E. (1983). Tilapiines fishes of the genera *Sarotherodon*, *Oreochromis* and *Danakilia*. London: British Museum (Natural History).
- Tuda, A. & Omar, M. (2012). Protection of Marine Areas in Kenya. The gorge Wright Forum **29**, 43-50.
- Turner, G. F. (2001). Fisheries Management, Biodiversity conservation and genetic stock structure.p.31. In: O. L. F. Weyl, & M. V. Weyl, (2001). Proceeding of the Lake Malawi Fisheries management symposium. National Aquatic Resource Management Programme (NARMAP). Lilongwe Malawi p.1–272.
- Turner, J. L. (1977). Changes in the size structure of cichlid populations of Lake Malawi resulting bottom trawling. *Journal of fisheries Research Board of Canada* **34**, 232–228.
- Tweddle, D. (2009). Integrated Management of Zambezi/Chobe River System-Transboundary Fishery Resource, Namibia/Zambia/Botswana, Final Evaluation Report.
- Tweddle, D. (2010). Overview of the Zambezi River system: Its history, Fish fauna, Fisheries Conservation. *Aquatic Ecosystem Health and Management* **13**, 224-240.
- Tweddle, D., Bills, R., van der Waal, B. C. W., Skelton, P., Kolding, J. & Nengu, S. (2003). Fish diversity and Fisheries in the Okavango Delta, Botswana. p. 97–100. In: L. E. Alonso., L. Nordin, (eds.). RAP 27. A rapid Biological Assessment of the Aquatic System of Okavango Delta, Botswana: High Water Survey. Washington (DC): Conservation International.

- Tweddle, D., Cowx, I. G., Peel, R. & Weyl, O. L. F. (2015). Challenges in fisheries management in the Zambezi, one of the great rivers of Africa. *Fisheries Management and Ecology* **22**, 99–111.
- Tweddle, D. & Hay, C. J. (2011). Fish protection areas; Documentation for their establishment in Sikungu and Impalila Conservancies, December 2011, Field Document no. MFMR/ NNF/ WWF /Phase II/6.
- Tweddle, D., Hay, C. J. & van der Waal, B. C. W. (2009). Final Technical Report, December 2009. Technical no. MFMR/NNF/WWF/Phase 1/3.
- Tweddle, D. & Marshall, B. E, (2007). *Oreochromis andersonii* In: IUCN 2012. IUCN Red list of Threatened species. Version 2012.2.
- Tweddle, D. & Turner, J. L. (1977). Age and growth and natural mortality rates of some cichlids fishes of Lake Malawi. *Journal of Fisheries Biology* **10**, 385–398.
- Tweddle, D., Skelton, P. H., van der Waal, B. C. W., Bills, I. R., Chilala, A., & Lekoko, O T. (2004). *Aquatic Biodiversity survey for the “Four Corners” Transboundary Natural Resources Management Area*. Final Report for African Wildlife Foundation, Kasane.xviii+202p.
- Tweddle, D., Weyl, O. L. F., Hay, C. J., Peel, R. A. & Shapumba, N. (2011) Lake Liambezi, Namibia; Fishing community assumes management responsibility. Technical Report No. MFMR/NNF/WWF/Phase II/3.
- UNESCO. (2010). World heritage List. Chobe Linyanti System. Department of National Museum and Monuments. Botswana.
- UNESCO. (2014). UNESCO World heritage Centre-World Heritage List reaches 1000 sites with inscription of Okavango delta in Botswana. UNESCO press.
- van der Waal, B. C.W. (1976). *’N Visiologiese studie van die Liambezimeer in die Oos-Capri mat verwysing na visontginning deur die bantobevolking*. Rand Afrikaans University, South Africa.

- van der Waal, B. C. W. (1980a). Aspects of Fisheries of Lake Liambezi Caprivi, *Journal of Limnological Society of Southern Africa* **6**, 19–31.
- van der Waal, B. C. W. (1980b). Aspects of the fishery of eastern Caprivi, Namibia. *Madoqua* **17**, 1–25.
- van der Waal, B. C. W. (1985). Aspects of the Biology of larger fish species of Lake Liambezi, Caprivi, South West Africa. *Madoqua* **14**, 101–144.
- van der Waal, B. C. W. (1990). Aspects of the fishery of the eastern Caprivi, Namibia. *Madoqua* **17**, 1–16.
- van der Waal, B. C. W. (1991). A survey of the fisheries in Kavango, Namibia. *Madoqua* **17**, 113–122.
- van der Waal, B. C.W., Hay, C. J. & Bakane, M. (2008) unpublished data; Zambezi/Chobe River Fisheries frame survey 2008, Chobe District, Botswana.
- van der Waal, B. C. W., Hay, C. J. & Naesje, T. F. (2011). The Katima Mulilo fish market data Analysis, November 2007 to May 2009. Technical Report No. MFMR/NNF/WWF/Phase II/2.
- van der Waal, B. C. W. & Skelton, P. H. (1984). Checklist of fishes of Caprivi. *Madoqua* **13**, 303–320.
- Varis, O., Tortajada, C. & Biswas, A. (2008). Management of Transboundary Rivers and Lakes., Berlin: Springer-verlag.
- Wallace, A. P. C., Milner-Gullard, E. J., Jones, J. P. G., Bunnefeld, N., Young R, & Nicholson, E. (2015). Quantifying the short-term conservation interventions for fisheries at Lake Alaotra, Madagascar PloS ONE 10 p. 1-15.
- Ward, J. V. & Stanford, J. A., (1995a). Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. Regulated Rivers. *Research and Management* **11**, 105–119.

- Ward, T. J., Heinemann, D. & Evans, N. (2001). The role of marine reserves as Fisheries Management tools: A review of concepts, evidence and international experience. Canberra, Australia, Bureau of Rural Science.
- Weatherly, A. H. & Gill, H. S. (1987). The biology of fish growth. London, academic press p.443.
- Weekend post 02 March, (2015). Government extends the fish ban at Lake Ngami, Botswana.
- Welcomme, R. L. (1979). Fisheries ecology of floodplain Rivers. London, Longman Group. Limited.
- Welcomme, R. L. (1985). River fishes. FAO Fisheries Technical Paper No.262, FAO, Rome.
- Welcomme, R. L. (2001). Inland fisheries ecology and management. Iowa State University Press Ames. Blackwell Science.
- Welcomme, R. L., Bene, C., Brown, C.A., Arthington, A., Dugan, P., King, J. M., Sugunam, V. (2006). Predicting the water requirements of river fisheries. *Ecological studies* **190**, 123–154.
- Weyl, O. L. F. & Hecht, T. (1998). The biology of *Tilapia rendalli* and *Oreochromis mossambicus* (Pisces, Cichlidae) in a subtropical lake in Mozambique. *South African Journal of Zoology* **33**, 178–188.
- Weyl, O. L. F., Mwakiyongo, K. R., & Mandere, D. S. (2004b). An assessment of the *nkacha* net fishery of Lake Malombe, Malawi. *African Journal of Aquatic Science* **29**, 47–55.
- Weyl, O. L. F., Nyasulu, T. & Rusuwa, B. (2005b) Assessment of catch, effort and species changes in the pair trawl fishery of Southern Lake Malawi, Malawi, Africa. *Fisheries Management and Ecology* **12**, 395–402.
- Weyl, O. L. F., Ribbink, A. J., Tweddle, D. (2010) Lake Malawi, Fishes, Fisheries, Biodiversity, health and habitat, South African institute of Aquatic Biodiversity, Grahamstown, South African, Sustainable seas Trust **13**, 241–254.

- Winemiller, K. O. & Kelso-Winemiller, L. C. (1994). Comparative ecology of the African pike, *Hepsetus odoe*, and tigerfish, *Hydrocynus forskahlii*, in the Zambezi River floodplain. *Journal of Fish Biology* **45**, 211–225.
- Winemiller, K. O. & Jepsen, D. B. (1998). Effects of seasonality and fish movement on tropical river food webs. *Journal of Fish Biology* **53**, 267–296.
- Winker, H., Ellender, B. R., Weyl, O. L. F. & Booth, A. J. (2010a). Validation of growth zone deposition in otoliths of two large endemic cyprinids in Lake Gariep, South Africa. *African Zoology* **45**, 133–138.
- Winker, H., Ellender, B. R., Weyl, O. L. F. & Booth, A. J. (2010b). Validating and corroborating the deposition of two annual growth zones in asteriscus otoliths of common carp *Cyprinus carpio* L. from South Africa's largest impoundment. *Journal of Fish Biology* **77**, 2210–2228.
- Wootton, R. J. (1990). Ecology of teleost fishes, 1<sup>st</sup> Edition. London: Chapman & Hall.
- Wootton, R. J. (1998). Ecology of teleost fishes, 2<sup>nd</sup> Edition, Fish and Fisheries series 24, Dordrecht, The Netherlands: Kluwer Academic publishers.
- WTT (2012), Tourism and Travel economic impact, Botswana.
- Yasmi Y., Schanz, H., & Salim. A. (2006). Manifestation of conflicts escalation in natural resources Management. *Environmental Science and Policy* **9**, 538–546.
- Zaret, T. & Rand, A. (1971). Competition in tropical stream fishes; support for the competitive exclusion principle. *Ecology* **52**, 336–342.

### Electronic references

- Simmon, R. (2012). NASA Earth Observatory Savuti River Map. <https://earthobservatory.nasa.gov/IOTD/view.php?id=78166> (accessed 20 July 2016).
- [http://www.mapcruzin.com/free-maps-botswana/botswana\\_sm\\_2008.gif](http://www.mapcruzin.com/free-maps-botswana/botswana_sm_2008.gif) (accessed 21 March 2017).

