DYNAMICS OF THE FLOODPLAIN FISHERIES OF THE ZAMBEZI AND CHOBE FLOODPLAIN, ZAMBEZI REGION, NAMIBIA

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ABSTRACT

Floodplain fisheries are typically multi-species and in most cases harvested with a variety of gears. In the upper- Zambezi, artisanal gillnet fishers mainly target three cichlids: *Oreochromis andersonii, Oreochromis macrochir* and *Coptodon rendalli*. However, their abundance is declining because of increased fishing pressure and their stocks are becoming vulnerable to overfishing. The principal aim of this PhD thesis was to assess the fish population dynamics in a highly variable system and the implications of these dynamics to fisheries management by investigating the response of floodplain fisheries to water flow and to determine fish harvesting patterns and catch rates on the Zambezi/Chobe floodplain. The specific objectives of this study were: (1) to link littoral fish colonization rates with water quality and water level in floodplain littoral habitats; (2) to determine the feeding ecology of *Hydrocynus vittatus* (Tigerfish) in the Zambezi/Chobe floodplain (3) to assess the fishing patterns and harvesting rates of the gillnet fishery on the Zambezi/Chobe floodplain; (4) determine the volume and turnover of fish exports from the Zambezi/Chobe floodplain and finally (5) to assess the significance of fish protected areas in protecting the fish stocks of the Zambezi/Chobe floodplains. Seine net surveys showed that the marginal zone of the Zambezi/Chobe floodplain were dominated by fishes of the fish families Cichlidae, Cyprinidae and Characidae. Individual fish densities of small fishes showed spatiotemporal variations among the different stages of flooding with a marked increase in juvenile cichlids during the peak flooding phase while cyprinids were most abundant during the receding (fall) phase. Among other environmental filters, dissolved oxygen and water level had a marked influence on the distribution and abundance of the littoral fish species.

The feeding ecology of *Hydrocynus vittatus* (Tigerfish) (Characidae), in the Zambezi River was investigated between February - December 2016. The findings indicated that large size classes of

H. vittatus (>176mm) were largely piscivorous, and showed a diet shift with change in size. The small size classes (<140mm) consumed mainly aquatic insects (21.1%), *Synodontis* spp. (17.8%), and *Micralestes acutidens* (12.1%). They later shifted to a diet in which *Synodontis* spp. (26.1%), *Brycinus lateralis* (15.2%) and *M. acutidens* (13.0%) dominated. The study showed that *H. vittatus* plays an ecological role with the ability of converting un-exploitable non-commercial species such as *B. lateralis* (15.2%) *M. acutidens* and *Synodontis* spp. into exploitable protein. Hence, the population of *Hydrocynus vittatus* must be of conservation priority to sustain a balanced fishery in the Zambezi River. The fishery on the Zambezi/Chobe floodplain was investigated by means of Catch Assessment Surveys (CAS) from 2010 to 2017. The fishery is dominated by gillnets in the form of monofilament net types. The principal species in gillnet catches were three cichlids: *O. andersonii*, *O. macrochir* and *C. rendalli*. Length at maximum selectivity for the three cichlids showed that they were caught at a length close to their reported length at 50% maturity, raising the fear, risk of growth overfishing. Analysis of annual catch rates of the three commercially important species; *O. andesonii*, *O. macrochir* and *C. rendalli* showed a significant decline from 2010 to 2017. Annual production from the 1700 km^2 of the Zambezi/Chobe floodplain was estimated at 2248 t/yr in 2010 dropping to 939 t/yr in 2017. A survey on the floodplain fish processing and exports was conducted at Wenela Border Post, north of Katima Mulilo. Daily fish loads destined for exports were weighed and recorded using a hanging scale at Wenela Border. The study showed that women are the key players in the fish processing and preservation on the Zambezi/Chobe floodplain. The major processing techniques employed by the fish vendors were sun drying and smoking. Approximately 1575.8 t/yr of fish products worth N$22 million were exported to foreign markets in Zambia between June 2015 and December 2016. The active involvement of women in the fish processing and export on the Zambezi/Chobe floodplain as well as the large markets available (both local and foreign) suggest that this sector has the potential to contribute immensely to improving the economic and livelihood of the Zambezi Region. However, the fish vendors faced challenges of inadequate cold storage facilities, poor weather and packaging. Thus, the study recommended private and government's intervention in the provision of storage facilities and training programs for the fish processors in hygienic handling of fish products, quality control and packaging of processed fish products to conform to human health standards. The fisheries of the Zambezi/Chobe River and its associated floodplains are currently threatened by an increase in fishing pressure. With increasing fishing pressure, fish populations may undergo a series of changes in size, species composition and abundance. As a result, two Fish Protected Areas (FPA) on the Zambezi/Chobe River (Kalimbeza Channel and Kasaya Channel) were recently established to protect and conserve the fish stocks of the Zambezi/Chobe River. However, accrued benefits from these FPAs have not been assessed. Comparative experiments using gillnets of a graded set of mesh sizes (12 mm -150 mm) were conducted between FPA (Kalimbeza channel) and non-FPA (Hippo channel) between March and December 2016 to test the hypothesis that FPA yield high fish abundance (CPUE) than non- FPA. Experimental fishing trials showed higher CPUE by weight and number ($p < 0.05$) of the five dominant species (*H. vittatus, Schilbe intermedius, Pharyngochromis acuticeps, M. acutidens* and *B. lateralis*) in the FPA than non-FPA. The study confirmed the importance of the protected areas in conserving fish resources in the Zambezi/Chobe River. Recommendations were made to manage the fish stocks of the Zambezi/Chobe Rivers by imposing restrictions on gear type, establish more fish reserves and advocate for community engagement in managing their own resources under strict guidance from government.

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DECLARATION

I, Evans Kamwi Simasiku, declare that this study is a true reflection of my own research, and that this work, or any part thereof has not been submitted for a degree in any other institution of higher education.

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CHAPTER 1: GENERAL INTRODUCTION

1.1 INTRODUCTION

The Zambezi Region, previously known as the Caprivi Region, is home to two large floodplain rivers, namely the Kwando/Linyanti and the Zambezi/Chobe (Peel, 2012). These floodplain rivers flow in a well-defined channel during periods of low discharge, but as result of seasonal variations in rainfall within the catchment area, they breach their banks annually, inundating a large mosaic of fringing plains. In their natural state, tropical river floodplain environments with their diverse fish communities are adapted to extreme seasonal fluctuations. Major disturbances such as the alteration of the natural flood regime (Bayley, 1995) or the introduction of highly competitive alien species may, however, undermine the resilience and productivity of river floodplain ecosystems. Floodplain rivers in the Zambezi Region harbour a diverse fish community, providing mainly for the subsistence riparian communities and the neighbouring countries of Zambia, Botswana, and Angola (Tweddle, 2010). Over 80 fish species have been documented in the region and large cichlids of the genera *Oreochromis*, *Tilapia*, *Serranochromis* and *Sargochromis* are the major target species of the subsistence and commercial gillnet fisheries in the Zambezi Region (Peel, 2012).

The cichlid assemblage in the Okavango and Upper Zambezi is made up of nineteen formally described species from seven genera, as well as several other species that are yet to be described (Tweddle *et al.*, 2004). Tweddle and Hay (2011) reported that the potential yield of the Zambezi Region's floodplains and its associated Lake Liambezi, amounted to over 6000 t/year. Despite these impressive figures, over-exploitation of the fish stocks by increased commercialisation, coupled with the use of illegal and destructive fishing gear, pose a threat to aquatic biodiversity (van der Waal *et al.*, 2011). Van der Waal (1980, 1990, 1996) was among the first authors to document the eastern floodplain fishery on the Zambezi/Chobe floodplain in the Zambezi Region. Although his study did not explore the fish and fishery response to the flood pulse and climate variability in depth, he discussed numerous ecological factors associated with wet/dry seasonality, population dynamics, diet shifts, species diversity, gear use and gear type. However, it is worth noting that a shift in mesh size preference was recently observed by Tweddle *et al.,* (2015). The use of smaller meshed (76 mm) stretched mesh size gill nets, as opposed to the larger 127 mm and 178 mm used in the 1980s, has recently peaked. Despite the laudable efforts of the Ministry of Fisheries and Marine Resources (MFMR) in conjunction with the Namibia Nature Foundation (NNF) in safeguarding the fish stocks in the Zambezi Region, catch rates of the larger, commercially valuable cichlid species have declined (Jul-Larsen *et al*., 2003; Hay and van der Waal, 2009). As local human populations continue to grow, pressure on the fish resources increases. Fishing effort is likely to increase as people turn to fishing as a full-time occupation, and commercialisation of the fishery increases as a result of improved infrastructure such as road and communication networks (Abbott, 2001; Peel, 2012). As the MFMR seeks solutions to manage the fishery in the light of increasing demand, it is critical to understand the relationship between seasonal flooding and productivity and also the fishing patterns and yield of the local fishery. In addition to over-exploitation, various future water developmental projects, such as irrigation of the Kalimbeza rice farm and expansion of municipal water supplies, are likely to affect the natural hydrology of the Zambezi/Chobe floodplain.

1.2 THESIS OUTLINE

The primary aim of this study is to assess the fish population dynamics in a highly variable system, and to gauge the implications of these dynamics on fisheries management for the Zambezi/Chobe floodplain. Secondly, the study aims to determine the harvesting patterns, harvesting rates, and the fishery yields of the Zambezi/Chobe floodplain and enhance recognition of the role of the floodplain fishery in the economy of the Zambezi Region. This aim is achieved by assessing the dynamics of the Zambezi/Chobe floodplain fishery based on seine netting, experimental gillnetting, and catch assessment surveys (CAS) of the subsistence fishers to obtain information for sustainable utilisation of the commercial target species and to propose management guidelines for the floodplain fishery on the Zambezi/Chobe floodplain.

This thesis is divided into nine chapters: Chapter 1 provides a general introduction, and Chapter 2 reviews the relevant literature on the African floodplains. This is followed in Chapter 3 by a brief description of the study area, the general sampling protocol and the data sources used in the thesis. Chapter 4 examines the influence of water level and water quality on the abundance of small fishes in the marginal zone of the Zambezi/Chobe floodplain. The ontogenetic diet shifts of *Hydrocynus vittatus* on the fish population of the Zambezi River is explored in Chapter 5, and Chapter 6 explores the harvesting patterns and yield of the Zambezi/Chobe floodplain fishery. Fish exports and marketing of the Zambezi/Chobe floodplain are presented and discussed in Chapter 7. Chapter 8 centres on the importance of Fish Protected Areas (FPAs) as a management strategy for the Zambezi/Chobe floodplain fishery. Chapter 9 discusses the general findings of the study and makes recommendations on the best management approach towards sustainable utilisation of the Zambezi/Chobe floodplain fishery.

CHAPTER 2: LITERATURE REVIEW ON AFRICAN FLOODPLAINS

2.1 AN OVERVIEW OF THE AFRICAN FLOODPLAINS

Seventeen major floodplains have been documented in Africa, covering an estimated area of 196 000 km^2 at peak floods (Welcomme, 1985). Junk *et al.*, (1989) defined a floodplain as an area of relatively low lying flat land, seasonally submerged by overspill from an adjacent river, lake or swamp or by local rainfall (Welcomme, 1979). During the dry season, nutrients accumulate on this flat land in the form of animal dung and rotting terrestrial vegetation. These nutrients rapidly dissolve in the encroaching flood waters during the earlier stages of flooding and combine with the river-borne silt, supporting rapid growth of aquatic plants, insects and other forms of aquatic life. This outburst of productivity affords the essential conditions for the reproduction, feeding and growth of the many species of fish which migrate onto the floodplain from the river channel with the rising waters. Chimatiro, (2004) demonstrates a statistical relationship between fish catches and the annual flood in the Lower Shire floodplain with the following results: (1) a positive correlation between fish catches and the flood peak, speculated as being associated with recruitment; (2) an association between catch and the water level that was possibly associated with competition, and (3) an association between low catch and severe low water discharge. Water level' is defined as the height reached by the water in a river or a floodplain, while 'low water discharge' is the lowest volumetric flow rate of water that is transported through a given cross-sectional area.

2.2 FISH MIGRATION ONTO THE FLOODPLAIN

According to Pullin and Lowe-McConnell, (1982), fish migrations seem to have developed as a mechanism to localise mature fish in favourable nursing sites and to place larval and young fish in favourable places for survival. The scale of migration varies greatly and can range from hundreds of metres, as in stream-dwelling fishes, up to thousands of metres and kilometres in highly migratory species such as Tigerfish (Binder *et al.*, 2011). Although the timing of migration usually takes place on a seasonal basis, some species display coordinated, consistent movements, for instance the mass upstream migration by most small cyprinids, mormyrids, distichodontids, characids, schilbeids, clariids and mochokids (van der Waal *et al*., 1996). As water levels rise, many fish migrate laterally onto newly flooded areas to feed on abundant allochthonous and rich invertebrate food resources (Ward, Tockner *et al.,* 1999). Lateral spawning migrations are common among most cichlids, and siluroid catfishes, including *Clarias gariepinus* and *Schilbe intermedius*, which move out onto complex vegetated flooded areas where eggs are securely laid on vegetation (van der Waal *et al*., 1996; Skelton, 2001). There is evidence that catfish, Barbus *spp*. and Tilapia spp. begin migration earlier than other species in the Zambezi River, with tilapia females tending to migrate earlier than males (Skelton, 2001). On the other hand, the mormyrid, *Marcusenius altisambesi*, employs nocturnal feeding migrations into well-vegetated inshore zones where it feeds on both aquatic and marginal terrestrial invertebrates (Skelton, 2001). Many species of the Upper Zambezi, such as the ubiquitous *Enteromius paludinosus* and *Enteromius poechii*, are primarily associated with floodplain habitats (Winemiller and Jepsen, 1998). These species inhabit littoral habitats on the edge of the main river channel during the dry season and migrate out onto newly inundated and well-vegetated floodplains for nourishing, breeding, and nursing during the rainy season (Skelton, 2001; Peel, 2012). As the flood water retreats, most fish disperse back to the main river channel, but small-sized and juvenile fish, in particular, can remain in structurally complex aquatic habitats of the floodplain characterised by minimal current and velocities (Simasiku, 2014). During this transition season, juveniles continue to grow, but encounter inter- and intra-species competition for food resources (Simasiku, 2014). A variety of predators, including humans, exploit the seasonal movement of fish from floodplains to river channels. During this time, fishers of the Upper Zambezi floodplain construct earthen dams (called ‘maalelos’ in the local Lozi language) along the margins of secondary channels. The dams have openings in which reed fences are placed to lead fish into traps. A great quantity and diversity of young of the year and adult fish are herded and obtained in this manner (Winemiller, 1991). In scenarios where secondary channels drain into the main river channel of the Zambezi, large flocks of cormorants feast on dense aggregations of young *Synodontis* spp. and catfishes (Winemiller, 1991). During the falling-water period of the Okavango Swamps located south of the Upper Zambezi, schools of *Clarias gariepinus* and *Clarias ngamensis* rove along the vegetated shoreline of the river channel where they feed on the great influx of small fishes, especially mormyrids (Merron, 1993). During the dry season, the remaining populations become stranded in isolated water bodies and suffer high mortality from hypoxic conditions and predation, but later rebound with a burst of reproduction following the first floods, characterised by clear waters. Other year-round inhabitants suffer high dry-season mortality and rebound during the wet season, either by taking advantage of an opportunistic strategy of rapid maturation, or by multiple spawning of small clutches (Winemiller, 1996). The application of technologies, such as radio-telemetry and stable isotope techniques, has shed light on fish migration in their natural habitats. Telemetry methods afford a better understanding of a species’ spatial occupancy and the movements of individuals and their use of particular habitats. Telemetry can unfold the relations between the habitat topography and the inhabitant members of a fish community, particularly given that the use of such features may vary with time (Welcomme, 1985). To date, much of our knowledge on fish movement has been limited to snapshot techniques such as netting or trapping fish during their long route migrations, while key details on fish dynamics and their interactions with other species are not captured.

2.3 LIFE HISTORY STRATEGIES OF THE FLOODPLAIN FISHES

Life-history traits can be defined as characteristics employed by an individual fish species to allocate energy and time between reproduction and growth (Peel, 2012). These characteristics can be classified as the physiology, behaviour, and general ecology of the species. Examples of general life-history trait categories include reproductive strategies, habitat associations, feeding affinities, phylogenetic associations, and physiological tolerances. Commonly, species exhibit physiological affinities and behavioural associations that confine the general association of a species to its natural environment. For instance, species inhabiting the river-floodplains of the Kavango and Zambezi Regions will most likely fall into the three endpoint strategies proposed by Winemiller and Rose (1992), and Peel (2012). Opportunistic strategists are defined and characterised by small adult size, fast growth and early maturity, protracted breeding seasons, and high reproductive strength (Winemiller and Rose, 1992). Such species are well adapted to benefit from newly or disturbed habitats such as floodplains (Zeug and Winemiller, 2007). Examples include many prolific species such as *Enteromius spp.* and characins such as *Brycinus lateralis*. These species undertake lateral spawning migrations out onto flooded plains as the water levels rise. They take advantage of the high productivity and increased, complex refuge associated with flooding of the terrestrial habitat (Skelton, 2001). The periodic strategies are defined by species that grow into large adults, and by late maturation, high egg-count fertility and successive reproduction episodes. Typically, the strategies include migration on a large geographical scale. This strategy is beneficial in cases where the conditions that determine survivorship of juvenile fish vary in space and time (Winemiller and Rose, 1993; Zeug and Winemiller, 2007). Examples include the large predatory *H. vittatus* with an estimated egg batch of 201 000 eggs/kg and a mean oocyte diameter of 0.72 mm, and *S. intermedius* with a mean relative egg batch of 346 900 eggs/kg and a mean oocyte diameter of 0.86 mm (Winemiller and Rose, 1993; Zeug and Winemiller, 2007). Other periodic species include larger cyprinids such as *Labeo cylindricus* and *Labeo lunatus* which undertake longitudinal spawning migrations, usually upriver to find suitable spawning conditions (Skelton, 2001; Weyl and Booth, 1999). Equilibrium strategists are defined by larger adult size, later maturity, large eggs, reduced fecundity and parental care (Winemiller and Rose, 1992). This strategy is expected to be optimal in stable habitats, such as in lakes and reservoirs, where food and space may be limited and density dependence is strong (Zeug and Winemiller, 2007). Examples include mouth-brooding cichlids such as *Serranochromis macrocephalus* and *Oreochromis macrochir*, as well as the bubble-nest builder, *Hepsetus cuvieri* (Skelton, 2001). These species have an extended spawning season and may have several broods in a season (Winemiller, 1991).

The reproductive periodicity of freshwater fish species is closely linked to seasonal variation, with reproduction taking place prior to or during the floods (Blache, 1964). The intensity of rainfall and hydrological patterns has a strong effect on the timing and duration of reproduction periodicity in fish species. Year-round spawners have bursts of spawning activity during the early wet period, which is characterised by heavy rains. Fish normally reproduce in the grass swamps at the edge of the advancing floods (Daget, 1957), although *Hepsetus odoe* construct floating bubble nests which permit deeper water spawning. Some species may spawn in the primary river channel prior to floods, as has been observed mostly for *Clarias* and *Tilapia* species in the Niger (Daget, 1957). Cichlids from the Kafue River, in particular, may reproduce prior to the floods and transport their eggs and fry onto the newly flooded plain (Dudley, 1972), and this is also true for *Hemichromis* and *Tilapia* species in the Ouémé River, Dahomey (Winemiller, 1996). The large eggs of these species allow the larvae to develop from endogenous reserves for many days while securely housed inside the parent's mouth (brooding), so that exogenous feeding can be delayed.

Flooding appears to be essential for the completion of the reproductive cycle of most species, and the failure of the floods due to the Sahelian drought brought about a decline in reproductive success of fish from the Central Delta of the Niger, the Senegal River, and Lake Chad (Peel, 2012). Reproduction during flooding allows juveniles to pursue protection from predators between flooded terrestrial plants and to take advantage of abundant food resources linked with flooding (Welcomme, 1985; Zeug and Winemiller, 2007). Usually, juvenile fish grow rapidly in the protection of vegetative cover and shallow water for approximately four to six months, and eventually move into deeper water (e.g. lagoons) as they grow larger. Within this time span, *Tilapia* species can reach an initial length of 100 to 120 mm and reduce the risk of predation (Booth *et al.*, 1995, Booth and Merron, 1996). The fastest growing individuals may actually spawn in their second flooding season, but many continue to apply most of their energy to somatic growth and spawn in their third flooding season. Growth in larger species slumps asymptotically once they become reproductively mature, but some individuals may live 10 to 13 years and continue to grow at a slower rate.

African pike (*H. cuvieri*) possess flexible spawning times and their bubble nests allow them to produce young, even when levels of dissolved oxygen (DO) are low. While spawning periodicity in cichlids is often independent of flooding, recruitment success has been shown to be negatively influenced by drawdown (Weyl and Hecht, 1998). As a result of high natural mortality, selection pressure tends to favour species with high fecundity, and rapid development and growth. Therefore, the populations contain relatively few year classes, life cycles are short, and generation turnover is fast. Mortality in exploited fish populations is a combination of fishing and natural mortality (Welcomme, 2001). The major factors influencing mortality rates in floodplain river systems include fishing, predation, stranding, disease, and adverse abiotic conditions such as temperature extremes and low dissolved oxygen (Welcomme, 1985). These conditions vary with the flood cycle. During the high water period when conditions for growth are optimal, mortality is assumed to be low (Welcomme, 2001). Juvenile fish are able to take refuge on the floodplain where they are less vulnerable to predation. Here they are able to feed on abundant food sources and grow rapidly before the floodwaters recede (Welcomme, 1979). Welcomme (1985) postulates that the more severe the drawdown, the greater the influence of the low water regime on recruitment the following year.

2.4 FISH PREDATION

Piscivorous fish such as *H. vittatus*, *H. cuvieri*, and the two omnivorous catfish, *C. gariepinus* and *C. ngamensis*, are the main group of predators that prey on juvenile and and small-sized fish in the Zambezi River. Among the cichlids, the genus *Serrenachromis* is predatory, targeting small growing species in shallow vegetated waters. *Hydrocinus vittatus* attack by pursuing their prey, while *H. cuvieri* and catfish are ambush predators. Prey species try to escape selection pressure by predatory fish mainly through avoidance. Generally, predation focuses on small-sized prey, thus large size is one of the best defences against piscivorous predators, since most predators are limited by mouth gape size (Zaret, 1980): the bigger the predator, the larger the target prey (Werner and Gilliam, 1983). As a consequence, predation pressure strongly favours rapid growth, and rapidly growing juveniles stand a better chance of survival than those that grow slowly, because they remain vulnerable to predation for a shorter period (Werner and Gillian, 1983).

At a behavioural level, small fish can opt to evade predation in several ways. They may form shoals, increase their vigilance, seek refuge from predators, or simply decrease their activity by reducing foraging distances or limiting feeding time and intake. Shoaling is a common response to predation and even relatively large fish gather in dense shoals. Shoals provide anti-predator benefits through dilution, confusion, and vigilance effects (Morgan and Colgan, 1987). Although shoaling does not always reduce the number of prey attacked by a piscivorous fish, taking cover in a structurally complex environment, such as littoral macrophytes, enhances the survivorship of prey. Aquatic vegetation cover may reduce encounter rates or predation rate (Hershey, 1985). However, some predators, such as the African pike, are adapted to ambushing and catching their prey among vegetation. Other predators may change their predatory tactics with change in the environment. For instance, some predatory fish may switch from searching to ambushing prey as plant density increases (Hershey, 1985). Predators may seek vegetated areas if the appropriate prey is present. Thus, structural complexity alone does not guarantee refuge from predators (Hershey, 1985). In order to survive and reproduce under intense size-selective predation, the prey species must either reduce its spatial and temporal encounters with the predator or develop the means of decreasing vulnerability to predation (Williamson *et al.*, 1989). This can be achieved by inhabiting the extensive shallow floodplain habitats which can be risky for large predatory fish such as *H. vittatus.*

2.5 FLOODPLAIN FISHERY

River floodplain fisheries are complex, being both multi-species and multi-gear in nature (Welcomme, 1979; Peel, 2012). They are generally highly resilient to increased effort and often display an asymptotic relationship between total effort and long-term yield (Jul-Larsen *et al*., 2003). There are three basic fisheries on the Zambezi/Chobe River floodplain: recreational, commercial, and subsistence (Purvis, 2002). The recreational fishery is centred close to lodges, while the commercial and subsistence fishery areas are more widespread (Purvis, 2002).

Subsistence fishers are opportunistic, responding to floodplain conditions and catching mainly for home consumption using relatively inexpensive, simple gear. This group includes landless labourers, small farmers, women and children (Simasiku, pers. obs.). Throughout the Zambezi system, subsistence fishers catch fish using traps, spears, hook and line, and gillnets. The most common modern gear are gillnets, drag nets, and hook and line (Tweddle *et al*., 2015). Gill nets are stationary gear normally operated by households, while drag nets are large, active gear (ranging from 100–300 m) operated by groups often consisting of hired fishermen (Tvedten, 2002). In spite of a local shortage of suitable large trees to cut wooden canoes from (van der Waal, 1990), and the levies and licences that must be paid to traditional authorities and the Department of Forestry for permission to cut a tree for a wooden canoe in community forests, boats are usually traditional dugout canoes, which differ in length, width and depth from district to district. The canoes are used to set and retrieve fishing gear in river channels or on the inundated floodplain, and to transport the catch to market. By far the most important species in the fisheries are *Oreochromis andersonii* and *Oreochromis macrochir*. These two species accounts for up to 60% of the overall fish biomass of the commercial and subsistence catch in the Kavango and Zambezi Rivers and in Lake Liambezi (Peel, 2012; van der Waal, and Hay, 2011). What is particularly noteworthy about the fishery developments in the Zambezi Region is the extent to which modern gear has replaced traditional gear. Traditional gear was still relatively common until the mid-1970s and, according to van der Waal, (1980), as many as 70% of the commercial fishermen in the region used traditional gear during the flooding season. Currently, over 80% of the households have diverged from traditional to modern gear and the proportion of households using traditional gear has dropped to less than 50% (van der Waal *et al.*, 2011). Several factors were conducive to such a change. Most importantly, the market economy has become increasingly valuable in the Zambezi Region, bringing with its employment and urbanisation, and hence an increasing demand for fish. This development coincided with the appearance of modern gear, particularly in neighbouring Zambia, where the government actively promoted inland fishery by the end of the 1950s. Owing to the close contact between Zambia and the Zambezi Region, modern gear soon found its way to the Zambezi Region (Tvedten, 2002).

2.6 FLOODPLAIN FISH YIELDS

Generally, fish landings from inland fisheries go unrecorded, partly due to the scattered, small-scale nature of individual fisheries, and the lack of easily definable fish landings (Welcomme, 1975). Fish are caught by the riparian communities on the floodplain using a wide range of fishing gear, for example, traps, weirs, scoop baskets, and spears. However, because the landing sites are remote, such catches are typically unrecorded and go directly to domestic consumption. For instance, Tweddle *et al.* (2004) observed catches by children fishing in lagoons on the Barotse floodplain using hook and line outweighed those landed for sale at markets. The same authors stress that recording systems based on catches from sampled fishermen, using factors such as number of vessels or fishing gear known to be employed in the fishery (e.g. Bazigos, 1972) work best in stable fisheries where fishermen are organised and sell their fish catch at recognised markets. Two approaches that have been employed to evaluate fisheries resources in rivers and floodplains are (i) evaluation of the performance of the fishery (stock assessment based on a series of biological parameters, catch assessment through sampling catch and fishermen, market analysis, analysis of consumption), and (ii) estimation of the magnitude of the stock using habitat environmental quality and quantity data (Welcomme, 2001). These resource evaluations can be achieved by using predictive models and simulations based on theoretical concepts of the ecology of the fish community (Chimatiro, 2004). Huet (1964) proposed the morpho-edaphic index (MEI), a model that predicts annual fish production ($kg.km^{-1}$) as a function of average width of the river, water temperature and conductivity. Another method is known as the "Habitat Quality Index", a method that was later developed in North America to predict standing stock (Binns and Eisermann, 1979) as a function of stream flow, temperature, substrate type, and food index. Other, more complex and data-demanding approaches, such as the ECOPATH approach (Chimatiro, 2004), have been developed and applied to aquatic ecosystems (Chimatiro, 2004). However, because of the scarcity of data in many African fisheries, this approach has not been generally or frequently applied, but has rather been restricted to fisheries where data are available (e.g. Lake Kariba) (Moreau *et al.*, 1997). Therefore, less complex but powerful empirical models have been developed using correlations between fisheries and environmental variables such as climate (Sissenwine, 1984).

Yields in tropical African floodplains have been reported to be lower (154.4±198.7 $kg.ha^{-1}.yr^{-1}$) than those in the temperate region (205.0±300.3 $kg.ha^{-1}.yr^{-1}$) (Welcomme, 1985) but no evidence has been put forward to account for the apparent low productivity of African floodplains. In the Zambezi Region, the MFMR collect statistical data on the fishery of the floodplain. P.14 Detailed figures for production of fish from the floodplains in the Zambezi are lacking; however, yields of about 1500 tons were reported annually in the early 1980s, with an estimated 700 active fishermen in 1989 (van der Waal, 1980). Recent estimates provided by Tweddle and Hay (2011) show that Lake Liambezi alone produced approximately 1700 tons in 2011 and that the Zambezi Region's floodplains as a whole produced over 6000 t/year. Fish products are conserved by a variety of means. Where electrical power is available, lake and river fishers use ice to conserve the catch on journey to markets. Where power is not available, most of the artisanal post-harvest sector still use traditional conservation techniques such as sun drying, salting and smoking, and fermented pastes and sauces for smaller fish. The smaller fish species are also economically important and are widely caught using traps and baskets on the floodplains of the Zambezi, Chobe and Linyanti Rivers where they are used for consumption, or dried for barter on the open market at Katima Mulilo.

2.7 FISHERIES MANAGEMENT

Fisheries management can be broken down into three major domains: management of the fish assemblages, management of the fishery, and management of the environment. The aim of fisheries management is to obtain the maximum (or optimum) sustained yield of fish from a water body without depleting the capital (standing stock or biomass) (Lowe-McConnell, 1987), thereby promoting sustainable economic and social well-being of the harvesting fisheries (Hilborn and Walter, 1992). Irrespective of the regulation measures, the fundamental difficulty typically lies with intense fishing pressure brought about by open access to the fishery resources and unregulated fishing effort. Restricting access is, however, not a simple solution because many fisheries are multi-gear, multi-species and complicated by social issues, such as traditional user rights and family obligations. In recognising the importance of freshwater fisheries in the country, the government of Namibia developed a policy (the white Paper "*Responsible Management of the Inland Fisheries of Namibia*") published in 1995, and the Inland Fisheries Resources Act, promulgated in 2003. The principal objectives of the national fisheries policy of the Government of Namibia are to (a) increase fish production, (b) alleviate poverty by expanding employment opportunities and improving socio-economic conditions of fishers, (c) fulfil the demand for animal protein, (d) achieve economic growth through foreign exchange from fish exports and (e) maintain ecological balance, conserve biodiversity, ensure public health and provide recreational facilities. The Inland Fisheries Policy gives priority to the interests of subsistence households over the commercialisation of the fish resource. Current management of the Zambezi/Chobe fisheries is based on the restriction of fishing effort by restricting the type of gear allowed, minimum mesh size, the maximum number of gillnets allowed per fisher, and the method used to catch fish (MFMR, 1995). The legal minimum mesh size in gillnets for the Zambezi/Chobe is 76 mm (MFMR, 1995); however, this mesh size was set on an ad-hoc basis, without due consideration of current levels of fishing or the biology of target species (Peel, 2012). Destructive gear types such as the monofilament gillnets are prohibited by the fisheries policy of 2003. Until recently in Africa, the material used for gillnets was multifilament nylon. Monofilament netting was identified to be three-fold more effective than multifilament gillnets because they are less visible in water, more elastic and are therefore more efficient (Simasiku, 2014). Monofilament net is made of a single nylon strand which is nearly invisible in water while multifilament net is composed of several filaments twisted or braided together. Initially, monofilament gillnets were not available in the Zambezi Region until the Zambian authorities allowed their import in 2007 (Simasiku, 2014). The monofilament nets can be detrimental to biodiversity, mainly because the net material is so light that it may remain suspended in water even when discarded by the owner, and continue to catch fish as 'ghost nets'. Other than catching fish, aquatic mammals, birds and reptiles are also entrapped in these nets.

Traditional management systems exist with the potential to regulate access to fishing sites as well as to protect fish stocks. The key management system is based on limiting access. For the perennial rivers like the Zambezi, Chobe and Kwando-Linyanti, there is a clear notion of community-based territorial rights. Rivers are demarcated into zones, each belonging to a ward under the jurisdiction of the village headman (Tvedten, 2002). Along the 60 km stretch of the Chobe River from Ngoma to Kasika, for example, the zones are recognised as Ngoma, Masikili, Ihaha, Ibilibizi, Mbalasite and Kasika. All fishermen know exactly where the boundaries are. Within these boundaries, people from the ward can, in principle, fish where they want; however, in practice there are sub-zones related to each individual village. Outsiders who want to fish in a given zone must approach the ward headman to ask for permission. It is generally acknowledged that, among outsiders, people from neighbouring wards are to be favoured, followed by people from other areas but belonging to the same ethnic group. In addition to territorial rights, management through gear restrictions is enforced at different levels. At the level of the traditional authority, the two most significant restrictions are a ban on the use of poison implemented in the 1970s, and the more recent, total ban on the use of drag nets. The ban on drag nets was announced as late as 1991 and recapped in 1993 (Tvedten, 2002). However, this ban is still not effectively implemented, mainly because of differences in opinion between the traditional authority who argue for the need to protect the fish resources, and traditional leaders at the village level who argue for the need to feed their people. Most recently the MFMR endorsed a closed season between December to end February, and two Freshwater FPAs on the Zambezi River: Kalimbeza channel, and Kasaya channel. Fishermen themselves argue against closed seasons, stating that the flooding cycle effectively closes seasons for them. In the south-western part of the region, that is, the areas bordering the Kwando and Linyanti rivers and swamps, traditional management practices are currently of limited significance, chiefly for two reasons. First, the establishment of the Mamili National Park, which effectively closed the traditional fishing grounds, and second, the general decrease in the fish stocks of the Kwando-Linyanti system (Tvedten, 2002).

2.8 THE ROLE OF FRESHWATER FISH PROTECTED AREAS (FPAs)

In conserving biological diversity, protected areas are significant cornerstones of sustainable development ideologies. Unfortunately, the importance of protected areas remains poorly understood despite their substantial monetary and non-monetary value. Many fisheries are now on the edge of collapse, and hence fishery managers are considering protected areas as an essential tool in their rescue (Roberts and Hawkins, 2003). Hannesson (1998) hypothesises that protected areas offer direct protection to the proportion of the total assemblage of fish stock within its delineation margins since fish migration would be restocking depleted areas, and so attaining sustainability. However, the extent and range of the spill-over of fish to the depleted areas depends on the dispersal characteristics of the fish populations that reside in the reserve. Protected areas also increase the market value of a fishery by boosting its species composition and increasing catchability. According to Williamson (2009), the area of closures is envisaged to allow and secure the breeding stocks.

Effectively applying FPAs requires an understanding of the life history and habitat requirements of freshwater migratory fish (Cooke *et al.*, 2012). Understanding the life history of different species provides depth of knowledge pertaining to which habitats are particularly important to safeguard such species, for instance, the spawning habitat or productive feeding zones (Rosenfeld and Hatfield, 2006). Although migratory fish inevitably switch between habitats within riverine systems at different life stages, they are likely to spend most of their time in discrete, definable habitats that should be considered important in the conservation context. The nature of activities permitted within the borders of an FPA is also important. For example, recreational angling has been beneficial for promoting conservation of some endangered freshwater migratory species, such as mahseer (*Tor spp.*) in India (Pinder and Raghavan, 2013) and taimen (*Hucho taimen*) in

Mongolia (Jensen *et al.*, 2009). Equally, when access to activities such as angling is limited or removed, support for conservation initiatives tends to decrease (Danylchuk and Cooke, 2011). This highlights the importance of balancing freshwater activities with the goals of Freshwater Protected Areas to ensure their sustainability, an approach which requires species-specific and often population-specific studies to evaluate viability.

2.9 THREATS TO FRESHWATER BIODIVERSITY

The Zambezi/Chobe Rivers are rich in fish species diversity with more than 80 species identified from the Zambezi Region (Peel, 2012). Natural systems are dynamic and fluctuate in time and space, hence freshwater biodiversity is endangered by a number of key factors that include overfishing, pollution, flow alteration, as well as water abstraction, devastation of habitat, and the negative impacts of invasive alien species. In addition to these threats, there is the impact of global climate change, as well as changes in precipitation and runoff patterns (Dudgeon *et al.*, 2006). The Upper Zambezi ecoregion contains several threatened endemic species of fish. *Clariallabes platyprosopos* has an extremely restricted range, with two of its four known localities occurring in this ecoregion at Katima Mulilo and Impalila in Namibia. The striped killifish *Nothobranchius capriviensis*, which is endangered, is known from two small rainwater pans at Gunkwe and Bukalo in the Caprivi Strip (Marshall, 2011). *Nothobranchius capriviensis* occurs in small number of rain pools. It has a specialised life cycle where eggs are laid on the bottom and development is suspended when the pool dries out. During the next rainy season, these eggs hatch, the fish mature and breeds before the pool dries up again. The life history of this species is threatened by any development projects such as roads.

2.10 THE IMPACT OF CLIMATE CHANGE ON THE ZAMBEZI BASIN

The African continent is highly vulnerable to climate change, and the Zambezi River Basin is particularly at risk. The Zambezi River Basin is expected to experience a significant warming trend over the next century. The general consensus emerging from modeling suggests an increase of 0.3-0.6° C per decade. Over the next century, the Zambezi River Basin is expected to experience a significant increase in the rate of potential evapotranspiration, based on projected increases in temperature coupled with decreased humidity associated with reduced rainfall (below). The Zambezi River Basin receives about 960 mm rainfall per year, mostly concentrated in the wet season. Shongwe *et al.*, (2009) project a decreasing rainfall trend with more extreme droughts in northern Botswana, western Zimbabwe, and southern Zambia; generally drier conditions in Zambia and Malawi; and less clear precipitation trends in eastern Zimbabwe and Central Mozambique during the 21st century.

The World Bank assessed the percentage change in runoff for each of the major Zambezi sub-basins by 2030, relative to the 1961-1990 baseline. They estimated a 16% reduction in runoff from the Upper Zambezi, 24-34% reduction in the Middle Zambezi, and 13-14% reduction in the Lower Zambezi. Maun, Botswana, just west of the Zambezi River Basin in the Okavango River basin, is predicted to have a 72% reduction in runoff corresponding to the same 10% reduction in rainfall. As result of the changes to freshwater systems discussed above, several additional changes may occur in the chemistry (i.e. pH, and disolved oxygen) of the inland waters. Drying of wetlands can result in oxidation of sulfidic minerals and generate acid sulfatesoils (Badwin and Mitchell, 2000). Thus increased drying as a result of climate change, followed by flooding may lead to major changes in water chemistry (i.e. depletion of oxygen and low Ph levels) resulting in fish kills (Badwin and Mitchell, 2000).

CHAPTER 3: DESCRIPTION OF THE STUDY AREA AND METHODOLOGY

3.1 THE ZAMBEZI REGION

The Zambezi Region borders on Botswana in the south, Angola and Zambia in the north, and Zimbabwe in the east (Figure 3.1). The area is home to two perennial rivers, namely the Kwando/Linyanti in the west, and the Zambezi/Chobe in the east. Kwando flows through the Zambezi Region (originally Caprivi Strip of Namibia) from north to south for 35 km and forms the border between Namibia and Botswana. It runs for a further 75 km as the Linyanti River before heading eastward in a swamp system and dries up into Lake Liambezi. The Chobe River originates from the Lake Liambezi flowing in eastward direction and join the Zambezi at the eastern point of Impalila. The Zambezi River itself forms the border between Namibia and Zambia; specifically between Katima Mulilo and Zambia. Rainfall in the Zambezi catchment is seasonal, with most of the rain falling in the summer months between November and April (Mendelsohn and Roberts, 1997; Mendelsohn and El Obeid, 2003). Rainfall in the Zambezi catchment decreases from 1400 mm at the source to 680 mm at Katima Mulilo (Mendelsohn and Roberts, 1997). The topography of the Zambezi Region is flat terrain ranging between 1100 m in the west and 930 m in the east. Seasonal floodwater therefore extends from the river catchments and spreads laterally by overflow, expanding the area of the wetland (Mendelson and Roberts, 1997). During high water flows, the Kwando and Zambezi Rivers breach their banks annually, inundating large plains. These seasonally inundated floodplains form extremely productive wetlands and account for much of the species richness found in the open waters of the region (Simasiku, 2014). The Zambezi wetlands support an important catfish and cichlid fishery involving more than 700 fishermen and yielding 6700 t/year (Tweddle and Hay, 2011). Households rely on daily consumption of fish, which are the most important source of protein after game and poultry (Turpie *et al.*, 1999).

3.2 THE ZAMBEZI/CHOBE RIVERS

Zambezi/Chobe River

The upper Zambezi River rises in Zambia and flows through eastern Angola, along the north-eastern border of Namibia and the northern border of Botswana, then along the border between Zambia and Zimbabwe to Mozambique, where it crosses the country to empty into the Indian Ocean (Figure 3.1). From its source, it flows westward into eastern Angola where it slowly changes course and begins to flow in a south-easterly direction back into Zambia (Figure 3.1). The river forms the border between Zambia and Namibia for approximately 120 km from just north of Katima Mulilo to Impalila Island at the Zambezi/Chobe junction (Hay *et al.,* 2002). Further down, the river forms the border between Zambia and Zimbabwe. The Chobe River extends from Lake Liambezi in the west, along the Botswana border to the Zambezi River at Impalila Island (Hay *et al.,* 2002, Peel, 2012). The Chobe River consists of a narrow channel near Lake Liambezi which rapidly becomes an extensive shallow floodplain above the Botswana border town of Ngoma where, again, the river is restricted to a narrow channel. Nearer its confluence with the Zambezi River, the river becomes wider and deeper with extensive swamp like floodplains on the northern border with Namibia and narrow floodplains in Botswana (Figure 3.1).

Hydrology

The Zambezi/Chobe floods annually, water level starts to rise in December with a drastic increase in February and March. During this time, a large area in the east is converted from exposed, sunbaked soil and grassland habitat into a productive marsh with diverse aquatic vegetation dominated by submerged emergent grasses, reeds and occasional trees and shrubs. Summer rainy season causes a natural rise in water levels, water temperatures, food and shelter (Junk *et al.,*1989).

Most species in this environment use these favorable conditions to breed, a process that typically results in temporal segregation of juvenile cohorts (van der Waal, 1985). The river reaches its peak between end of March and beginning of May after which the level recedes until the end of September. During high floods in the Zambezi River, usually from February to May, the Zambezi River backs up the Chobe River, occasionally as far as Lake Liambezi, supplying Lake Liambezi with water (Hay *et al.,* 2002). The direction of water flow in the Chobe River changes seasonally, depending on floodwater levels in the Zambezi and the Kwando/Linyanti and Lake Liambezi (Hay *et al.,* 2002). Under normal conditions, the Chobe River flows from Lake Liambezi when full, eastwards to the Zambezi River (Hay *et al.,* 2002). When Lake Liambezi has had little inflow from the Kwando/Linyanti, and the Zambezi River does not back up as far as Lake Liambezi, the Chobe River simply forms a large backwater to the Zambezi River. In times of exceptional flooding, the Kwando/Linyanti and Zambezi/Chobe River systems are inter-linked, and large parts in the eastern Zambezi Region become one large floodplain (Hay *et al.,* 2002). During the driest months (November-April), the aquatic habitat is reduced to a network of mud-bottom pools blanketed by Salvinia *spp*. Large permanent water bodies stretching along the Zambezi and Chobe River includes Mutwalwizi and the Kasaya channel with open water habitat to maintain fish communities. The aquatic vegetation in these water bodies consist of submerged weed beds, floating weeds, lilies, reeds and aquatic grasses (Peel, 2012). The water quality of the Zambezi River has been investigated by Abah *et al.* 2018. The system was generally characterised with pH values between 6.68 and 8.93. Temperature ranged between 18.40 and 28.73°C while conductivity ranged between 37.73 and 105.27 ($\mu S\ cm^{-1}$). Dissolved oxygen levels were sufficiently high >5.01-7.92 mg L^{-1}. Ammonia levels were (0.13 mg/l mg/ℓ). Overall, the quality of the Zambezi River was considered within the safe limits of aquatic fauna (Class B) (Abah *et al.,* 2018).

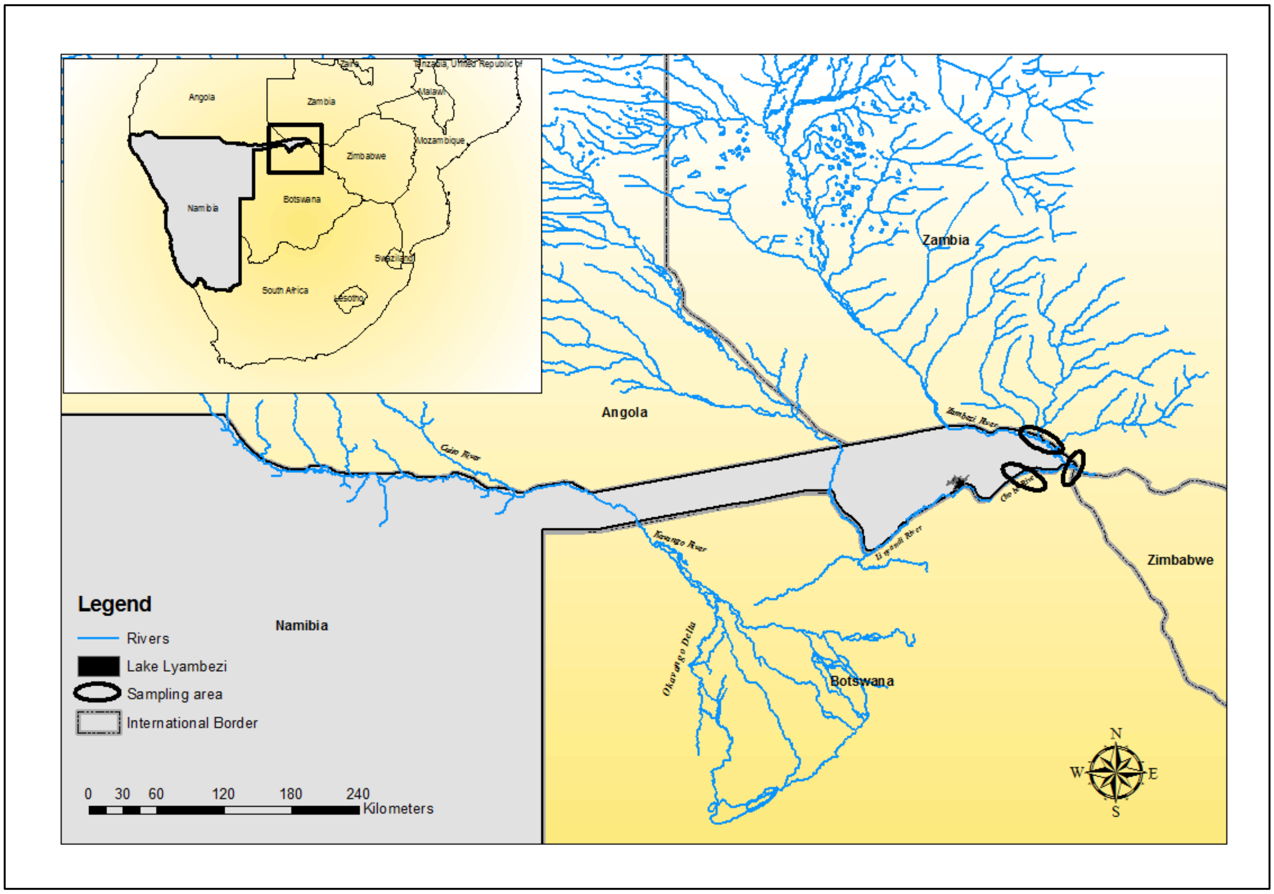

Figure 3.1 Map of the Zambezi Region showing the Zambezi/Chobe River and Lake Liambezi and its associated floodplains, generated using ArcGIS 9.3.

Physical characteristics

The Zambezi/Chobe River is characterised by a diverse range of habitats including a deep, wide main stream with many small vegetated islands and sandbanks, small side streams, backwaters, lagoons and floodplains (Hay *et al.*, 2002). The substrate of the main river channel and the associated side channels is predominantly sandy, while the lower lying areas of the floodplain usually have muddy substrates with large amounts of vegetative detritus (Hay *et al.*, 2002). The main river channel and large side channels are characterised by abundant marginal vegetation. Terrestrial marginal vegetation may consist of overhanging or fallen trees, shrubs and terrestrial grasses which are submerged during high floods (Hay *et al.*, 2002; Peel, 2012). Aquatic marginal vegetation includes emergent plants, reeds and sedges. There is little submerged aquatic vegetation in the main channel as it is not possible for plants to anchor themselves on the constantly shifting sandy substrate (Hay *et al.*, 2002). Many oxbows and shallower pools along the tributary of the river have extensive submerged aquatic plant beds.

Fish fauna of the Zambezi/Chobe River

The fish community and biology of the fish species in the Upper Zambezi have been described in a number of reviews and research works (van der Waal, 1984; Tweddle *et al.*, 2004; Peel, 2012). Only a few reports of collections from the Zambezi/Chobe River itself have been published. Van der Waal (1984) sampled different water bodies in the Zambezi Region and recorded 76 different species. A synthesis of the collection by Tweddle *et al.* (2004) culminated in the most recent checklist on the fish fauna of the eastern Zambezi/Chobe River. Over 80 fish species have been documented along the 156 km stretch. The fish fauna of the Zambezi/Chobe is characterised by swamp- and floodplain-loving fish species. The following species belong to this group: *Petrocephalus catastoma, Rhabdalestes maunensis*, *Enteromius poechii*, and *Enteromius paludinosus.* Cichlids of the genus *Oreochromis*, *Sargochromis*, and *Serranochromis* are, however, the most diverse (Tweddle *et al.*, 2004; Peel, 2012).

3.3 GENERAL SAMPLING METHODS

The Zambezi/Chobe River was sampled at three major stations: Kalimbeza, Kasika, and Impalila (Figure 3.2). These sampling stations fell within the sites sampled by the MFMR during their annual biological surveys. Fish export surveys were exclusively conducted at the Namibian border (Wenela Border Post), north of Katima Mulilo. Monthly field sampling was conducted between March 2010 and December 2017 using seine netting, experimental gillnetting, catch assessment surveys (CAS) from the subsistence gillnet catches, and fish export data. Hydrological data of the Zambezi/Chobe River were sourced from the Ministry of Agriculture and Forestry, Hydrology Department. Specific methods are elaborated in each chapter.

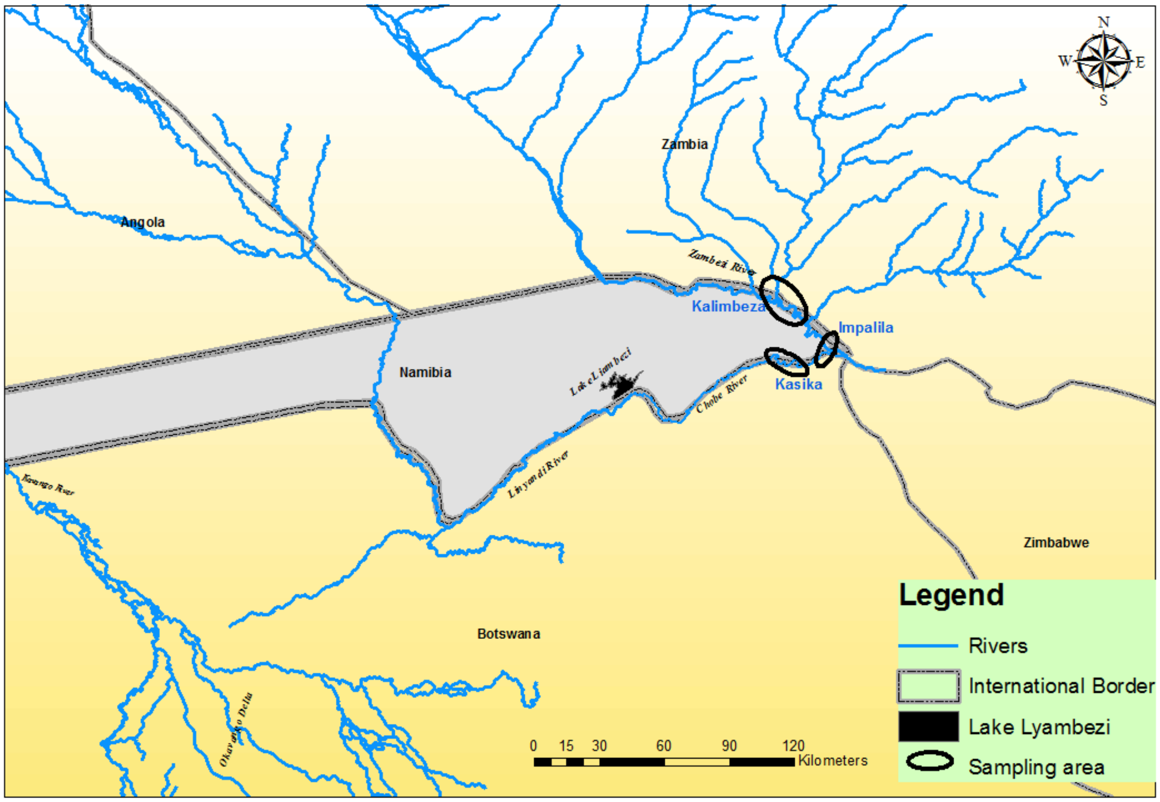

Figure 3.2 Map of the Zambezi Region showing the sampling areas along the north-eastern Namibia, generated using ArcGIS 9.3. Sampling sites not to scale.

Seine netting

Littoral ichthyofaunal along the Zambezi/Chobe floodplain was sampled using a 10 m long x 1.5 m deep seine net with 12 mm stretched mesh size with a 2 m bunt (Figure 3.3). Three marginal zones between 10 and 20 m wide were selected for seining. Seining was restricted at Kalimbeza due to lack manpower and easy accessibility during the flooding season. Five hauls were performed per site as this has been proven to yield sufficient sample sizes (Simasiku, 2014). All fish specimens were identified to species level and measured to the nearest millimeter total length (TL) or fork length (FL) and weighed to the nearest gram.

Figure 3.3 Beach seining along the marginal zones of the Zambezi/Chobe floodplain between March 2017 and February 2018.

Diet assessment of Hydrocynus vittatus

In order to assess the feeding ecology of the predatory Tigerfish (*Hydrocynus vittatus*) on new recruitments inthe main channel of the Zambezi River, a total of 150 specimens of *H. vittatus* (Figure 3.4) were dissected, and their gut content spilt on trays. Visual assessment of the gut content was achieved in the field and each prey item was identified to species or genus level, measured to the nearest millimetre TL or FL depending on the species, and weighed to the nearest gramme.

Figure 3.4 Large specimen of *H. vittatus* caught in the Kalimbeza channel for gut analysis.

Catch assessment surveys

Creel surveys were conducted bi-weekly at major designated landing sites along the Zambezi/Chobe floodplain (Figure 3.5). Landing sites fell within the three identified fishing villages namely Kalimbeza, Kasika and Impalila. Individual fishermen landing their catches at major landing sites were approached and questioned regarding their canoes, net types, stretched mesh sizes, net length and frequency of fishing. Daily fish landings were assessed and only a sub-sample of fish caught per canoe was identified to species level, measured to the nearest millimeter (TL) or (FL) and weighed to the nearest gram (Figure 3.6).

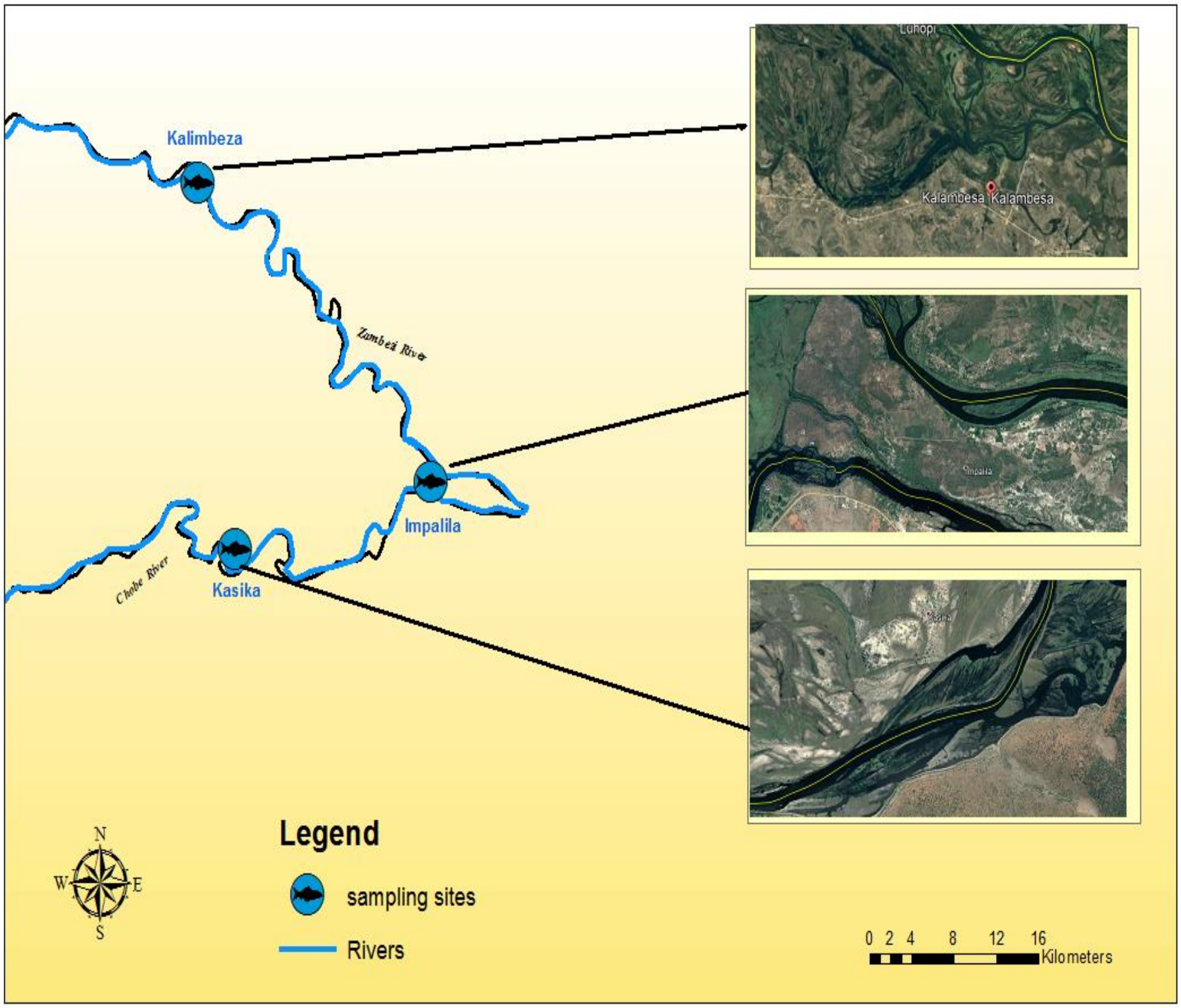

Figure 3.5 Major landing sites along the Zambezi/Chobe Rivers. Map not to scale. Map generated using ArcGIS 9.3.

Figure 3.6 Subsistence catch assessment surveys (CAS) at major landing sites along the Zambezi/Chobe Rivers.

Fish export surveys

The author and two technical assistants from the MFMR monitored all fresh and dried fish leaving Namibia through the Wenela Border Post into Zambia during the daylight hours (07h00–17h00), between June 2015 and December 2016 (Figure 3.7). Records included the number of bags or cartons leaving the border by bus, truck or pickup, taking note of their place of origin and destination. Bags and cartons of all fish going out were weighed using a hanging weighing scale fitted with a platform.

Figure 3.7 Weighing hessian fish bags using a hanging scale with a platform at Wenela Border Post between June 2015 and December 2016.

Experimental gillnetting

Two distant sites were selected on the Zambezi River: one within a Fish Protected Area (Kalimbeza channel), where fishing is strictly prohibited, and the other, an open access fishing area (Hippo channel) (Figure 3.8 a-d). Six-ply, brown multifilament nylon nets with stretched mesh sizes of 12, 16, 22, 28, 35, 45, 57, 73, 93, 118 and 150 mm, were employed (Figure 3.8). Each fleet was 110 m long by 2.5 m deep and consisted of eleven randomly distributed 10 m mesh panels. Nets were surface set for two nights in the upper, mid and lower channel at 17h00 in the evening and retrieved at 07h00 next morning. All fish caught were identified to species level, except where identification was in doubt, measured to the nearest millimetre TL or FL depending on the species, and weighed to the nearest gramme.

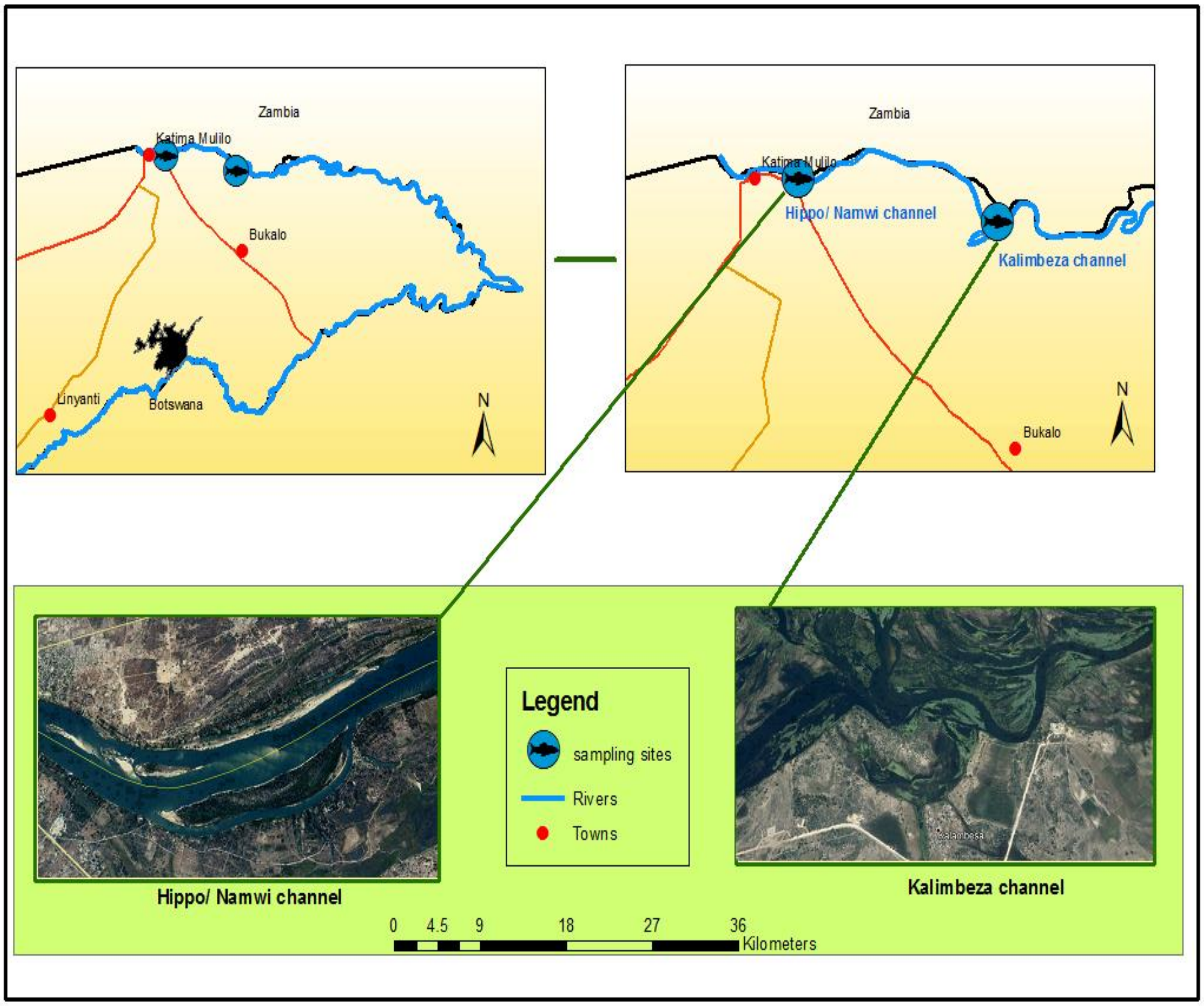

Figure 3.8 Map of the Zambezi Region, showing the Hippo and Kalimbeza channels on the Zambezi/Chobe River where gillnets were set during the study. (Map generated using QGIS software version 3.2 with Google map add-in).

CHAPTER 4: LINKING FISH COLONISATION RATES WITH WATER LEVEL AND WATER QUALITY IN THE LITTORAL ZONES OF THE ZAMBEZI/CHOBE FLOODPLAIN

4.1 THE LITTORAL ZONE

The littoral is a land-water ecotone occurring along main river channel margins and extending onto the floodplain during high water. Thus, this ecotone composed of a variety of habitats from which communities are assembled upon (Townsend, 1989; Bayley, 1995; Arrington, 2002; Petry *et al.*, 2003). The significance of the littoral zone to aquatic organisms can never be overemphasized and has been documented in many aquatic systems (Vono and Barbosa, 2001). The littoral zone can support aquatic vegetation such as macrophytes which in turn can provide macro-habitats and promote higher fish diversity, abundance and species richness (Petry *et al.*, 2003). During the dry season there is an accumulation of nutrients on the plain in the form of domesticated and wild animal dung, rotting vegetation (i.e. macrophytes). Periodic flooding integrates the stream with its floodplain, flushing organic material into the stream, depositing silt and minerals on the floodplain, creating ephemeral ponds. This stimulates much of the primary production, supporting aquatic organisms (Junk *et al.*, 1989).

For instance, when the Zambezi River breaches its banks during the annual flood pulse, fish move into the adjacent highly nutrient rich floodplain habitats characterised with good water quality suitable for both spawning and feeding (Junk *et al.*, 1989). As water levels gradually recede, many fish disperse back to the river channel, but juveniles in particular can remain in structurally complex aquatic habitats of the floodplain where current velocity is lower (Winemiller, 1996). However, littoral patch habitats (e.g., woody snags) may be exposed and dry out as the flood waters recede to the main river. As a result, littoral species are forced to continually disperse across the landscape in response to water levels. These patterns may result into a re-shuffle of small fish communities on the floodplain (Hurtt and Pacala, 1995). Early models had been proposed as consideration of how spatiotemporal environmental variation and species movement affect community dynamics (Leibold *et al.*, 2004; Holyoak *et al*., 2005). The *patch dynamics model* hypothesizes that community assemblages are driven by trade-off interactions between competitive ability and dispersal ability (Hutchinson, 1953 and Townsend, 1989) such that competitively inferior species tend to colonise habitat patches and persist until they are displaced by competitively superior species or impacted by a subsequent disturbance. In contrast, the *species sorting model* predicts that community structure is a result of environmental heterogeneity and the habitat selection and environmental filtering that result from it (Whittaker, 1962 and Holt, 1985). The *mass effect model* proposes that source‑sink population dynamics allow for competitively inferior species to persist in local patches by immigration of individuals from environmentally favorable patches (Leibold *et al.,* 2004). The *neutral model* indicates that species are equivalent in their dispersal and competitive abilities so that community structure largely results from random processes. The interactions of both the physical and chemical properties of water equally play a significant role in shaping fish species composition, distribution, abundance, movements and diversity (Leibold *et al.,* 2004). Despite these proposed environmental drivers in fish communities, no quantitative studies have been conducted to address the response of small fish communities to a change in water level and water quality in the littoral zone of the Zambezi/Chobe floodplain. The aim of this chapter was to assess the influence of water level change and physicochemical parameter on the colonisation rates of small fish in the littoral habitats of the Zambezi/Chobe floodplain. To do this, three hypotheses were tested:

1) Species composition in the littoral zone of the Zambezi/Chobe floodplain was similar between the hydrological phases of flooding (rise, peak, fall and low).

2) Littoral species diversity were similar between hydro-periods (rise, peak, fall and low)

3) Juvenile fish densities catch per unit effort (CPUE) of the most abundant taxa were similar between sampling months.

4.2 MATERIAL AND METHODS

General sampling

Littoral surveys on the Zambezi/Chobe floodplain were conducted from March 2017 to February 2018. Sampling was conducted during the four hydrological periods: rising flooding phase (February – March), peak flooding phase (April), receding flooding phase (May – June) and low flooding phase (August – January). Littoral margins along the Zambezi/Chobe floodplain were sampled at Kalimbeza River (see Figure 3.2 in Chapter 3). This was found to be suitable on account of its high water retention which enabled long-term sampling over the entire study period.

Sampling for physicochemical variables

The littoral zone is characterised by broad variations in its abiotic parameters (especially temperature and dissolved oxygen). These conditions may restrict the presence of sensitive species within the littoral zone. To gain some insight into the influence of water quality on small fish communities, water parameters were measured *in situ* per site, prior to fish sampling. Physicochemical parameters such as dissolved oxygen (mg/*l*), conductivity (µS/cm), pH, and temperature (ºC) were measured using a multi-function sensor HQ40d portable meter. Monthly replicate readings of dissolved oxygen, conductivity, pH, and temperature measurements were averaged per flooding phase over the entire study. Data on daily water levels for the entire sampling period was obtained from the Hydrology Department under the Ministry of Agriculture and Water Affairs.

Sampling for littoral fish species

A 20 m long x 1.5 m deep anchovy seine net with 5 mm stretched mesh size with a 1 m bunt was used to sample littoral ichthyofauna. The net was laid out and hauled from a distance of 10 m offshore; fish were herded into the net by disturbing the vegetation or substratum that might have provided refuge. Hauls were conducted per sampling event as recommended by Siziba *et al.* (2011). As a result, five consecutive hauls at distinct sites were conducted per sampling event. Sampling sites were adjusted according to the water level. The seine and its content were carefully taken ashore to remove the fish. The catch per haul within a hauled distance of 10 m was used as an index of relative abundance (CPUE). This CPUE assumed that the seine efficiency remained uniform in all areas since there were no modifications to the net over time. After sorting by species, all specimens were measured to the nearest millimetre TL or FL, and weighed to the nearest gramme (g). A subsample (20 individual per species fish) was measured when a large number of fish was caught and the rest of the fish were then counted and weighed.

Statistical analysis

All data were first checked for normality and homogeneity of variance using Kolmogrov-Smirnov and Levene's test in SPSS. As environmental variables conformed to the assumptions of parametric tests, they were then grouped by hydro-periods (rising, peak, receding and low water phase) and subsequently compared between flooding stages using one-way Analysis of Variance (ANOVA) (Zar, 1984). To describe the assemblages for small fish between hydro-periods, the Shannon-Weiner's diversity (H') and Pielou's evenness (J') indices were calculated. The non-parametric test, Kruskal-Wallis, was then applied to compare these indices among the hydro-periods. Variations in fish assemblage structure based on fish densities among hydro-periods were examined using the non-metric multi-dimensional scaling (NMDS) ordination with two dimensions (k=2) based on Bray-Curtis similarity matrices (Holland, 2008). Density of small fishes was log-transformed ($\log[x + 1]$) to improve on the assumptions of normality and homogeneity before a one-way ANOSIM was employed to assess the statistical differences across different phases of flooding. When significant differences in community structure were detected, similarity percentage procedures (SIMPER) were used to determine which species contributed to the highest dissimilarity. All NMDS analyses were computed based on species presence/absence data. Associations between physicochemical and fish CPUE data were explored using Principal Correspondence Analysis. All multivariate tests were performed using Canoco 5 and Primer Software 7 (Clarke and Warwick, 1994). Significant associations at $p<0.05$ were identified using the Bonferroni correction test.

4.3 RESULTS

Physicochemical water parameters

The physicochemical parameters varied with the different phases of flooding (rising, peak, fall and low) (Table 4.1). Values of dissolved oxygen varied significantly among hydro-periods (ANOVA, df=3, $p=0.005$), being highest during the peak flooding phase (5.7±1.0 (mg/l) and lowest during low flooding phase (4.3±0.1 (mg/l). The highest pH value of 7.9 was recorded during the peak flooding phase, and the lowest 6.4 during the rising flooding phase (ANOVA, $p=0.001$). Similarly, water conductivity differed significantly among hydro-periods, being highest during the rising flooding phase (116±1.7 μS cm) and lowest during the peak flooding phase (43.2±4.9 μS cm) (ANOVA, $p=0.001$). While temperature varied slightly among hydro-periods, it was significantly highest during the peak flooding phase (27.6±1.1 °C) and lowest during the receding flooding phase (22.9±1.2 °C) (ANOVA, *p*=0.002) (Table 4.1).

Table 4.1 Values and standard deviation of selected water quality variables grouped by hydro-periods of the Zambezi/ Chobe floodplain, * = significant values.

Variable	Rising	Peak	Fall	Low	p value
Oxygen (mg/l)	4.3±3.2	5.7±1.0	5.6±4.8	4.3±0.1	0.005*
pH	6.4	7.9	7.4	6.8	0.001*
Conductivity (µS/cm)	116±1.7	43.2±4.9	92.9±21.3	100.3±12.9	0.001*
Temperature (°C)	26.4±1.4	27.6±1.1	22.9±1.2	26.5±4.15	0.002*

Catch composition

A total of 4914 fish representing 31 different species and seven families was recorded between March 2017 and February 2018 (Table 4.2). A total of 349 individuals were captured during the rising phase, followed by 723 during the peak, 1836 during the flood recession, and 2006 during the low water level. During the rising phase, 17 species were recorded, the most numerous of which were *Enteromius bifrenatus* (14.6%), *Enteromius paludinosus* (15.2%) and *Rhabdalestes maunensis* (15.5%). During the peak flooding phase, 27 species were recorded; the most numerous species were *Pharyngochromis acuticeps* (20.5%) and *Coptodon rendalli* (19.1%). During the receding phase, 28 species were sampled, with *E. paludinosus* (23.6%), *Pseudocrenilabrus philander* (11.0%) and *Tilapia ruweti* (16.8%) accounting for most of the total catch. During the low flooding phase, 23 species were sampled and *E. paludinosus* (19.8%), *R. maunensis* (19.7%) and *T. ruweti* (17.6%) were the most abundant species (Table 4.2). Cichlidae, dominated by juvenile (*C. rendalli*, *P. philander* and *T. ruweti*), Characidae (*R. maunensis*) and Cyprinidae (*Enteromius spp.*) were the most abundant fish families in the study area (Table 4.2). These three families accounted for 89.9% of the total catch. Densities of small fish by number varied among hydro-periods with a marked increase in cichlids (63.1%) during the peak flooding phase while cyprinids (45.3%) were most abundant during the flood recession phase (fall) (Table 4.3). Fish species richness was significantly highest during the flood recession phase and lowest during the rising phase (Kruskal-Wallis test, $p<0.001$) (Table 3.4). Despite the observed variation in species richness between hydro-periods, species diversity was similar among hydro-periods (Kruskal-Wallis test, $p>0.05$)

(Table 4.4).

Table 4.2 Species composition of all fish taxa sampled during the different flooding phases in the littoral zone of the Zambezi/Chobe floodplain between March 2017 and February 2018.

	Rising		**Peak**		**Fall**		**Low**	
Cyprinidae	No	%No	No	%No	No	%No	No	%No
Enteromius afrovernayi	-	-	6	0.8	2	0.1	2	0.1
Enteromius bifrenatus	51	14.6	44	6.1	98	5.3	276	13.8
Enteromius eutaenia	-	-	-	-	1	0.1	-	-
Enteromius haasianus	17	4.9	4	0.6	64	3.5	84	4.2
Enteromius multilineatus	1	0.3	-	-	33	1.8	10	0.5
Enteromius paludinosus	53	15.2	28	3.9	434	23.6	398	19.8
Enteromius poechii	7	2.0	7	1.0	64	3.5	16	0.8
Enteromius radiatus	5	1.4	6	0.8	31	1.7	7	0.3
Enteromius unitaeniatus	-	-	-	-	1	0.1	-	-
Opsaridium zambezense	-	-	44	6.1	5	0.3	-	-
Labeo spp.	8	2.3	56	7.7	99	5.4	27	1.3
Characidae								
Brycinus lateralis	1	0.3	4	0.6	17	0.9	25	1.2
Rhabdalestes maunensis	54	15.5	15	2.1	89	4.8	396	19.7
Micralestes acutidens	-	-	36	5.0	41	2.2	-	-
Hydrocynus vittatus	-	-	2	0.3	-	-	-	-
Cichlidae								
Oreochromis andersonii	32	9.2	23	3.2	96	5.2	29	1.4
Oreochromis macrochir	-	-	5	0.7	1	0.1	3	0.1
Coptodon rendalli	15	4.3	138	19.1	93	5.1	55	2.7
Pharyngochromis acuticeps	-	-	148	20.5	29	1.6	8	0.4
Pseudocrenilabrus philander	11	3.2	28	3.9	202	11.0	103	5.1
Serranochromis macrocephalus	-	-	-	-	3	0.2	-	-
Tilapia ruweti	30	8.6	20	2.8	308	16.8	353	17.6
Tilapia sparrmanii	37	10.6	41	5.7	71	3.9	27	1.3
Tilapia spp.	11	3.2	9	1.2	-	0.0	-	-

Hemichromis elongatus	1	0.3	44	6.1	16	0.9	1	0.0
Poecilidae								
Micropanchax hutereaui	-	-	2	0.3	-	-	3	0.1
Micropanchax johnstoni	15	4.3	2	0.3	20	1.1	176	8.8
Micropanchax katangae	-	-	1	0.1	1	0.1	4	0.2
Anabantidae								
Ctenopoma multispine	-	-	9	1.2	12	0.7	3	0.1
Clariidae								
Clarias gariepinus	-	-	-	-	3	0.2	-	-
Schilbeidae								
Schilbe intermedius	-	-	1	0.1	2	0.1	-	-
Total	**349**		**723**		**1836**		**2006**	

Table 4.3 Numeric percentage contribution of the most abundant fish family sampled during the different flooding phases in the littoral zone of the Zambezi/ Chobe floodplain.

Fish Family	**Rising**	**Peak**	**Fall**	**Low**
Cyprinidae	40.7	27.0	45.3	40.9
Characidae	15.8	7.9	8.0	21.0
Cichlidae	39.3	63.1	44.6	28.9
Poecilidae	4.3	0.7	1.1	9.1

Table 4.4 Diversity, evenness and richness indices of small fish taxa sampled during the different flooding phases in the littoral zone of the Zambezi/ Chobe floodplain. * = significant values.

Diversity indices	**Rising**	**Peak**	**Fall**	**Low**	**p value**
Species richness (S)	17	27	28	23	0.001*
Pielou’s evenness (J')	0.9	0.8	0.8	0.7	0.31
Shannon-Weiner (H)	2.5	2.5	2.5	2.3	0.11

Fish assemblage structure in the littoral zone

Aggregated fish assemblages per hydro-periods were hierarchically grouped into three clusters. Species richness was most similar between low and rising, a cluster that was similar with peak flooding phase and flood recession phase (Figure 4.1a & b). It is apparent that the peak flooding phase (dominated by cichlids) is clearly distinguishable from fall, low, and rising phases (dominated by cyprinids) (Table 4.3 and Figure 4.1). SIMPER analysis detected a 61.91% dissimilarity in fish assemblages between the four stages of flooding due to differences in abundances of *P. acuticeps*, *C. rendalli*, *E. paludinosus*, *T. ruweti*, *R. maunensis*, *O. zambezense*, and *H. elongatus.*

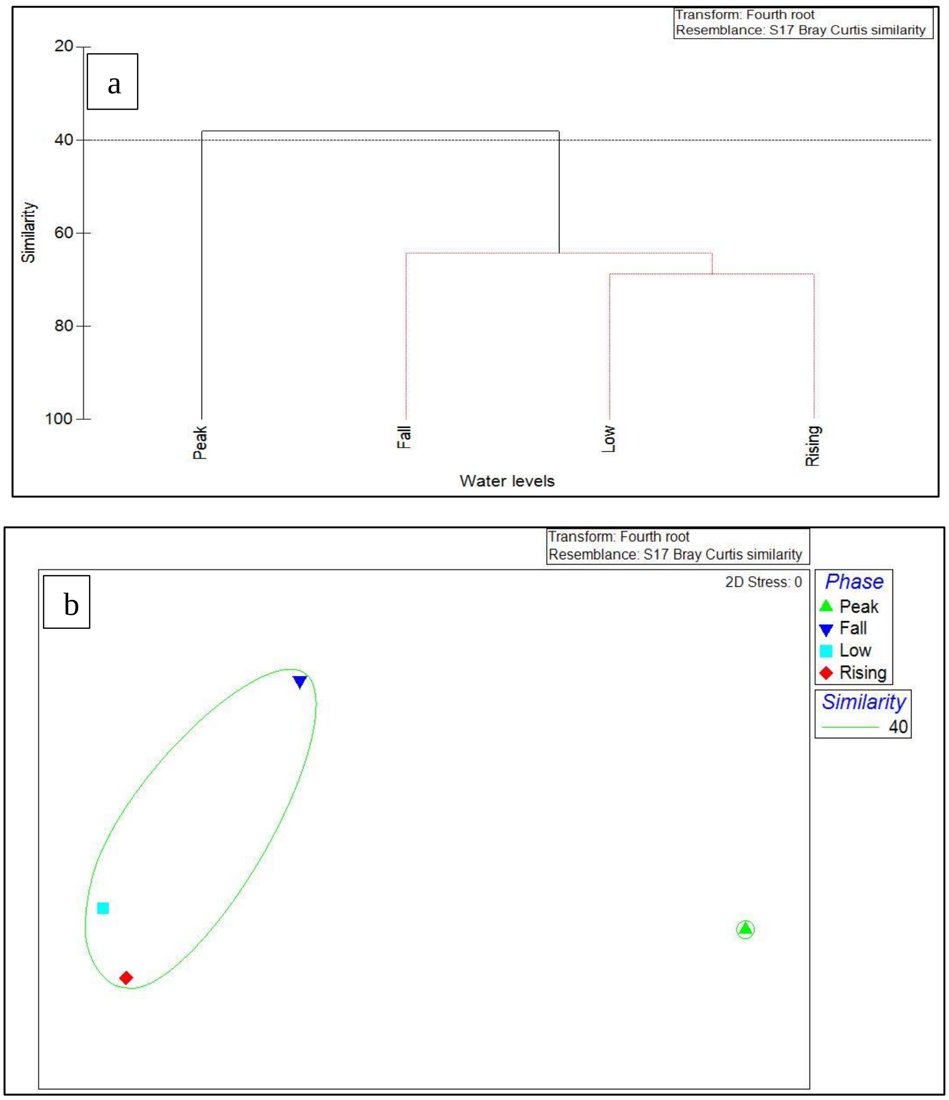

Figure 4.1 Dendrogram for hierarchical clustering analysis (a) and the multi-dimensional scaling (MDS) ordination (b) based on species richness grouped by hydro-periods (rising, peak, fall, and low flooding phase) in the Zambezi/Chobe floodplain, based on catch per unit effort (CPUE) and Bray-Curtis similarities (stress = 0.00).

Principal component analysis (PCA) based on fish abundance and the three environmental variables recorded at different flooding phases yielded three pairs of redundancy analyses (RDA) (across dissimilarity coefficients for canonical) explaining 70.5% of variation in the dataset (Figure 4.2). Only three variables (flooding phase, dissolved oxygen and conductivity) had a marked influence on fish abundance. The following species, *Enteromius multilineatus*, *Enteromius poechii*, *Enteromius haasianus*, *Micralestes acutidens*, *P. philander*, *T. ruweti* and *Micropanchax johnstoni* were inversely related to conductivity and significantly positively associated with dissolved oxygen ($p < 0.001$) whereas *R. maunensis* was directly related to water level.

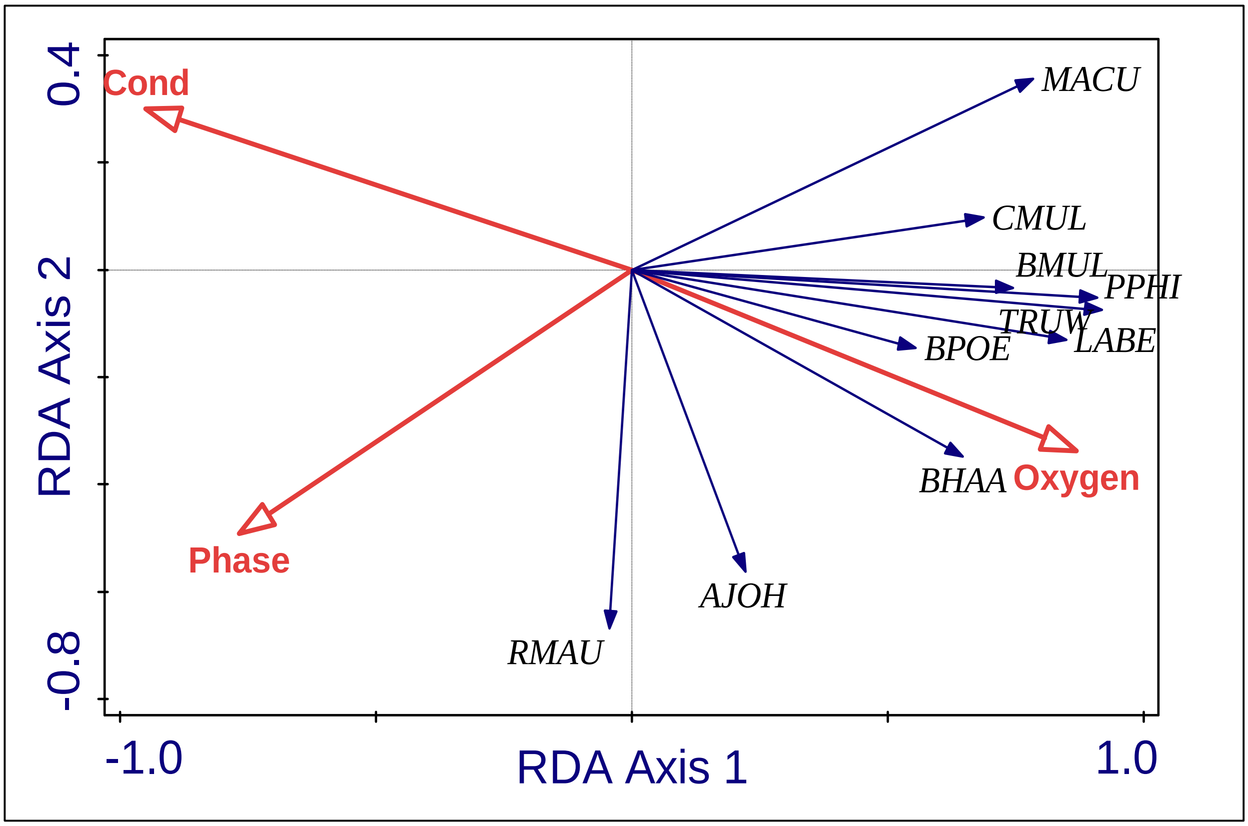

Figure 4.2 Principal Correspondence Analysis (PCA) of fish CPUE in the littoral zone of the Zambezi/Chobe floodplain and the three physicochemical variables (Cond=conductivity, Water phase, and dissolved oxygen) collected in 2016/2017. Principal component analysis (PCA) explaining 70.5% of variation in the dataset. RMAU=*Rhabdalestes maunensis*, AJOH=*Micropanchax johnstoni*, BHAA=*Enteromius haasianus*, BPOE=*E. poechii*, LABE=*Labeo* spp, TRUW=*Tilapia ruweti*, PPHI=*Pseudocrenilabrus philander*, BMUL=*E.*

Catch rates of selected species

Only four species, *Oreochromis andersonii*, *C. rendalli, T. ruweti,* and *P. philander* were collected in sufficient numbers at different flooding phases to determine their response to different water levels. Community structure of the four selected species in the littoral zone were interpreted from the monthly CPUE data and the mean size histograms (TL or FL mm) (Figures 4.3 and 4.4). *Oreochromis andersonii* was significantly more abundant in May 2017 (flood recession phase) than in September 2017 (low flooding phase) (Kruskal-Wallis test, df=4, $p<0.001$). Higher significant abundance of *C. rendalli* was recorded in April 2017 (peak flooding phase) than in December 2017 (low flooding phase) (Kruskal-Wallis test, df=4, $p<0.001$) (Figure 4.3). *Tilapia ruweti* and *P. philander* had a similar pattern in their monthly catch rates on the floodplain (Figure 4.3). The highest CPUE for both species was recorded in July (flood recession phase) and they were least abundant from September 2017– February 2018 (low flooding phase) (Figure 4.3). These differences were significant for both *T. ruweti* and *P. philander* (Kruskal-Wallis test, df =4, $p<0.001$).

Size structure of selected species

Of the four species, *O. andersonii* and *C. rendalli* are large-sized species, whereas *T. ruweti* and *P. philander* are small-sized species that rarely grow larger than 130 mm. While there is limited information on maturity length of *T. ruweti* and *P. philander,* both species are reported to attain maturity at a length below 90 mm (TL) (Skelton, 2001). The reported length at 50% maturity for *O. andersonii* is 240 mm (TL) and 214 mm (TL) for *C. rendalli* (Peel, 2012). Juvenile *O. andersonii* and *C. rendalli* (between 30 and 50 mm TL) were recorded during the rising phase in March 2017 (Figure 4.4) while larger specimens of both species (50 mm–80 mm TL) were recorded during the flood recession phase (June 2017) (Figure 4.4). These differences were significant for both *O. andersonii* (Kruskal-Wallis test, df=2, *p*=0.001) and *C. rendalli* (Kruskal-Wallis test, df=2, *p*=0.001). Unlike *O. andersonii* and *C. rendalli*, the emergence of small-sized *T. ruweti* and *P. philander* between 40 mm and 50 mm (TL), were observed during the non-flowing season (July 2017) (Figure 4.4). However, there were no clear patterns in seasonal mean size of *T. ruweti* and *P. philander* owing to their smaller body size and hence their recruitment patterns were inconclusive on the Zambezi/Chobe floodplain. However, larger *P. philander* (55 mm TL) and *T. ruweti* (60 mm TL) were observed during the low flooding phase (October 2017– January 2018) (Figure 4.4). These differences were significant for both *T. ruweti* (Kruskal-Wallis test, df=2, *p* <0.001) and *P. philander* (Kruskal-Wallis test, df =2, *p*=0.024).

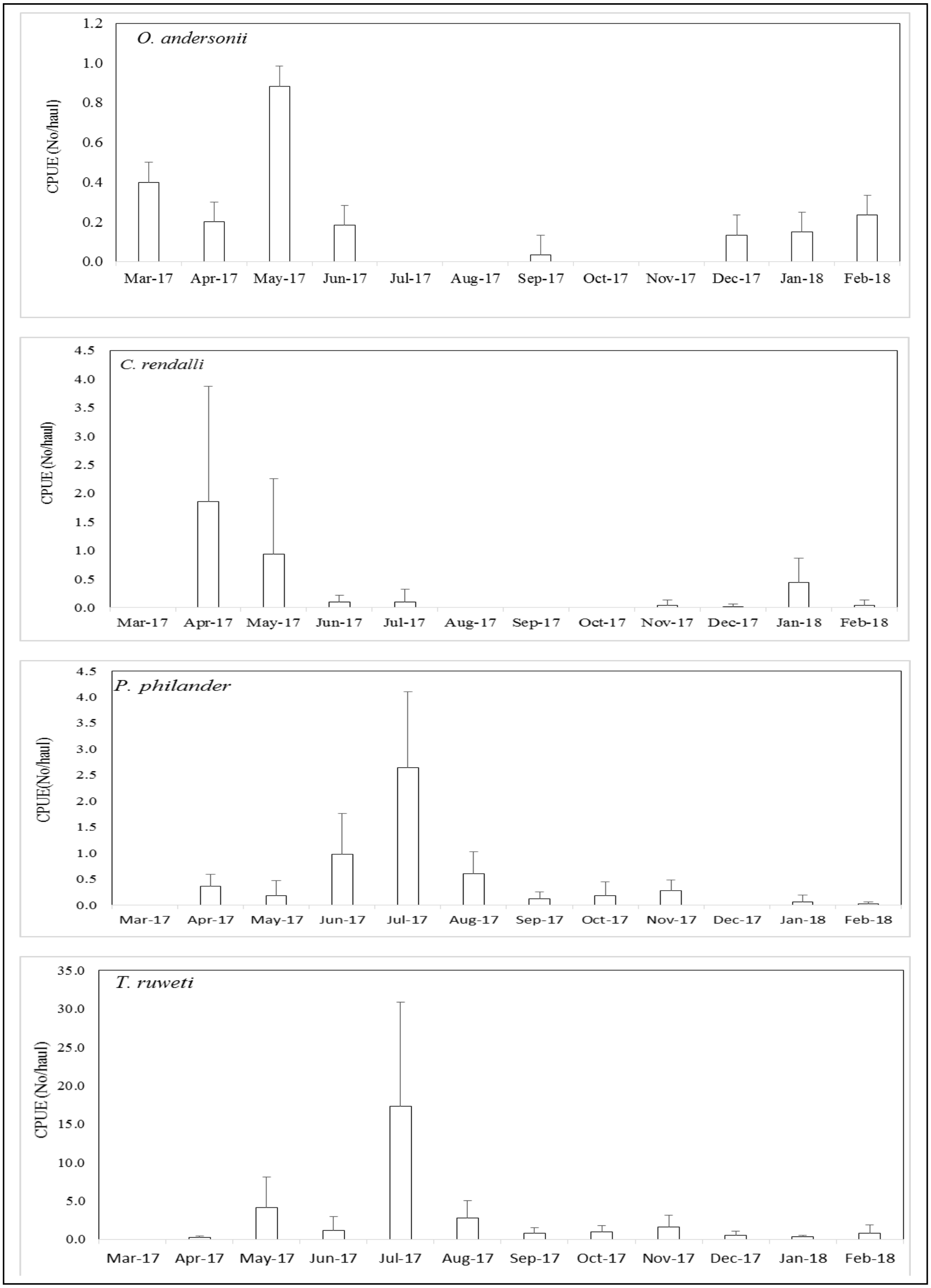

Figure 4.3 Monthly catch per unit effort of *O. andersonii*, *C. rendalli*, *T. ruweti* and *P. philander* sampled on the Zambezi/ Chobe floodplain.

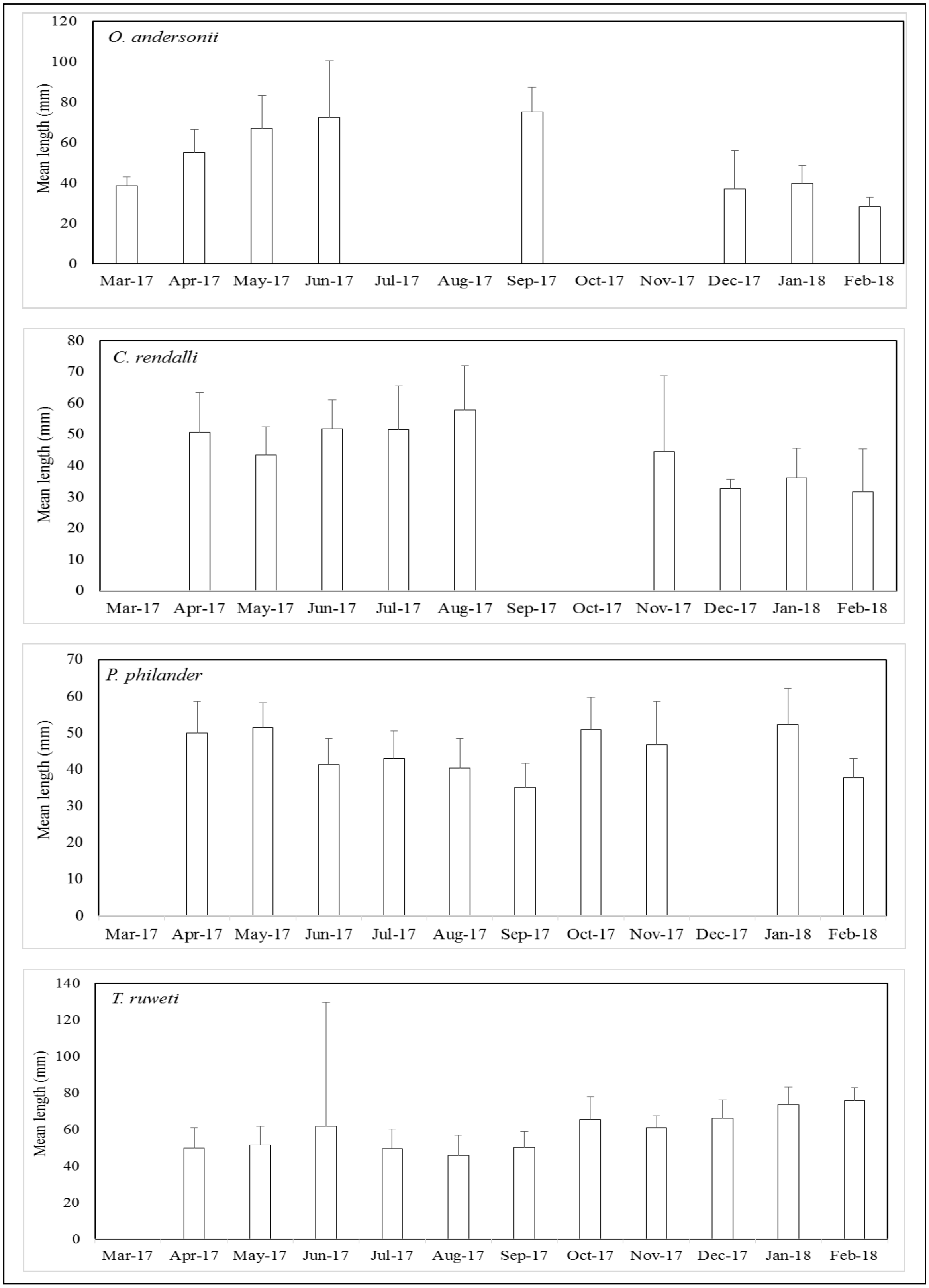

Figure 4.4 Monthly mean sizes (mm) of *O. andersonii*, *C. rendalli*, *T. ruweti* and *P. philander* sampled on the Zambezi/ Chobe floodplain.

4.4 DISCUSSION

Littoral fish communities

The aim of this chapter was to examine the influence of hydrological variability on small fish assemblages and abundance patterns within the littoral zone of the Zambezi/Chobe floodplain. The current study shows no significant difference in littoral species diversity between hydro-periods, accepting the null supposition that species diversity was similar among hydro-periods. Of the 80 different fish species documented on the Upper Zambezi River (Tweddle *et al.*, 2015), 31 species were sampled in the littoral zone of the Zambezi/Chobe floodplain. This is relatively higher than 24 species recorded by Simasiku (2014) in littoral zones of the Kavango floodplain but lower than 38 species recorded by Siziba *et al.* (2011) on the temporary floodplains of the Okavango Delta. This variation may be attributed to sampling equipment, sampling design and effort employed by various studies. Siziba *et al.* (2011) used a cast net in conjunction with Lundgren gillnets, while the current study employed a small seine net. The two sampling techniques employed by Siziba *et al.* (2011) may have effectively collected more fish families than the present study. Cichlids, characids and cyprinids dominated the catch in this study, accounting for more than 80% of the total fish captured. The prevalence of cichlids and cyprinids on the floodplains supports the studies of Høberg *et al.* (2002); Siziba *et al.* (2011), and Simasiku (2014) who conversely reported a high incidence of juvenile cichlids within the temporary floodplains of the Kavango floodplain. This high incidence of small fish has been reported as an "ecological" adaptation (Jobling, 1995), an adaptation that is promoted by the fact that, during low flows, floodplains dehydrate and support terrestrial processes such as the growth of terrestrial flora and foraging by wildlife (Bonyongo, 2004; Ramberg *et al.*, 2006). These terrestrial processes, together with the dead, decomposing macrophytes of the previous flooding season, make nutrients available during the inundation of encroaching flood waters which support a large biomass of aquatic macrophytes (Junk *et al.*, 1989). In turn, these aquatic macrophytes play a vital role in stabilising sediment and providing habitat diversity and shelter, substrata for periphyton and sites for abundant food production for invertebrates and fish (Wetzel and Hough, 1973; Pelican *et al.*, 1978; Ramberg *et al.*, 1978; Howard-Williams, 1981; Machena, 1997).

Small fish assemblages in the littoral zone

When the ichthyofaunal similarity by flooding phase is taken into account, three groups were retrieved: (i) peak flooding (ii) fall, (iii) low and rising phase. Species composition differed significantly between hydro-periods, rejecting the null hypothesis of no difference in species composition between hydro-periods in this study. This is possibly related to specific hydro-phase characteristics. The peak flooding phase exhibited a series of characteristics that distinguish it from the other stages of flooding stages. Peak flooding was characterised by high levels of dissolved oxygen, high water temperature, slightly alkaline pH, but lower conductivity. The prolonged receding phase was comparably characterised by harsh environmental conditions such as high water temperatures, low dissolved oxygen and high conductivity. Hence the variations in species composition observed between hydro-periods may be reflecting the influence of environmental filters and food availability on fish species. Among other parameters, dissolved oxygen, conductivity, and water level (flooding phase) were identified as determinants of the abundance of small fish in the littoral zone. With regard to water quality, oxygen plays a major role in aquatic organisms' respiration (Mbalassa *et al.*, 2014).

Higher densities of small fish (especially cichlids) were netted during the peak flooding phase. Hence the observed difference in fish populations at rising and decreasing flood levels may be related to food availability. Cichlid populations tend to dominate in response to high water levels when aquatic hydrophytes have had time to establish. High densities of invertebrate fauna are known to develop soon after the flooding and of these, zooplankton form an important source of food for juvenile fish as noted above. As a result, these favourable feeding grounds might have attracted and accounted for the high abundance of cichlids on the study floodplain. Similar findings on the prevalence of cichlids during peak water levels in the Kavango floodplain were reported by Hocutt and Johnson (2001). This might help to account for improved cichlid production in floodplain systems during high floods (Siziba *et al.,* 2011).

In contrast to cichlids, cyprinids were more prevalent during the low water stage of flooding in this study; their dominance during the low flooding phase may be explained by their high tolerance of harsher environmental conditions (Skelton, 2001). Cyprinids are reported to survive low dissolved oxygen conditions, showing signs of suffocation only when the oxygen concentration is below 1.5-2.0 (mg/l) (Alabaster and Lloyd, 1980). Cyprinids may have exploited the floodplain more efficiently and became abundant in isolated pools during the flood recession phase. This finding agrees with Siziba *et al.,* (2011) who report a dominance of cyprinids during the terminal phase of desiccation with low concentrations of oxygen in the Okavango delta. These observations are confirmed by the species sorting model where aquatic hypoxia during the dry season favour tolerant species such as cyprinids and poeciliids (Agostinho *et al.,* 1997b). Lower dissolved oxygen during the flood recession period could be the result of the high rate of decomposition of organic matter from high density of aquatic plants covering the floodplain (Miranda and Hodges, 2000).

Temperature is known to be a critical factor that influences both aquatic life and other physicochemical processes in the aquatic system (Mbalassa *et al.*, 2014); however, the temperature and pH data from this study showed no relation to small fish community assemblages. Temperature is relatively constant in tropical streams and is therefore considered to be less of an influence on fish behaviour than in temperate catchments (Lowe- McConnell, 1987). Tropical species grow best at temperatures between 20 and 32 °C (Lowe-McConnell, 1987) and the water temperatures on the floodplain remained within this range year-round. Leveque and Quensiere (1988) rank water level among the most important factors affecting community structure in shallow lakes. Indeed, the flooding phase, in conjunction with water oxygen and conductivity, were the prime factors noted as influencing community structure in this study.

The influence of reproduction periodicity on fish assemblages in the littoral zone

Juvenile *O. andersonii, C. rendalli, P. philander* and *T. ruweti* were used as indicator species for recruitment because of their large sample size. *Oreochromis andersonii* and *C. rendalli* are both commercially important species while *P. philander* and *T. ruweti* serve as an important food source for the higher trophic levels in an aquatic food chain (Siziba *et al.*, 2011). The abundance of *O. andersonii* and *C. rendalli* was highest in February–March (rising phase) while *P. philander* and *T. ruweti* were most abundant in May–July. The CPUE of *O. andersonii* and *C. rendalli* differed significantly between sampling months (March 2017 – April 2018) while that of *P. philander* and *T. ruweti* remained stable. The null hypothesis that CPUE of the most abundant species were similar between sampling seasons was accepted for *P. philander* and *T. ruweti* but rejected for *Oreochromis andersonii* and *C. rendalli*. The observed peaks in abundance of *O. andersonii* and *C. rendalli* during the rising phase follow their biological cycle, coinciding with their reported breeding periodicity from August to March (Peel, 2012; van der Waal, 1985). The early abundance in juvenile *O. andersonii* and *C. rendalli* in this study could therefore be attributed to spawning season. Similar observations on the timing of recruitment were reported on the Zambezi floodplain where high concentrations of nesting *C. rendalli* were observed from November–March (van der Waal, 1985). Similarly, in Lake Chicamba high juvenile densities of

Oreochromis mossambicus and *C. rendalli* coincided with the warm, wet season in March (Weyl and Hecht, 1998). High availability of food resources and habitat complexity on the floodplain may have enhanced their spawning success and contributed to an increase in recruitment during the early flooding stage. By contrast, peaks in abundance of *T. ruweti* and *P. philander* were observed outside their reported peak breeding season in September, which may be related to the species' extended breeding cycle, spanning from early spring to late summer (Skelton, 2001). High densities of juvenile *T. ruweti* and *P. philander* during the flood recession indicate that breeding patterns of these species are not restricted to flooding, so supporting the notion that breeding in cichlids is independent of flooding (Junk *et al.*, 1989).

Possible influence of predation on small fish recruitment patterns

Densities of *O. andersonii*, *C. rendalli*, *T. ruweti* and *P. philander* were rapidly depleted to very low numbers as the floodwaters started to recede in August 2017-February 2018 and habitats of choice became less available. Predation has been inferred to drive fish community changes in floodplain habitats as the water level falls and fish densities increase. The "predator-prey wave" theory states that piscivorous predators target prey of specific size and that prey are relatively safe from predation once they are above that critical size (Savill and Hogeweg, 1999). Among other predators observed in this study, *Schilbe intermedius* and *Clarias gariepinus* are ecologically adaptable species, inhabiting a range of habitats from floodplains to river channels (Skelton, 2001). These predatory species were observed during the low flooding phase and may have contributed to a regulatory effect on small fish during the low flooding phase in this study. Similarly, predation by wading birds in the Everglade Swamp decreased fish abundance and biomass by 75 – 80% in isolated water bodies (Bruton and Jackson, 1983). Declines in juvenile densities of bluegill bream (*Lepomis macrochirus*) after severe drawdown was ascribed to high predation pressure by the largemouth bass, reinforcing the patch dynamics model where less-competitive species are initially common during the flood pulse, and largely replaced by superior competitors and predators during the drawdown events (Hutchinson, 1953; Townsend, 1989).

The influence of life stage on fish assemblages in the littoral zone

One of the most necessary attributes of fish and other mobile animals is the ability to move away from unsuitable conditions (Siziba *et al.*, 2011). During the flood recession phase, the floodplain habitat starts to shrink, and fish populations are expected to vacate to the main river stream (Chapman and Kramer, 1991; Chapman *et al.*, 2000). This implies that a switch in use of the littoral and open deeper water in river streams by fish is life-stage dependent. Mainly juveniles inhabit the littoral zone and only extend into deeper offshore zones at a size big enough to withstand predation pressure from open water predators. Hence, it might be the case that juvenile *O. andersonii* and *C. rendalli* vacated the littoral zone after attaining an average size of 80 mm (TL) just before the connection with the main river channel was lost. This is herein supported by the movement of juvenile *Oreochromis mossambicus* into open deep waters channels in the East Kleinemonde Estuary after attaining an average size of 80 mm (Ellender *et al.*, 2008). Simasiku (2014) observed that *O. andersonii* and *O. macrochir* migrated out of the marginal area of the Kavango floodplain after attaining average sizes between 80 mm and 90 mm (TL), leaving smaller sized individuals <50 mm TL. Jackson (1961) also found that juvenile *O. macrochir* in Lake Mweru in Zambia live along the swampy edge of the lake and enter the open water at a length >80 mm when they are active enough to withstand predation by *H. vittatus.* This may partially account for the source of variation in fish sizes in the littoral zone of the study floodplain.

The influence of drawn down on fish recruitment patterns

While spawning periodicity in cichlids is often independent of flooding, recruitment success has been shown to be negatively influenced by drawdown (Weyl and Hecht, 1998). Further declines in densities of *C. rendalli* and *T. ruweti* may be attributed to the lethal effects of the drawdown events on egg and larval mortality as reported by Weyl (1998). Rapidly decreasing water levels have been shown to lead to poor hatching success as a result of nest desertion, poor egg survival, and disrupted spawning (Weyl, 1998). Both *C. rendalli* and *T. ruweti* are nest spawners which guard their eggs and fry for an extended period. The fact that both species prefer to spawn in shallow vegetated areas may have increased the likelihood of desiccation of their eggs and larvae at drawdown. Sinking water levels during the drawdown period thus might have resulted in complete loss of a year class as their eggs displaced to drying land. It is also possible that nests were deserted as a consequence of exposure to air by receding waters and this may have interfered with their breeding activities. The lethal effects of drawdown events on mortality of eggs and larvae have been reported in centrarchids (Ploskey, 1986) where drastic drawdown in water level has been identified as the cause of poor hatching success due to nest desertion, poor egg survival, and disrupted spawning (Ploskey, 1986). This phenomenon may partly account for the observed variation in juvenile fish abundance and mean sizes in this study.

CONCLUSION

Flooding of the Zambezi/Chobe floodplain forms a crucial habitat for cichlids and cyprinids. Fish assemblages in the littoral zone varied among hydro-periods. These variations were driven by the flooding stage and water quality. The prevalence of cichlids during the peak flooding phase was related to spawning periodicity, enhanced microhabitats, and the abundance of food suitable for lavae and juveniles, while a severe decline in fish abundance during the flood recession period was allied to fish migration and a consequence of deteriorating water quality at low water phase. Juvenile *O. andersonii* and *C. rendalli* were reduced to lower numbers during the low flooding phase, suggesting that they migrated out of the floodplain into permanent water bodies just before the connection between the floodplain and the main river was lost.

CHAPTER 5: THE FEEDING ECOLOGY OF TIGERFISH (*HYDROCYNUS VITTATUS*) IN THE KALIMBEZA CHANNEL OF THE ZAMBEZI RIVER, NAMIBIA

5.1 INTRODUCTION

Studies on fish feeding can yield relevant information that can affect competition, mortality, fecundity and growth in fish communities. The stomach contents of many African inland water fishes have been studied with a view to ascertaining their dietary requirements in their natural habitats and discerning the relationships between the fish and their biotic environment (Sandon and Tayib, 1953; Verbeke, 1959; Corbet, 1961; Chilvers and Gee, 1974; Lewis, 1974; Whyte, 1975).

The Tigerfish *Hydrocynus vittatus*, a member of the Alestiidae, a piscivore and a ferocious pelagic predator, is widely distributed in the Zambezi River (Jackson, 1961; Skelton, 2001). This species can grow up to 70 cm in length and weigh up to 15 kg, although such large specimens are rare (Marshall, 2011). *Hydrocynus vittatus* supports an important commercial and recreational fishery in the Zambezi/Chobe, Okavango Rivers and Lake Kariba (Winemiller and Kelso-Winemiller, 1994).

Predation by *H. vittatus* has been shown to strongly affect fish community structure via direct and indirect mechanisms (Jackson *et al.*, 2001). Jackson (1961) hypothesized that many smaller fish species are excluded from open water habitats of primary river channels where large *H. vittatus* patrol, and are restricted to floodplain, backwater and marginal habitats, possibly leading to different assemblages in particular pools or riffles because prey species move to sites providing less risk of predation (Gilliam and Fraser, 2001). Prey species may opt to inhabit areas where predators such as *H. vittatus* have difficulty in accessing them (Schlosser and Angermeier, 1990), and these may be habitats different from those selected when predators are not present. For instance, Winemiller and Kelso-Winemiller (1994) found that predation by *H. vittatus* excludes the African pike, *Hepsetus odoe*, from the main river channel of the Upper Zambezi, but the pike is common in the main river channel of the Kafue River where *H. vittatus* is absent. The brown spot largemouth, *Serranochromi thumbergi*, an open water predatory cichlid, is only common in the Kafue River and the lower reaches of the Okavango Delta where *H. vittatus* is absent (Tweddle *et al.*, 2004). When prey species alter their choice of habitat and foraging to reduce predation risk, they may experience corresponding changes in life history and fitness reduction.

In addition to predation, interspecific competition for food play an important role in structuring fish communities of *H. vittatus* (Jackson *et al.*, 2001). The different size class of the same species may play functionally different ecological roles. In essence, this means that food requirements for juvenile *H. vittatus* can be completely different from the adult stages (Welcome, 2001).Where there are no differences in diet between adult and juvenile fish, inter-cohort competition may significantly influence juvenile survival (Jackson *et al.*, 2001). Juvenile mortality has been significantly positively correlated to adult density as juveniles are forced to inhabit areas associated with poorer food resources and greater risk of predation (Ward *et al.*, 1999).While several studies have been conducted on the feeding ecology of *H. vittatus* in large dams and lakes (Lewis, 1974; Mhlanga, 2003; Dalu *et al.*, 2012), no study has systematically analysed their feeding ecology in the Kalimbeza Channel of the Zambezi River. The aim of this study was to assess the feeding feeding of *H. vittatus* in the Kalimbeza Channel of the Zambezi River. To achieve this aim, the following hypotheses were tested:

1. There is no shift in prey selection between small, medium and large *H. vittatus*.
2. There is no seasonal shift in prey selection of *H. vittatus*.

5.2 MATERIAL AND METHODS

Field sampling

Monthly sampling was conducted in the Kalimbeza Channel (Figure 5.1b) from February to December 2016. The sampling programme was conducted using two fleets of multifilament gillnets with stretched meshes of 12, 16, 22, 28, 35, 45, 57, 73, 93, 118 and 150 mm. Each fleet was 110 m long by 2.5 m deep and comprised eleven randomly distributed 10 m mesh panels. Gillnets were set between 17h00 and 19h00 in the evening and retrieved between 06h00 and 08h00 the following morning. Nets were set in open waters with their end top ropes anchored to aquatic vegetation. Freshly caught specimens of *H. vittatus* were collected and measured to the nearest millimetre FL, and weighed to the nearest gramme. Fish stomachs were dissected out and carefully split open using a pair of pointed-nose scissors. Stomach contents were spread out on white treys in the field and visually assessed. Each item in the diet was identified to the lowest possible taxonomic level (using the guides by Skelton, 2001; Gerber and Gabriel, 2002), counted and measured to the nearest millimetre standard length (SL), and weighed to the nearest gramme after drying on paper towels.

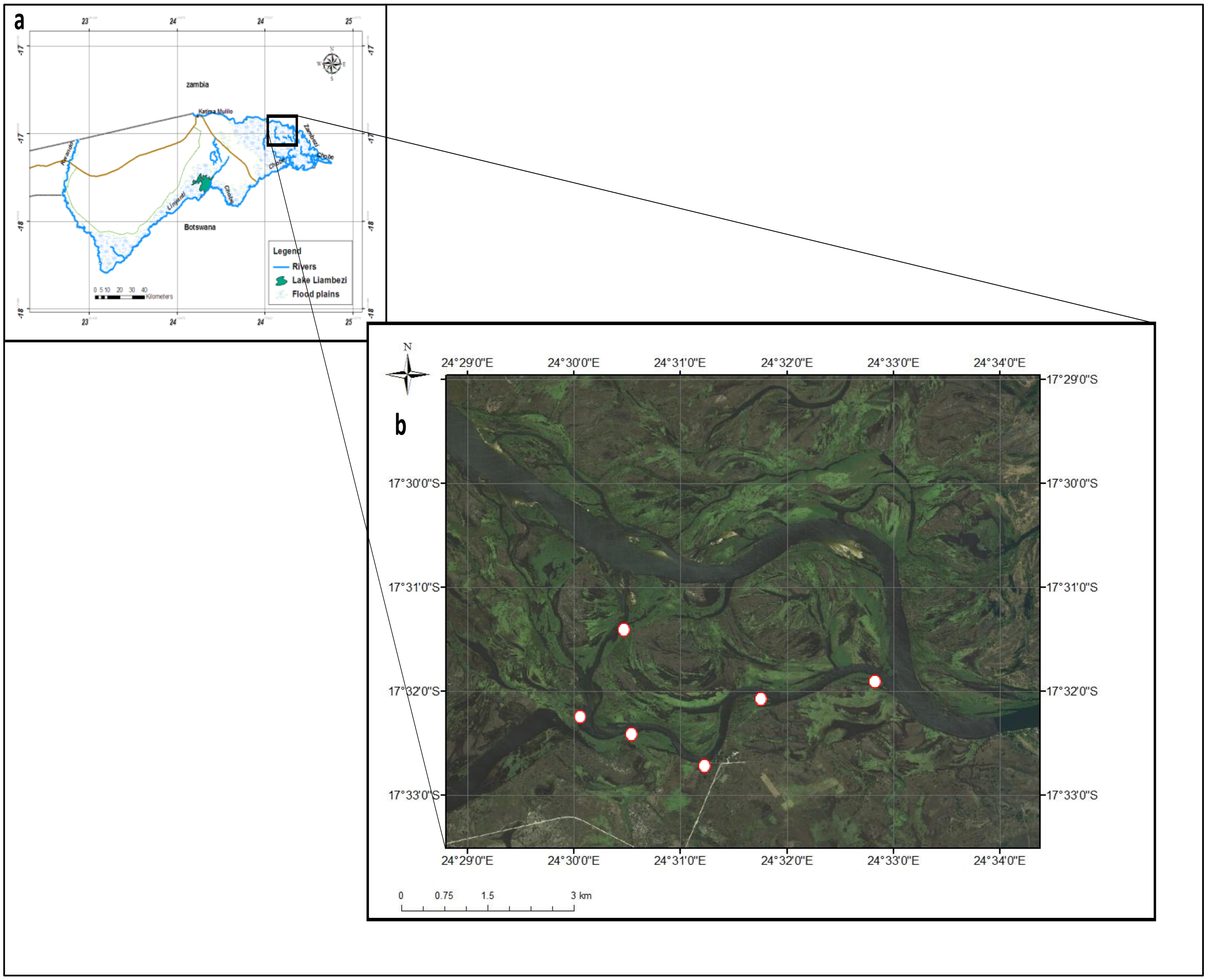

Figure 5.1 Map of the Zambezi Region (a), showing the Kalimbeza Channel on the Zambezi/Chobe River (b), Zambezi Region. ○ = Gillnet sites. Generated using ArcGIS 9.3. Map not to scale.

Diet analysis

The diet was determined by the frequency of occurrence and percentage number method according to Hyslop, (1980). Frequency of occurrence accounts for the number of stomachs in which each prey item occurs and is expressed as a percentage of the total number of stomachs examined.

Frequency of occurrence**:** $O_i = \frac{J_i}{P} \times 100$

Where *Ji* is number of fish containing prey ***i*** and *P* is the number of fish with food in the stomach.

Number method: the number of individuals of each food type in each stomach is counted and expressed as a percentage of the total number of food items in the sample studied, or as a percentage of the gut contents of each specimen examined, from which the total percentage composition is estimated (Zengeya and Marshall, 2007).

Percent by number**:** $N_i = \frac{N_i}{\sum_1^Q N_i} \times 100$

Where N*i* is the number of prey item *i*

The food items were then combined into broader taxonomic categories for quantitative comparisons and the percentage of empty stomachs was determined. In order to determine whether there was a change in food composition among the different size groups, the fish were separated into several FL size classes: small (<140 mm), larger juveniles; further referred here in as medium size class (141–175 mm), and immature larger fish; further referred here in as large (>176 mm). Length class selection was based on the biology and life history of *H. vittatus* according to Skelton (2001) and past research on the feeding ecology of *H. vittatus* in the Upper Zambezi (i.e. Dalu et *al.*, 2012). Actual data on stomach contents by season (wet and dry) and size (small, medium and large) were first checked for normality and homogeneity of variances using Levene's test. To improve on the assumptions of normality and homogeneity of variances, data were log10 transformed. In cases where transformation failed to normalise the data, the equivalent non-parametric Mann-Whitney U test was employed to test for the differences in stomach contents between seasons while the Kruskal-Wallis test ($p<0.05$) was employed to test for the differences in stomach contents between fish sizes of *H. vittatus.* A linear regression was used to assess the relationship between the predator and prey length. Statistical analyses were performed using SPSS statistical software.

5.3 RESULTS

Diet composition of *Hydrocynus vittatus*

A total of 498 specimens of *H. vittatus* were collected during the survey (Table 5.1). Of the 498 stomachs dissected, 176 (35.3%) contained food. Twenty-five different prey items were identified and categorised into 18 broad groups (Table 5.1). Of the fish prey items, 21.1% could not be identified as they were in an advanced stage of digestion. The major prey groups were cichlids, characids, cyprinids, mochokids, mormyrids, *Micropanchax* spp., schilbeids and aquatic insects. Figure 5.2 shows the cumulative number of unique prey species observed in the stomachs of *H. vittatus* over time. The results show a rapid observation of new prey species from day 1 up to day 28, after which the graph stabilises from day 29 to 40. One or two new prey species were observed between day 41 and 42 and eventually the graph stabilises for the next 48 sampling days and no new species were observed thereafter. The sample size was considered sufficient as no additional prey items were observed during the later days of sampling (Figure 5.2). No single stomach content was observed on day 16, as denoted by the gap in the graph. The frequency of empty stomachs observed between July and September was generally higher than that observed between January and June (Figure 5.3). The results show that *Synodontis* spp. were the most important dietary component by percentage number (15.2%) and frequency of occurrence (17.8%), followed by *Micralestes acutidens* (10.3%) (12.1%), *Brycinus lateralis* (7.8%) (9.2%) and aquatic insects (21.1%) (7.5%) (Table 5.1). Other prey occurred less frequently, for instance *Petrocephalus catastoma*, *Enteromius fasciolatus*, *Enteromius unitaeniatus*, *Cyphomyrus cubangoensis*, *Rhabdalestes maunensis* and *Schilbe intermedius* contributed less than 5% to the total number of prey consumed (Table 5.1). Insects and fish were the two major groups in the diet. Fish prey items were the most important food item and accounted for 80% of the total prey identified. Aquatic insects of the order Trichoptera and Odonata were the important groups of insect found in the stomachs of *H. vittatus*.

Table 5.1 Major prey categories and their importance in the diet of *Hydrocynus vittatus* in the Kalimbeza channel of the Zambezi River (February - December 2016). N = total number of prey items, while FO = Frequency of occurrence.

Prey items	**N**	**%N**	**FO**	**%FO**
Brycinus lateralis	16	7.8	16	9.2
Enteromius fasciolatus	2	1	2	1.1
Enteromius poechii	7	3.4	7	4
Enteromius radiatus	6	2.9	6	3.4
Enteromius unitaeniatus	2	1	2	1.1
Cyphomyrus cubangoensis	1	0.5	1	0.6
Micropanchax johnstoni	2	1	2	1.1
Marcusenius altisambesi	11	5.4	11	6.3
Micralestes acutidens	21	10.3	21	12.1
Pollimyrus castelnaui	1	0.5	1	0.6
Petrocephalus catastoma	5	2.5	5	2.9
Rhabdalestes maunensis	1	0.5	1	0.6
Schilbe intermedius	1	0.5	1	0.6
Synodontis spp.	31	15.2	31	17.8
Cichlids	11	5.4	11	6.3
Aquatic insects	43	21.1	13	7.5
Unidentified fish	43	21.1	43	24.7
Total	**204**	100	**174**	100

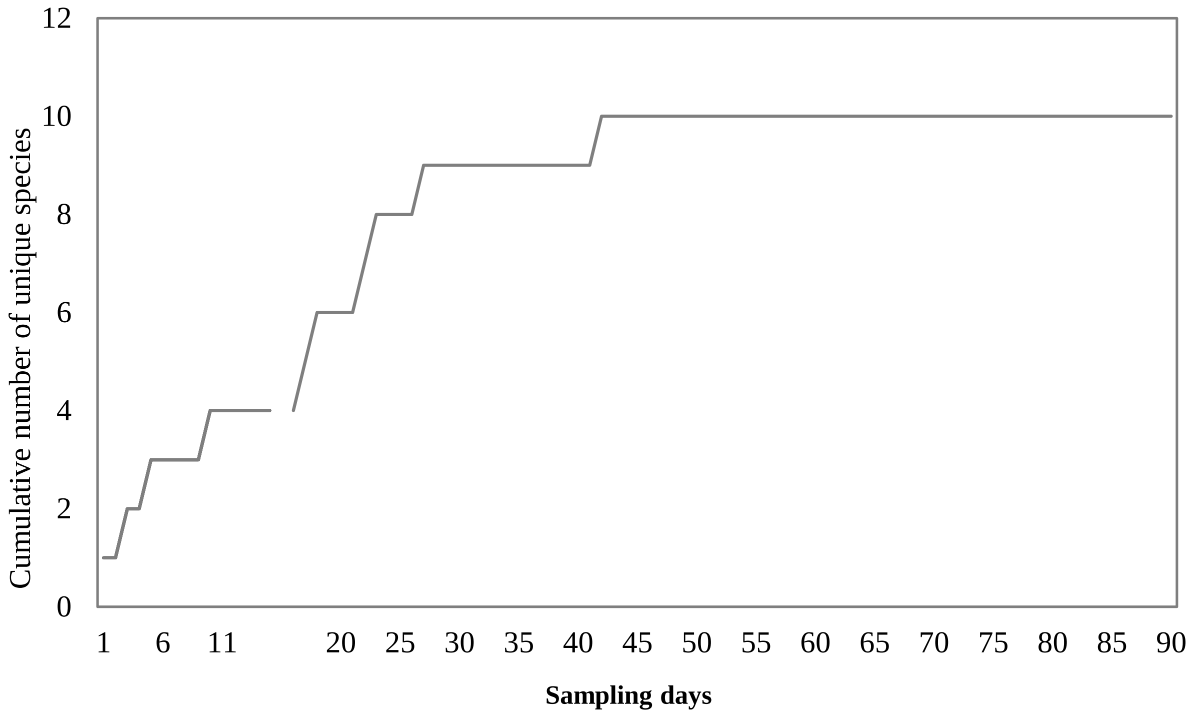

Figure 5.2 Cumulative number of unique prey items observed in the stomach of *Hydrocynus vittatus* in the Kalimbeza Channel, Zambezi River (February - December 2016).

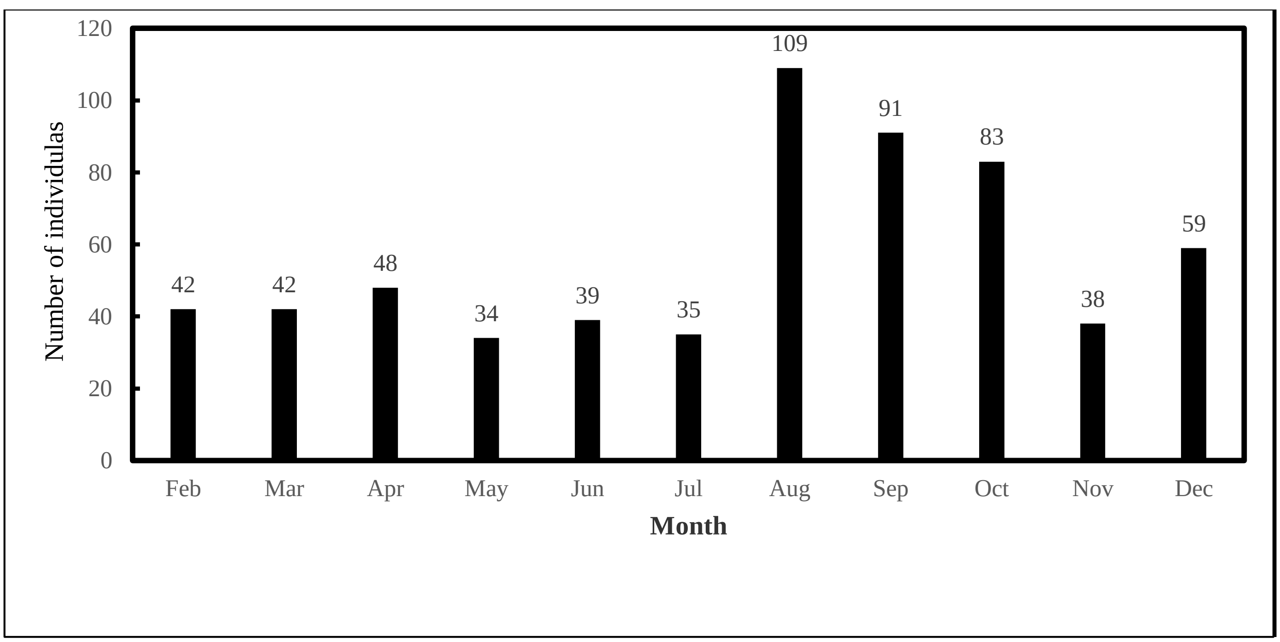

Figure 5.3 Incidence of empty stomachs in 498 specimens of *Hydrocynus vittatus* in the Kalimbeza Channel, Zambezi River (February - December 2016).

Change in diet relative to size class of Hydrocynus vittatus

The length of specimens sampled ranged from 58 mm to 603 mm. The body weight also varied from 6.6 g to 2910 g. Out of the 172 *H. vittatus* specimens with observable prey items in their stomachs, 69 individuals were observed in the small size class, 59 in the medium size and 44 in the large size class respectively (Table 5.2). Most prey (95%) were ingested whole while the remaining 5% were dismembered in pieces. The small *H. vittatus* (less than 144 mm FL) size class predominantly fed on *Synodontis* spp. (14.1%), *M. acutidens* (9.9%) and aquatic insects (8.4%). *E. unitaeniatus*, *E. fasciolatus*, *Micropanchax johnstoni*, *Marcusenius altisambesi*, *P.catastoma* were observed in small quantities. Medium sized *H. vittatus* (141-175mm) had a total of 14 different prey items in the stomachs. This group preyed heavily on *Synodontis* spp. (24.7%), *M. acutidens* (17.3%) and aquatic insects (15.8%). Species such as *E. fasciolatus*, *Enteromius radiatus*, *E. unitaeniatus* and *Pollimyrus castelnaui* were observed in small quantities.

Large adults size class (>176mm) showed a diet in which *Synodontis* spp. (26.1%), *B. lateralis* (15.2%) and *M. acutidens* (13.0%) dominated. There were significant differences in prey items consumed between small, medium and large sized *H. vittatus* (Kruskal-Wallis test, df = 3, p = 0.001). Tukey's Post hock test showed no differences in prey items observed between small vs. medium size class, while significant differences were observed between small vs. large and medium vs. large size classes (p<0.05).

Table 5.2 Percentage diet composition of *Hydrocynus vittatus* in the Kalimbeza Channel, Zambezi/Chobe River (February – December 2016).

Prey items	**<140mm (n=69)**	**141-175mm(n=59)**	**>176m (n=44)**
CICHLIDAE	7.1	12.3	8.6
CYPRINIDAE			
Enteromius fasciolatus	1.4	2.5	2.2
Enteromius poechii	2.8	4.9	4.3
Enteromius radiatus	1.4	2.5	8.7
Enteromius unitaeniatus	1.4	2.5	2.2
Sub-total	7	12.4	17.4
MORMYRIDAE			
Marcusenius altisambesi	1.4	2.5	2.2
Pollimyrus castelnaui	1.4	2.5	4.4
Petrocephalus catastoma	2.8	4.9	2.2
Sub-total	5.6	9.9	8.8
CHARACIDAE			
Brycinus lateralis	5.6	9.9	15.2
Micralestes acutidens	9.9	17.3	13
Sub-total	15.5	27.2	28.2
Synodontis spp**.**	14.1	24.7	26.1
AQUATIC INSECTS	8.4	15.8	-
SCHILBEIDAE	-	-	2.2
POECILIIDAE	1.4	2.5	-
Unidentified fish	40.8	71.7	8.7

Change in diet relative to wet and dry seasons

The observed diet components of *H. vittatus* in the wet season (November–March) and dry season (April–October) are presented in Table (5.3). The frequency of occurrence of the different prey consumed were significantly higher during the wet season (n=90) than the dry season (n=84) (Mann-Whitney test, p<0.05). During the wet season, *H. vittatus* consumed larger numbers of aquatic insects (17%), *B. lateralis* (7.8%), and *Synodontis* spp. (6.6%). Similarly, during the dry season, *H. vittatus* showed a diet which was dominated by *Synodontis* spp. (29.8%), *B. lateralis* (10.7%) and *Cyphomyrus cubangoensis* (13.1%). However, aquatic insects were consumed in small proportion (2.4%). The least important prey items were *R. maunensis*, *C. cubangoensis* and *P. castelnaui*. During the wet season, *M. acutidens* (13.2%), aquatic insects (9.4%) and *Synodontis* spp. (9.4%) were dominant prey items of the small size class (<140 mm) while *M. acutidens* (20.6%), aquatic insects (11.8%) and *Synodontis* spp. (11.8%) were the most dominant prey items of the intermediate size class (141–175 mm) (Table 5.3 b). *Synodontis* spp. (31.8%), *M. acutidens* (13.6%), and equal proportions of *B. lateralis* (9.1%), and aquatic insects (9.1%) were the most dominant prey items in larger size class (>176 mm). During the dry season, the most important food items in the small size class of *H. vittatus* were: *Synodontis* spp. (33.3%), *B. lateralis* (20.0%), and cichlids (13.3%). Aquatic insects (59.6%), *M. acutidens* (15.4%), and *P. castelnaui* (9.6%) were the predominant food categories of the intermediate size class (141–175 mm). *Rhabdalestes maunensis* (22.2%) and *M. acutidens* (16.7%) were the dominant food categories of the large size class (Table 5.3 b).

Table 5.3 (a) Percentage frequency of occurrence of each prey component of *Hydrocynus vittatus* in the Kalimbeza channel, Zambezi River, between seasons (February – December 2016).

Species	**Wet (n= 90)**		**Dry (n=84)**	
	FO	%FO	FO	%FO
CICHLIDAE	1	1.1	10	11.9
CYPRINIDAE				
Enteromius poechii	1	1.1	6	7.1
Enteromius radiatus	1	1.1	5	6
Enteromius fasciolatus	-	-	2	2.4
Enteromius unitaeniatus	2	2.2	-	-
Sub-total	4	4.4	13	15.5
MORMYRIDAE				
Marcusenius altisambesi	-	-	11	13.1

Pollimyrus castelnaui	-	-	1	1.2
Petrocephalus catastoma	1	1.1	4	4.8
Cyphomyrus cubangoensis	-	-	1	1.2
Sub-total	1	1.1	17	20.3
CHARACIDAE				
Brycinus lateralis	7	7.8	9	10.7
Micralestes acutidens	16	17.8	5	6
Rhabdalestes maunensis	-	-	1	1.2
Sub-total	23	25.6	15	17.9
AQUATIC INSECTS	11	12.2	2	2.4
SCHILBEIDAE	1	1.1	-	-
POECILIIDAE	2	2.2	-	-
Synodontis spp.	6	6.6	25	29.8
Unidentified fish	41	45.6	2	2.4
Total	**90**	**100**	**84**	**100**

Table 5.3 (b) Percentage frequency of occurrence of each prey component of *Hydrocynus vittatus* in the Kalimbeza Channel, Zambezi River (February – December 2016).

Prey items	**Wet season**			**Dry season**		
Size group	**<140**	**141-175**	**>176**	**<140**	**141-175**	**>176**
CICHLIDAE	3.8	2.9	4.5	20	1.9	16.7
CYPRINIDAE						
Enteromius poechii	1.9	5.9	-	-	1.9	11.1
Enteromius radiatus	1.8	2.9	9.1	-	-	11.1
Enteromius fasciolatus	-	-	-	6.7	-	5.6
Enteromius unitaeniatus	1.9	-	4.5	-	-	-
Sub-total	5.6	8.8	13.6	6.7	1.9	27.8
MORMYRIDAE						
Marcusenius altisambesi	-	2.9	-	6.7	15.4	5.6
Pollimyrus castelnaui	-	-	-	6.7	9.6	-
Petrocephalus catastoma	-	-	-	-	3.8	5.6
Cyphomyrus cubangoensis	-	2.9	-	-	-	-
Sub-total	-	5.8	-	-	-	-

CHARACIDAE						
Brycinus lateralis	1.9	8.8	9.1	20	3.8	-
Micralestes acutidens	13.2	20.6	13.6	-	1.9	16.7
Rhabdalestes maunensis	-	-	-	-	1.9	22.2
Sub-total	15.1	29.4	22.7	20	7.6	38.9
AQUATIC INSECTS	9.4	11.8	9.1	6.7	59.6	-
SCHILBEIDAE	-	-	-	-	-	5.6
POECILIIDAE	1.9	2.9	-	-	-	-
Synodontis spp.	9.4	11.7	31.8	33.3	-	-
Unidentified fish	54.7	26.5	18.2	-	-	-

Prey predator length relationships

The prey length in relation to the predator length for *H. vittatus* is presented in Figure 5.4. Of the 126 *H. vittatus* with discernible, measurable food stomach contents, the study shows that *H. vittatus* feed primarily on fish less than 200 mm (20 cm) TL, a similar finding to that of Winemiller and Kelso-Winemiller (1994) and Dalu *et al*. (2012) who note that *H. vittatus* feed on fish less than 25 cm SL. The predator-prey length relationship shows that the prey-predator lengths ratio range from 11.0 to 43% (Figure 5.4).

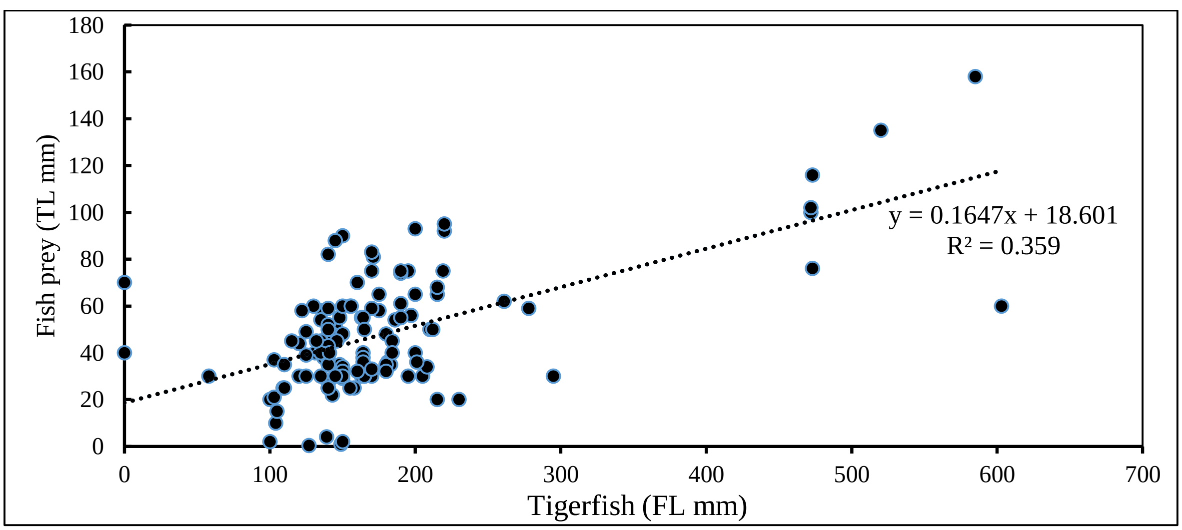

Figure 5.4 Relationship of prey standard length and predator standard length for Tigerfish, *Hydrocynus vittatus* (Regressions, P<0.05).

5.4 DISCUSSION

Diet composition of Hydrocynus vittatus

The current study shows that *H. vittatus* feeds extensively on non-cichlid fish species such as *Synodontis* spp., *M. acutidens, B. lateralis* and aquatic insects. In a similar study, Mhlanga (2003) reports that *H. vittatus* in Lake Kariba feed on Clupeidae (*Limnothrissa miodon*) (55%), cichlids (20%), other fishes, including Clariidae (catfish), *Synodontis* spp. (squeaker fish); macroinvertebrates (12%), and Alestiidae (*Brycinus* spp.) (<5%). Winemiller and Kelso-Winemiller (1994) also report that *H. vittatus* feed intensely on cichlids and *Synodontis* spp. (over 50%) in the Zambezi River floodplain, suggesting that fish were their major food source in this study. Evidently, *H. vittatus* habitually feed on diet components of animal origin (fin fish); the species is thus an exclusive piscivore.

The results of the stomach analyses in this study confirm the evidence of the high incidence of empty stomachs as observed by Mhlanga (2003) in Lake Kariba, and Dalu *et al*. (2012) for the Malilangwe reservoir. These findings are common in predatory fishes such as *H. vittatus* and the African pike. A high proportion of empty stomachs observed in this study may imply an infrequent encounter of prey as it is common for predators to live off large, high-quality, but infrequent meals or could be attributed to fish voiding their stomachs during stressful situations such as being trapped in the net.

Evidence of diet shift with size in Hydrocynus vittatus

There is evidence of diet shifts for *H. vittatus* by size: both small and medium sized classes fed on mixed proportions of aquatic insects (Odonata and Chiroptera) and fish, while adults were predominantly piscivorous and fed exclusively on fin fish. Hence the null hypothesis of no ontogenetic shift in prey selection by size is accepted for small vs. medium *H. vittatus* but rejected for small vs. large and medium vs. large *H. vittatus.* Changes in the food composition and feeding habits of fish in relation to the size or age of fish have been noted as a biological aspect common to many tropical fish species. The observed diet shift for *H. vittatus* by size in this study might be allied to their mouth size gape as postulated by Winemiller and Winemiller, 1994 and Olojo *et al*. 2003. Firstly, the size of the mouth gape of small sized and juvenile fishes restricts them to fairly small prey items, such as insect larvae (Keast, 1985a), and this may explain the observed mixed diet (insects and fish) for small and medium sized *H. vittatus* in this study. However, the observed shift to piscivory for the large sized *H. vittatus* might be beneficial to individuals in the sense that it promotes fast growth and survival (Dalu *et al.,* 2012). This is further supported by the optimal foraging theory which suggests that early switching to piscivorous diet result in faster growth, because predatory fish derive higher energetic returns from fish prey than aquatic insects (Dalu, et al., 2012). The occurrence of common prey categories in all sizes also points to a likelihood of intraspecific competition in small and medium size classes of *H. vittatus*. For instance, medium and large *H. vittatus* in this study are likely to compete for prey items such as *Synodontis* spp. Although there is evidence of overlap among prey items such as *M. acutidens, B. lateralis*, aquatic insects and cichlids, there are qualitative differences in the items recorded. The dominant food items in the diet of one particular size group match with those which are of only minor importance in another size group.

Seasonal shift in the diet of Hydrocynus vittatus

Seasonally, all the diet components were encountered during wet and dry seasons throughout the study period accepting the null hypothesis that there was no seasonal shift in the diet of *H. vittatus*. However, distinctive numerical variations in total number of prey observed during the wet relative to the dry season were evident. A total of 112 prey items by number was recorded in the wet season as compared to 92 prey items observed in the dry season. This imbalance may be explained by the abundance of prey items in the wet season and a decline in availability of prey item selection by *H. vittatus* in the dry season (Winemiller and Winemiller, 1994). The prominence of primary producers (e.g. algae, diatoms), and zooplankton during the wet season could be linked to nutrient-rich flood waters that might have stimulated greater primary and secondary productivity (Winemiller and Winemiller, 1994). In turn, primary producers such as macrophytes might have provided new habitats and served as an alternative food for small fish and insects preyed upon by Tigerfish (Winemiller and Winemiller, 1994). Variability in prey availability due to seasonal change has a direct effect on the food composition of *H. vittatus*, implying that this species does not have a strict food regime, a characteristic which gives it a better chance of survival. During the dry season, *H. vittatus* was observed to have switched prey preference for *M. acutidens* to *Synodontis* spp. (Winemiller and Winemiller, 1994). During this 'crunch period', target prey becomes limited due to hostile, shrinking water bodies (Winemiller and Winemiller, 1994) and the total number of potential prey species such as *M. acutidens* and *B. lateralis* is reduced below sufficient levels to meet the daily energy demand, while hardy and tolerant species such as *Synodontis* spp. persist in bulk. These outcomes justify the observation that seasonal differences in food composition of *H. vittatus* could be derived from differences in relative prey abundance in the resident habitats rather than from prey selection by *H. vittatus.*

CONCLUSION

This study showed *H. vittatus* are able to consume a diverse array of prey items and thus able to optimise food consumption at different sizes and in different seasons, depending on prey availability. Small and medium size classes of *H. vittatus* feed on both fish material and insects, while larger size class feed exclusively on fish. The overall pattern that arises from this study shows that *H. vittatus* is a generalist piscivore. This may be a survival strategy because they decrease dependence on seasonal sources and on sources of prey food in short supply, such as insects. Prey selected were less than 50% the predator's length. *H. vittatus* serves as an ecologically important species with the ability to convert un-exploitable small sized non - cichlid species into exploitable protein dish to local fishers. Hence their population must be maintained to ensure a balanced fishery in the Zambezi River.

CHAPTER 6: ASSESSMENT OF THE FISHERY ON THE ZAMBEZI/CHOBE FLOODPLAIN

6.1 INTRODUCTION

The fishery of the Zambezi/Chobe floodplain is diverse, highly dispersed, and fragmented into fishing villages (Hay and van der Waal, 2009; van der Waal *et al.*, 2011). Fishing activity on the floodplain is practised by the riparian communities. Fishing can be categorised as subsistence (catch for daily food supply), or commercial (catch for income) (Purvis, 2002). Typically, subsistence fishing is conducted by one or two people using a canoe or small boat and employing simple fishing techniques (Simasiku, 2014). These fishery activities play a vital role in the lives of the communities in terms of employment and nutrition (Purvis, 2002). During flooding, fishers construct temporary fishing camps around the floodplain for easy access to adjacent fishing grounds (Turpie *et al*., 1999). The gear employed in fish capture on the floodplain consists of gillnets, hook and line, spears and fence traps (Simasiku, pers. obs.). The different fishing gear complement each other, targeting a diversity of fish communities (Turpie *et al*., 1999). Gillnets are the most common gear, with 98% of fishing households reportedly using an average of two nets at any one time (van der Waal *et al*., 2011). Gillnets are set by two fishers operating from a wooden canoe: one man manoeuvres the canoe with a paddle and the other man deploys the net into the water. The top of the net is kept afloat using sedge or Styrofoam floats threaded on a thin line and the bottom rope weighed at irregular distances using bricks or clay (Simasiku, 2014). As a passive gear, gillnet mesh size largely determines both the size and type of fish caught. The most frequently used mesh sizes on the floodplain range between 51 mm to 127 mm (Hay and van der Waal, 2009). The largest capture of the fishery are cichlids of the genus *Oreochromis*, *Serranochromis, Sargochromis, Coptodon* species, and *Clarias gariepinus* (Hay and van der Waal, 2009; Peel, 2012). The most important species in the fisheries are *Oreochromis andersonii* and *Oreochromis macrochir* which make up to 60% of the biomass of the commercial and subsistence catch in the Kavango and Zambezi Rivers and in Lake Liambezi (Simasiku, 2014). *Coptodon rendalli* is less important, but still a significant component of the fisheries, reported to have contributed up to 10% of the total catch in 1990 (Peel, 2012).

The fishery is managed through effort limitation measures in the form of gear restrictions, mesh size regulation, and length of gillnets (Peel, 2012). These management measures are aimed at protecting commercially valuable cichlid species, while the lesser valued non-cichlids are partially incorporated. A permit system is in place and serves as a guide on the permissible number of gillnets per fisher. Despite these management mechanisms in place, fishing activities has intensified. Stocks of the larger, commercially important species are declining but only a few reports has been published to support these perceptions (i.e. Hay *et al.,* 2009; Tweddle *et al.,* 2015). The only attempt to describe the fishery of the Zambezi/Chobe floodplain in depth was an early survey conducted in the 1970s (van der Waal, 1990) and a later frame survey on fishing activities in the Zambezi Region (van der Waal *et al.,* 2011). Current scientific information is mainly in the form of unpublished technical reports and theses. Experimental multifilament gillnet surveys, operated by the Ministry of Fisheries and Marine Resources have been used for biological data collection since the 1990s, but experimental gillnets do not reflect the community structure and composition of the subsistence catches. This is mainly because experimental gillnets are made of short panels while the subsistence gillnets are made of long mesh panels. Consequently, the current status of the subsistence fishery remains uncertain. A serious gap exists in the knowledge of the fishery structure and the impact of the fishery on the fish community.

The aim of this chapter, then, is to assess the fishing patterns and catch rates of the Zambezi/Chobe floodplain fishery by addressing the following questions:

1) What are the fishing gears used and species composition of the Zambezi/Chobe floodplain fishery?
2) Is there a change in annual catch rates and mean length of the most important species?
3) What is the annual total catch of the Zambezi/Chobe floodplain?

6.2 MATERIAL AND METHODS

General sampling

Fish landings were sampled at three major fishing villages (Kalimbeza, Kasika, and Impalila) between August 2010 and December 2017. These stations cover a large section of the Zambezi/Chobe floodplains and include all major habitat types. Six fisheries enumerators working in pairs were allocated to each station and sampled the landing sites on randomly selected days, with equal probability (Chimatiro, 2004). Each sampling station was sampled for 8 days per month. The author and two officials from the Namibian Nature Foundation accompanied the enumerators at random days to ensure consistence in data collection. Individual fishermen landing their catch were approached and questioned regarding their canoes, net types, stretched mesh sizes, net length and frequency of fishing activities using a questionnaire in (appendix A). The daily catch of fish per canoe was sorted into species, according to the gear type and net type using taxonomic keys (Skelton, 2001). All fish were sorted into species, measured to the nearest millimeter total length (TL) or fork length (FL) depending on the species and weighed to the nearest kilogram (kg). A subsample was measured and weighed when a large number of fish was landed. The rest of the fish for each species were then counted and weighed. The hydrology in the representative fishing area was registered monthly at Katima Mulilo hydro-station to gain an insight on the influence of water level on the seasonal catches. Data was obtained from the Hydrology Department under the Ministry of Agriculture and Forestry.

Catch composition

An Index of Relative Importance implemented in Pasgear II was used to determine the most important species captured by each fishing gear by number, weight and frequency of occurrence, and was calculated as:

$$IRI = (\%N + \%W) \times (\%FO)$$

Where %N and %W are the percentage contribution of each species by number and by weight to the total catch and %FO is the percentage frequency of occurrence of each species in the total number of net settings.

Gillnet selectivity

Selectivity is a quantitative expression of the probability of capture of a certain size of fish in a certain type of gear or mesh size. It was opted to determine the selectivity pattern for all mesh sizes and individual net type combined, and not individually.

Catch per unit effort (CPUE)

Gear efficiency refers to the catch of a fishing gear for a given amount of effort; the mean CPUE was calculated using the following equation (Naesje *et al.*, 2004):

$$CPUE = C_i/E_i$$

Where C_i is the catch of species i (weight) and E_i is the effort expended to obtain i. CPUE was standardised to kg/net/12hrs duration. Despite being one of the most common pieces of information used in assessing the status of fish stocks in this study, relative abundance indices based on catch per unit effort (CPUE) data are notoriously problematic. Hence CPUE was standardized to kilogram per net set (kg/net/12hrs duration) in order to remove the effect of factors that bias CPUE as an index of abundance. Even if CPUE is standardized appropriately, the resulting index of relative abundance, in isolation, provides limited information for management advice or about the effect of fishing. Hence fish mean sizes was used as a reference point to determine the effect of the fishery on the commercially target specie. The length of the nets was not taken into account when calculating the CPUE due to the inaccuracy of the net lengths reported by the fishers on the floodplain. Seasonal CPUE was pooled across the years.

Annual total catch

Catch rate and effort estimates from the sampled landing sites were used to estimate the total catch for the whole floodplain. Since most canoe owners were full-time fishers and fished over the whole year (Simasiku, 2014), the total number of canoes was used as a causal expression of effort. Annual total catch for the floodplain was estimated for fishers operating from canoes using the equation:

TC (kg) = mean annual CPUE (kg/net/12hrs × fishing days/year × effort (number of canoes).

Statistical analysis

Data reporting for 2014 was doubtful to a certain degree, and hence excluded from further analysis. Data were first checked for normality and homogeneity of variances using the Kolmogorov-Smirnov test and Bartlett's test, respectively (Zar, 1984). Where data were found to be skewed, a natural logarithmic (X = Ln (X + I)) transformation was performed to normalise the data. In the event when the square root transformation could not satisfy the assumption of normality, logarithmic transformation was used instead. In cases where data failed to meet the normality assumption, the non-parametric Kruskal-Wallis test was used to determine differences in spatial and temporal CPUE. Similarities in catch composition between sampling stations were assessed using the Bray-Curtis similarity analysis for species abundance. The tests were performed using Primer 7 software (Clarke and Warwick, 1994). Linear regression was undertaken in Pasgear II to determine the statistical distinction of species abundance and fish mean length over the years. The non-parametric Spearman's rank correlation coefficient was used to assess the correlations between CPUE and water level.

6.3 RESULTS

Gear utilization

A total of seven (7) different types of fishing gear were identified as operating within the study area (Table 6.2). Major gear categories on the Zambezi/Chobe floodplain were gillnets, hooks and line, spears, fishing funnels, pangas (hatchet), traps and baskets. According to fishers, monofilament and multifilament gillnets were generally fished year-round while other gear such as spears, hooks and line, traps, pangas and baskets were seasonal. With gillnets, mesh size is one of the principal factors determining both the species and fish sizes caught by the fishers. Figures 6.1–6.3 show a change in mesh sizes and net types over the years used by the fishers on the floodplain.

Different mesh sizes were classed into three categories, namely small 25 – 64 mm (1–2.5 inch), medium 76–89 mm (3–3.5 inch), and the large mesh sizes 102–140 mm (4–5.5 inch). There has been a significant increase in the use of medium mesh sizes (Linear regression, r^2=0.28, p< 0.001) with a subsequent decline in the use of large mesh sizes (Linear regression, r^2=0.13, p=0.003). A switch in gear use from multifilament to monofilament gillnets was also apparent (Figure 6.3). More than 60% of the fishers on the floodplain fish for 5.2 days a week while another 16% fish for seven days a week. As a result, an average of 5.2 fishing days in a week was found appropriate for yield calculations in this study (Table 6.1).

Catch composition

The proportion and contribution of each species to a particular gear, expressed as percentage Index of Relative Importance (%IRI) of all the fish sampled from the catches at three sites over seven years is depicted in Table 6.2. A total of 42 640 fish weighing 16 737.5 kg and comprising 33 different species were sampled during the study. Species that were caught in low numbers are grouped as 'Others' in Table 6.2. *Oreochromis andersonii* (33.2%), *C. rendalli* (23%) and *Oreochromis macrochir* (12%) dominated the catch in gillnets, while *Clarias ngamensis* (52.3%), *Hydrocynus vittatus* (18%) and *Tilapia sparrmanii* (7.6%) contributed the most to hook and line catches (Table 6.2).

The two catfishes, *C. gariepinus* (83.1%) and *C. ngamensis* (16.4), dominated the catch from spear fishing. In traps, *C. gariepinus* (32.8%), *C. rendalli* (30.0%) and *O. andersonii* (17.2%) were the most important species. *Mormyrus lacerda* (32.1%), *Sargochromis giardi* (14.2%) and *Serranochromis angusticeps* (10.2%) were the largest component in fishing funnels while *C. ngamensis* (64.2%) and *C. gariepinus* (38.5%) dominated the catch in panga fishing. *Labeo lunatus* (99.0%) dominated in fishing baskets (Table 6.2). The most important species accounting for >70% IRI in gillnets were *O. andersonii*, *O. macrochir* and *C. rendalli*. These species were selected for a more detailed analysis of selectivity, CPUE and yield.

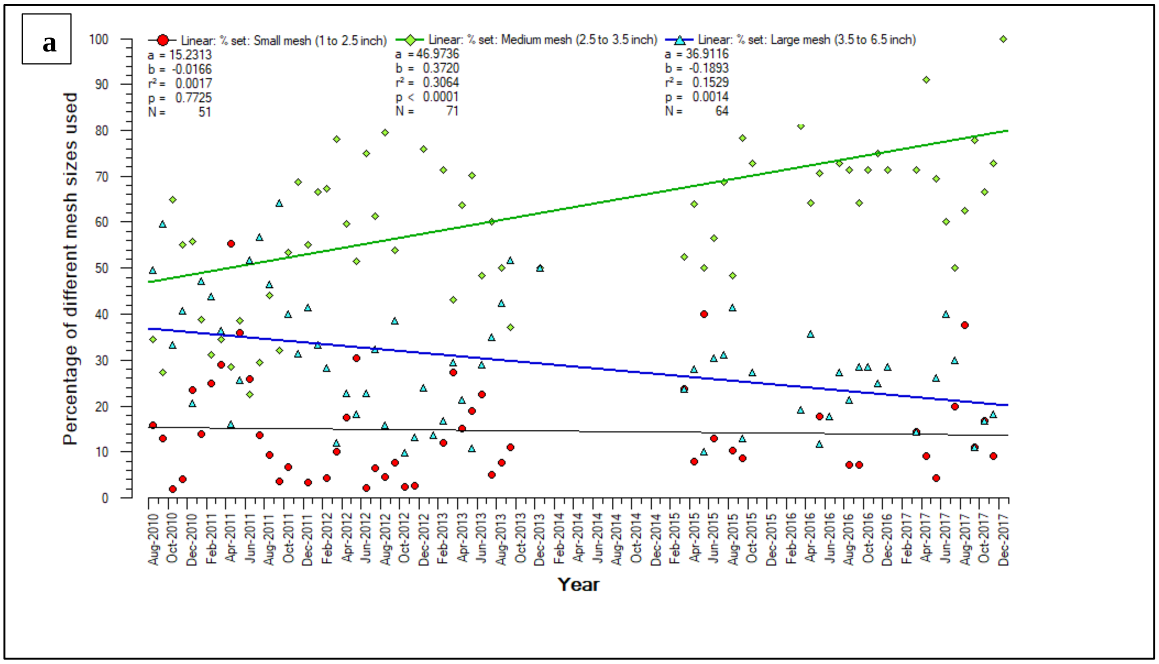

Figure 6.1 Trend over seven year's period in mesh sizes used by the fishermen on the Zambezi/Chobe floodplain between August 2010 and December 2017.

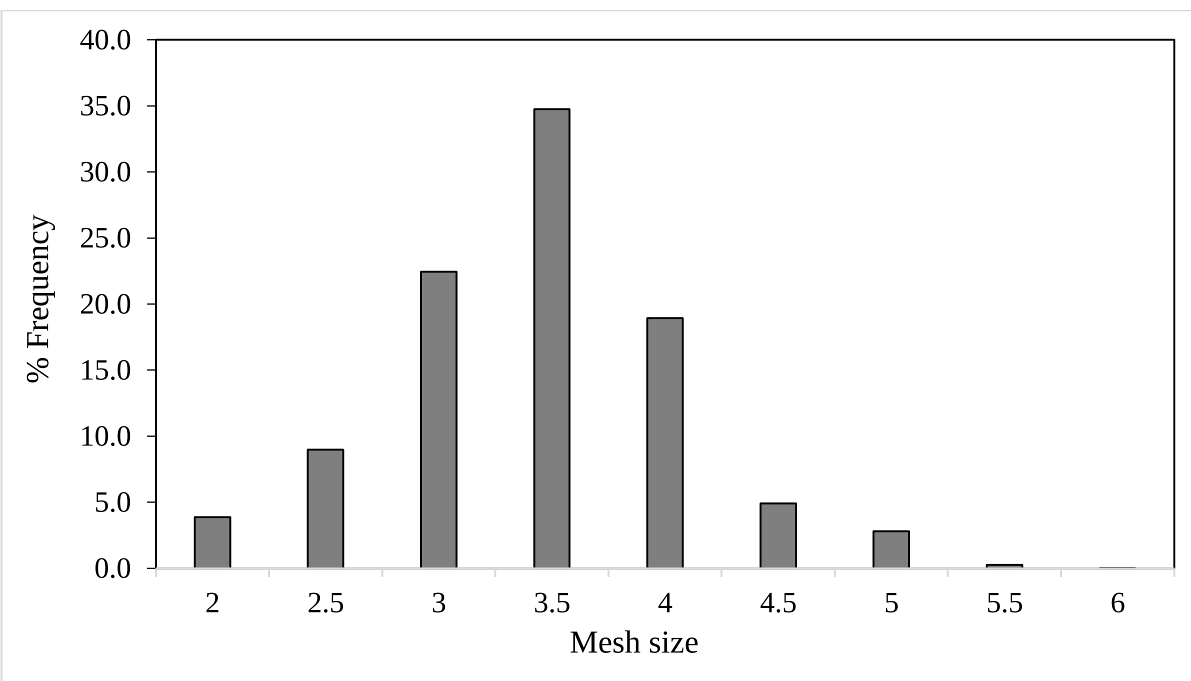

Figure 6.2 Mesh size preferences by fishers on the Zambezi/Chobe floodplain between August 2010 and December 2017.

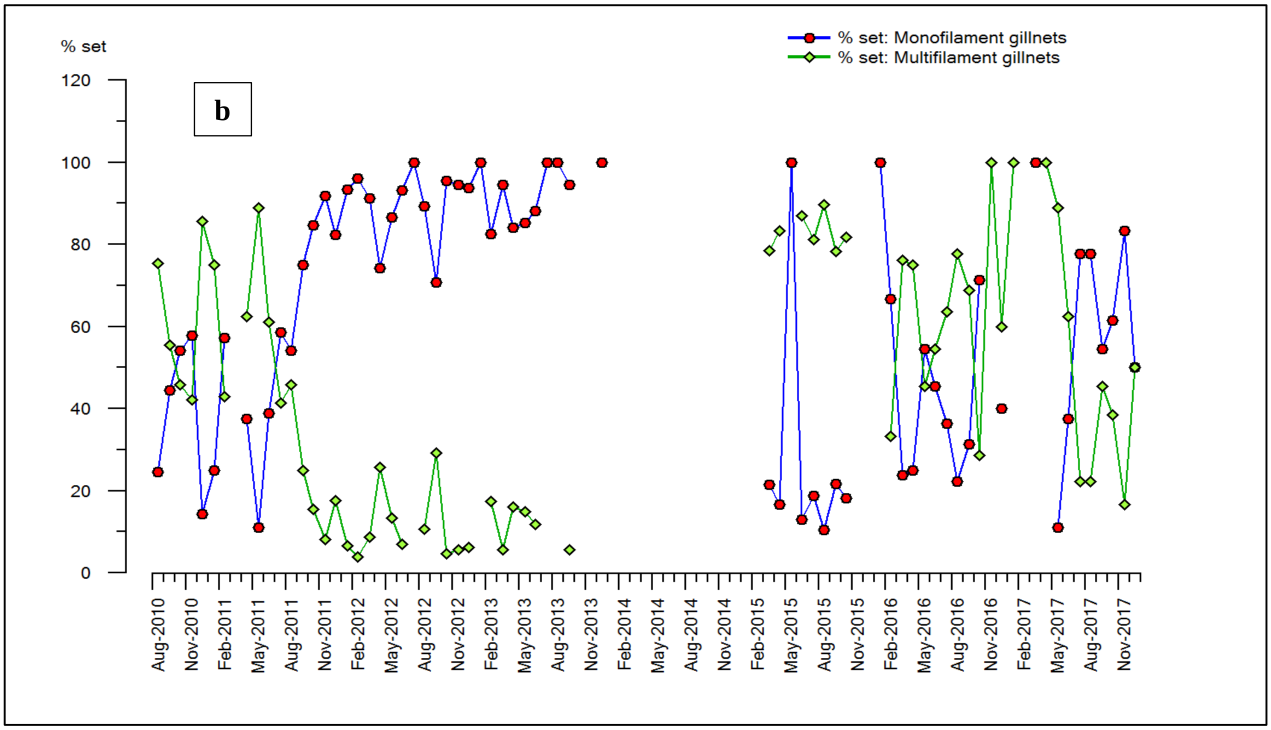

Figure 6.3 Trend in net types used by the fishers on the Zambezi/Chobe floodplain over seven-year period between August 2010 and December 2017.

Table 6.1 Percentage distribution of fishers in terms of fishing frequency on the Zambezi/Chobe floodplain.

Status of fishers	Number recorded	Percent
Once a week	1	1
Twice a week	4	4
Three times a week	0	0
Four times a week	10	9.4
Five times a week	70	66.0
Six times a week	5	4.7
Seven times a week	17	16.0
Total	107	100
Average number of fishing days/fishers=sum of fishers/number recorded	**5.29**	

Table 6.2 Index of Relative Importance (%IRI) of all fish species caught by gillnet, hook and line, spear, trap, funnel, panga and basket in the total catch sampled from August 2010 to December 2017.

Species	Gillnet	Hook & Line	Spear	Trap	Funnel	Panga	Fishing basket
Oreochromis andersonii	33.20	5.60	0.20	17.20	6.00	-	-
Coptodon rendalli	23.00	5.30	1.10	30.00	-	-	-
Oreochromis macrochir	12.30	4.00	-	10.80	8.50	-	-
Clarias gariepinus	5.80	2.80	82.10	32.80	7.50	38.50	-
Hydrocynus vittatus	6.50	18.00	-	-	2.10	-	-
Clarias ngamensis	2.80	52.30	16.40	3.10	-	64.20	0.70
Serranochromis macrocephalus	3.50	0.30	0.10	0.00	0.60	-	-
Sargochromis giardi	2.30	2.80	-	3.30	14.20	-	-
Schilbe intermedius	2.40	-	-	-	-	-	-
Serranochromis altus	1.90	0.10	-	0.40	6.40	-	-
Synodontis spp.	1.40	0.10	-	-	0.00	-	-
Serranochromis angusticeps	1.30	0.30	-	-	10.20	-	-
Marcusenius altisambesi	1.10	-	-	-	5.00	-	0.30
Mormyrus lacerda	0.80	0.40	-	-	32.10	-	-
Tilapia sparrmanii	0.60	7.60	-	1.70	2.30	-	-
Hepsetus cuvieri	0.60	0.10	-	-	-	-	-
Sargochromis carlottae	0.20	-	-	-	4.10	-	-
Sargochromis codringtonii	0.10	-	-	-	0.30	-	-
Serranochromis robustus	0.10	-	-	0.20	0.60	-	-
Labeo lunatus	-	-	-	-	-	-	99.00
Others	-	0.30	-	0.20	0.20	-	-

Gillnet selectivity

The length frequency distribution of each species in gillnet catches is illustrated in Figure 6.4. This is for all the mesh sizes (2–6 inch) and all stations combined. The red arrows indicate the length at 50% maturity for *O. andersonii*, *O. macrochir,* and *C. rendalli* according to Peel, 2012. It is clearly evident that the gillnet fishery selects for *O. andersonii* and *O. macrochir* at modal lengths close to their reported length at 50% maturity.

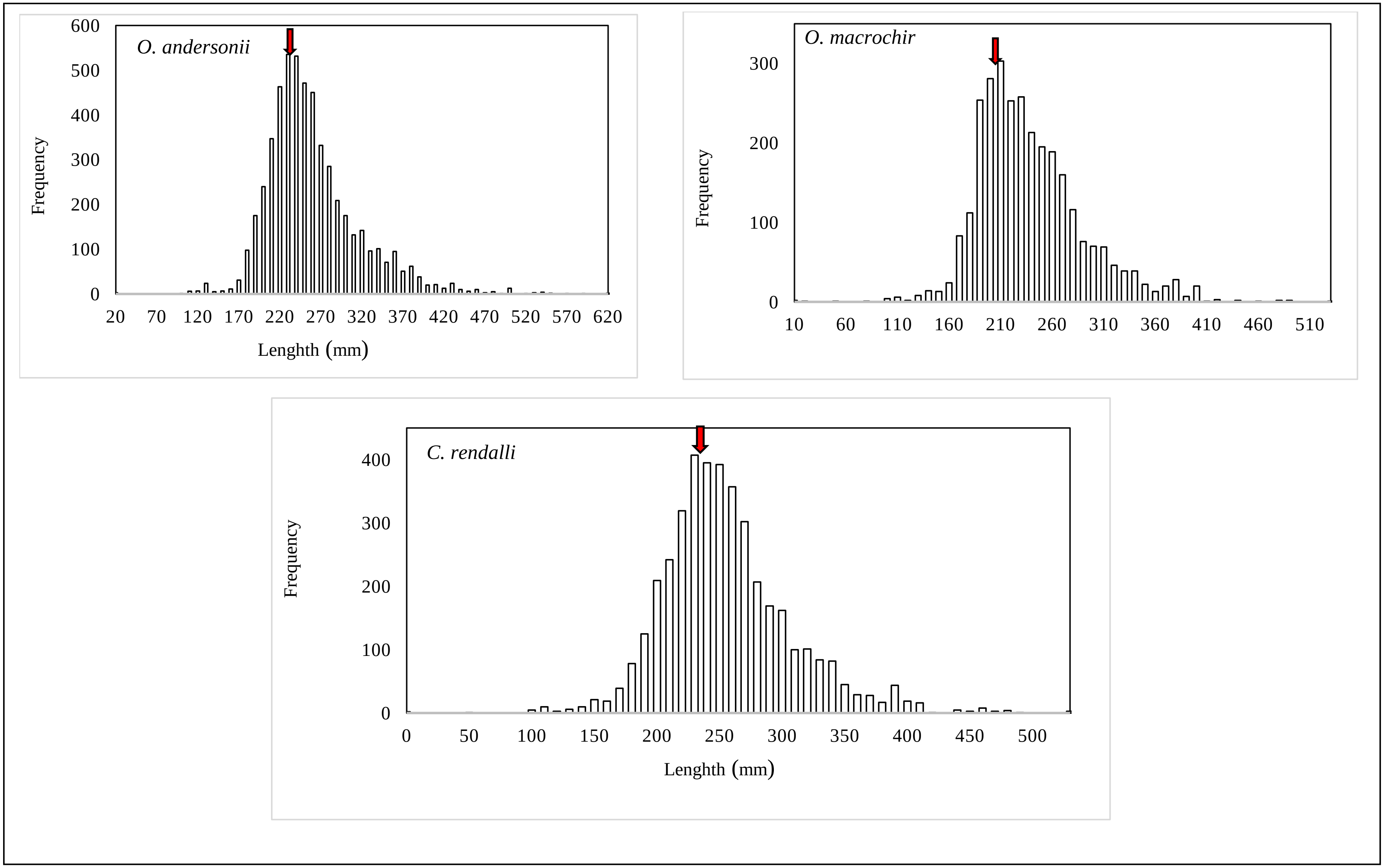

Figure 6.4 Length frequency (number) distribution in gillnets for *O. andersonii*, *O. macrochir* and *C. rendalli* in the Zambezi/Chobe floodplain fishery sampled from August 2010 to December 2017. The red arrow reflects the length (mm) at 50% maturity of *O. andersonii*, *O. macrochir*, and *C. rendalli* in the Zambezi/Chobe River according to table 6.3 below.

Table 6.3 Length (mm) at 50% maturity of *O. andersonii*, *O. macrochir,* and *C. rendalli* in the Zambezi/Chobe River.

Species	*ML* 50%(mm)	System	Author
O. andersonii (TL)	240	Zambezi/Chobe	Peel, 2012
O. macrochir (TL)	254	Zambezi/Chobe	Peel, 2012
C. rendalli (TL)	214	Zambezi/Chobe	Peel, 2012

Trends in annual catch rates (CPUE) by sampling station

Annual CPUE by sampling station of the three commercially important species is depicted in Figures 6.5 – 6.7. In Kalimbeza, *O. andersonii, O. macrochir* and *C. rendalli* showed a decline in catch rates from 2010 to 2017 (Figure 6.5). These trends were significant for *O. andersonii* (Linear regression, r^2=0.53, p<0.001), *O. macrochir* (Linear regression, r^2=0.45, p<0.001) and *C. rendalli* (Linear regression, r^2=0.14, p =0.0009). The highest catch rates of *O. andersonii* and *O. macrochir* were observed in 2010 and 2011 (Figure 6.5) while no clear peaks were observed for *C. rendalli.* In Kasika, the catch rates of *O. andersonii* (Linear regression, r^2=0.05, p=0.04) and *C. rendalli* (Linear regression, r^2=0.08, p=0.01) declined significantly from 2010 to 2017 while that of *O. macrochir* were consistent over the entire study period (p>0.05) (Figure 6.6). A peak in catch rates of *O. andersonii* and *C. rendalli* was observed in 2011 and 2015 but no clear peaks could be discerned for *O. macrochir* (Figure 6.6). In Impalila, a significant decline in catch rates of *C. rendalli* was observed from 2010 to 2017 (Linear regression, r^2=0.22, p<0.001) (Figure 6.7) while that of *O. andersonii* and *C. rendalli* were consistent over the entire study period (Figure 6.7). Peaks in catch rates of *C. rendalli* were observed in 2011 (Table 6.7).

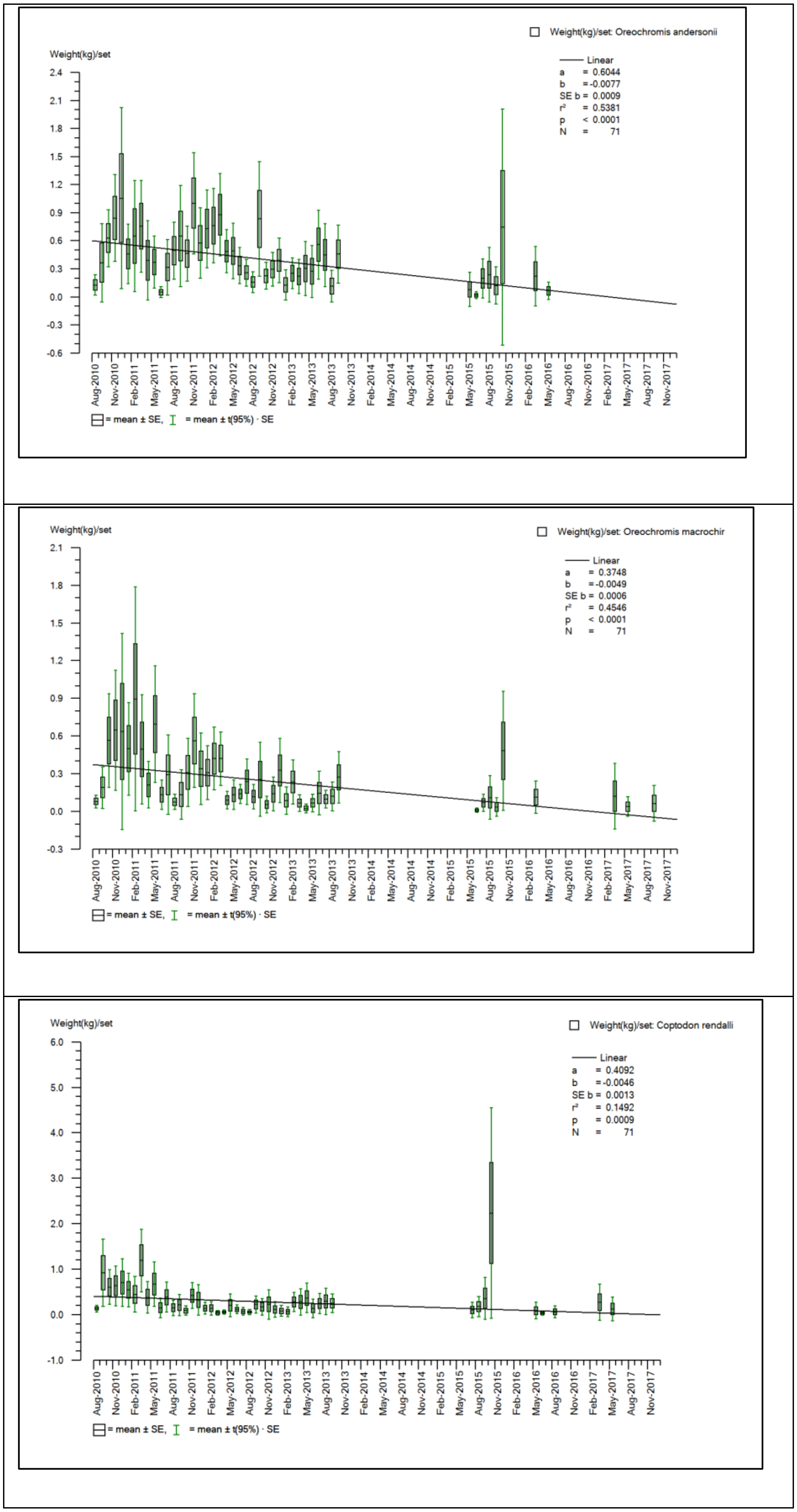

Figure 6.5 Annual catch per unit effort (CPUE) ± SE in gillnets and the regression coefficient of *O. andersonii*, *O. macrochir* and *C. rendalli* at Kalimbeza, sampled from August 2010 to December 2017. CPUE = Kg/net night.

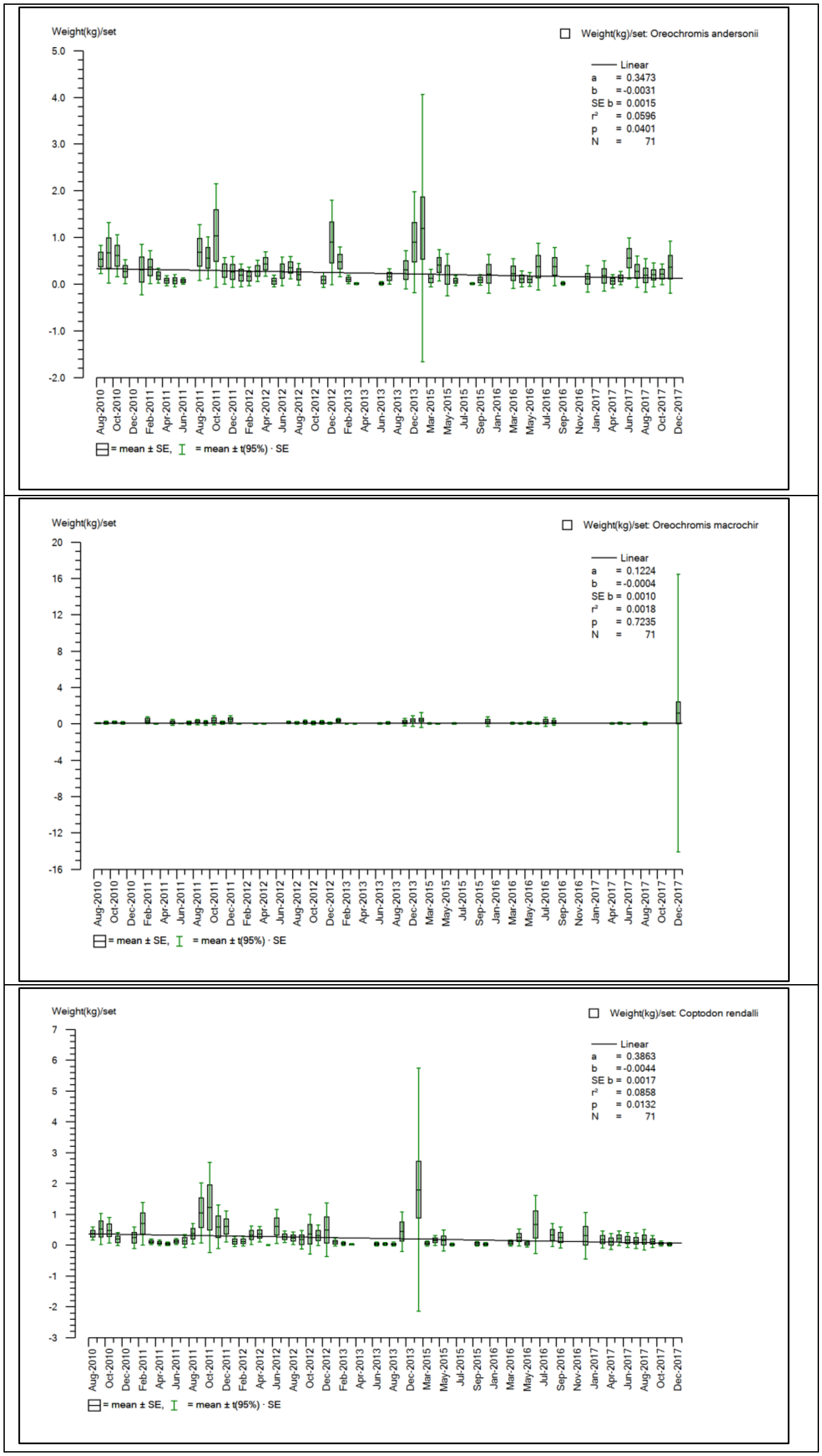

Figure 6.6 Annual catch per unit effort (CPUE) ± SE in gillnets and the regression coefficient of *O. andersonii*, *O. macrochir*, and *C. rendalli* at Kasika, sampled from August 2010 to December 2017. CPUE = Kg/net night.

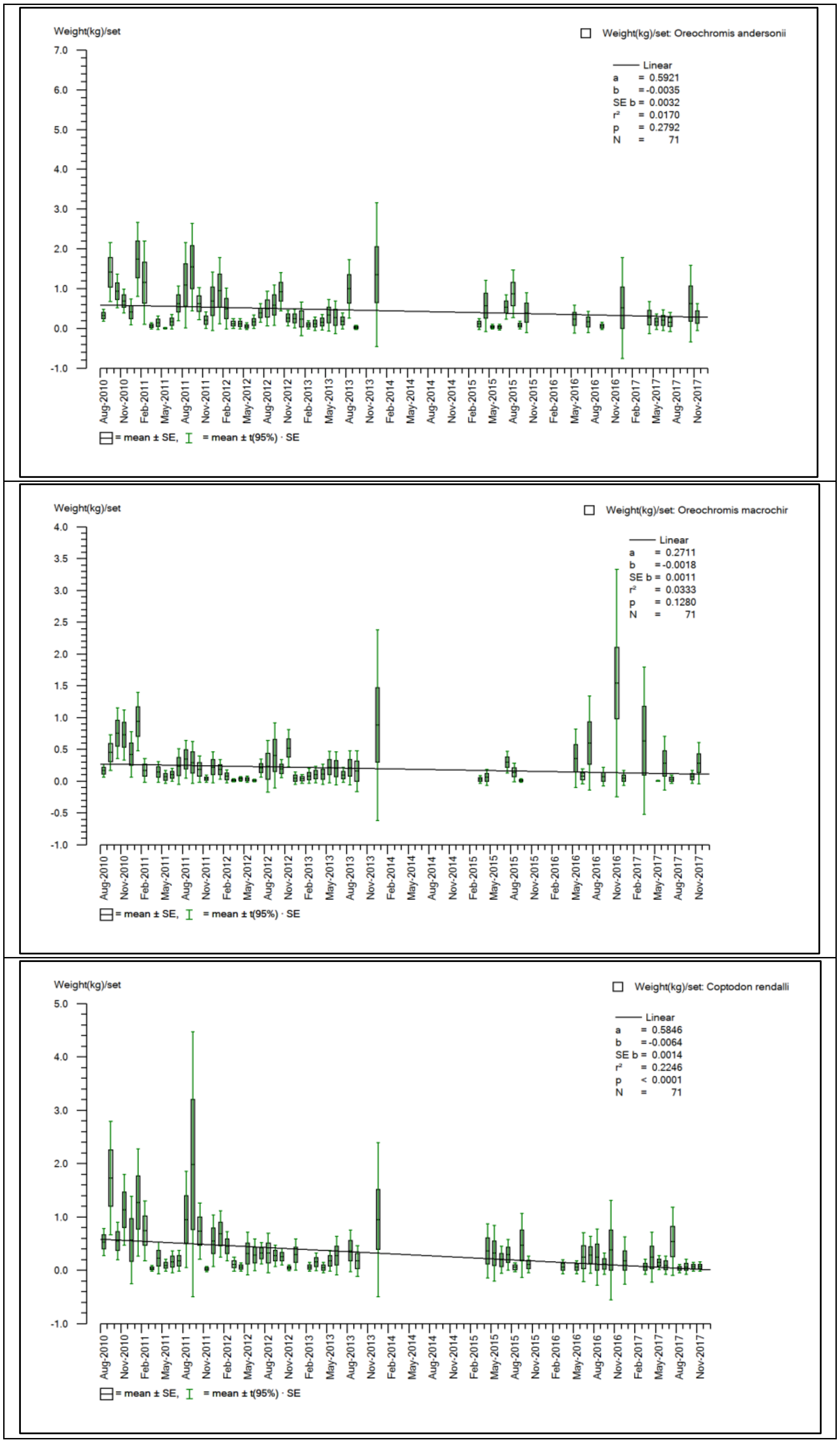

Figure 6.7 Annual catch per unit effort (CPUE) ± SE in gillnets and the regression coefficient of *O. andersonii*, *O. macrochir*, and *C. rendalli* at Impalila, sampled from August 2010 to December 2017. CPUE = Kg/net night.

Annual mean fish sizes by sampling station

In Kalimbeza, the average size of all three commercially important species, *O. andersonii, O. macrochir* and *C. rendalli,* remained stable from 2010 to 2017 (p>0.05) (Figure 6.8). However larger specimens of *O. andersonii* were recorded in 2010, while no clear peaks in mean size could be observed for *O. macrochir* and *C. rendalli* (Figure 6.8). Similarly, in Kasika, *O. andersonii*, *O. macrochir* and *C. rendalli* showed no significant change in mean size from 2010 to 2017 (p>0.05). No clear peaks in mean size could be observed for any of the three species (Figure 6.9). In Impalila, the average size of *O. andersonii, O. macrochir,* and *C. rendalli* were also consistent over the entire period from 2010 to 2017 (p>0.05) (Figure 6.10b). Larger specimens of *O. macrochir* were recorded in 2013 while no clear peaks in mean size could be discerned for *O. macrochir,* or *C. rendalli* (Figure 6.8).

Seasonal catch rates of *O. andersonii, O. macrochir* and *C. rendalli*

Furthermore, catch rates had strong seasonal variation (Kruskal Wallis test, df =2, p< 0.05), with the highest catch in summer (November – January), when the flood water reduced in volume, and the lowest catch during the peak floods in early winter (June)(Figure 6.11). Separate correlation analyses were performed to assess the relationship between the annual CPUE of *O. andersonii, O. macrochir* and *C. rendalli* with the mean annual water level. No correlation was observed between the CPUE of *O. andersonii, O. macrochir* and *C. rendalli* with the actual water level (p >0.001).

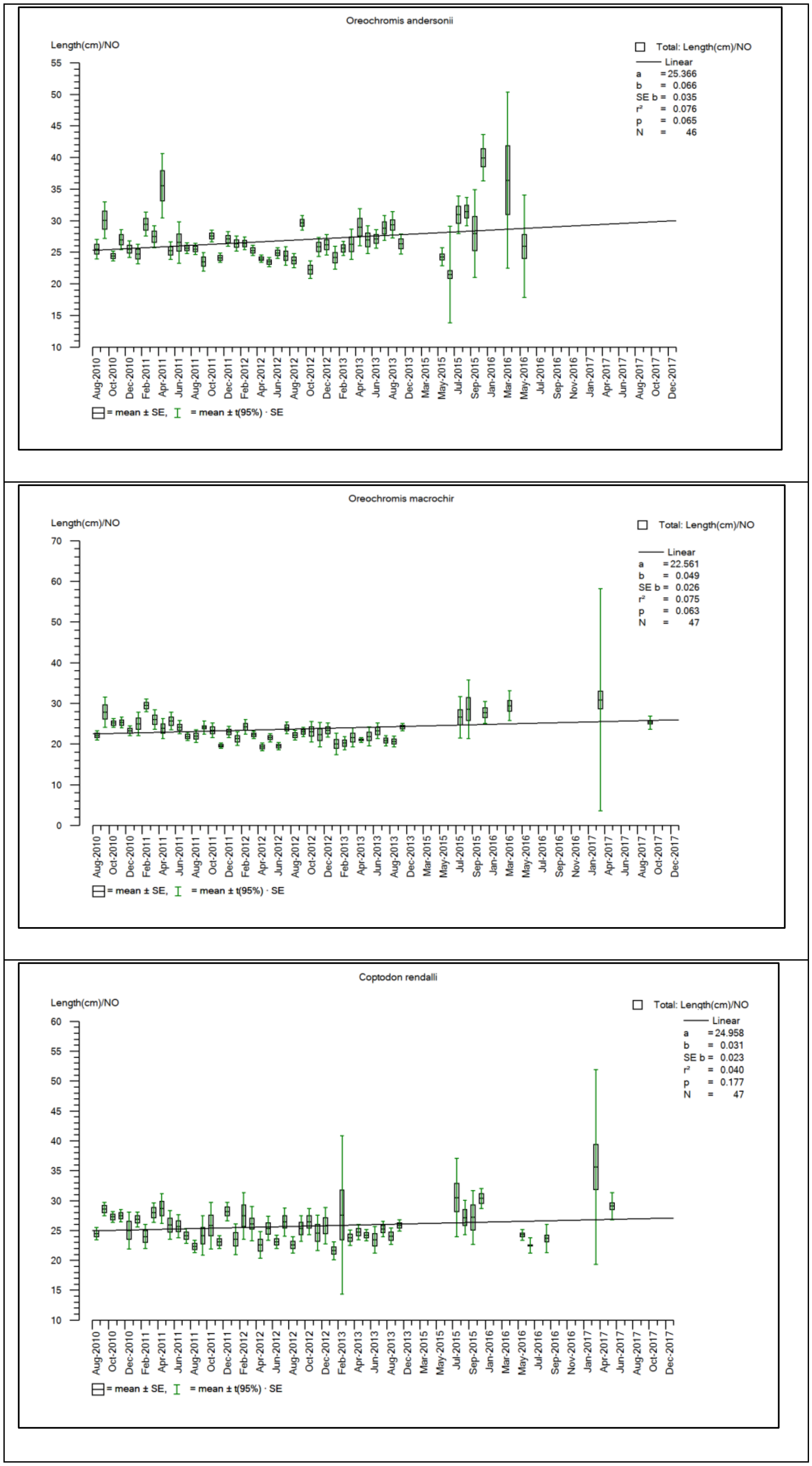

Figure 6.8 Annual mean length ± SE (mm) in gillnet catches and the regression coefficient of *O. andersonii*, *O. macrochir* and *C. rendalli* at Kalimbeza, sampled from January 2010 to December 2017.

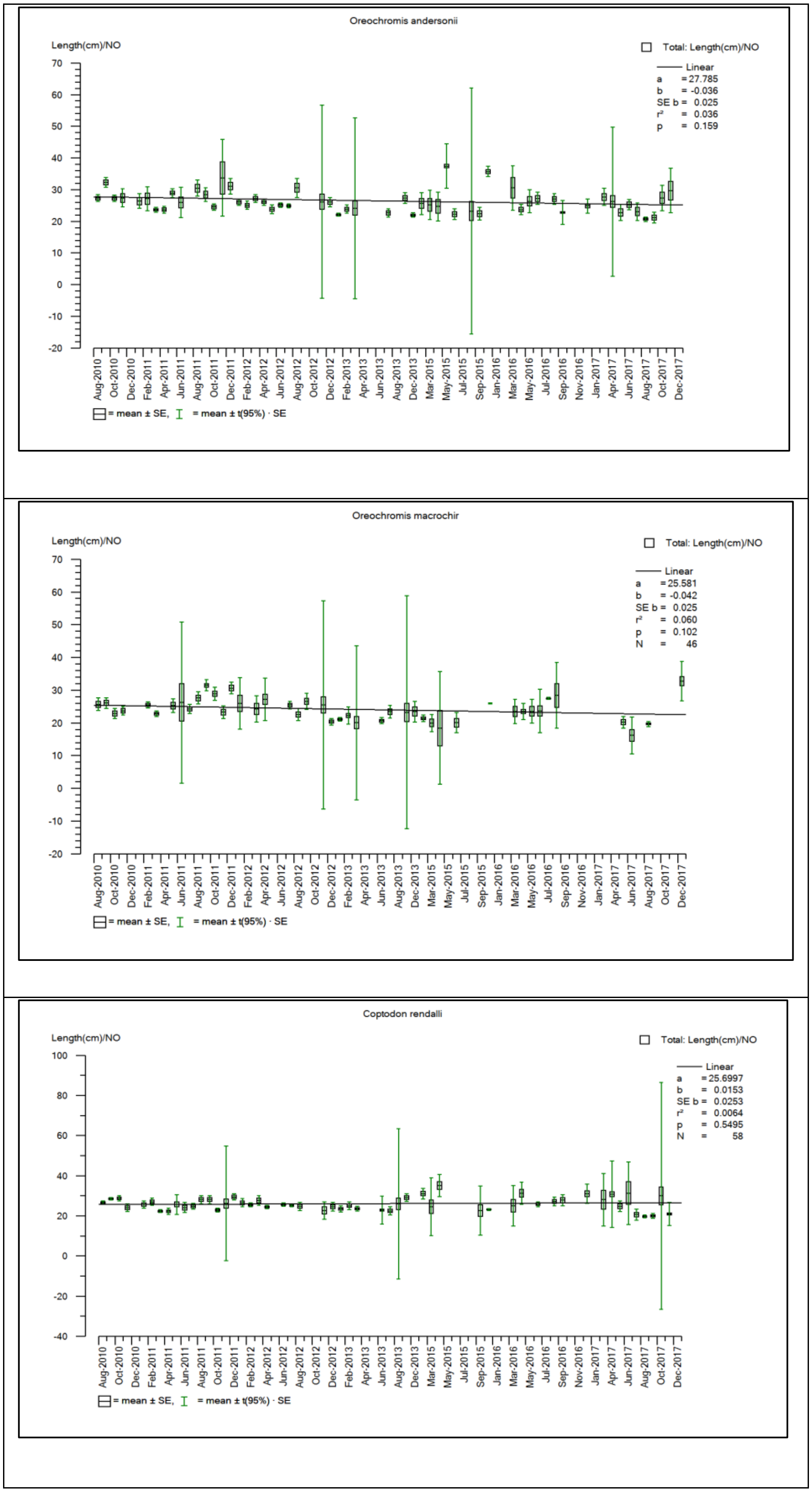

Figure 6.9 Annual mean length ± SE (mm) in gillnet catches and the regression coefficient of *O. andersonii*, *O. macrochir*, and *C. rendalli* at Kasika sampled from January 2010 to December 2017.

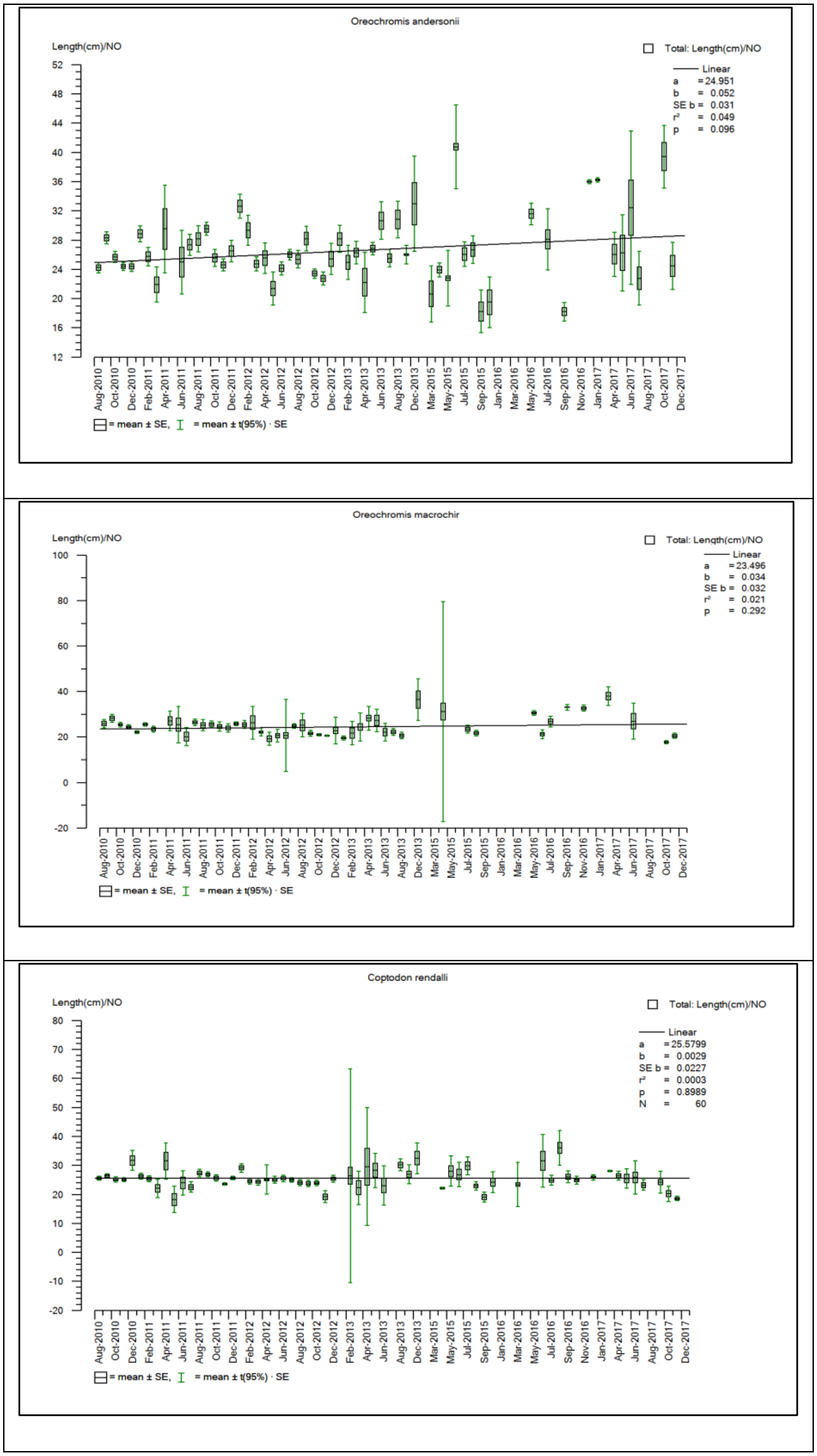

Figure 6.10 Annual mean length ± SE (mm) in gillnet catches and the regression coefficient of *O. andersonii*, *O. macrochir* and *C. rendalli* at Impalila sampled from January 2010 to December 2017.

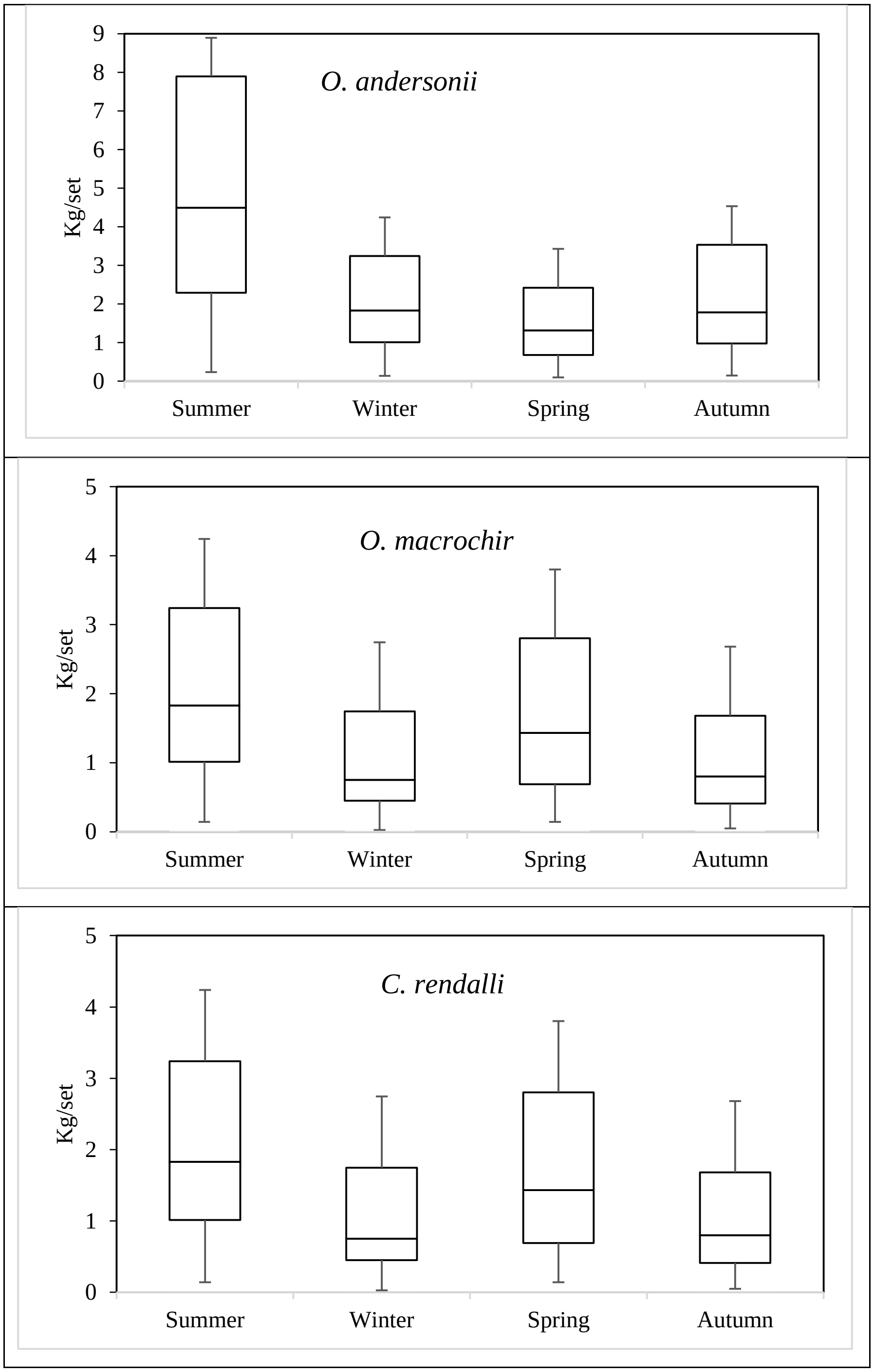

Figure 6.11. Seasonal catch per unit effort (CPUE) of *O. andersonii*, *O. macrochir*, and *C. rendalli* in gillnets in the Zambezi/Chobe floodplain fishery from January 2010 and December 2017.

Fishing effort and total catch

Effort was determined as the total number of canoes operating on the Zambezi/Chobe floodplain for 5.2 days/week (Table 6.1). A total of 1900 canoes was computed by Hay and van der Waal (2009) on the Zambezi/Chobe floodplain. Presumably 50% of the total number of canoes goes out fishing on any particular fishing day of the week. Based on these assumptions, approximately 950 canoes were used as a raising factor of effort. Canoes were found appropriate as a proxy of effort because they can last up to 40 years in the fishery (van der Waal, 1990). Total catch was therefore computed separately for each year, based upon an average catch of all three sampled stations (kg/canoe/year), determined from an estimated number of 950 active canoes in the fishery, and 5/7 weekly fishing days of 365 days in a year (260 days). Using these values, an estimated production value of 2248t/yr was computed in 2010 relative to 939 t/yr in 2017(Table 6.10). Separate correlation analyses were performed to test for any relationship between the annual catch rates of all three target species (*O. andersonii*, *O. macrochir*, and *C. rendalli*) combined with the water level. However, no correlation between the annual catch rates of the above noted species and water level ($P>0.05$) was found.

Table 6.4 Annual gillnet catch of fish on the Zambezi/Chobe floodplain, sampled between August 2010 and December 2017

	2010	2011	2012	2013	2015	2016	2017
Annual CPUE(Kg/set)	9.1	8.4	4.5	4.9	5.4	5.5	3.8
Total catch (Tons)	2248	2075	1112	1210	1334	1359	939
Mean water level (m)	2.93	3.02	2.36	2.44	1.41	1.89	3.39

6.4 DISCUSSION

Generally, the gillnet fishery on the Zambezi/Chobe floodplain selects the large growing cichlid species such as *O. andersonii*, *O. macrochir*, and *C. rendalli*. Van der Waal (1980) also found that cichlids made up three-quarters of the commercial gillnet fishery catch in Lake Liambezi prior to it drying up, half of which was *O. andersonii* (van der Waal, 1980). The current catch composition on the floodplain is similar, with *O. andersonii* (33%) dominating the gillnet catch. A radio tagging study done on this species showed that, *O. andersonii* moves over shorter distances and fishers have mastered their migration route, making it vulnerable to gillnets on the Zambezi River (Okland *et al*., 1999). The above contention may partly explain the dominance of *O. andersonii* in the gillnet fishery on the Zambezi/Chobe floodplain. However, such selective fishing may become very detrimental as it contradicts the non-selective fishery concept where all the trophic levels in a fish community structure are harvested proportionally to their biomass (Jul-Larsen *et al.,* 2003).

Despite the high floods of 2009 and 2010 which could be expected to yield a positive link between the annual catch rates and the flood regime (Welcomme 1975), the annual catch rates of *O. andersonii*, *O. macrochir* and *C. rendalli* declined significantly over the years. The current decline is also reinforced by the fisheries independent data from experimental gillnet catches (Peel, 2012) and by a major decline in recreational catch data from anglers fishing on the Zambezi River (Tweddle, *et al.,* 2015). This decline may be attributed to a change from multifilament gillnets to monofilament gillnets as observed by this study, rather than the influence of flood intensity (Bulirani *et al.,* 1999). An important factor for change could be attributed by the high catching efficiency associated with monofilament nets than multifilament nets (Balik, 1998). Typically, the white multifilament net twine is more visible to fish in water than the fine twine monofilament nets. Therefore, fish can more easily notice multifilament nets. As a result, monofilament gillnets were three times more efficient in catching cichlids than multifilament gillnets in Lake Liambezi (Simasiku, 2014). Elsewhere in the temperate regions, Balik (2000) also found that monofilament nets catch 2.08 times more tench than multifilament nets in Lake Beysehir in Turkey. These observed efficiency of monofilament gillnets further support the observed change in gear type as demonstrated by this study. This innovation may have initially boosted more economic fishing activity on the part of the local fishers, but eventually led to a long-term decline in catch rates of *O. andersonii*, *O. macrochir* and *C. rendalli* as demonstrated by the current study.

In addition to a decline in annual catch rates, the annual mean sizes of *O. andersonii* and *O. macrochir* at Kasika showed a decline over the study period. This decline may be explained by the use of smaller mesh sizes on the floodplain. The study showed that, 15% of the fishers on the floodplain employed small mesh sized gillnets (64 mm) in the fishery (Figure 6.2), raising a serious concern of growth overfishing (catching recruits before they contribute to overall biomass). Although the present legal minimum mesh size according to the Inland Fisheries Resources Act (2003) is 76 mm, small mesh sizes <76 mm are still being used in the fishery. Peel (2012) cites the incidence of small mesh sizes on the Zambezi and Kavango Rivers and on the Kafue floodplain: over 47% of gillnets used had mesh sizes smaller than the legal mesh size of 76 mm (Tweddle *et al*., 2015). The prevalence of juvenile cichlids in major landing sites on the Barotse floodplains was similarly allied to the frequent use of small-meshed gillnets between 25 and 50 mm stretched mesh (Tweddle *et al*., 2015). It has been postulated that, in the absence of the large, valuable cichlids (mainly due to heavy fishing pressure), fishers tend to reduce their mesh sizes to boost their daily catches (Jul-Larsen *et al.*, 2003: Welcomme, 1985). This may partly account for the use of small mesh sizes by 15% of the fishers' on the Zambezi/Chobe floodplain. Such practices have negatively affected the floodplain fishery and resulted in failure of the cichlid fisheries and the rarity of certain valued species from the fisheries of Lake Malombe in Malawi and the Kariba Dam in Zambia/Zimbabwe (Tweddle *et al.*, 1994; Simasiku, 2014). These scenarios should serve as salutary leassons for the possible danger of using small mesh sized gillnets in the Zambezi/Chobe fishery.

Lake Malombe is a small, shallow lake (390 km^2) on the Shire River. In the 1960s and 1970s, the littoral zone of the lake was covered with an extensive weed bed that provided cover for predators and prey. The introduction of small-meshed, Nkacha seine nets resulted in heavy fishing pressure on adult and juvenile size classes of *Oreochromis karongae.* The seine nets removed fish of all sizes and scraped the lake bed clean of vegetation, removing shelter and food resources for juvenile *Oreochromis spp*. (Weyl, 2003). This led to the collapse of the fishery in the early 1980s (Tweddle *et al.*, 1995). In Lake Malawi, the Chambo (*Oreochromis spp*.) fishery collapsed as a result of the introduction of purse seines called "kauni" nets. The gear was operated offshore as an active gear in combination with the inshore gillnetting with sizes of 95 mm. The net selected for two-year old fish between 150 mm and 230 mm TL. This resulted in catch rates declining below sustainable level.

Catch rates in the Zambezi/Chobe floodplain were also subjected to seasonal variations regulated by the hydrological cycle as reported by Welcomme, 1985 and Merron *et al.*, 1988. The highest catch rate of *O. andersonii*, *O. macrochir* and *C. rendalli* was observed during low water level in summer (November – January), and the lowest catch during the peak floods in winter (June/July), coinciding with the draw down. These observations may be associated with the flood dilution and concentration effect. Welcomme (1979) reports that fish production can be related to the flood levels in the same year and concludes that the abundance of fish alters periodically as a function of fluctuations in flow rate. This implies that as the warm wet season progressed and the aquatic environment regressed each year, more individual fish were caught and landed on the Zambezi/Chobe floodplains. This view agrees with the concept of a seasonal cycle, typical of tropical ecosystems (Welcomme, 1985; Lowe-McConnell, 1987; Welcomme, 2001; Chimatiro, 2004). Welcomme and Hagborg (1975) report that for African floodplain fisheries, flood intensity, duration, and drawdown conditions produce corresponding fluctuations in fish densities. Fish are vulnerable to exploitation (i) when they return to the main channel as the water drops in June/July (ii) and when they are confined to the main channel during November (dry season) (Welcomme and Hagborg, 1975). This may in part explain the current observed seasonal variations in catch rates of *O. andersonii*, *O. macrochir* and *C. rendalli*.

Annual catch rates, fishing activities and total effort were employed as parameters to estimate total production of the Zambezi/Chobe floodplain. Taking into consideration the surface area of 170 000 ha for the Zambezi/Chobe floodplain (Turpe *et al.*, 1999), the total annual estimated yield of 2248 tons/yr is computed for the year 2010 and about 939 tons/yr for 2017; this translates to a cropping rate of 13.2 $kg.ha^{-1}$ in 2010 and 5.5 $kg.ha^{-1}$ in 2017. These observations evidence a decline in annual yields emanating from a significant decline in annual catch rates of the target species in the study area. A summary of the total yield estimates from this study compared with a number of African lakes and swamps is depicted in Table 6.3. The current computed figure for the year 2017 in this study is considerably similar to 4.7 $kg.ha^{-1}$ reported for the Barotse floodplain, 200 km north of the Zambezi Region (Tweddle *et al.*, 2015), but higher than the 0,5 $kg.ha^{-1}$ of the under-utilised Okavango Swamps (Merron, 1991). The current computed floodplain fish production in this study is lower than the 9 $kg.ha^{-1}$ previously reported for the Zambezi/Chobe floodplain in 2003 (Hay and van der Waal, 2009). The difference in yield estimates may reflect a serious drop in CPUE as result of overfishing as demonstrated in this study.

Table 6.5 Fish yield from selected water bodies in Africa

Water body	Yield (kg/ha/year)	Surface area (km^2)	Reference
Lake Kainji	4.7	1270	Balogun & Ibeun (1995)
Lake Kariba	57	5364	Machena (1995)
Lake Nasser	39	900	Rashid (1995)
Lake Volta	52	8300	Braimah (1995)
Lake Mweru	108	5175	Jul-Larsen *et al*. (2003)
Bangweulu swamps	1.9	15100	Jul-Larsen *et al*. (2003)
Lake Chilwa	160	750	Jul-Larsen *et al.* (2003)
Lake Malombe	77	390	Jul-Larsen *et al. (2003)*
Lake Chiuta	100	199	GoM (2005)
Lake Liambezi	106	300	Simasiku (2014)
Zambezi/Chobe floodplain	10	1700	This study

CONCLUSION

Continuous increase in destructive gears have caused a significant decline in fish stocks of the Zambezi/Chobe floodplain. *Oreochromis andersonii*, *O. macrochir,* and *C. rendalli* have shown signs of over-utilisation due to the selective nature of the floodplain fishery. Fishermen are believed to contribute to these changes through intensified utilization of modern gillnets. In the near future, these three species may not be able to sustain the burden of heavy fishing and natural predation. This situation calls for effective management options that will ensure sustainable harvest practices for the floodplain fishery. The importation and distribution of gillnets should be controlled as these were found the most important factors impacting the fishery. The study advocates for a total ban of monofilament gillnets and the use of small mesh sizes (< 76 mm) in the Zambezi/Chobe floodplain fishery. Fishing communities are also knowledgeable about the fisheries in their particular sectors, hence must be granted an opportunity to manage their own resources sustainably by adhering to agreed-upon fishing methods and patrol programs on the floodplains. It is necessary to make the gradual and minimal changes now to protect, and hopefully enhance, the state of the fishery, while it is still possible, rather than attempting to make changes after further degradation.

CHAPTER 7: FISH PROCESSING, MARKETING AND EXPORTS ON THE ZAMBEZI/CHOBE FLOODPLAIN

7.1 INTRODUCTION

The Zambezi/Chobe Rivers and their associated wetlands support an important cichlid fishery involving more than 700 fishermen and yielding 6700t/year (van der Waal *et al.*, 2011). In the Zambezi Region, the gillnet fishery on the Zambezi/Chobe floodplain plays an economic role for riparian communities (Alexander, 2012). A large number of people, many of whom live below the poverty line, find employment in fishery sector as fishermen, processors, traders, intermediary transporters, and day labourers (Ahmed, 2007). In this region, the key players in the fish handling and processing are the fishermen, fish traders and fish vendors (Alexander, 2012). Fishers land their catches and sell them to fish traders who buy fish, usually in bulk, and sell them wholesale to fish vendors at local or regional markets (van der Waal, 1980; van der Waal *et al.*, 2011; Simasiku, 2014). The target species caught on the Zambezi/Chobe floodplains are *Oreochromis andersonii* (Castelnau, 1861), *Oreochromis macrochir*, *Coptodon rendalli*, *Clarias spp.* and *Hydrocynus vittatus* (Van der Waal, 1980; Peel, 2012). Normally the fish landing sites are distant from the market place and fish are highly susceptible to deterioration (Okonta and Ekelemu, 2005). Spoilage proceeds as a series of complex enzymatic bacterial and chemical changes in fish upon being caught (Okonta and Ekelemu, 2005). Preservation and processing therefore, becomes a requirement of the commercial fisheries (Okonta and Ekelemu, 2005). The process ensures that the fish remain fresh for a long time, with a minimum loss of flavour, taste, odour, and nutritive value. Hence fish processors employ various methods in order to preserve the harvested fish products and prolong its shelf life (Al-Jufaili and Opara, 2006). Most fish are either taken, fresh on ice, directly to markets, or split dorsally, salted and dried in the villages (Tweddle *et al.*, 2011). Drying involves dehydration, that is, the removal of the moisture content of the fish, so that the bacterial decomposition or enzymatic autolysis is greatly reduced. When moisture content is reduced to 10%, the fish do not become spoiled provided they are stored in dry conditions (Okonta and Ekelemu, 2005). Fish drying can be achieved naturally using sunlight or artificially by smoking under low temperature (<150 degrees). Once the fish are dried, they can be stored until large enough quantities are amassed, at which time the dried product is transported straight to local and foreign markets (Tweddle *et al.*, 2011). Most of the fish from the floodplain destined for export or local consumption pass through the Katima Mulilo Open Market, making it a critical component in the distribution chain of the fish trade. The main fish species exported from Namibia are large bream (tilapia) exported as fresh, dried, salted and smoked products. Most fish are exported through the Namibian/Zambia border (Wenela Border Post) and sold at various markets in Zambia, the DRC, and Congo (Tweddle *et al.*, 2011). However, this very active trade goes unrecorded and is largely unregulated owing to the fact that the Zambezi River forms a long and permeable border (140 km) where both Namibian and Zambian fish traders move freely back and forth between the two countries (Tweddle *et al.*, 2011). Gaining an understanding into post-harvest activities and the chain of trade centred on the Zambezi/Chobe floodplain is an essential step towards fisheries management. The sector is often neglected in rural development and in the planning of interventions, but should be regarded as an important component of the livelihood system and can be the principal way that the exploitation of a resource is transformed into a direct family income.

A good understanding of the present processing techniques and the problems identified by the participants at different stages in fish processing, preservation, and export is crucial before any interventions can be considered; any improvement must be technically correct and in line with the desires and aspirations of the fish processors. Therefore, the aim of this chapter is to assess the fish processing techniques employed by fish processors, hereafter referred to as fish vendors, to preserve fish products, and to quantify the volume of fish exported from the Zambezi/Chobe floodplain through the Wenela Border Post. This study partially focuses on fish vendors because they are directly involved with the collection and processing of fish on the Zambezi/Chobe floodplain. The following questions were addressed:

1. What is the demographic profile of fish processors/vendors involved in fish processing and preservation at the Katima Mulilo Open Market?
2. What are the common fish processing and preservation techniques employed by processors /vendors to prevent fish spoilage between the time of landing and supply?
3. What is the total volume, source, destination and turnover of fish exported from the Zambezi/Chobe floodplain and its associated lakes in Namibia?

7.2 MATERIAL AND METHODS

Fish export surveys were undertaken between June 2015 and December 2016. All fresh and dried fish leaving Namibia through the Wenela Border Post were monitored and recorded for two days in a week. These days were alternated each week in order to cover all seven days of the week. Records included the number of hessian bags and cooler boxes of variable sizes leaving the border by taxi, truck, or pickup during operating hours (06h00–18h00), taking note of their place of origin and destinations. Each bag or carton was weighed to the nearest kg using a weighing scale which was strategically placed next to the driveway at the border (Figure 7.1). Heavy bags were measured for dimensions, calculated for volume depending on the shape (square/cylindrical) and these were converted to estimate weights using the conversion tables (Table 7.1). Conversion values were derived by measuring the volume and then weigh a number of bags in order to determine an estimate of length to weight relationship empirically.

Fresh fish in ice were corrected using a factor of 0.4 to eliminate the weight of the ice. In addition to export surveys, a short survey of fish processors (vendors) who were directly involved in fish processing and preservation of fish for export was carried out for 30 days at the Katima Mulilo Open Market. Vendors were interviewed on a range of different topics related to the mode of processing, processing duration, and different problematic areas faced during processing. Vendor characteristics were obtained during the morning and afternoon when most fish vendors were present. A validated and pre-tested, structured questionnaire was filled in for every new fish vendor in order to obtain some socio-economic background of the individual fish vendors (see Appendix B). The market was purposely selected for the study as most fish for export from the Zambezi/Chobe floodplain pass from fishers to vendors who make the final sale to consumers and wholesalers at the market (Simasiku, 2014). Dried fish products were converted to wet weight using the correction factor of 0.33, as proposed by Lewis and Tweddle, (1990).

Statistical analysis

Descriptive statistics (such as frequency counts, percentages, mean and standard error) were used to describe and summarise the data of the characteristics of vendors and volumes of fish exports. Data on fish export (expressed as kg/day) were first checked for normality and homogeneity of variances using Levene's test. To improve on assumptions of normality and homogeneity of variances, data were log10 transformed, but failed to normalize. Hence the non-parametric Kruskal-Wallis test ($p<0.05$) was employed to test for any difference in daily weight of fish exports among sampling months and between areas of origin and destination.

Figure 7.1 Weighing hessian fish bags using a hanging scale (a) and measuring dimensions of oversized and heavy hessian bags at Wenela Border Post (b), between June 2015 and December 2016.

Table 7.1 Conversion factors used for determining estimated weight of fish bags at Wenela Border Post.

Square bags	**Conversion factors**	**Linear regression**
Fresh weight	(Volume + 8043.1)/3817	R=0.58
Dry weight	(Volume - 20429)/5284.5	R=0.39
Ice fresh weight	(Volume - 54981)/2349	R=0.27
Salted dry weight	(Volume +500180)/12315	R=0.59
Cylinder bags		
Fresh weight	(Volume - 13288)/1881.7	R=0.32
Dry weight	(Volume - 72699)/4401.1	R=0.33
Ice fresh weight	(Volume + 1.66683)/8694.1	R=0.57
Salted dry weight	(Volume /14139)^1/0.7775)	R=0.51

7.3 RESULTS

Vendor demography

A total of 80 fish vendors were interviewed at Katima Mulilo Open Market between March and October, 2016 on a weekly basis. Dried fish vendors (n=50) consistently outnumbered fresh fish vendors (n=30) on the days of the interviews (Table 7.2). All vendors in the market were women and indicated that they were Namibians. The majority of fresh fish vendors indicated that they were single and that they were the head of their households. A large proportion of dried fish vendors cited that they were spouses of their household heads (Table 7.2a). The majority of the vendors interviewed who were engaged in fish processing had basic education up to primary level (Table 7.2 b). The age categories for both fresh and dried fish vendors ranged between 24 to 65 years. The most representative age group for the fresh fish vendors was 41–45 years, while the 36–40 age group dominated the group of dried fish vendors.

Table 7.2 Distributions of the Vendors by: (a) positions in the household (b) level of education.

	Fresh vendors		**Dried vendors**	
a)Position in household	No	%No	No	%No
Head	16	53.3	20	40.0
Spouse	8	26.7	23	46.0
Daughter	2	6.7	5	10.0
Relative	4	13.3	2	4.0
n	30	100	50	100

	Fresh vendors		**Dry vendors**	
b)Level of education	No	%No	No	%No
No education	2	6.7	5	10.0
Primary	24	80.0	42	84.0
Secondary	4	13.3	3	6.0
n	30	100	50	100

Mode of processing and preservation

Fresh fish preservation

The technique involved in fresh fish preservation is quite expensive owing to the fact that fresh fish products are susceptible to spoilage in the absence of adequate cold storage facilities. The fish preservation techniques indicated by most of the fresh fish vendors surveyed at the Katima Mulilo Open Market include cooling fresh fish using ice, or freezing. Most of the fresh fish vendors (80%)

used ice in the market. Vendors travelled a day in advance to villages on the floodplain, bought fresh fish from fishers early in the morning, and conveyed the fish to Katima Mulilo Open Market. Depending on the demand and supply, vendors sold their fish locally at retail prices or as wholesale for export. Fish products were typically transported in small (16.5 kg), medium (37 kg), and large (67 kg) cool boxes to the Katima Mulilo Open Market. However, most fresh fish vendors identified the lack of cold storage for fresh fish preservation as the most challenging factor (Table 7.3). Vendors complained about the scarcity and high price of ice at the market.

Fish drying

The dried fish vendors indicated that they always travel to distant fishing villages on the floodplain and camp for a week or two to enable them to buy fresh fish directly from the fishers and process them into dried products. Processing un-salted dried fish involves washing fish in clean water, cutting and splitting them dorsally in order to remove their visceral organs and minimise spoilage. Most dry fish vendors indicated that they dry their fish for two days in summer and smoke them under low heat (< 150 degrees) for 10-15 minutes on the third day. Dried fish vendors identified bad weather as the most challenging factor they face (Table 7.3). The preparation of salted dried fish is very similar to the method of drying the un-salted fish. For salted dried fish, a layer of salt is placed at the bottom of a container and a single layer of fish is placed on it with the flesh facing down. The first layer of fish is covered with more salt before another layer of fish is added. The process is continued until the container is full; preparing fresh fish under these conditions can take some hours. Thereafter, the fish is laid out and sundried on raised, multi-purpose racks (Figure 7.2 a). The final dried products are packaged systematically (Figure 7.2 b), wrapped in big sacks and loaded on a pickup van, or truck for shipping to both local and regional markets (Figure 7.2 c).

Table 7.3 Factors affecting fish processing and preservation in the study area, expressed as actual numbers and percentages.

	Bad weather	Insect attack	Lack of cold storage	No buyers	Lack of fire wood
Fresh vendors	5(10%)	-	25(50%)	20 (41%)	-
Dry vendors	16 (54%)	8 (28%)	-	3 (10%)	2 (8%)

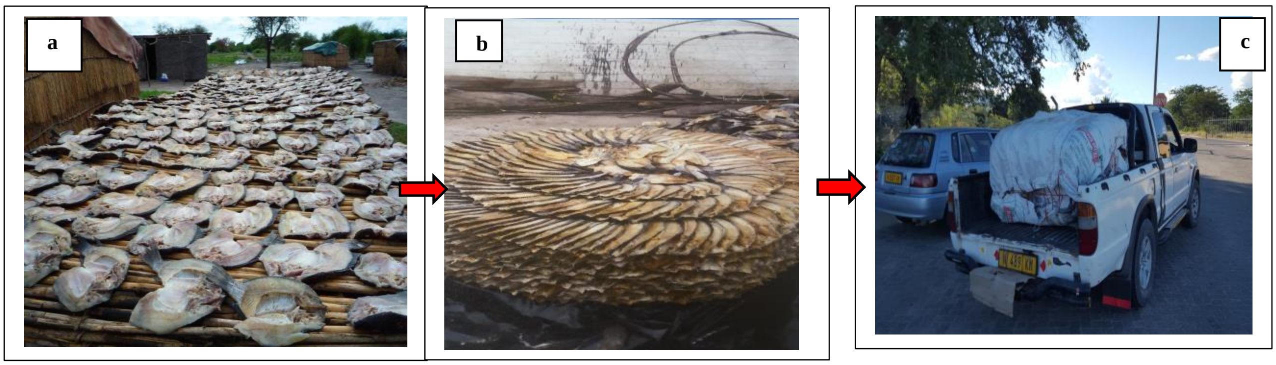

Figure 7.2 Salted drying fish (a) and systematically packed smoked fish (b) destined for exports (c) in the Zambezi Region.

Fish exports

Monthly volumes

A total of 2515 bags was weighed and recorded in 122 days from June 2015 to December 2016 at Wenela Border Post, Katima Mulilo, Namibia. Different processed fish species were exported as dried products, salted dried, and fresh on ice (Figure 7.3). A significant difference in fish products for export was detected (Kruskal-Wallis test; df=3, p=0.001), with most of the fish being exported as dried salted fish.

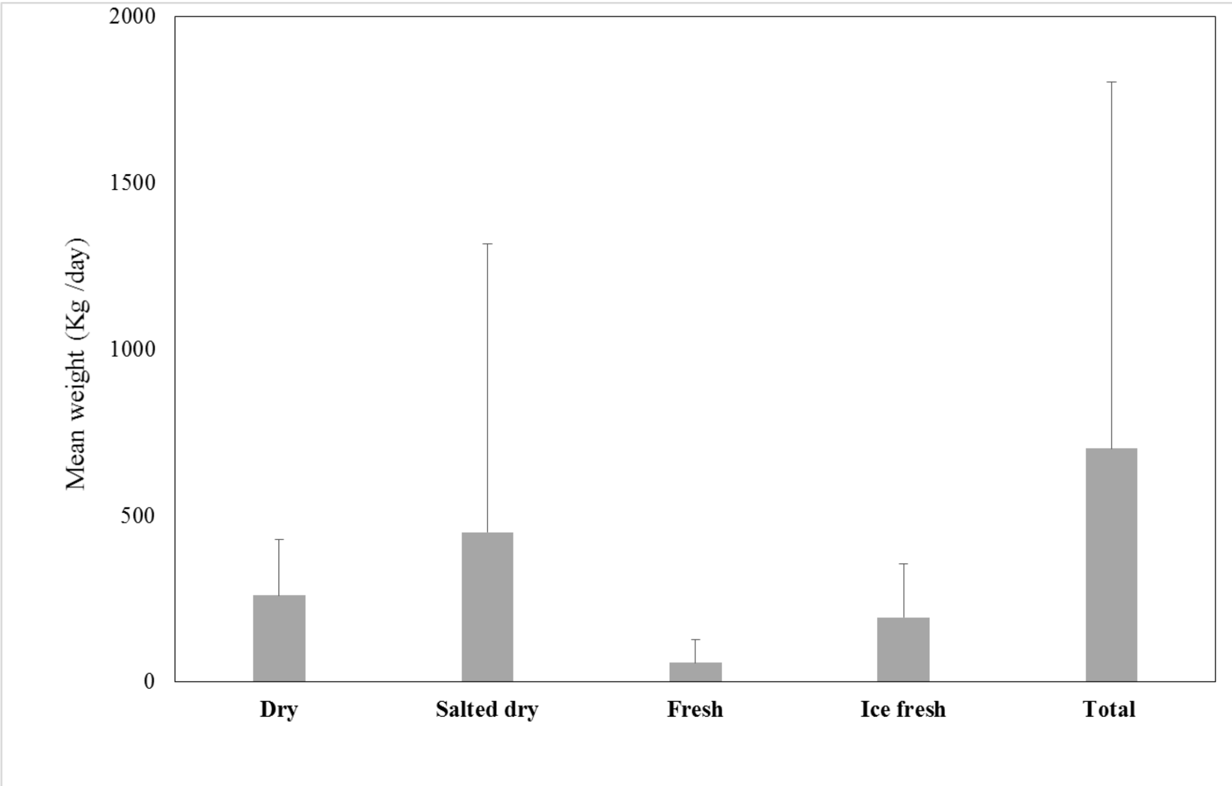

Figure 7.3 Fish products for export, recorded at Wenela Border Post between June 2015 and December 2016.

Monthly fluctuations in fish exports (expressed as kg/day) were observed between June 2015 and December 2016 (Figure 7.4). The volume of fish for export per day differed significantly between seasons (Kruskal-Wallis test; df=18, p=0.001) with distinctive peaks observed in April, July and November in 2015 and 2016 (Figure 7.4). Major declines were observed in August, September and December. Generally, there was a significant increase in dried fish which outweighed fresh fish products over the entire sampling period (Figure 7.5).

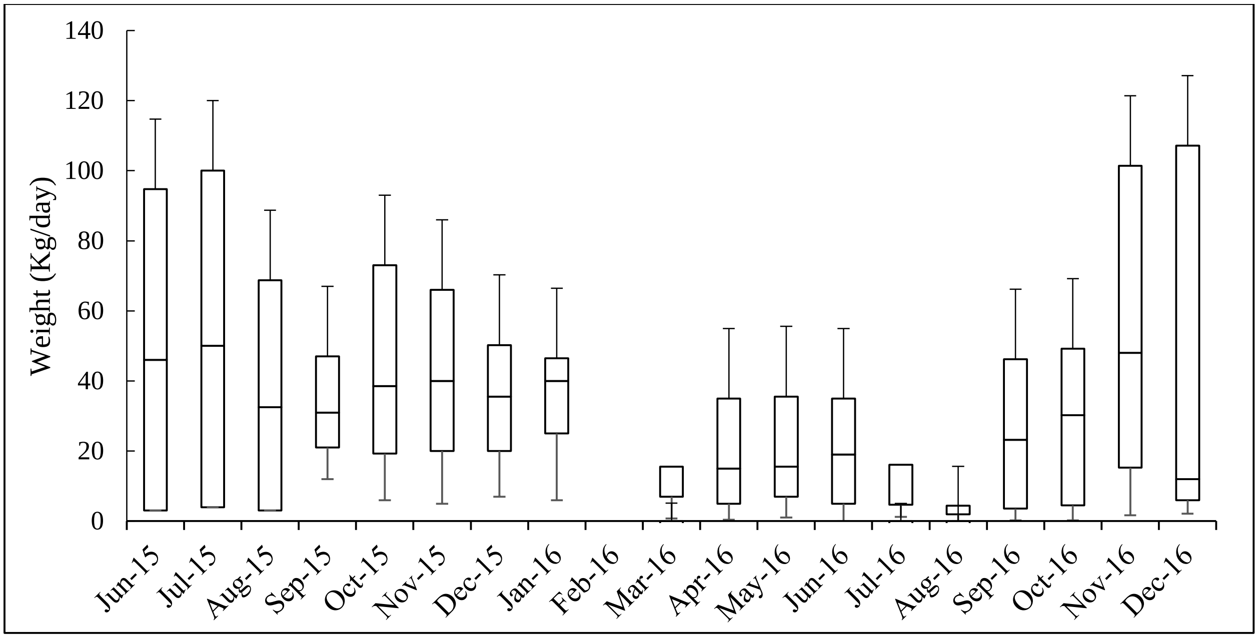

Figure 7.4 Box and whisker plots of monthly wet weights of different fish products for export, taken at Wenela Border Post between June 2015 and December 2016. Boxes represent the median and upper and lower quartiles; whiskers represent the minimum and maximum.

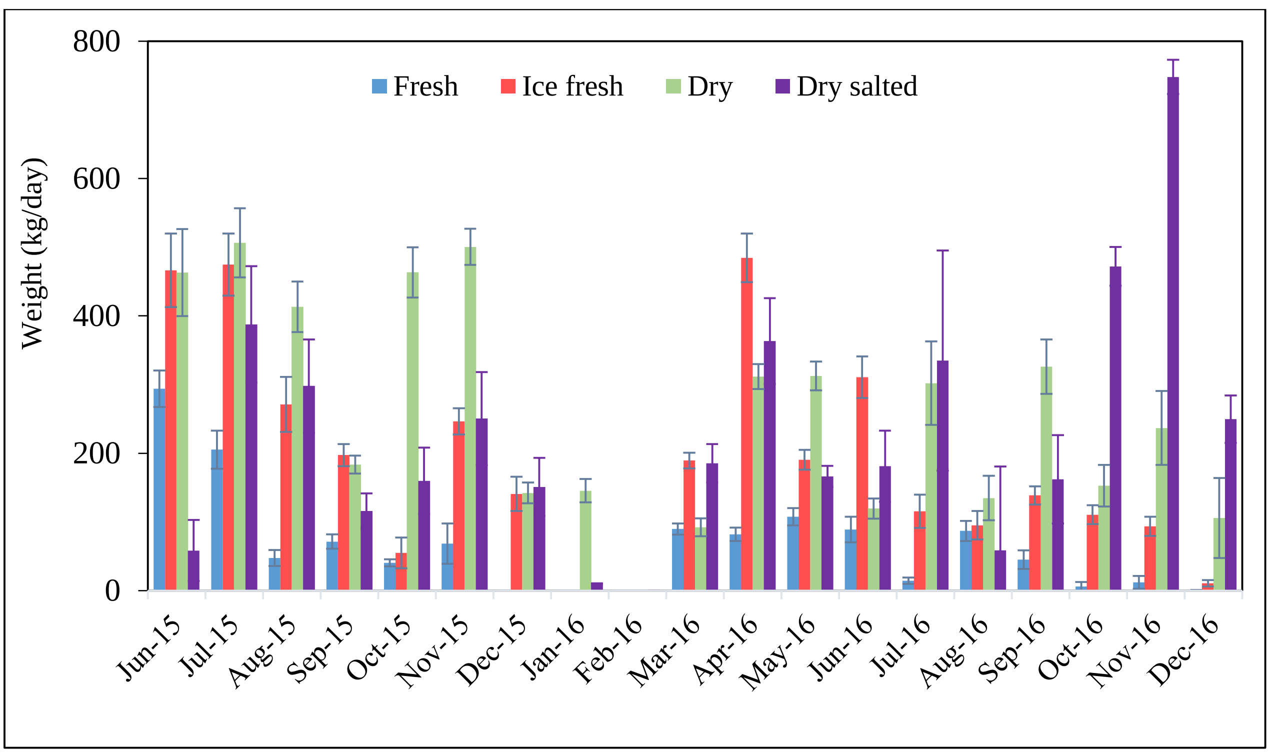

Figure 7.5 Monthly weights of different fish products for export, taken at Wenela Border Post between June 2015 and December 2016.

Area/village of origin

Table 7.4 shows different areas of origin of the fish products exported from the Zambezi/Chobe floodplain between June 2015 and December 2016. The results show that the fish products came from 25 different areas in the Zambezi Region. Large volumes (expressed as kg/day) of the fish came from Katima Mulilo Open Market (44.75%) followed by Muyako village (39.23%) and Imusho (4.37%) (Table 7.4) (Figure 7.7). It is important to note that, the majority of fish recorded at the Katima Mulilo fish market originates from a pool of villages along Lake Liambezi viz; Muyako, Zilitene, Kwena, Lusu, and Masokotwani (Figure 7.6) (Simasiku, 2014). Daily volumes of the fish for export differed significantly between areas of origin (Kruskal-Wallis test; df=3, p=0.001). Most of the salted and dried fish came from Muyako village, while most fresh fish were bought from the Katima Mulilo Open Market in Namibia (Table 7.4).

Region of destination

This study found that the different fish products are exported to thirty different destinations (markets) in Zambia (Table 7.5). Large volumes of the fish were exported to Kasumbalesa (48.92%), the border point between Zambia and the DRC, followed by Sesheke (21.90%), Livingstone (12.27%), and Katima in Zambia (7.82%) (Figure 7.7). Fish volumes for export differed significantly, depending on destination. The Bonferron's multiple test revealed a significant difference between Katima in Zambia and Sesheke; (p=0.023) and between Katima in Zambia and Kasumbalesa (p=0.021).

Table 7.4 Composition of fish products (kg/day) from different areas that passed through the Wenela Border Post (June 2015 to December 2016). Take note of Katima as a common name for both Namibia and Zambia.

Area of origin	**Fresh**		**Ice fresh**		**Dry**		**Salted dry**	
	kg	**%**	**kg**	**%**	**kg**	**%**	**kg**	**%**
Imusho	1.8	0.01	-	-	789.90	4.14	41.80	0.22
Katima Mulilo	1116.3	6.11	3467.60	18.18	2368.14	12.42	1414.54	7.42
Masokotwani	1.6	0.01	0.00	0.00	158.30	0.83	230.80	1.21
Muyako	108.4	0.60	135.20	0.70	1146.49	6.01	6089.20	31.92
Lusu	15.2	0.08	0.00	0.00	85.40	0.45	97.30	0.51
Ngala	-	-	-	-	-	-	67.00	0.35
Kapani	1.0	0.01	-	-	70.00	0.37	-	-
Linyanti	-	-	-	-	-	-	28.30	0.15
Lyansulu	-	-	-	-	1.85	0.01	-	-
Malundu	-	-	-	-	58.30	0.31	-	-
Zilitene	1.8	0.01	-	-	0.18	-	541.40	2.84
Angola	-	-	-	-	43.10	0.23	-	-
Bukalo	53.0	0.28	-	-	-	-	-	-
Ihaha	-	-	-	-	3.20	0.02	-	-
Kalimbeza	0.7	-	-	-	-	-	-	-
Kwena	0.2	-	-	-	0.28	-	41.50	0.22
Libula	-	-	-	-	4.50	0.02	-	-
Lisikili	-	-	-	-	1.40	0.01	-	-
Machita	1.5	0.01	-	-	18.10	0.09	-	-
Musanga	-	-	-	-	1.70	0.01	-	-
Nachisangani	-	-	12.80	0.07	-	-	-	-
Nakabolelwa	-	-	-	-	8.12	0.04	-	-
Namwi	-	-	-	-	16.30	0.09	-	-
Ngoma	-	-	-	-	10.70	0.06	-	-
Sangwali	-	-	-	-	0.30	-	-	-
Total	1301.4	5.7	3615.6	18.9	4786.3	25.1	8551.8	44.8

Table 7.4 Composition of fish products (kg/day) and their region of destination recorded at the Wenela Border Post (June 2015 to December 2016). Take note of Katima as a common name for both Namibia and Zambia.

Region of destination	**Fresh**		**Ice fresh**		**Dried**		**Salted dried**	
	kg	**%**	**kg**	**%**	**kg**	**%**	**kg**	**%**
Boma	-	-	41.00	0.22	-	-	-	-
Choma	-	-	-	-	194.33	1.06	44.40	0.24
Kalomo	8.30	0.05	-	-	-	-	-	-
Kashongami	-	-	-	-	3.13	0.02	-	-
Kasumbalesa	86.8	0.48	96.10	0.53	634.91	3.48	8110.0	44.43
Katima in Zambia	451.0	2.47	624.50	3.42	322.70	1.77	28.60	0.16
Kazungula	-	-	14.50	0.08	3.86	0.02	-	-
Kitwe	3.3	0.02	11.70	0.06	273.11	1.50	-	-
Likanda	1.2	0.01	-	-	1.43	0.01	-	-
Livingstone	5.1	0.03	911.10	4.99	1181.65	6.47	141.60	0.78
Lusaka	-	-	56.40	0.31	425.68	2.33	105.50	0.58
Lusu	2.5	0.01	-	-	1.10	0.01	-	-
Lyamangu	0.9	0.01	-	-	4.00	0.02	-	-
Mangamu	-	-	-	-	1.38	0.01	-	-
Manyekanaga	-	-	-	-	0.76	-	-	-
Mayondo	-	-	-	-	10.50	0.06	-	-
Mazabuka	-	-	-	-	76.17	0.42	-	-
Mukusi	-	-	-	-	0.18	-	-	-
Mwandi	52.5	0.29	-	-	2.14	0.01	-	-
Mulobezi	-	-	-	-	0.71	-	-	-
Mushukula	-	-	-	-	0.83	-	-	-
Nalisa	0.4	-	-	-	3.65	0.02	-	-
Nangula	0.5	-	-	-	-	-	-	-
Sikauzwe	-	-	7.50	0.04	1.67	0.01	-	-
Sililo	-	-	-	-	80.33	0.44	-	-
Simungoma	-	-	-	-	8.13	0.04	-	-
Sesheke	592.8	3.25	1664.8	9.12	1630.73	8.93	101.80	0.56
Sizuka	-	-	0.10	-	-	-	-	-
Nambwe	-	-	-	-	1.00	0.01	-	-
Nakatindi	-	-	-	-	226.33	1.24	-	-
Total	1205.2	6.60	3427.61	18.78	5090.40	27.88	8531.94	46.74

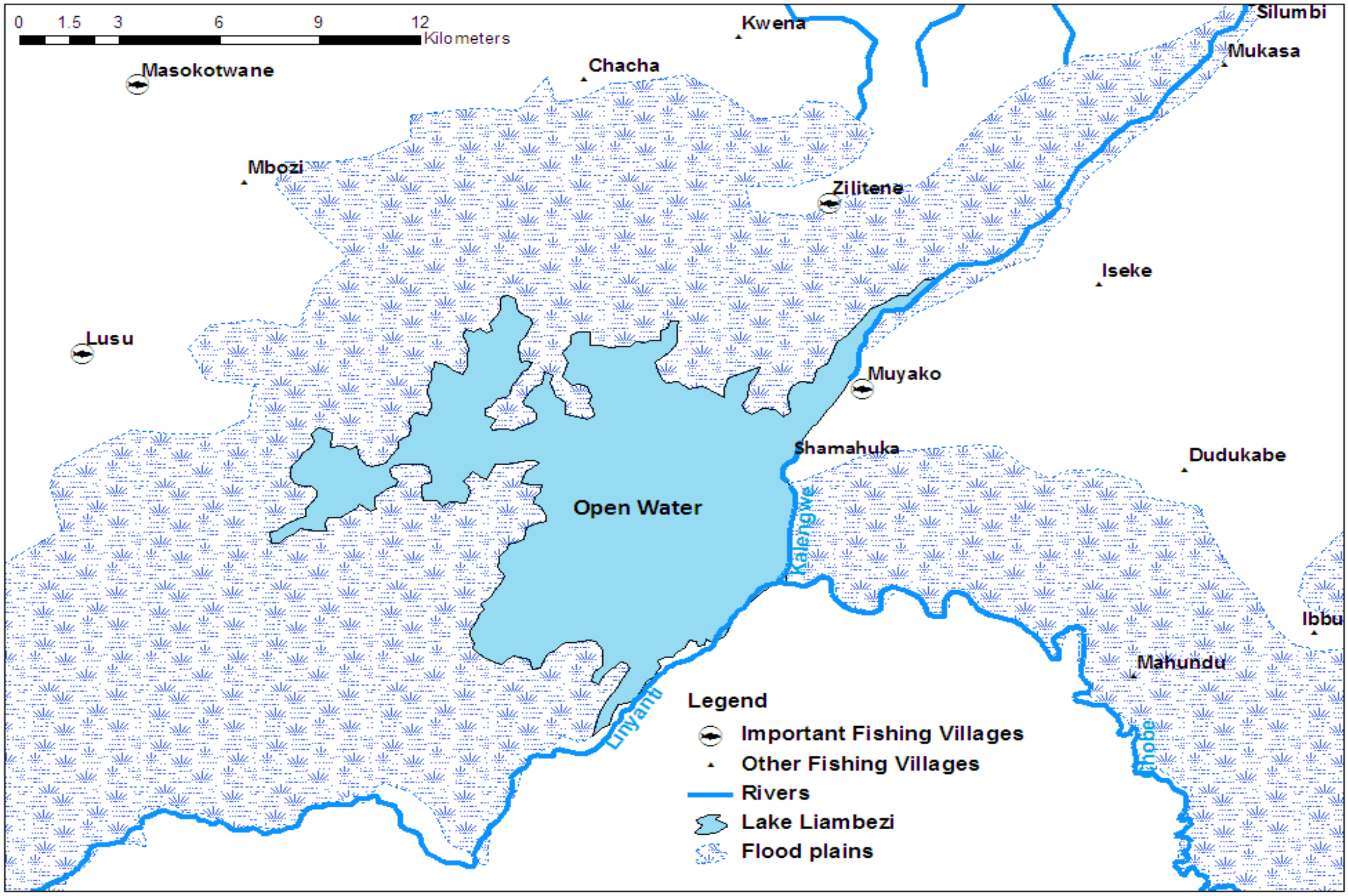

Figure 7.6 A map of Lake Liambezi showing the major fishing villages along Lake Liambezi. Map generated with ArcGIS 9.3, 2012.

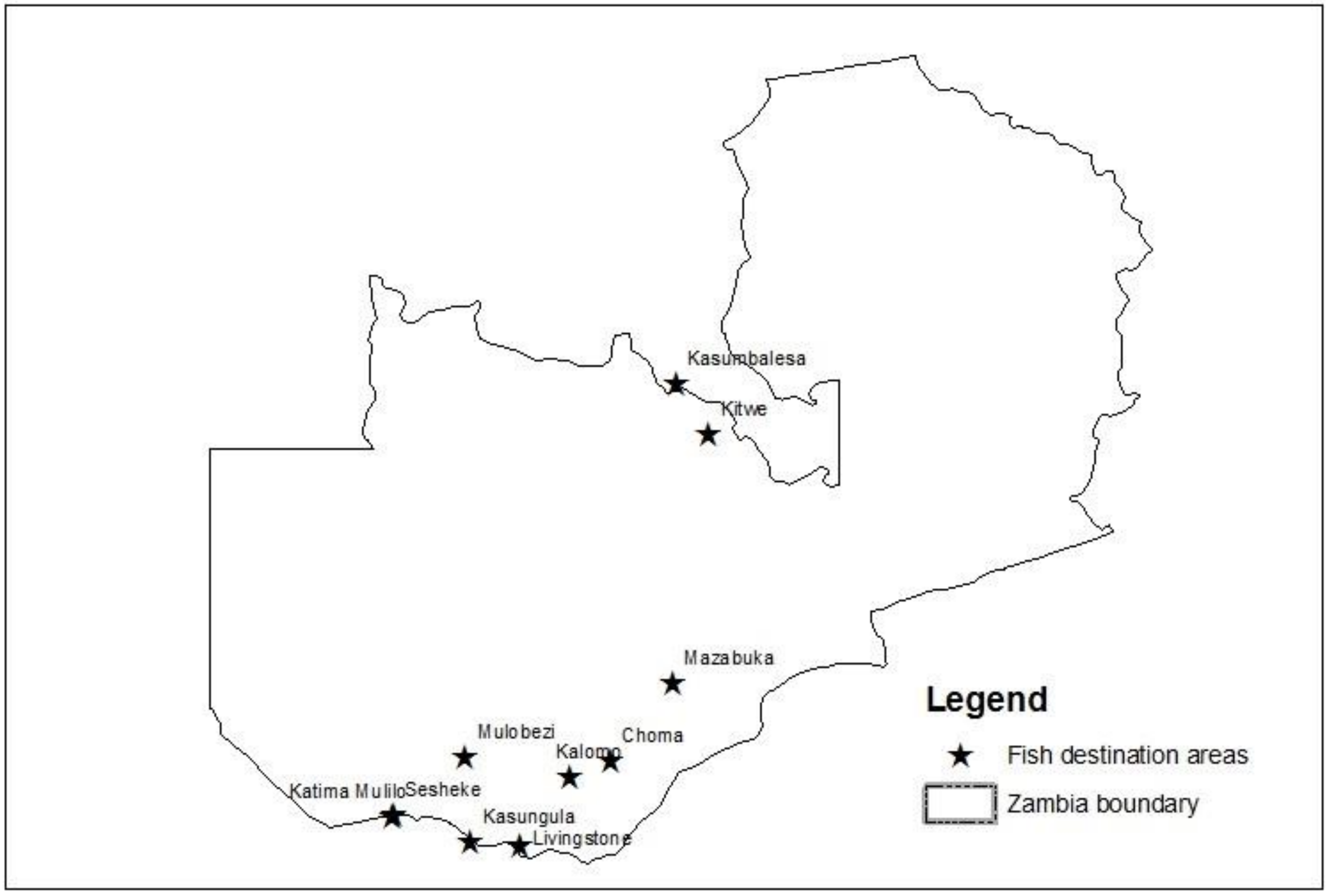

Figure 7.7 A map of Zambia showing major regional markets for fish, as recorded at Wenela Border Post between June 2015 and December 2016. Map generated with ArcGIS 9.3, 2012.

Total weight of fish exports

Using the correction factor of 0.33 for converting dried fish products to fresh weight, the analysis shows an average total wet weight of 2385.6 kg/day of fish for export recorded at Wenela Border Post (Table 7.6). By extrapolating this value to an average of 30 days in a month, this figure translates to approximately 859 t/yr of fish for export recorded at Wenela Border Post (Table 7.6).

Table 7.6 Mean weight (kg/day) of fish products exported via the Wenela Border Post between June 2015 and December 2016, N= 570 days.

Fish products	Fresh	Ice fresh	Dried	Dried salted	Total
Actual mean weight (kg) exported/day	57	194	261	450	963
Mean weight exported (kg) per day (dry weight converted to wet weight)	57	194	782	1351	2385
Mean weight (kg) exported per month (dry weight converted to wet weight) (extrapolated to a one-month period)	1722	5829	23 481	40 536	71 568
Total weight (kg)/year	20 664	69 948	281 772	486 432	858 816
Total weight (kg) exported for the period June 2015 to December 2016 (dry weight converted to wet weight)	32 718	110 751	446 139	770 184	1 359 792

Economic values

The price of fish bought as wholesale for export from various areas in the Zambezi Region depends on quantity and demand. The average price at the Katima Mulilo Open Market was set at N$27/kg for fresh fish and N$80/kg for dried fish (1US$=N$13.00 in 2015/16) (Simasiku, 2014). Based on the above figures, the results show that daily fish products worth N$63 699 were recorded for exports through the Wenela Border Post between June 2015 and December 2016 (Table 7.7). This value translates to approximately N$1.9 million per month and N$22 million per year (Table 7.7).

Table 7.7 Total value (expressed in Namibian dollars) of fish exported through the Wenela Border Post between June 15 and December 2016. (Average price for each fish product calculated according to Simasiku, 2014).

Product type	Fresh	Ice fresh	Dried	Dried salted	Total
Mean weight (kg)/day	57.4	194.3	260.9	450.4	963
Value/ kg	N$27/kg	N$27/kg	N$80/kg	N$80/kg	
Total value/day	N$1549.80	N$5246.10	N$20 872	N$36 032	N$63 699.9
Total value/month	N$46 494	N$157 383	N$626 160	N$1 080 960	N$1 910 997
Total value/year	N$557 928	N$1 888 596	N$7 513 920	N$12 971 520	N$22 931 964

7.4 DISCUSSION

Characteristics of fish processors

The current study identified women as key players in floodplain fish processing and preservation in the Zambezi Region. As the fish are landed, the female family member (usually) takes over to sort the catch for different uses. Where the fisher is part of a traditional household, the most common entry point for fresh and dried fish into the marketing chain is through the wife or a female relative of the fisher (Purvis, 2002). Similarly, the majority of fish processors in central riverine zones of Nigeria were predominantly women (Emere and Dibal, 2013). Past reports also cite the involvement of women as a key player in post-harvest activities important for fish processing and marketing (Purvis, 2002; Tweddle *et al.*, 2011). The observed dominance of female vendors in fish processing and trading in the current study may be explained by the migration of men to fishing camps and urban centres, compelling women to take up duties traditionally performed by men. Consequently, women have taken up fish trading and processing as a source of income. In-depth interviews with the fish vendors showed that most women who were involved in fish processing were single; 53% of fresh fish vendors and 40% of dried fish vendors describe themselves as household heads. These findings match the results of a previous market survey which reported a significantly higher proportion of fresh fish vendors in the Zambezi Region have take up the sole responsibility as household heads of their families as reported by Abbott, 2007; van der Waal and Hay, 2011. Gladwin *et al.* (2001) have suggested that female headed households are likely to be poorer stressing the importance of fish handling, processing and preservation as a cheap source of livelihood in the Zambezi Region.

Further results show that most respondents have basic education up to primary level. This is in line with Ikiara (1999), who reports that most fish processors in Kenya are poorly educated, with 65% registered as not having gone beyond primary education. Medard (2001) concludes that education in Tanzania was the key-influencing factor determining the roles of fish processors in society. These findings may be explained by a lack of schooling preventing most woman from learning how to read or write. This is mainly because, they are too busy working at home to be able to provide for their families. Most women assert that it has affected the direction of their lives and limits their opportunities to fish processing and handling (Mutoro, 1997).

Mode of preservation and processing

Fish is a perishable food commodity; it requires preservation for future uses. Choosing whether to sell fresh or dry fish is another important choice to reduce the risk of spoilage. The common modes of preservation on the Zambezi/ Chobe floodplain are drying and smoking. These techniques are widely used around the world and have proven to be efficient (Emere and Dibal, 2013). A small proportion of fish processors dry fish in conjunction with salting and smoking. Salting promotes quick drying and reduces the accumulation of mould. Purvis (2002) further reports that salting fish can inhibit attacks by blowflies, especially in the wet season when conditions are humid. The main aim of these modifications is to extend the shelf-life of fish so that they reach their target markets.

Distribution channels

The fishery products from the Zambezi/Chobe floodplain are exported to both local and foreign markets by land transport, specifically by pickups (Alexander, 2012, and this study). The choice of transportation is based on affordability, availability, and accessibility. The current methods for shipping fish products to regional markets are generally basic and include the use of sacks, cooler boxes and plastic bags.

The study shows that foreign markets are preferable because of the high demand for fresh and dried fish (Tweddle *et al.*, 2011). The main fish species exported from Namibia are large bream (*Oreochromis* and *Coptodon spp.*) and catfish (*Clarias spp.*) and the study shows that fish products of these species were exported to 30 regions in Zambia. The bulk of fish products was shipped to Kasumbalesa, Sesheke, Livingstone, and Katima Mulilo in Zambia, accounting for over 90% of the total fish exports between June 2015 and December 2016.

Fish destinations are influenced by the mode of preservation. Most fresh fish were exported to nearby towns such as Sesheke, Livingstone, and Katima in Zambia (Figure 8), while most dried fish were shipped to distant markets such as Kasumbalesa, the biggest foreign market by "volume" for fishery products (Alexander, 2012) and one which serves as the trading channel for fish traders from the DRC. The location of Kasumbalesa on the Zambia Democratic Rebublic of the Congo border makes trading fish with the DRC easier (Figure 7.6). The customers at Kasumbalesa border are Congolese and prefer dried and salted fish. They come from Lubumbashi in Katanga Province, buy fish at the border and sell it at the Njenya local market, in Katanga province. Some fish are sold in Kasai province in DRC (Tweddle *et al.*, 2015).

With regard to the origin of the fish, it appears that the majority of fish being shipped for export at Wenela Border came from a limited number of areas (25 fishing villages) relative to the total number of consignments shipped. Large volumes of fish for export come from the Katima Mulilo Open Market and Muyako village, situated along Lake Liambezi. Liambezi is about 300 km^2 in size and is a shallow (<6m deep), productive lake in the Zambezi Region. When full, the lake supports a highly productive fishery and when dry, part of the lake is used for agriculture and grazing (Simasiku, 2014). The current study demonstrates the significance of an ephemeral water body such as Lake Liambezi for fish exports when flooded. In an early market survey, three tons of fresh fish per day was recorded to have passed through the Katima Mulilo Market en route to Zambia, of which 90% came from Lake Liambezi (Tweddle *et al.*, 2011). This situation has changed dramatically over time as the lake has been deprived of enough water from its main sources such as the Zambezi/Chobe River. As the lake gradually dries out, the whole fishery is progressively collapsing (Simasiku, pers. obs.). The lake played an important role in local living and wildlife, but it is essentially drying out. About two-thirds of the 400 or so families in the surrounding area, many of which survived by fishing in the lake, have already left the area to seek out a living elsewhere. Meanwhile, thousands of Hippos and birds, including pelicans, have vacated due to the drying up condition of the lake. Drought, climate change and low floods from the lake’s primary source of water are largely credited with contributing the lake’s low water levels.

Monthly volume exports

The monthly volume of fish for export differs significantly between seasons, with distinctive peaks in June and November each year. The study computed an estimated yield of 1359.8 tons of fish exported via Wenela Border Post between June 2015 and December 2016. This figure was obtained based on an average rate of 9.6 tons/day and 71.6 tons/month. Peak supply in fish export coincided with peak fish landings in the areas of origin, as reported in Chapter 6. For instance, peak landings were observed during summer (November) on the Zambezi/Chobe floodplain (see Chapter 6) reinforcing the preposition that fisheries are subject to seasonal variations regulated by the hydrological cycle (Welcomme, 1985). The only exception to this pattern was observed in April when more fish exports coincided with the peak floods on the Zambezi/Chobe floodplain. It is possible that the sampling days in April could have coincided with good fishing conditions.

A decline in fish exports between December and March is allied to a closed fishing season imposed by the Ministry of Fisheries and Marine Resources from the 1st December to 28th February (MFMR, 2005) indicating effective law enforcement in this regard. Establishing closed seasons is one of the management options in the Inland Fisheries Act and currently one of the regulations in place on the Upper Zambezi River (MFMR, 1995). During this period, riparian fishers are limited to making use of traditional gear such as traps, reed fences, and baskets and may fish only for subsistence (Purvis, 2002). In conjunction with the closed season, the bad road networks leading to various fishing villages during heavy summer rain on the Zambezi/Chobe floodplain might contribute to a decline in fish exports between December and March. The tracks leading from the floodplains are sandy and muddy, and they flood quickly when the river level begins to rise at the beginning of the year. Vendors are then obliged to limit their purchases, making trade difficult (Purvis, 2002).

Export value

At the time of the study, the market price was set at N$27.00/kg for fresh fish and N$80.00/kg for dried fish according to Simasiku, 2014. Based on these figures and the total computed volume of 1 575 818.20 kg/yr, computed between June 2015 and December 2016, the total value of fish exports is likely to be in excess of N$ 22 million per annum. This annual turnover is considerably higher than the quoted value of N$ 15.8 million computed from a market survey in 2011–12 (Simasiku, 2014). The difference in estimated values between this study and the former can be attributed to the route of distribution. Firstly, it was assumed in the former study that the Katima Mulilo fish market was the hub of all fish for export from the Zambezi/Chobe floodplain (Simasiku, 2014). By contrast, the current study shows that a large proportion of fish are shipped directly from their area of origin straight to Wenela Border for export, bypassing the market. For instance, over four tons of salted, dried fish from Lake Liambezi was shipped straight to Wenela Border for export and this was not captured by the market records. This oversight led to a general underestimation of the tonnage and economic value of the floodplain fishery the preceding study in the Zambezi Region.

Constraints to and opportunities for fish exports

On one hand, during the wet season, when weather conditions are wet, cloudy and humid, drying fish efficiently is very difficult and slow (Purvis, 2002). On the other, most fresh fish processors stress a lack of efficient, reliable cold storage facilities as a major constraint limiting their businesses. Purvis (2002) also identified the absence of efficient and reliable storage as a major constraint in fresh fish trade in the Zambezi Region. A freezing room established on Lake Liambezi in the 1970s was a good innovation by the Works Department in 1975 (Van der Waal, 1976), but technical problems and breakdowns of the cooling facility in 1977 interrupted the marketing of fresh fish in the region. The cooling facility was leased to a private entrepreneur and by 1978, the freezing equipment was restored to operation, but maintenance remained a major constraint. Nevertheless, the recent extension of power supply to remote areas and major landing sites by the regional council will see many improvements to maintain the quality of fish, by ensuring that fish processors/vendors have access to ice and cold storage at the earliest possible time. This innovation should maximise returns to fisher folk by ensuring that most of the fish are sold. However, such developments may impose serious consequences on the fishery by intensifying fishing pressure. Currently the fish products from the Zambezi/Chobe floodplain are preserved through drying and smoking in very unhygienic conditions (i.e. open air drying on elevated shelters or traditional houses) exposing the products to microbial and insect infestation. During a short visit at Wenela Border, the author observed a heap of poorly packed dry fish in the back of a mini-bus trailer in-transit to Kasumbalesa (Figure 7.7). The re-use of old hessian sacks and television card boxes in poor condition were also observed. Such poor packaging may expose fish products to growth of mould, pest attacks and dust. There is a need to improve the hygiene and quality of fish products by reducing pest attacks and so reduce risks to human health. One such innovation is the use of adequate packaging in attractive and labelled hard plastic packets (Medard, 2001). Packaging not only promotes consumption of healthy foods but also increases product shelf life.

Figure 7.7 Unhygienic packaging and transportation of salted dried catfish in-transit to Kasumbalesa via the Wenela Border between June 2015 and December 2016.

CONCLUSION

This study highlights the role of woman as fish processors in floodplain fisheries in the Zambezi Region. Despite their significant input to the artisanal fish industry, women have received little attention from either the government or non-governmental organisations. It is important to promote women as social actors who have the potential to improve their family situation, communities, fishery, and their country. The main processing techniques employed by woman in the Zambezi/Chobe floodplain fishery are sun drying and smoking; techniques that are widely employed in fish preservation for both local and the foreign markets chiefly centred in Zambia and the DRC. Most salted dried fish were destined for distant markets such as Kasumbalesa while the freshest fish were destined for nearby markets in Sesheke, Livingstone, and Katima Mulilo in Zambia. Major areas of origin identified were Muyako village, Katima Mulilo fish market, and Imusho. The majority of fish recorded at the Katima Mulilo fish market came from the villages along Lake Liambezi such as Muyako, Kwena, Lusu, Machita and Masokotwani. Other important fishing villages such as Lisikili, Ngala, Mahundu and Malengalenga also contributed to the fish supply to the fish market (Simasiku, 2014). Approximately 1360 tons of fish worth N$22 million were exported to foreign markets between June 2015 and December 2016, confirming the significant contribution of the fish trade to the economy in the Zambezi Region. Major constraints in fish processing and preservation ranged from the combined effects of climate, lack of cold storage, and proper packaging for exports. The study calls for recognition of the need to identify training programmes dedicated to training fish processors in hygienic handling of fish products, quality control and packaging of processed fish products to conform to human health standards. Such training will ensure a stable supply of healthy fish products, which in turn, would result in stable incomes for traders.

CHAPTER 8: AN ASSESSMENT OF FISH ASSEMBLAGES IN PROTECTED AND NON-PROTECTED AREAS ON THE ZAMBEZI/CHOBE RIVER

8.1 INTRODUCTION

Globally, the integrity of freshwater ecosystems is diminishing due to a range of threats, including habitat modification through pollution, (e.g. eutrophication), hydrological manipulation (e.g. dam construction), and over-exploitation of commercially and recreationally valuable species (Saunders *et al.*, 2002; Suski and Cooke, 2007). As a result, the loss of biodiversity in freshwater is believed to exceed that observed in either terrestrial or marine environments (Ricciardi and Rasmussen, 1999). Freshwater fishes, for example, may be the most threatened group of vertebrates on earth after amphibians (Bruton, 1995). In view of the above, scientists and managers must seek alternative measures to protect fish stocks. One such option is to designate and implement Fish Protected Areas (FPAs).

Fish Protected Areas are defined as "clearly defined aquatic areas devoted to protect spawning areas and spawning time periods, nursery sites where juveniles can mature and disperse from" (Richardson *et al.*, 2010). Many terrestrial protected areas encompass freshwaters, and many such freshwaters have been designated as FPAs, although it has been argued that such designations hardly serve their intended purpose (Abell *et al.*, 2007). Because freshwater catchments often transverse two or more institutional boundaries, their effective protection may require collaboration of political, social, and jurisdictional systems. These shortcomings have resulted in a perceived failure of FPAs as a conservation tool for aquatic systems (Abell *et al.*, 2007). Discussion on the benefits of spatial closures in the literature has focused mainly on marine ecosystems. Marine Protected Areas (MPAs) can yield an increased species diversity, greater density, biomass and size of key species compared to non-protected areas (Halpern, 2003).

Although there is little information regarding benefits of FPAs, some studies have indicated benefits similar to those of MPAs (Kocovsky and Carline, 2001).

Biodiversity can be monitored through constant reviews of species abundance and composition, with protected areas serving as control areas in terms of biodiversity (McClanaham and Kaunda-rara, 1996). Fish abundance is the parameter used to estimate and monitor fish populations. There are several methods for estimating fish abundance and species composition, but the traditional approach to estimating fish abundance involves choosing sites or sampling units within a water body and then counting fish from catches within the chosen sites (Thomson, 2000).

Over 70% of the world's commercially targeted fish species are documented by Food and Agricultural Organisation (FAO) as fully fished, overexploited, depleted or slowly recovering (Tweddle *et al.,* 2015). For instance, *Oreochromis karongae* is one of the most targeted species in Malawi, and populations collapsed in the 1990s due to overfishing (Tweddle *et al.,* 2015). Most recently, the fisheries of the Zambezi have experienced increased fishing pressure (see Chapter 6). With increasing fishing pressure, fish populations are subjected to a series of modifications in assemblages, size, and abundance (Peel, 2012; this study) because fishers opt to catch the largest or most valuable species in a fish community (Welcomme, 2001). As larger individual species are caught, there is a decline in the average size of fish in the population (Welcomme, 1999).

Fish Protected Areas (FPA) selected, designed and managed for freshwater biodiversity are a recent development in the Zambezi Region of Namibia (Tweddle and Hay, 2011) and were established in response to concerns expressed by the local fishing communities and by the tourist organisations that the fishery was in serious decline as a result of widespread use of illegal and destructive fishing methods (Peel, 2012, see Chapter 6). In view of these concerns, two extensive year-round FPAs (Kalimbeza and Kasaya channels) were established on the Zambezi/Chobe River with the expectation that these areas would, in time, maintain and yield high species richness and abundance through enhanced recruitment under reduced disturbance (Tweddle and Hay, 2011). It was also expected that the designated areas would seed and colonise depleted areas through adult and juvenile emigrations (Tweddle and Hay, 2011). The potential use of these reserves for conservation of freshwater fish species deserves special attention and needs to be assessed. Although there have been a few assessments on the performance of FPAs (Kocovsky and Carline, 2001), none has been devoted to freshwater systems in Namibia. The aim of this study is to improve our understanding of the performance of FPAs in Namibia and investigate whether they are achieving their intended goals.

To achieve this aim, the following hypotheses are addressed:

1) Species composition and diversity was similar between FPAs and non-FPAs.
2) Catch rates (CPUE) of the abundant species was similar between FPAs and non-FPA.
3) Mean sizes of the most abundant species were similar between FPAs and non-FPA.

8.2 MATERIAL AND METHODS

Study sites

The study was carried out in two areas on the Zambezi River: one three-kilometre stretch within the Hippo Channel and a second 12-kilometre stretch in the downstream Kalimbeza Channel (FPA) (see Chapter 3). The unprotected sites around the Hippo Channel consist mainly of agricultural land and rural hamlets. The surrounding land in Kalimbeza area is protected for conservation purposes and is composed of grasslands, deep forest, and marshy lowlands and provides sustenance and protection for terrestrial wild animals (Simasiku, pers.obs.).

Sampling

Monthly sampling was conducted from January to December 2016 using a 15-horsepower motorised boat. However, sampling was interrupted by heavy rains and the theft of gillnets at selected sites, hence data for January and February 2016 could not be collected. Fish were collected using a fleet of brown, multifilament nylon nets with stretched mesh sizes of 12, 16, 22, 28, 35, 45, 57, 73, 93, 118 and 150 mm. Each fleet was 110 m long and 2.5 m deep with eleven randomly distributed 10 m mesh panels. Gillnet sampling was done in each area for two nights per month. Gillnets were set in open waters from 17h00 to 06h00 the next morning, allowing a setting time of 13 hours. For each species, total length (mm), weight (g) and the mesh size in which the fish were caught were recorded. All specimens collected were identified using Skelton's (2001) classification system. Temperature (^{o}C), Dissolved oxygen (mg/L), Conductivity (µS/cm) and pH were taken at each experimental gillnet site.

8.3 **DATA ANALYSIS**

Catch composition

The index of relative importance (IRI) (Hay *et al.*, 2002) was applied to describe the species composition of experimental gillnet catches in the Zambezi. The IRI was used to determine the most important species in gillnet catches among sites by number, weight and frequency of occurrence, and was calculated as:

$$IRI = (\%N + \%W) \times (\%FO)$$

where %N and %W are the percentage contribution of each species by number and by weight to the total catch of each system, and %FO is the percentage frequency of occurrence of each species in the total number of net settings.

Variation in fish composition among the two sampling areas was examined based on species presence-absence data using the Sorensen dissimilarity index (Mourelle and Ezcurra, 1997) and was calculated as:

$$QS = (b+c)/(2*a+b+c)$$

Where: a = the number of shared species at the two sites, whereas b and c are the numbers of species unique to each site (Mourelle and Ezcurra, 1997).

Species diversity

Species diversity can be separated into two components: species richness and species evenness. Species diversity per area was determined using the Shannon-Wiener Diversity Index in Pasgear (Kolding, 1999). The Shannon-Wiener Diversity Index is a measure of species richness, weighted by their relative abundance or evenness and was calculated as:

$$H' = -\sum p_i \log p_i.$$

Where p_i is the proportion of individuals found in the ith species.

Catch per unit effort (CPUE)

Relative fish abundance per area was expressed as catch per unit effort (CPUE), and was expressed in numbers and in weight.

CPUE was calculated as:

$$CPUE = \frac{Ci}{Ei}$$

where *Ci* is the catch of species (in numbers or weight) and *Ei* is the effort expended to obtain *i*.

Statistical analysis

Data on CPUE and fish sizes by area and mesh sizes were first checked for normality and homogeneity of variances using Kolmogorov–Smirnov procedure and Levene's test. To improve on assumptions of normality and homogeneity of variances, data were log10 transformed. The independent t-test was then applied to compare species CPUE and fish mean sizes between FPA and non-FPA on the Zambezi/Chobe River. In cases when data failed to normalise, the nonparametric Mann-Whitney U test was employed to test for differences in species CPUE, fish mean sizes, and diversity indices between FPA and non-FPA. Further analysis on species CPUE and mean size were conducted for the most abundant species from the two sampling areas (FPA vs. non-FPA). All analyses were carried out using Passgear, R version 3.1.3 and SPSS Inc 2015 statistical packages.

8.4 RESULTS

Physicochemical environment

Table 8.1 presents the average values of water properties for both FPA and non-FPA during the study. The average conductivity was significantly higher in the FPA than in the non-FPA (74.17 ± 25.36 µS/cm versus 70.17 ± 21.13 µS/cm, t-test, $p=0.04$). However, levels of dissolved oxygen were found to be significantly lower in the FPA than in the non-FPA

(6. 1 ± 1.31 mg/L versus 6.9 ± 0.5 mg/L, t-test, p=0.01). Recorded water pH was similar between FPAs (7.3) and non-FPAs (7.5) (t-test, *p*=0.12). Likewise, similar values of mean temperature were observed in the FPAs (24.9 ± 3.2 ºC) and non-FPAs (25.96 ºC) (t-test, *p*=0.12). Water temperature ranged between a winter minimum of 18.0 ºC and a summer maximum of 28.0 ºC.

Table 8.1 Water quality parameters in Kalimbeza Channel and Hippo Channel between March and December 2016.

Area	**Conductivity (µS/cm)**	**Dissolved O_2 (mg/L)**	**pH**	**Temperature ºC**
Kalimbeza Channel	74.17 ± 25.37	6.17 ± 1.31	7.32	24.9 ± 3.26
Hippo Channel	70.0 ± 21.61	6.97 ± 0.5	7.57	25.96 ± 3.04

Species composition by sampling areas

Catch composition and %IRI for each species in each area are depicted in Table 8.2. A total of 12 204 fishes representing ten families and 37 species was sampled in both areas between March and December 2016. The Sorensen index of similarity detected a 37% dissimilarity in species composition between FPA and non-FPA, implying a higher degree of similarity in species composition between sampling sites. However, species in both areas differed in terms of importance (as per %IRI, %N, %W, Table 8.2). In the FPA (Kalimbeza Channel), 9150 fishes representing ten families and 34 species were sampled in 48 net nights. The most numerous species were the large predatory characin *Hydrocynus vittatus* (14.3%) and *Schilbe intermedius* (14.3%) while the former species contributed the most in weight (35.6%). The five most important species, accounting for 88.9 % IRI in the FPA, were *H. vittatus* (40.1%), followed by *S. intermedius* (18.5%), *Brycinus lateralis* (17.9%), *Synodontis* spp. (8.5%) and *Pharyngochromis acuticeps* (3.9%). By contrast, in the non-FPA (Hippo Channel), 3054 fishes representing ten families and

28 species were sampled in 48 net nights. The silver catfish, *S. intermedius* (25.7%), was the most numerous species while the large predatory characin, *H. vittatus*, contributed the most weight (43.1%). The five most important species, accounting for 96.9 % IRI were *H. vittatus* (40.7%), followed by *S. intermedius* (30.4%), *Micralestes acutidens* (16.3), *B. lateralis* (7.7%), and *Synodontis* spp. (1.8%).

Species richness and diversity

Species richness by family in both areas is illustrated in Table 8.2, with the FPA being more species rich (n=34) than the non-FPA (n=28). Cichlidae (11 species) and Cyprinidae (eight species) were the most speciose rich family in the FPA, whereas the most speciose rich family in the non-FPA, was the Cyprinidae (nine species) and Cichlidae being second with five species. Species diversity on the other hand, was similar in both the FPA (2.28) and non-FPA (1.92), (Mann-Whitney U test, df=2, p=0.63).

Catch per Unit Effort (CPUE) by sampling area

CPUE by number in each sampling area is illustrated in Figure 8.1. Overall CPUE by number differed significantly between sampling areas (t-test, p=0.001) with higher CPUE in the FPA (1.97 ± 0.096 fish/net. night) than in the non-FPA (1.45±0.09 fish/net. night). Similarly, CPUE by weight differed significantly between areas (t-test, p=0.003), with the highest CPUE being observed in the FPA (4817.06 ± 755.5 g/ net. night) than in non-FPA (1948.3 ± 329.5 g/ net night) (Figure 8.2). Monthly catch rates by number and weight were generally higher in the FPA than in the non- FPA (t-test, p= 0.001) (Figures 8.3 and 8.4). Both areas showed fluctuations in monthly catch rates by numbers and weight (Figures 8.3 and 8.4). There was a sharp decline in mean CPUE by number in July in the FPA and in August in the non-FPA (Figure 8.3). In contrast, CPUE by weight declined in October in the FPA, and in April and July in the non-FPA (Figure 8.4).

Table 8.2 Experimental gillnet catch composition expressed in percentage number (%N), percentage weight (%W) and percentage frequency of occurrence (%FO) and the percentage index of relative importance (%IRI) of all fish species sampled at Kalimbeza and Hippo channels during the period March 2016 to December 2016.

	Kalimbeza			**Hippo**		
	% No	**% Weight**	**% IRI**	**% No**	**% Weight**	**% IRI**
Mormyridae						
Marcusenius altisambesi	3.4	2.2	1.6	0.3	0.1	0
Petrocephalus catostoma	3.2	0.6	0.8	0.3	0.1	0
Cyphomyrus cubangoensis	0.3	0.2	0	0.7	0.2	0.1
Pollimyrus castelnaui	0.3	0.1	0	0	0	0
Mormyrus lacerda	0	0.2	0	-	-	-
Cyprinidae						
Enteromius poechii	10.3	1.3	3.8	3.2	0.8	1
Enteromiusradiatus	0.5	0.1	0.1	1	0.4	0.1
Enteromius unitaeniatus	0.1	0	0	0.4	0	0
Enteromius eutaenia	0.1	0	0	0.4	0	0
Enteromius fasciolatus	-	-	-	0.1	0	0
Enteromius bifrenatus	-	-	-	0	0	0
Labeo lunatus	1.8	2.3	0.8	1.4	1.1	0.4
Labeo cylindricus	1	0.8	0.2	0.3	0.1	0
Labeo spp	0.2	0.2	0	-	-	-
Opsaridium zambezense	0.1	0	0	0.5	0.1	0
Characidae						
Hydrocynus vittatus	14.3	35.6	40.1	14.1	43.1	40.7
Brycinus lateralis	25	10.2	17.9	15.3	6	7.7
Micralestes acutidens	10.1	1	2.9	29.8	2.5	16.3
Hepsetidae						
Hepsetus cuvieri	0.1	0.8	0	0	0.1	0
Claroteidae						
Parauchenoglanis ngamensis	0.1	0.1	0	0	0.2	0
Schilbeidae						
Schilbe intermedius	14.3	14.7	18.5	25.7	28.4	30.4
Clariidae						
Clarias gariepinus	0.1	14.4	0.6	0.1	5.6	0.1
Clarias ngamensis	-	-	-	0	1.4	0
Mochokidae						
Synodontis spp.	7.3	10.3	8.5	2	6.7	1.8
Synodontis nigromaculatus	0.1	0.3	0	-	-	-

Cichlidae						
Pharyngochromis acuticeps	5.9	3.1	3.9	3.4	1.6	1.3
Hemichromis elongatus	0.2	0.3	0	0.5	0.5	0
Tilapia sparrmanii	0.4	0.2	0.1	-	-	-
Serranochromis macrocephalus	0.2	0.4	0	0.1	0.3	0
Coptodon rendalli	0	0	0	0.3	0.5	0
Sargochromis carlottae	0.1	0.2	0	0.1	0.3	0
Pseudocrenilabrus philander	0.1	0	0	-	-	-
Oreochromis macrochir	0	0.1	0	-	-	-
Serranochromis altus	0	0.1	0	-	-	-
Sargochromis codringtonii	0	0	0	-	-	-
Ctenopoma multispine	0.1	0	0	-	-	-
Distichodontidae						
Nannocharax spp.	0.1	0	0	0	0	0

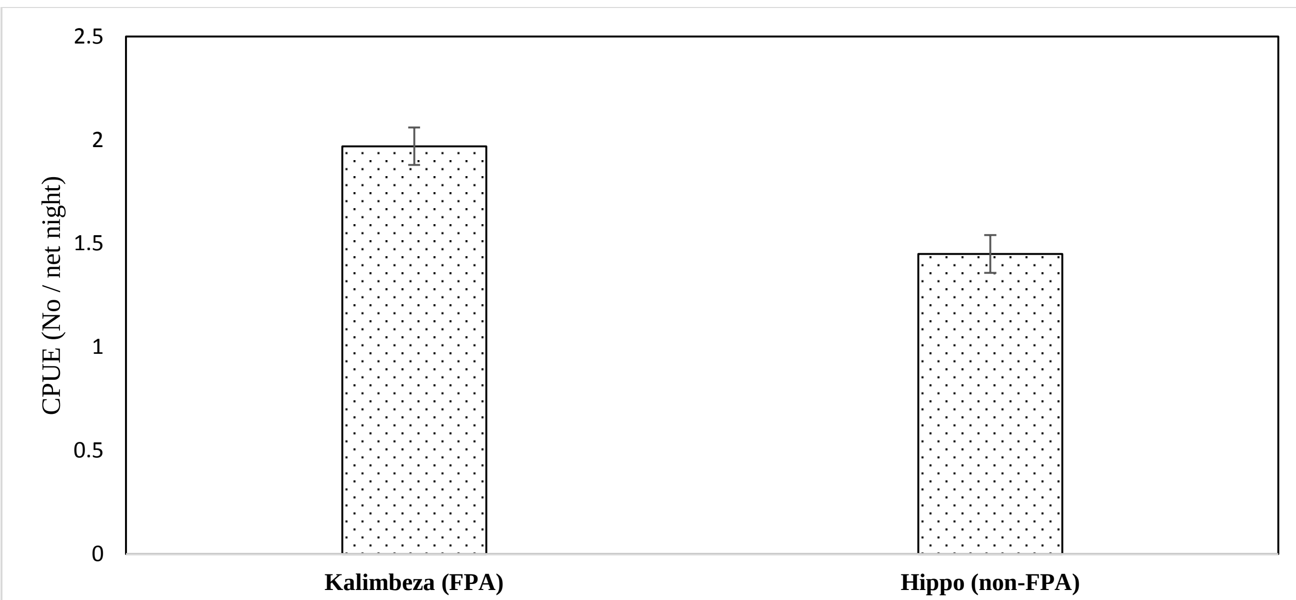

Figure 8.1 Catch per unit effort ± standard error by number in experimental gillnet catches, for all mesh sizes (12–150 mm) combined in Kalimbeza (FPA) and Hippo channels (non-FPA), sampled between March 2016– December 2017.

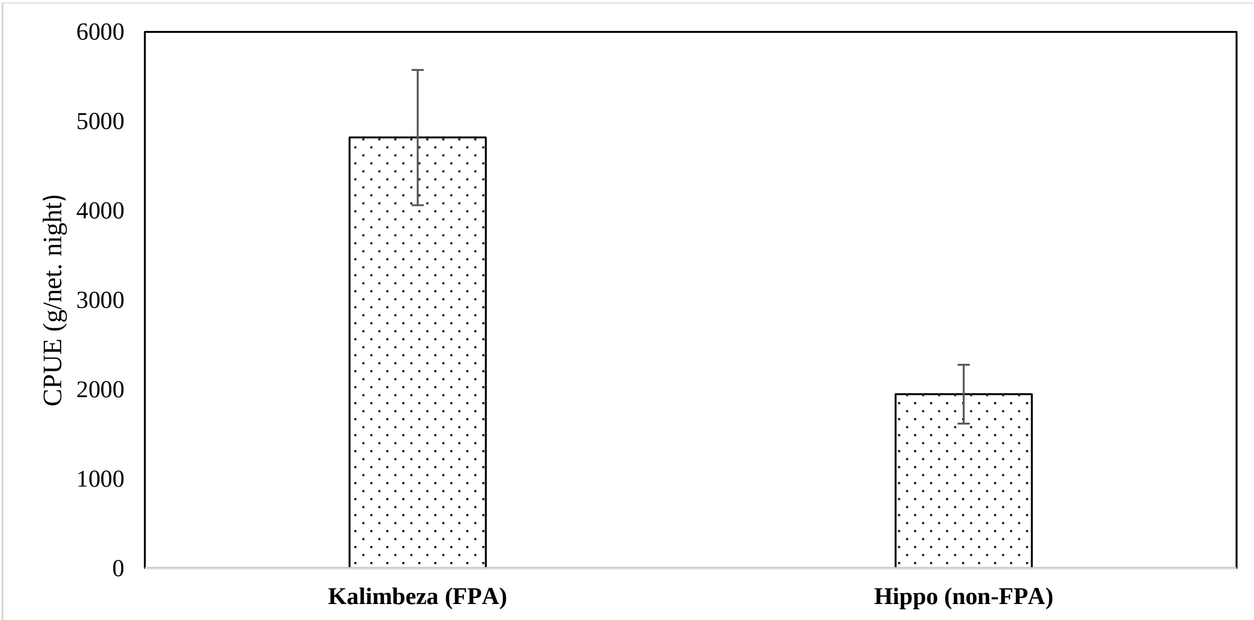

Figure 8.2 Catch per unit effort ± standard error by weight in experimental gillnet catches, for all mesh sizes (12–150 mm) combined in Kalimbeza (FPA) and Hippo channels (non-FPA), sampled between March 2016–December 2017.

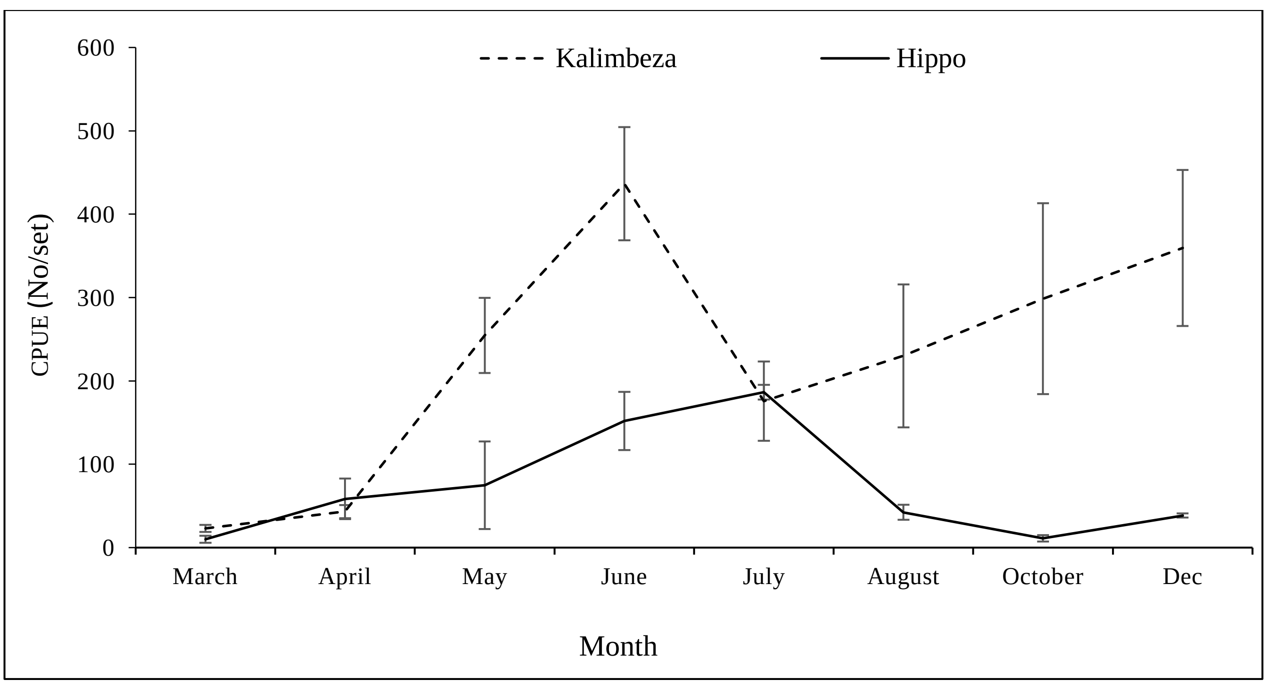

Figure 8.3 Monthly catch per unit effort ± standard error by number in experimental gillnet catches, for all mesh sizes (12–150 mm) combined in Kalimbeza (FPA) and Hippo channels (non-FPA), sampled between March 2016–December 2017.

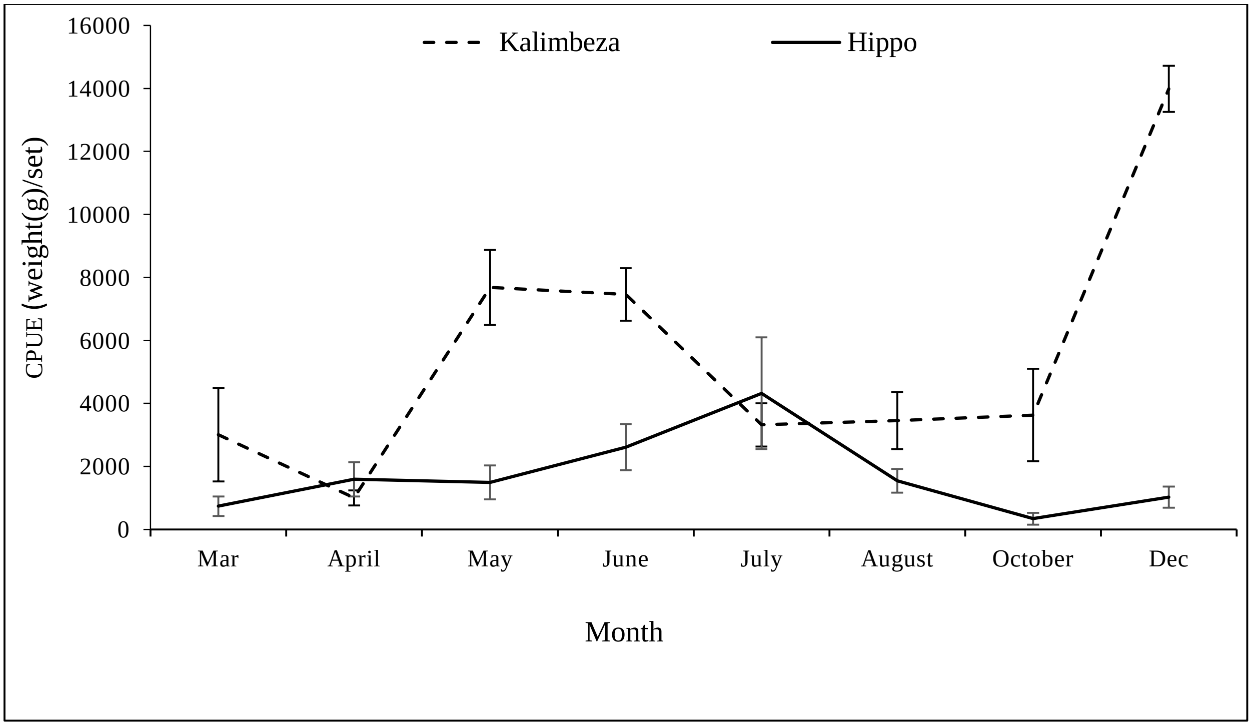

Figure 8.4 Monthly catch per unit effort ± standard error by weight (b) in experimental gillnet catches for all mesh sizes (12–150 mm) combined in Kalimbeza (FPA) and Hippo channels (non-FPA), sampled between March 2016–December 2017.

CPUE by mesh-size groups

Catch per unit effort by number in both FPA and non-FPA was generally highest in mesh group 22–28 mm, whereas CPUE by number differed significantly between areas for mesh groups; (22–28 mm, t-test, p=0.01), (35–45 mm, Mann-Whitney, p=0.002), (57–73 mm, Mann-Whitney, p=0.003) and (93–150 mm, Mann-Whitney, p=0.001), being higher in the FPA than non-FPA (Table 8.3). No significant differences in CPUE by number was observed for the small mesh group (12–16 mm) between FPA and non-FPA (t-test, p=0.23). CPUE values by weight differed significantly between FPA and non-FPA for mesh groups (22–28 mm, t-test, p=0.01), (35–45 mm, Mann-Whitney, p=0.002), and (57–73 mm, Mann-Whitney, p=0.003), (93–150 mm, Mann-

Whitney, *p*=0.004) with higher CPUE by weight being observed in the FPA than non-FPA. No significant differences were detected in the CPUE by weight for the smaller mesh group (12–16 mm, t-test, *p*=0.23) (Table 8.4).

Table 8.3 CPUE by number per mesh group in Kalimbeza Channel (FPA) and Hippo channel (non- FPA).* Denotes significant difference. CPUE = number of fish/set.

Mesh size (mm)	Kalimbeza/SE	Hippo/SE	P value
12-16	34.0±12.0	20.2±6.8	0.23 (t-test)
22-28	127.0±24.5	29.0±7.0	0.01* (t-test)
35-45	43.7±9.0	15.5±4.4	0.002* (Mann-Whitney-U test)
57-73	2.4±0.5	1.4±0.3	0.003* (Mann-Whitney-U test)
93-150	29.1.0±5.9	9.4±1.9	0.001* (Mann-Whitney-U test)

Table 8.4 CPUE by weight per mesh group in Kalimbeza Channel (FPA) and Hippo Channel (non-FPA). * Denotes significant difference. CPUE = average weight (g)/set.

Mesh size	Kalimbeza/SE	Hippo/SE	P value
12-16	111.0±30.4	46.2±15.2	0.23 (t-test)
22-28	1549.9±254.2	465.2±126.5	0.01* (t-test)
35-45	1740.8±312.3	710.2±161.3	0.002* (Mann-Whitney-U test)
57-73	408.7±89.7	261.3±69.4	0.003* (Mann-Whitney-U test)
93-150	1713.9±323.1	838.9±186.0	0.004* (Mann-Whitney-U test)

CPUE of the most abundant species by area

Among all species, *H. vittatus* was the only commercially and recreationally important species. In the FPA, CPUE by number was dominated by the small characin, *B. lateralis,* while *M. acutidens* dominated in the non-FPA (Table 8.5). CPUE by number differed significantly between sampling areas for four out of five species, namely; *H. vittatus* (Mann-Whitney, *p*=0.01), *S. intermedius* (t-test, *p*=0.03), *B. lateralis* (t-test, *p*=0.004) and *Pharyngochromis acuticeps* (t-test, *p*=0.012) with higher CPUEs recorded in the FPA than in the non-FPA. Catch per unit effort by numbers for *M.*

acutidens was similar between sampling areas ($p > 0.05$) (Table 8.5). Similarly, CPUE by weight differed significantly between sampling areas for *H. vittatus* (Mann-Whitney, p=0.01), *S. intermedius* (t-test, p=0.02), *B. lateralis* (t-test, p=0.016) and *P. acuticeps* (t-test, p=0.002) with higher CPUE observed in the FPA than non-FPA (Table 8.6). No significant differences in CPUE by weight was observed between the FPA and non-FPA for *M. acutidens* (p=0.15) (Table 8.6).

Table 8.5 CPUE by number of the most abundant species in Kalimbeza (FPA) and Hippo channels (non-FPA). * Denotes significant difference. CPUE = average number of fish/set.

Species	Kalimbeza/St error	Hippo/St error	P value
Hydrocynus vittatus	29.1±5.91	9.4±1.9	0.01* (Mann-Whitney -U test)
Schilbe intermedius	29.0±6.6	17.1±6.2	0.03* (t-test)
Brycinus lateralis	50.9±10.7	10.1±3.4	0.004* (t-test)
Micralestes acutidens	20.6±9.1	19.8±7.5	0.89 (Mann-Whitney -U test)
Pharyngochromis acuticeps	12.0±3.6	2.2±0.9	0.012* (t-test)

Table 8.6 CPUE by weight of the most abundant species in Kalimbeza (FPA) and Hippo channels (non-FPA). * Denotes significant difference. CPUE = average weight (g)/set.

Species	Kalimbeza/St error	Hippo/St error	P value
Hydrocynus vittatus	1713±323.1	839±186.4	0.01* (Mann-Whitney -U test)
Schilbe intermedius	706±166.2	17.1±197.0	0.02* (t-test)
Brycinus lateralis	489±108.0	10.1±44.0	0.016* (t-test)
Micralestes acutidens	48±18.8	49.8±19.4	0.67 (Mann-Whitney -U test)
Pharyngochromis acuticeps	12.0±23.7	2.2±20.7	0.002* (t-test)

Mean sizes of the most abundant species by area

Statistical analysis on fish size of the most abundant species is illustrated in Table 8.7. Fish mean length differed significantly between sampling areas for *S. intermedius* (Mann-Whitney, p=0.05), *B. lateralis* (t-test, *p*=0.018), *M. acutidens* (Mann-Whitney, *p*=0.012) and *P. acuticeps* (t-test, *p*=0.001). *S. intermedius* and *P. acuticeps* showed larger mean sizes in the FPA than in non-FPA, whereas the mean size of *B. lateralis* (Mann-Whitney, *p*=0.018), and *M. acutidens* (Mann-Whitney, *p*=0.12), were often significantly larger in the non-FPA than the FPA. However, the mean size of the commercially important species *H. vittatus* was similar in the FPA and non-FPA.

Table 8.7 Mean size (Fork length) per species in Kalimbeza (FPA) and Hippo channels (non-FPA). *Denotes significant difference.

Species	Kalimbeza/St error	Hippo/St error	P value
Hydrocynus vittatus	402.56 ±26.77	384.47±46.34	0.11 (Mann-Whitney -U test)
Schilbe intermedius	192.01±5	191±16.0	0.05 (Mann-Whitney -U test)
Brycinus lateralis	79.2±0.76	84.13±1.04	0.18 (t-test)
Micralestes acutidens	53.13±0.91	53.91 ±0.81	0.012 (Mann-Whitney -U test)
Pharyngochromis acuticeps	89.24±1.189	82.53±3.33	0.001*(t-test)

8.5 DISCUSSION

In this study, with the exception of conductivity, all other water parameters monitored in both FPA and non-FPA were within the values recommended by Abah *et al.* (2018) for healthy aquatic systems. The average annual water temperature values for both FPA (24.9 ºC) and non-FPA (25.9 ºC) were within the recommended range of (20–32 ºC) for optimal fish growth in tropical water systems. Similarly, dissolved oxygen in both areas fell within the range of (5.0–9.0 mg/l) as recommended Abah *et al.* (2018) for good water quality, suitable for aquatic organisms. The significant higher values of dissolved oxygen in the FPA relative to the non-FPA is probably associated to the high organic enrichment of vegetation that was observed in the FPA. The observed pH values of (7.3–7.5) were also within the suitable range of (6.0–9.8) for maximum productivity in aquatic environments. Therefore, both habitats were of ‘high habitat quality’.

Parallel experiments in the Zambezi River showed that, 34 different species were caught in the protected area (Kalimbeza Channel) compared to 28 species which were caught in non-protected areas (Hippo Channel). These results indicate that fish may have benefited from the protection of the FPA compared to non-FPA. While no benchmark on species richness is available for the FPA prior to its declaration, it is speculated that this richness is a consequence of four years of undisturbed habitat structure within the protected areas, which are highly diverse and structured and which include a network of small backwater channels, wetlands, and the presence of in-stream structures (undercut banks, woody logs and debris, overhanging vegetation, and dense riparian vegetation). It is generally accepted that vegetation enhances refuge from predation, particularly for the young fish, and increases structural complexity and availability of food as well as forming nursery beds. This notion is supported by Lubbus *et al.* (1990) who show that fish abundance, biomass and species richness are significantly correlated with high macrophyte biomass in the Chesapeake Bay (USA). In turn, these results align with findings by Sanchirico (2000), who postulates that protected areas are effective in a number of ways: protecting critical habitats, as spatial havens for targeted and intensely exploited species, as sources of stock for adjacent areas, and as potential buffers against management blunders.

Fish species composition and diversity indices were similar between protected and non-protected areas, accepting the null hypothesis that diversity was similar between sampling areas. This trend may be accounted by the high connectivity between the FPA and the non-FPA on the Zambezi River. The Zambezi River is typically lotic, and hence could permit an exchange of water and fish between the FPA and the non-FPA year-round. The pattern of connectivity between geographically close environments is fundamental to their high similarity, as pointed out by Agostinho *et al.* (1997b). It is predicted that protected areas in aquatic ecosystems function to enhance fishery yields through recruitment subsidies to fished areas from improved populations within the protected areas (spill-over effect).

Fish densities and biomass were significantly higher in the protected areas than in the non-protected areas, rejecting the null hypothesis of no difference in fish densities between sampling areas. Protection affects individual species differently. Catch per Unit Effort (CPUE) of the five most abundant species, *H. vittatus*, *S. intermedius*, *B. lateralis*, *M. acutidens* and *P. acuticeps,* declined in the non-FPA over time. One interesting observation pertains to the non-significant difference in CPUE of *M. acutidens* between the FPAs and non-FPAs. A possible explanation for this observation would be that, *M. acutidens* is able to increase rapidly in numbers and might have occupied the vacant niche left by commercially cropped species in the non-protected areas. Additionally, *M. acutidens,* like other small sized but mature fish species, are not selected commercially in the minimum legal mesh size of 76 mm. Similar observations were made in the Kwando River where *S. intermedius* was reported to have occupied the vacant predatory niche left by *H. vittatus* (Peel, 2012). Likewise, in the Kariba system, Zimbabwe, the non-commercially target species, *Synodontis zambezensis* showed the ability to expand rapidly and occupy the habitats left vacant by other commercially cropped fish species (Sanyanga *et al.*, 1995). This biological phenomenon could result in the establishment of fish stocks of low economic value in the non-protected area which would eventually destroy the fishery (Tweddle *et al.*, 2015).

Mean fish sizes on individual species varied considerably between sampling areas with higher mean sizes for *P. acuticeps* observed in the protected area. However, no differences in mean sizes were observed for *H. vittatus* between the FPA and non-FPA. The null hypothesis that mean sizes of the abundant species was similar between FPA and non-FPA was rejected for large growing species *H. vittatus.* The large home-range migratory behaviour of *H. vittatus* could compromise positive results found for the protected areas (Okland *et al.*, 2005), implying that species that exhibit a large home range (i.e. *H. vittatus*), may not be efficiently conserved in FPA (Murawski *et al.*, 2000). Mason and Lowe (2010) note that long-range migratory species face a diverse range of pressures during their extensive movements and are now among the most threatened animals. It is proposed that small sanctuaries can be effective in protecting endangered animals that exhibit high levels of site fidelity (Mason and Lowe, 2010). Secondly, it should also be emphasised that FPAs selected, designed and managed for freshwater biodiversity are only a recent development in the Zambezi Region (Tweddle and Hay, 2011). The Kalimbeza Channel in the Sikunga Conservancy, and the Kasaya Channel in Impalila Conservancy were recently gazetted in 2013 (Tweddle and Hay, 2011), hence the fish communities could be stabilizing or still be in a recovery state, therefore positive results on mean size may only reflect in the near future. The age, use, and level of compliance of a protected zone are important elements for achieving long-term conservation goals. Older effective reserves show better results than younger reserves, with densities of fish increasing by approximately 5% per year in protected areas paralleled to unprotected areas (Molloy *et al.*, 2008). Furthermore, data on the densities and age structure of fish are less reliable in young reserves (<10 years) than older reserves (>15 years) (Molloy *et al.*, 2008). In Hawaii, the duration of protection in sanctuaries had a significant effect on mean fish length, abundance and fish maturity (Sackett *et al.*, 2014). In contrast to *H. vittatus*, prolific small sized species such as *B. lateralis* and *M. acutidens* showed significantly bigger sizes in the non-FPA than FPA. These observations may be associated with high selective fishing pressure for large growing species in the non-FPA.

It should also be emphasised that Kalimbeza Channel was established as a sanctuary for the breeding and growth of economically important but overexploited large cichlid (bream/tilapia) species. Despite their importance in the commercial and subsistence fisheries, cichlid catches were poorly represented in both the FPA and the non-FPA (Table 2). Peel (2012) reports low probability of capturing cichlids in the Kavango and Zambezi River and postulates that low probability of capture is obvious when sampling rare species or species with low vulnerability to sampling gear (Maunder and Punt, 2004). For instance, *Coptodon rendalli* is suspected of evading capture in stationary gillnets (Karenge and Kolding, 1995a). Therefore, the fact that cichlids are a major component of the subsistence and commercial fishery in the Zambezi/Chobe floodplain fishery (see Chapter 6) would perhaps imply that these species are not rare as such, but rather low in their vulnerability to the experimental gillnets which were used in this study. Experimental gillnets are made of short mesh panels of 10 metres while commercial and subsistence gillnets are about 100 metres in length. In addition to net length, a subsistence or commercial fishers would use a canoe to set his nets in shallow and highly vegetated waters zones that are assumed to harbour flocks of cichlid, while experimental gillnets are mainly set in the open waters by a motorised boat. Henceforth, the mode of setting the net and net length may have an underlying effect on targeted species between the experimental gillnet compared to the subsistence's fishers gillnet. Despite these inconsistent features, an increasing trend in fish densities and mean length of some species in this study (i.e. *S. intermedius*, and *P. acuticeps*) in the protected area, provides promising results regarding the future benefits of the FPAs in the Zambezi River as a stepping stone to a wealth of information on this subject. High abundance of juvenile *H. vittatus* (mean size 29 mm FL) in the protected area, suggests that Kalimbeza Channel was implemented to protect the nursery ground of fish, and positively affects juveniles by limiting their exploitation and ensures recruitment. The high abundance of juveniles within the protected areas also implies that Kalimbeza FPA was set aside as a breeding area, and thus the area is expected to have bigger fish that are sexually mature and able to give rise to many other individuals (Kasulo, 2000).

Although the conservation zone was implemented to enhance fisheries production, there is limited enforcement to ensure compliance. The conservation zone is about 12 km and, therefore, difficult to enforce with the limited resources and personnel. Fishers have been observed illegally setting gillnets in the conservation zone and have adopted practices to minimise the chance of being caught by the local authorities. This low level of compliance, combined with an increasing demand for fish products from the local community driving the need or desire to fish the conservation zone, compromises the FPA ability to achieve its goal of enhancing fisheries production, and to maintain biodiversity (Fu *et al.*, 2003). Increasing resources for more effective enforcement, or any other strategy for that matter, is limited because the conservation zone generates limited income from tourism or other activities. Such issues related to inadequate resources are likely to be issues for the management of conservation zones in the Zambezi Region. Management of the conservation zone in the region, irrespective of whether it serves to enhance fisheries production or conserve biodiversity, requires a combination of top-down and bottom-up approaches. In isolation, both approaches have their successes and shortfalls (Jones, 2002). However, as argued by Jones, (2002), both approaches have a significant role to play in the region. Regardless of the approach, there is a clear need for science to inform and improve management in the Zambezi Region where limited information is available on the effectiveness of FPA as a management tool.

CONCLUSION

Fish Protected Areas are associated with an increase in species density relative to unprotected areas. The general increase of some species may be attributable to a number of advantages offered by the FPA, for example, the establishment of vegetation could have led to an increased habitat diversity and the availability of food items. The lack of large length classes in the length frequency distribution of the most abundant fish species within the FPA must be the effect of illegal fishing and high migratory behaviour of the large predatory and commercially important species, *H. vittatus*. However, the record of high fish densities in the FPA than non-FPA supports the notion that FPAs have been part of successful management and conservation programmes designed to protect freshwater environments in the past, and that the results from this study add value to ample biological evidence to suggest they should be applied to conservation issues in the future.

CHAPTER 9: GENERAL DISCUSSIONS AND MANAGEMENT RECOMMENDATIONS FOR THE ZAMBEZI/CHOBE FLOODPLAIN

The influence of hydrological variability and physicochemical parameters on small littoral fish in the Zambezi/Chobe floodplain was assessed. Cichlids dominated by *Oreochromis andersonii*, *Coptodon rendalli*, *Tilapia ruweti* and *Pseudocrenilabrus philander* were most prevalent, accounting for more than 80% of the total fish captured on the floodplain. The results showed that the littoral zones serve as important nursery grounds for small fish, particularly cichlids and cyprinids. Juvenile seasonal catch rates of the most abundant key commercially important species (*O. andersonii* and *C. rendalli*) varied between hydro-periods. The null hypothesis that CPUE of the most abundant species was similar between hydro-periods was rejected for *O. andersonii* and *C. rendalli*. Higher densities of these two species were realised during the high water phase characterised by high levels of dissolved oxygen, neutral pH, low conductivity and moderate water temperature. Further explanation for these observations was linked to successful breeding, as well as the preference of young cichlids for shallow, warmer waters for both feeding and refuge. Cichlids usually begin to spawn shortly before flooding occurs due to an increase in day length and temperature (Chimatiro, 2004). Breeding peaks during the warm wet season are also reported by Peel (2012), who reports breeding peaks of *O. andersonii*, *O. macrochir* and *C. rendalli* from January to March, with reproductive activity throughout summer, September – April. In Lake Liambezi, van der Waal, (1985) also reports that *O. andersonii* and *O. macrochir* have a long breeding season with ripe females found from August to March. It can be assumed that the rising flood promotes spawning in September and April, during which multiple broods may be raised, accounting for the observed high densities of cichlids in the littoral zone of the Zambezi/Chobe floodplain (Peel, 2012). It is important to note that *C. rendalli* is are multiple spawners’’ while *O. andersonii* spawns only once or twice per season (Simasiku, 2014).

However, densities and mean sizes of *O. andersonii* and *C. rendalli* decline during the low water phase. During the flood recession, fish populations are expected to vacate to the main river stream (Chapman and Kramer, 1991; Chapman *et al.*, 2000) as the floodplain habitat starts to shrink. It is most likely that juvenile *O. andersonii* and *C. rendalli* undertook early migration off the ephemeral floodplain habitats during the recession phase into deeper main channels and lagoon habitats as a strategy to avoid predation and harsh environmental conditions in isolated pools. In view of the above, water level is considered as the main driver for the dynamics of littoral fish communities in river floodplain systems. Hence a conclusion drawn in this study is that the extent of flooding is the key determinant of the fish community structure in the littoral zone of the Zambezi/Chobe floodplain. Various water developmental projects such as irrigation, hydropower dams, and expansion of municipal water supplies have been proposed by Angola, Namibia, Zambia and Botswana. These are all expected to decrease water inflows into the Zambezi/Chobe River (Siziba *et al.,* 2011). Therefore, any decline in the amount of water reaching the Zambezi/Chobe floodplain in the future and might negatively affect fish recruitment, particularly the cichlids that rely heavily on the flooded wetlands. Cichlids are an ecological and economical important human food source, and their decline in fish catches will negatively affect trophic structures and livelihoods.

The feeding ecology of Tigerfish (*Hydrocynus vittatus*) was investigated in order to assess their ecological role in the Zambezi River. The study shows that *H. vittatus* has a high diet selection for non-cichlids such as *Synodontis* spp., *Micralestes acutidens* and *Brycinus lateralis.* Dalu *et al.* (2012) shows a high diet selection for cichlids in the diet of *H. vittatus* of the Malilangwe reservoir (Zimbabwe). In Lake Kariba, *H. vittatus* feeds on Clupeidae (*Limnothrissa miodon*), Cichlidae and Clariidae (Mhlanga, 2003). These findings provide evidence that *H.vittatus* prey is determined by the availability of different species in different systems. Therefore the dominance of prey items such as *Synodontis* spp., *M. acutidens* and *B. lateralis* in the diet of *H. vittatus* presented in this study was allied to the fact that, these species are pelagic and they occupy the habitat where *H. vittatus* patrols (Skelton, 2001), and are therefore readily available to the predator.

Further analyses on prey selection by different length class showed that both small and medium *H. vittatus* feed on a mixed diet of insects and fish, while adults feed exclusively on fish. However, there was no shift in prey selected between small and medium *H. vittatus* in this study despite the fact that, at early stages of ontogeny, the food items selected were small; but, as the predator grew in size, a similar increase in the size of the selected prey organisms became apparent (see figure 5.4 in Chapter 5). Bhatt (1970, 1972) studied the food of Indian catfish, *Mystus seenghala* (Sykes) and *Mystus vittatus* (Bloch). He also found that the diets changed with size of the fish. These observations, together with the findings of this study, were justified by a change in mouth size gape of *H. vittatus*. The study showed that the small size of the mouth gape of small *H. vittatus* restricts them to exploit fairly small prey items such as larvae of aquatic insect and small, prolific fish species such as barbs. Furthermore, the nutritional value of insect larvae delivers the advantage of rapid growth (Bhatt, 1970). The overall pattern from this section of the study showed that *H. vittatus* is a generalist piscivore and this may be a survival strategy because they decrease dependence on seasonal and short supply of prey food such as insects. It was concluded that *H. vittatus,* has an ecological role of converting un-exploitable small sized species (i.e. Characins and *Synodontis* spp.) into exploitable protein dish to local fishers on the floodplain. This ecological role will ensure a balanced fishery, where all species across the trophic levels are cropped in the Zambezi River.

The gillnet fishery on the Zambezi/Chobe floodplain was investigated and described in Chapter 6. The study records seven types of fishing gear that were actively employed in catching fish on the Zambezi/Chobe floodplain. However, the fishery is dominated by destructive gears in the form of monofilament gillnets and the frequent use of small mesh sizes < 73 mm. The fishery is clearly demand driven, selecting the species that fetch a much higher price in the market, such as *O. andersonii*, *O. macrochir* and *C. rendalli*. Annual catch rates of these three target species declined significantly from 2010 to 2017. This decline was ascribed more to the use of monofilament gillnets rather than to the influence of the hydrological patterns. Evidently, a switch from multifilament to monofilament nets between 2010 and 2017 in order to boost the daily catches may have initially improved the economic fishing activities for the riparian communities, but had eventually reduced the catches of the three commercially important species *O. andersonii*, *O. macrochir*, and *C. rendalli* noted in this study. Monofilament gillnets were initially restricted by the Ministry of Fisheries & Marine Resources, but eventually spread from Zambia where they were freely vended and exported to Namibia. By the end of 2012, nearly all gillnets on the Zambezi/Chobe floodplain were made out of monofilament nets (Tweddle *et al.*, 2015; Simasiku, 2014). This innovation has eventually led to a long term threat towards commercially targeted species in the Zambezi/Chobe floodplain fishery.

A decline in fish densities was accompanied by a decline in mean sizes of *O. andersonii* and *O. macrochir* at Kasika due to use of smaller mesh sizes by 15% of fishers on the floodplain. The existing pressure to boost the catches has driven fishermen to use smaller meshed gears, leading to declining mean fish sizes over the past seven years (see Chapter 6, Figure 6). Van der Waal (1980) and Tweddle *et al.* (2011) all report the low frequency of larger fish species and large specimens in the large mesh (>102 mm). These findings further coincide with the market survey data showing the prevalence of immature cichlids for sale and reflect the use of small mesh in the floodplain fishery (Van der Waal and Hay, 2009). Consequently in the near future, smaller short-lived species may replace larger long-lived species as the fishery matures because the short-lived species can better withstand high fishing pressure due to their short turnover rates. As a result, fishers might be compelled to change to smaller mesh sizes for economic gains.

The total annual yield for the Zambezi/Chobe floodplain ranged from 2248 tons/yr in 2010 to a mere 939 tons/yr in 2017, reflecting a serious decline over the last seven years. This is only for gillnets and does not include all the other fishing sampling gears in this study. These estimations are valuably acceptable if a total of 950 canoes were actively engaged in fishing for five days in a week. However, the noted decline in fish production of the Zambezi/Chobe floodplain fishery may be related to other floodplain fisheries in Africa. For instance, the Chambo Fishery in southern Lake Malawi crashed from 5000 t/year in 1992 to less than 2000 t/year by 1999 (Peel,2012), and the annual catch rates of *Oreonchromis lidole*, *Oreonchromis squamis* and *Oreonchromis karongae* declined from 9300 tons in 1982 to a mere 200 tons from 1993 onwards. This decline is associated with heavy fishing pressure and a high proportion of illegal fishing gear, as highlighted in this study. The current study suggests that the observed impact of small mesh sizes (65 mm) coupled with the use of destructive fishing gear (monofilament gillnets) has negatively affected the fish stocks of the Zambezi/Chobe floodplain and has resulted in the failure of cichlids fisheries of Malombe, Lake Malawi and the Kariba Dam (See Chapter 6). The conclusion drawn in this section of the study is that, if the fishery is not properly managed, the fish resource will continue to decline in biomass and fish size to the point where fishermen will adapt their fishing methods to enable them to have enough protein for the family. This may result in fish depletion of the most target *Oreochromis* species in the Zambezi/Chobe system.

Fish processing and fish exports of the Zambezi/Chobe floodplain fishery was investigated and identifies women as key players in floodplain fish processing and preservation of the catch. Past reports also cite the involvement of women as key players in post-harvest activities important for fish processing and marketing (Purvis, 2002; Tweddle *et al.*, 2011). Similarly, the majority of fish processors in central riverine zones of Nigeria are women (Emere and Dibal, 2013), implying that fishers depend on women to convert their fish catch into cash to sustain livelihoods.

Drying and smoking are the main techniques of preservation employed by the fish processors on the floodplain. Major constraints in fish processing and preservation ranged from the effects of climate, lack of cold storage, and poor packaging for export products. Insufficient supply of ice in the markets is one of the most serious problems for vendors in the Katima Mulilo Open Market. Ice is fundamental for good quality fish storage and preservation. Having ice readily available on the premises would facilitate appropriate fish handling. It is therefore necessary to establish a sufficient number of ice stores for marketing of quality fish products. In realisation of the above situation, the study recommends a cooperative that deals specifically with fish processing and marketing. This cooperative might consist of six members who own a fish processing plant or smoking kilns, a fish store, a transport vehicle and rent a fish vending stall in the Katima Mulilo open market. Such a cooperative could purchase the catches of its members at a certain predetermined beach price, process the catch if necessary, market it at the best possible price and, after deduction of expenses, divide the profits among its members in proportion to the value of the catch they delivered to the cooperative. In the 1970s, a successful fishery cooperative operated from Satau, Botswana, where they established a market and provided ice for fishermen on Lake Liambezi (van der Waal, 1980). This could serve as a benchmark for the proposed cooperative for the Zambezi/Chobe floodplain fishery.

Fish community assemblages on the Zambezi River in FPAs (Kalimbeza Channel) and non-FPAs (Hippo Channel) were assessed. The study shows similarities in species composition and diversity between the two areas accepting the null assumption that diversity was similar between sampling areas. However, abundance within the protected area is significantly higher than that recorded in the non-protected area, rejecting the assumption that fish abundance was similar between the sampling areas. This finding is consistent with Kocovsky and Carline, (2001) who report higher fish species richness in protected areas than in non-protected areas. Hay and van der Waal (2009) also reported higher fish abundance and fish biomass in a conserved area of the Kwando River in the Zambezi Region. In general, these observations indicate that minimal disruption in the protected areas can enhance high fish densities.

Distinct variation in mean sizes of the most abundant species were observed in protected and non-protected areas. Although *H. vittatus* was the only large growing species collected, no statistical difference in mean sizes of this species were observed between protected and non-protected areas. Despite the notion that FPA are considered as management tools established to protect older fish, protection did not appear to increase the size of *H. vittatus.* The lack of statistical difference in mean sizes of *H. vittatus* between fished and protected areas was related to the large home-range migratory behaviour of *H. vittatus* that might have compromised positive results for the protected areas (Pelletier *et al.*, 2008). As a result, it is suggested in this study, that small reserves such as the Kalimbeza Channel could be more effective in protecting cichlids with high levels of site fidelity than adult migratory species such as *H. vittatus.* This conception should be regarded as a guideline for establishing FPA's in the Zambezi Region. Moreover, Fish Protected Areas are only a recent development on the Zambezi/Chobe River, therefore decades of protection would yield noticeable results for the Kalimbeza Channel. Since fish population recovery is a cumulative process, it is likely that the fish communities within these areas could still be stabilizing and would only yield positive results in the near future.

MANAGING THE FLOODPLAIN FISHERY

Conclusions drawn from Chapters 6 and 7 make it clear that, besides the economic benefits accruing through fish trade, the fish stocks of the Zambezi/Chobe floodplain have declined over the past seven years. Despite a series of strict measures stipulating the appropriate gear types, mesh sizes and gear length by the Inland Fisheries Act of 2003, the use of destructive fishing gear and smaller mesh sizes in the Zambezi/Chobe floodplain was evident in this study. This low level of compliance, combined with an increasing demand for fish products from the local community, has compromised the recovery of heavily exploited *Oreochromis* species. This situation demands effective adaptive management options to protect the remaining stocks and ensure recovery of *Oreochromis* species in the Zambezi/Chobe floodplain fishery as follows:

Participatory community co-management

In order to contain the current problems in the Zambezi /Chobe floodplain fishery, the government must empower and support the local communities through participatory co-management processes, especially in the areas of monitoring, surveillance and control of all activities associated with the fisheries sector. The biggest present threat to the fish communities, and especially to the cichlids, is the use of large monofilament dragnets during the low water periods when these species move to shallower areas to build nests. Despite the fact that the Act explicitly prohibits the use of these nets, drag netting takes place throughout the system on both sides of the river (Simasiku, pers. obs.). The best means to deal with this issue is to include the communities in the management structures and impose stiff measures for law breakers, such as confiscation of all fishing gear and transport vessels/vehicles, plus fines. Only with the support of the fishing communities and traditional authorities in compelling adherence to agreed-upon fishing methods and patrolling the protected areas, will the sustainability of the Zambezi/Chobe floodplain fishery become a reality. Such an approach will minimise costs because fishers themselves can provide first-hand information on fishing patterns (indigenous knowledge), catches, and the status of the resources. Currently the Namibian government recognises the role of communities but devolving of powers to local communities lags behind that recognition. Co-management can only work with fisheries that still have existing or potential value; fisheries that have already been destroyed have to be brought back to stability before being handed over to the communities (Tweddle *et al.*, 2015). The observed stable mean sizes common to all three commercially target species at Kalimbeza and Impalila (see Chapter 6) may reflect the potential for successful intervention by government through FPA established in these two aforementioned areas (see Chapter 8).

Continuous monitoring based on catch assessment surveys (CAS)

Regardless of the management approach, there is a clear need for science to inform and improve management in the Zambezi Region where limited information is available on the floodplain fishery. The communities themselves recognise that the fishery is overexploited, but unless they are informed on the status of the stocks in relation to catch statistics, they cannot be expected to respond to calls to reduce the amount of fish harvested. It is imperative that the fishery statistics are improved because the resources represent a valuable commodity to the riparian states not only in terms of export earnings from trade (Chapter 7), but also as sources of income, employment and protein for the local people (Chapter 7). The present mode of data collection for stock assessment on the Zambezi/Chobe floodplain is based on annual biological surveys, using experimental gear. It has been argued that while this gear is suitable for insight into stock assessment and biodiversity, it is not reasonable to expect such results will adequately reflect the exploitation patterns of the commercial and subsistence gillnets, for various reasons. Experimental gillnets differ in their design from the commercial gillnets operated by the fishers on the Zambezi/Chobe floodplain. Experimental gillnets are made out of eleven different mesh sizes, ranging from 12 mm to 150 mm, and are designed to target all fish species; commercial gillnets consist of a uniform sheath of large mesh sizes that are selective to large cichlids (See Chapters 6 and 8).

The current study advocates for continuous monitoring of the fishery based on catch assessment surveys (CAS) at major landing sites through a community participatory approach. The incorporation of the communities to ensure a relatively inexpensive way of recording data on a monthly basis will provide robust year-round source of data reflecting actual exploitation levels as demonstrated in Chapter 6. The rationale for instituting fish catch and effort data collection using CAS is suggested for a number of reasons, primarily, the state of Ministry of Fisheries and Marine Resource where insufficient resources negate efforts towards sustaining data collection. The required resources in this regard include finance, trained personnel, equipment and other research facilities. Secondly, the conventional fishery data collection along the Zambezi/Chobe floodplain demands more resources and technical establishment. Landing times for many fishers vary, and most of the fishing trips go unrecorded because of budgetary and logistical constraints. It is essential that collection of catch statistics is improved to demonstrate the importance of the fisheries and the vital role they play in rural livelihoods. This will also ensure that any changes are interpreted and the correct management steps taken to ensure that the valuable fish stocks are not over utilised. This may be achieved by establishing satellite offices at three major landing sites (Kalimbeza, Kasika, and Impalila) and assigning permanent staff who will minimise costs and ensure continuous quality data collection.

Another major issue on the Zambezi/Chobe floodplain arises from the difficulty in obtaining a fishing licence or registering a gillnet. Only the Regional Council at Katima Mulilo and constituency offices have the authority to issue angling and netting licences to riparian fishermen in the Zambezi Region. The proposed satellite office space for the Ministry of Fisheries and Marine Resources at major identified landing sites should be equipped to assist in issuing licences and registering gillnets along the Zambezi/Chobe floodplain. The funds raised through issuing licences will be invested in the area where the licences are issued and be used to apply the law and manage the fisheries activities in that particular area.

Advocate for balanced fishery harvesting

The current study showed that, the gillnet fishery on the Zambezi/Chobe fishery was more selective towards larger, more valuable species and this has resulted in fish depletion of the commercially important cichlids on the Zambezi/Chobe floodplain. Kolding and van Zwieten (2014) stated that ‘a fishing pattern that distributes a moderate mortality across the widest possible range of species and sizes in an ecosystem in proportion to their biological production, so-called balanced harvesting (Tweddle *et al.*, 2015), will satisfy both fishery objectives and conservation objectives’. Selectivity towards large growing species is neither economically nor biologically resource efficient as demonstrated in Chapter 6 and 7. ‘Balanced harvesting’ in the Zambezi fisheries therefore must incorporate management of the riverine, lacustrine and large lagoon systems to ensure optimal exploitation of the large, economically valuable cichlid species, while encouraging diverse fishing methods on the floodplains such as spears, baskets, funnel to exploit the numerous prolific and generally smaller but less economically valuable species (refer to Chapter 6). In contrast to the valuable cichlid fisheries in lakes, lagoons and large rivers, fisheries based on floodplain fishes of small adult size are resilient, with such pioneer species adapted to fluctuating environments. Adaptive species traits include rapid growth and maturation, multiple spawning and strong migratory instincts that result in the species occupying all available habitats. Natural mortality is exceptionally high through predation and habitat variability (especially natural desiccation), allowing intensive exploitation when such species are present on the floodplains.

Need for more fishery reserves on the Zambezi/Chobe River

The Ministry of Fisheries should engage with the riparian communities and introduce more fish reserves on the Zambezi/Chobe River. This may contribute more to the survival and the sustainable use of the fish resource of the Zambezi/Chobe Rivers than closed seasons, which only cover a short period of the eight month-breeding period for cichlids. The present closed season (December to February) may not be inclusive and beneficial to all species due to the temporal difference in breeding strategies of the different species (see Chapter 4). Sufficient and effective reserves will enhance the fisheries. Proposed reserves should be large enough to incorporate the home ranges of the economically important species (see Chapter 5). These designated areas must be accessible for communities to assist in patrolling and monitoring shifts.. Patrols to stop netting and arrest offenders could be conducted by conservancy fish guards through cooperation with the Ministry of Fisheries and Marine Resources. Fish guards should be assisted by the Ministry of Fisheries inspectors, and by the Namibian Police and the Ministry of Environment and Tourism. Prudent development of tourist angling safaris where local fishermen use their canoes and knowledge in designated areas, can generate valuable income to the local population and authorities. Potential sites for more fishery reserves exist on the Zambezi/Chobe channels. Five such potential sites are; Lake Lisikili in the Kalimbeza district, Ntonga Channel at Kasika, Mpukano backwater at Ikaba village and the Simasiku lagoon at Impalila respectively. Such initiatives would require trans-boundary cooperation between Namibia, Zambia and Botswana.

RECOMMENDATION FOR FUTURE RESEARCH

Further research examining the seasonal, mass upstream migration of juvenile cyprinids (*Labeo* spp.) in the Zambezi River is essential. At the peak of the annual flood, large schools of juvenile *Labeo* undertake upstream migrations in the Zambezi River. Riparian communities along the Zambezi River have initiated ingenious methods to intercept large schools of juvenile *Labeo* for their livelihood. Although there is wealth of information on large fish migration in tropical rivers, juvenile migrations are still poorly understood. Understanding the dynamics of this migration at is crucial for developing fisheries management guidelines for migratory species in Africa. Increased species-specific knowledge will enable the subsequent grouping of species into ecologically appropriate management units.

Regular flooding was the main driver shaping the assemblages of littoral species on the Zambezi/Chobe floodplain (see Chapter 4). This observation requires a study to focus on the impact of climate change on the intensity and duration of water bodies in the Zambezi Region. A decrease of flow regime would result to the isolation of crucial habitats on the floodplain that are important for the production of juvenile cichlids. Unpredictable change in climate might, in turn, have effects on the recruitment success of the cichlids into the fishery.

The assessment of trophic interactions that constitute food webs is essential to a broad range of ecological studies. Food web dynamics studies using traditional and trophic relationships between species should be conducted between fish in protected and non-protected areas in the Zambezi/Chobe and should also be examined to yield information on the impact of fishing in each ecosystem.

Long-term research (> 10 years) examining the difference in fish communities between protected and non-protected areas, based on a simulation experiment of the commercial/subsistence gillnets should be conducted in order to assess the significance of these sites as breeding and growth of economically important but overfished large cichlids in the Zambezi/Chobe Rivers. This will resolve the existing gaps in Chapter 6.

Concluding remarks

The study showed that juveniles of the commercially important species; *O. andersonii, O. macrochir* and *C. rendalli* utilised the marginal zone on the Zambezi/Chobe floodplain for nursing, feeding, refuge and vacated to the main river channel as the inundated habitat started to shrink during the flood recession phase. Successful recruitment occurred at an average size of 80 mm TL, for both *O. andersonii* and *C. rendalli*. However, recruits were still considered vulnerable to predation and fishing mortality in the main river channel. An assessment of the catch and effort on the floodplain showed, there has been a definite shift towards the use of destructive fishing gears in form of monofilament. This has resulted in a significant decline in catch rates and mean sizes of the commercially important species, *O. andersonii* and *O. macrochir* over the past seven years. A recommendation has been made to establish more fishery reserves and promote for integrated co-management in order to conserve spawner stocks and improve recruitment. In consideration that, the Ministry of Fisheries and Marine Resources in Namibia has limited resources for monitoring, control and surveillance of the fishing activities over the entire floodplain, it would be more prudent to adopt closed areas as a management option rather than restricting mesh sizes and gear types according to Peel, 2012.

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APPENDICES

Appendix A: Questionnaire used for a fish vendor survey of (both fresh and dry) at the Katima Mulilo market

FISHERIES MONITORING DATA SHEET

MINISTRY OF FISHERIES AND MARINE RESOURCES and NNF/EU COMMUNITIES CONSERVATION FISHERIES IN KAZA

CONSERVANCY ………………………………………………………………. PAGE NO……………………….

Instructions: 1 Measure and weigh all fish in each gillnet 2 Measure net length with 2m string or reed and record length when bought [in yards]

DATE	TIME	PLACE RIVER	LANDING SITE HARBOUR	RECORDER

MOKORO NUMBER [fisherman name]	FISHING GEAR/ net material	NET LENGTH		MESH SIZE Stretched mm	FISH SPECIES Abbreviation/ vernacular	LENGTH TL/FL mm	WEIGHT kg	Total number per species	Total weight per species
		Measured m	Length Bought yards						
Conversancy manager				date			recorder		

Appendix B: Questionnaire used for a fish vendor survey (both fresh and dry fish) at the Katima Mulilo market

Recorder……………………….   Date………………..

F=fresh vendor D= dry vendor ……………………………

Age & Nationality	**Marital status**	**Level of education**	**Experi in marketing fish**	**Position in household**	**Other source of income**	**Source of fish**	**Mode of processing**	**Drying Duration**	**Constraints in processing**	**Alternative markets**	**Expenditure**	**Price for 1kg fish in market and at landing.**
Country **N**= Namibia **Z**= Zambia **B**= Botswana= Namibia	1.Single 2.Married 3. Divorced 4.Widower 5.Other	1.No educ 2.Primar 3.Secon 4.Other	1. <6 2.6-10 3.11-15 4.16-20 5.>20	1.Head 2.Son/daughter 3.Brother/sis 4.Grandchild 5.Relative 6.Domestic worker 7.Visitor 8.Other	1. Cattle 2.Crops 3.GRN 4.Remitances 5. Pension 6.Grants 7.Shop/trade 8.Piece work 9.Other	1.Fishermen 2.Relatives 3.Husband 4. Other	1.Sundry 2.Sundry & smoke 3.Salting 4.fresh on ice 5. Other	1. Two days 2.Three days 3. Four days 4.Five days 5. Other	1.Bad weather/roads 2. Insect attack 3.lack of cold storage 4.Poor hygiene 5. Others	1. Bukalo 2.Kasane 3. Mambva 4. Satau 5. Central north 6. Other	1.Transport 2.Ice 3.Packaging 4.Main power 5. Others	1. N$50 2. N$100 3. N$150 4. N$200 5. N$250 6. Other

Comments………
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