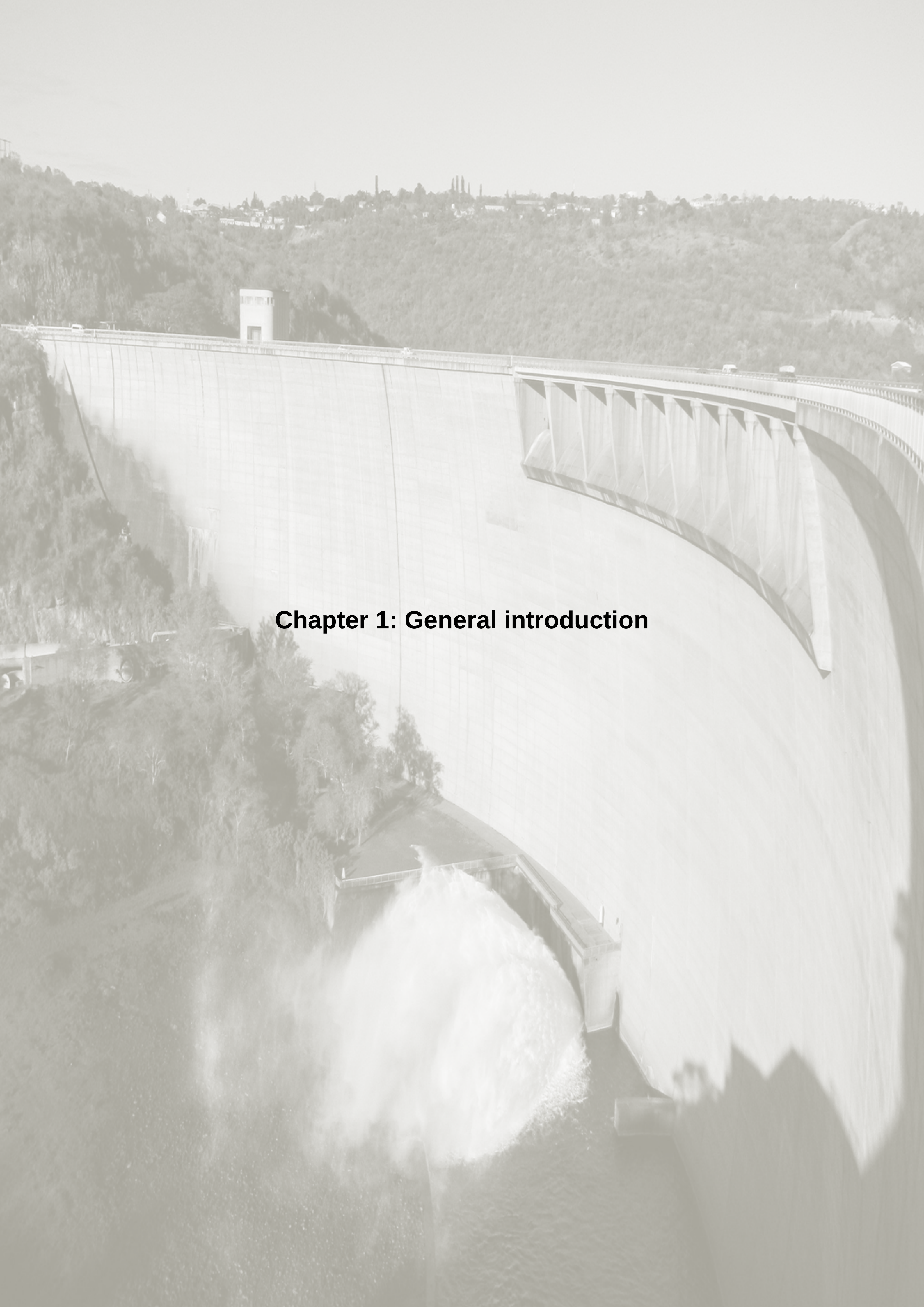

Chapter 1: General introduction

1.1 Introduction

The management of water resources is one of the most important aspects of environmental conservation, as water sustains all life on earth, but it has not received the attention that it requires, especially in the 21st century. Understanding the intrinsic variability of habitat-specific faunal communities is important to ecosystem management as this knowledge can direct decisions concerning harvest strategies, risk analysis, habitat protection and study design (Naghibi & Lence, 2012; Cote *et al.,* 2013). Mismanagement of fresh water resources by re-distribution or over-extraction is a global problem affecting the quality and quantity of aquatic habitat for wildlife and humans (Holmlund & Hammer, 1999; Kobza *et al.,* 2004). More often than not, artificial flood releases alter ecosystems dramatically, and changes in the downstream flow regime contribute to the loss of habitat and refuge areas for fish, which in turn can lead to the extinction of such species within that specific area (Freeman *et al.*, 2001; Kobza *et al.*, 2004). Conserving biological resources native to large river systems depends on how the flow-regulated segments of these rivers are managed (Freeman *et al.,* 2001).

Managing river flow through flood releases is a crucial element in the conservation and restoring of fish communities and populations and is often associated with uncertainty and complexity (Naghibi & Lence, 2012). According to Naghibi & Lence (2012), quantitative approaches for estimating immediate and long-term impacts of flow events on fish populations have not been sufficiently addressed. Rapid loss of river ecosystems and associated floodplains in recent years, coupled with the invasion of non-native species, has exacerbated the challenge of managing such habitats (Naghibi & Lence, 2012). Management of these resources is also faced with the difficulty of managing social and economic aspects as well as balancing ecology and the environment with human needs such as agriculture. Extensive water extraction from fresh water resources also results in the lowering of water tables and in turn the loss of habitat and refuge for a whole range of amphibians and fish from groundwater dependant ecosystems (Kobza *et al.*, 2004). Stream flow management in rivers like this has become a critical element in the conservation or restoring of riverine fisheries, protected species or more generally, the ecological integrity of flow regulated reaches. Therefore, it is fundamental that the management of wetlands and floodplains must set minimum hydrological standards to ensure the integrity of the habitats of aquatic organisms (Kobza *et al.,* 2004).

1.2 The Phongolo Floodplain

The Phongolo River rises at 2 200 m above sea level near the town of Wakkerstroom in the Mpumalanga Province and descends steeply for a major part of its length to the west in a valley between the Lebombo and Ubombu mountain ranges known as the Pongola Poort. In the early 1950s a dam was planned within Lebombo and Ubombu mountain ranges that could support and supply water to a proposed 50 000 ha sugarcane irrigation scheme on the fertile Makatini Flats (Van Vuuren, 2009). In addition, the dam would boost the economy and development of the area. The planning was however largely based on assumptions and the envisioned large-scale irrigation scheme was not achieved due to a sudden steep drop in the sugarcane price (Van Vuuren, 2009). Of the projected 50 000 ha, only 3 000 ha are currently being cultivated (Van Vuuren, 2009).

The Pongolapoort Dam, also called Jozini Dam, because of its close proximity to the town Jozini, is situated in the Pongola Poort close to the border of Swaziland (Van Vuuren, 2009; Heath & Plater, 2010). Pongolapoort Dam, completed in 1973, was until work started on the Gariep Dam the largest dam in South Africa and is the 5th biggest in South Africa (Van Vuuren, 2009). The dam is a medium thin, double curvature arch dam with a maximum height of 89 meters and a crest length of 515 m, which allows a gross capacity of 2 500 million m^3 (Van Vuuren, 2009).

An abrupt change in the gradient has led to the formation of a broad alluvial plain known as the Phongolo Floodplain, which is one of South Africa's most biologically diverse ecosystems (Van Vuuren, 2009). Here a series of lakes, lagoons, marshes, forests, and grasslands provide habitat for a variety of fish, amphibians, birds and wildlife alike (Bouwman *et al.,* 1990). The inundated Phongolo Floodplain covers approximately 10 265 ha at high flow and at low flow about 2 600 ha. and consists of approximately 98 pans (Heeg *et al.,* 1980; Merron *et al.*, 1993a; Heath & Plater, 2010). This floodplain is directly dependant on the seasonal floodwaters from the Phongolo River (Heeg & Breen, 1982; Heath & Plater, 2010). Downstream of the Pongolapoort Dam the Phongolo River flows predominantly in a northern direction, towards Mozambique. The Phongolo River continues in this northerly direction and flows into the Maputo River in Mozambique, which eventually decants into the sea at Maputo Bay. Average rainfall is 600–800 mm/year along the floodplain and mainly occurs during the summer months (Heath & Plater, 2010). During the summer of 1984, Cyclone Domoina hit this area (Merron *et al.*, 1993a; Heath & Plater, 2010). The average annual temperature along the floodplain is 23 °C and evaporation rates vary from 82.3 mm per month in winter to 189.4 mm per month in the summer (Watkeys *et al.*, 1993).

1.3 Community structures

Fish community structures can be used to determine the integrity of diverse systems, ranging from rivers to dams to wetlands (Moerke & Lamberti, 2003; Quinn & Kwak, 2003; Kobza *et al.*, 2004). Fish are often used to detect river impairment because of their response to physical, chemical and biological disturbances (Moerke & Lamberti, 2003). Fish communities are directly affected by flow regimes, whether natural or artificial (Bain *et al.,* 1988). The importance of the resilience of the Phongolo Floodplain fish community was emphasized by Merron *et al*. (1993a), not only for management issues, but for understanding the ecology of this diverse ecosystem. Only with this information can the socio-ecological consequences of flow alterations from the dam be evaluated and managed.

Community variability is driven by many environmental impacts such as habitat changes, environmental fluctuations, mortality, recruitment, chemical characteristics and temperature etc. (Gorman & Karr, 1987; Moerke & Lamberti, 2003; Cote *et al.,* 2013). Kushlan (1976) describes seasonal fluctuation of water levels as having the most critical environmental impact on fish communities. Another impact on community structures is over-exploitation of fish as this has a negative impact on the community structure, because people tend to target the larger individuals (pers. obs.). This in effect shifts the balance of the community structure toward the smaller individuals and reduces the abundance of the reproducing members of the community (Jennings *et al.,* 1999). Fish community structure is also affected by predators and omnivores. If a system is dominated by predators, the smaller individuals of that community will be under pressure and often the numbers of these species struggle to reach equilibrium or never do so. Conversely, when a system is dominated by omnivores, they over-populate the river due to no natural predators. Thus the balance of such a system is particularly imperative.

An increase in habitat increases the species richness, species diversity and consequently the biomass increases (Mitchell *et al.,* 2012). Water depth, current velocity and substrate are factors that influence the habitat composition, which directly impacts fish community structures (Bain *et al.*, 1988). Smaller species take refuge from predators in vegetated or structural sections of rivers (Skelton, 2001).

1.4 Population structures

Knowledge of the current and future status of the biological diversity and integrity of lotic and lentic water bodies is of paramount importance (Olden *et al.*, 2002). The modification and loss of aquatic habitats resulted in the research of the above-mentioned factors on the conservation of fish populations and communities. The necessity to understand the link between local and regional habitat changing factors and habitat use by fish has led to the implementation research findings as the central basis on fish research (Olden *et al.*, 2002; Jia & Chen, 2013). Statistical models can contribute to the understanding of fish habitat relationship as well as providing a framework on which spatial and temporal patterns in species presence or abundance can be assessed (Naghibi & Lence, 2012).

Consequently, species habitat models can contribute significantly to the management and conservation of fish populations (Holmlund & Hammer, 1999; Olden, 2002). Model predictions can be used to (1) estimate habitat suitability, (2) forecast the effects of habitat change, (3) establish potential locations for species reintroduction, (4) predict the likelihood of invasion by exotic species, and (5) predict 'hotspots' of species persistence for the conservation of biodiversity.

Fish habitat is a commonly used attribute for the assessment of the ecological integrity of rivers. However, in the case of extreme flooding fish and egg loss are not considered and are crucial aspects of fish population dynamics (Bain *et al.,* 1988; Kleynhans & Louw, 2007; Naghibi & Lence, 2012). Fish populations are considered as a holistic environmental attribute in water management decisions, because they can be used to indicate immediate and long-term impacts on the ecosystem (Bain *et al.,* 1988; Naghibi & Lence, 2012; Jia & Chen, 2013).

Naghibi & Lence (2012) assess the impacts of high flow events on fish populations. According to their findings, a fish population in a river is considered to be in ecological equilibrium under normal river flow conditions, meaning that ecological factors that increase and decrease are in balance. The ability of an ecological system to absorb disturbance without moving from one equilibrium to another is known as ecological resilience (Naghibi & Lence, 2012). It is therefore important to understand the ecological drivers of balance. This includes the flow requirements of ecologically and economically important fish species, particularly with regard to their population structure, breeding habitat and recruitment success.

1.5 Age determination

Fish age determination can be done using calcified tissue such as scales or otoliths (Campana, 1999). Although scales were traditionally used to age various fish species, otoliths have been found to be more accurate (Abecasis *et al.*, 2008; Gerber *et al.,* 2009). For decades scientists were only aware of the annuli (annual rings) deposited in the calcified structures of otoliths, until Pannella (1971) discovered the formation of circuli (daily increments) in otoliths. This exciting breakthrough in science meant that accurate age-specific growth rates could be determined and led to various studies in the following years. Campana (1999) in a review paper on fish otoliths established that during the 13 years, from 1985 to 1998, otoliths became increasing popular as a subject of study. By investigating their chemical composition scientists are now able to use otoliths for the reconstruction of life and temperature history, the detection of anadromy, age validation, stock identification and migration pathways (Campana, 1999). Otoliths are widely used in long-term fishery monitoring programmes. Chapter Four will give an in-depth literature review on age determination. This aspect will be discussed in greater detail in Chapter Four of this dissertation.

1.6 Previous work

Following the completion of the Pongolapoort Dam in 1974, a multidisciplinary research programme was carried out, led by Professor Charles Breen and Jan Heeg of the University of Natal (Van Vuuren, 2009). The focus of the research was to ensure that flood releases are to be managed and simulate the natural flow regime and not only to compensate for the amaThonga people's dependence on the floodplain but also to understand the ecology and ensure the integrity of the ecosystem services (Van Vuuren, 2009).

The construction of the Pongolapoort Dam in 1974, and concerns regarding changes in the flow regime of the Phongolo Floodplain, resulted in a number of extensive studies by (Heeg *et al.,* 1980; Weldrick, 1996; Lankford *et al.,* 2011). Heeg *et al*. (1980) emphasized the importance of the system in the maintenance of social and ecological services provided by fish communities. Heeg *et al*. (1980) listed the following reasons for conserving the Phongolo Floodplain:

1. It is the only major floodplain incorporating a series of pans within the borders of South Africa.
2. It is the most southern distribution of several tropical aquatic organisms, notably fish, and is therefore of considerable ecological importance and scientific interest.
3. It is an important winter feeding ground for a large number of winter fowl such as the White Faced Duck, which is dispersed during other times of the year, and the White Pelican from St. Lucia, which feed their young with fish from the floodplain.
4. It is of immense importance in the subsistence economy of the local inhabitants.

5. The natural beauty of the floodplain, together with several rare species included in the biota and good angling makes it potentially one of the most aesthetically pleasing and intrinsic conservation areas in South Africa.

Heeg *et al*. (1980) highlighted the important role of flooding events during particular times of the year and the effects of these floods on certain species, for example tigerfish (*Hydrocynus vittatus*). In 1996 an estimated 100 000 people living in the area (Weldrick, 1996) had direct access to the floodplain and use the river as a primary source of protein by catching fish (Lankford *et al.,* 2011). Irregular flood releases from the dam may potentially have a negative influence on fish community structure and diversity within the floodplain (Bain *et al.*, 1988; Naghibi & Lence, 2012). Extensive studies in the Phongolo Floodplain from 1993 to 1994 assessed the changes in fish communities in the area during and after a severe drought and Merron *et al*. (1993a) concluded that the correct manipulation of the flood regime of the floodplain is of fundamental importance for the fish communities and fisheries in this area.

The Phongola area contains two endemic malaria areas of KwaZulu-Natal (KZN) which are of particular interest, namely the Ubombo and Ingwavuma districts (Sereda & Meinhardt, 2005). Dichlorodiphenyltrichloroethane (DDT) has been used to control malaria in this area. DDT is known to be detrimental to human health and was banned from most developed countries after 1970 (Beard, 2006).

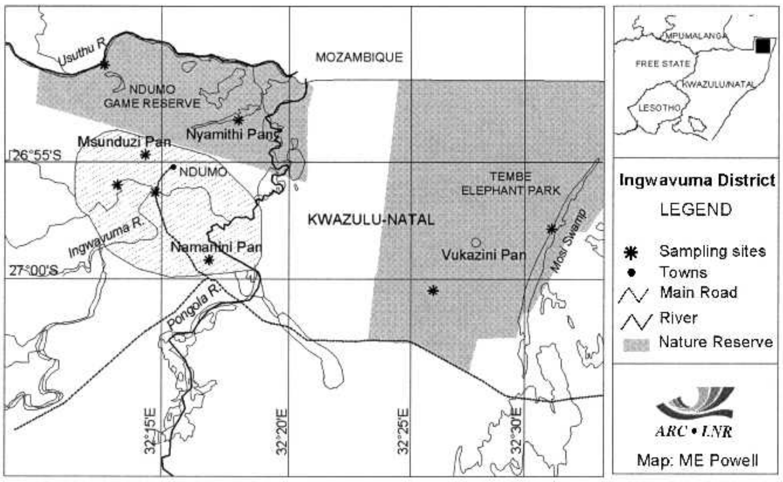

Figure 1.1: Map of the Ingwavuma district where Sereda & Meinhardt (2005) sampled for DDT contaminants. ***(Adapted from Sereda & Meinhardt 2005).***

A study to determine the effect of DDT contamination of water resources found that extensive organochloride contamination existed in the area (Figure 1.1) and this was attributed to the prior use of DDT in the area (Sereda & Meinhardt, 2005). After the discovery of the high DDT levels in the Phongola area, an assessment of the histological health status of *H. vittatus* from the Pongolapoort Dam found no external, histological or organ abnormalities in but recommended that bioaccumulation of DDT in the muscle tissue of these species should be investigated (McHugh *et al.,* 2011). This led to a study to assess the seasonal bioaccumulation of organohalogens in *H. vittatus* in Pongolapoort Dam (Wepener *et al.,* 2012) which found very high levels of DDT in the muscle tissue of *H. vittatus* and attributed it to the position of these species in the food chain. Because *H. vittatus* is an apex predator at the top of the aquatic food chain, the levels of organohalogens will be higher in their muscle due to the bioaccumulation effect (Skelton, 2001; Wepener *et al.,* 2012).

Extensive work on the genetics and age structures of *H. vittatus* in the Pongolapoort Dam Phongolo River found that they display low genetic differences and that males can live up to five years, while females can reach ages of nine years (Soekoe, 2010). The study concluded that *H. vittatus* from Pongolapoort Dam displayed large variation in growth rates, maturity and maximum sizes when compared to populations from Lake Kariba, Okavango Delta and Lake Bangweule (Soekoe, 2010).

The Ndumo Game Reserve contains the only section of the Phongolo River that is not directly influenced by humans, whether through fish exploitation, agriculture or irrigation. The 15 km section of river and the associated floodplain pans in the game reserve possibly serve as refugia for a number of fish species and thus it forms an important conservation area with regard to fish diversity and abundance in the Phongolo River. A paucity of information exists on the fish communities, population, health and diversity within the reserve.

1.7 Economically important species

Cichlids are the preferred species of subsistence fisheries in the Phongolo Floodplain. Fish is one of the main protein sources for the people living in the floodplain. As of 1996 over 100 000 people have been dependent on the floodplain and the implication is that several tonnes of fish are removed from the system annually (Merron *et al.,* 1993a; Weldrick, 1996).

1.7.1 *Oreochromis mossambicus*

Oreochromis mossambicus (Peters, 1852), the Mozambique tilapia, is the most abundant species in the Phongolo Floodplain and the most important from a subsistence fisheries point of view (Merron *et al.*, 1993a) and preferred by the indigenous people from the amaThonga (pers. obs). *Oreochromis mossambicus* is a relatively large, deep bodied, cichlid with a wide temperature tolerance ranging from 10 °C to as high as 42 °C (Skelton, 2001; Russell *et al.,* 2012) (Figure 1.2). This species has a wide environmental tolerance range, an omnivorous diet and reproduces fast, which makes it a preferred aquaculture species across the world (Russell *et al.*, 2012). In southern Africa it occurs in the east coastal rivers from the lower Zambezi River system to the Bushman's River system in the Eastern Cape and further south to the Phongolo River system (Skelton, 2001). Due to a high salinity tolerance, *O. mossambicus* can breed in fresh water and marine environments (Skelton, 2001; Dalu *et al.,* 2013). It thrives in still standing water with a sandy substrate, where it forms a saucer-shaped nest for breeding. This species breeds every three to four weeks during summer and can reach an age of 10 years (Weyl & Hecht, 1998; Skelton, 2001; Russell *et al.,* 2012). James and Burton (1992) estimated that *O. mossambicus* from small water bodies in the Eastern Cape can reproduce up to five times in a 133 day period. This species is fast growing and can mature and reproduce within a year (Skelton, 2001). Juveniles obtain optimum growth at temperatures ranging from 25 to 28 °C, while adults can inhabit a range of 22 to 30 °C (Russell *et al.*, 2012). *Oreochromis mossambicus* can tolerate low levels of dissolved oxygen (e.g. < 1 mg L^{-1}), which enables them to survive in pans and lakes that are periodically cut off from a fresh source of water (Russell *et al.*, 2012). One of the reasons that *O. mossambicus* is such an adaptable species with a high tolerance for a wide range of environmental conditions is because of phenotypic plasticity (Russell *et al.*, 2012). This species has the ability to shift their life history style along a continuum between altricial and precocial (Weyl & Hecht, 1998; Russell *et al.,* 2012). Juveniles feed mainly on diatoms but also prefer algae and detritus, while larger individuals will prey on insects and invertebrates (Skelton 2001; Russell *et al.,* 2012).

Oreochromis mossambicus, was recently added to the Threatened or Protected Species list (NEMBA, 2013) mainly because of the threat posed to the genetic integrity of the species caused by potential to hybridize with the alien Nile Tilapia, *Oreochromis niloticus* (van der Bank & Deacon, 2007).

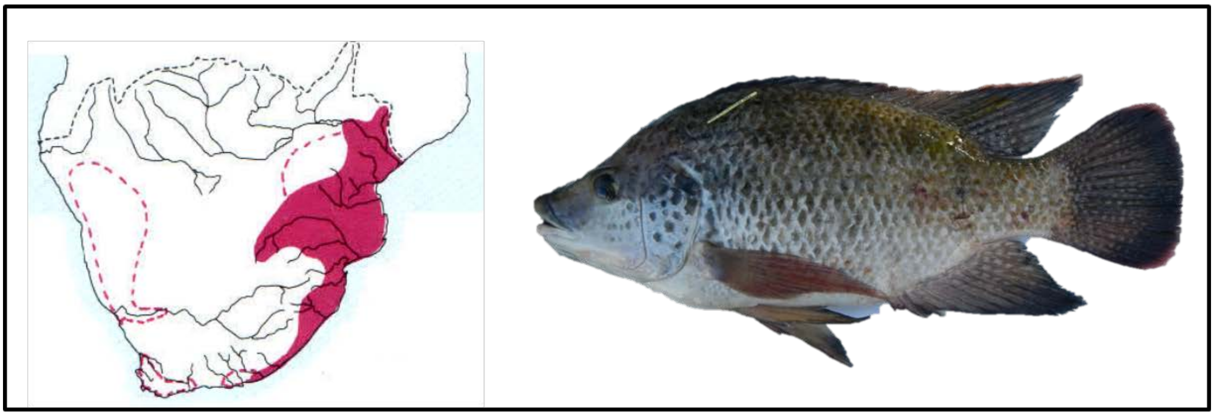

Figure 1.2: Distribution map of *Oreochromis mossambicus* in Southern Africa and an example of this species caught in Nyamiti Pan. *(Map adapted from Skelton, 2001)*

1.7.2 *Coptodon rendalli*

Tilapiines form a major part of the African cichlid family and are widely distributed across the continent. The genus, *Tilapia* at one stage were all characterized as tilapiine species in southern Africa but now it is restricted to the substrate spawning species (Skelton, 2001). *Tilapia* species have a distinct black spot on the base of the soft dorsal fin referred to as a 'tilapia spot' (Skelton, 2001). *Coptodon rendalli*, was previously known as *Tilapia rendalli* (Dunz & Schliewen, 2013). *Coptodon rendalli* (Boulenger, 1896), the Red Breast tilapia is deep bodied, olive green to brown in colour with a distinct 'tilapia spot' and bright red breast (Skelton, 2001) (Figure 1.3). Like *O. mossambicus, C. rendalli*, also prefers slow flowing to standing, well vegetated water bodies (Skelton, 2001). It has a wide temperature tolerance (11–37 °C) and feeds primarily on algae and water plants. Adults construct a nest about half a metre in diameter in which they breed and the breeding pair will guard the nest for several weeks. The species is a multiple spawner and breeds several times during summer and can reach an age of 16 years (Weyl & Hecht, 1998; Skelton, 2001)

Coptodon rendalli was introduced in several estuaries south of the Phongolo River system but did not survive due to the fact that it cannot tolerate salinities higher than 19% (Whitfield & Blaber, 1976). This species is also used for aquaculture across the African continent and is valued by recreational fishermen. Indigenous people utilize and target these species in subsistence fisheries in the Phongolo River and floodplain.

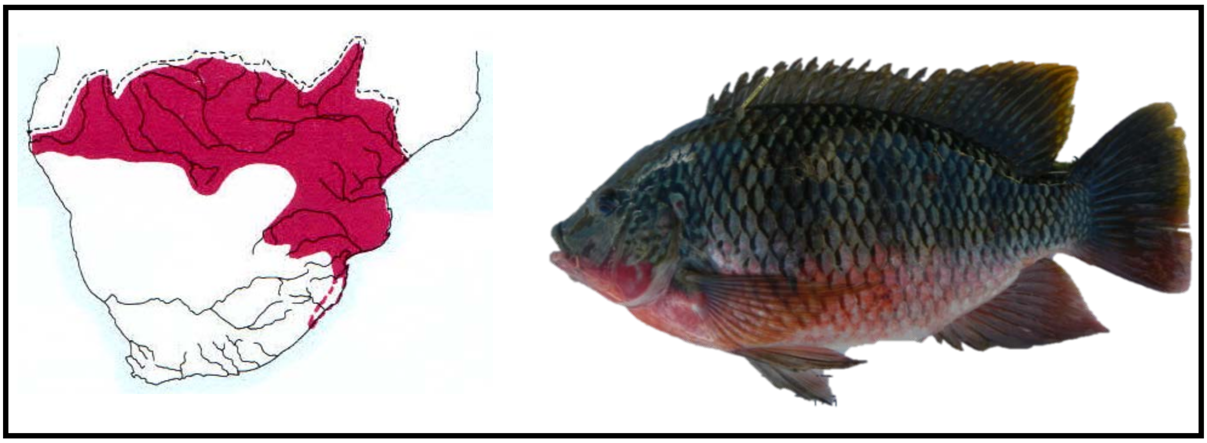

Figure 1.3: Distribution map of *Coptodon rendalli* in southern Africa and an example of this species caught in Nyamiti Pan. *(Map adapted from Skelton, 2001)*

1.7.3 *Hydrocynus vittatus*

Hydrocynus vittatus (Castelnau, 1861) has been re-classified from the Characidae family to the Alestidae family (Murray & Steward, 2002). The name *H. vittatus* means 'striped waterdog' but it is known worldwide as the tigerfish (Van Loggerenberg, 1983).

Hydrocynus vittatus is a sender bodied fish with clear horizontal black stripes along its body and bright red fins (Figure 1.4). This species has a hard, bony head with large protruding teeth that interlock, which with its strong jaw muscles makes this a formidable predator. Female *H. vittatus* grow larger than males and can weigh in excess of 15 kg. Males rarely weigh more than 2 kg (Skelton, 2001; Gerber *et al.,* 2009). Males do, however, grow older than females and Gerber *et al*. (2009) found that the Okavango Delta males reached an age of 20 years while females reached only 16 years. The species prefers warm, well oxygenated, clear water in large rivers and water bodies such as dams and lakes. This species breeds during summer, although there is a paucity of literature available on exactly how they breed; they may breed at night (Skelton, 2001). Steyn *et al*. (1996) reported that *H. vittatus* spawns on sandy substrate in close vicinity to aquatic vegetation. *Hydrocynus vittatus* may be a flood dependant spawner, which means that the reproductive organs mature in response to increases in temperature and it will only breed in the warmer summer flood waters (Heeg *et al.*, 1980). Although opportunistic juvenile *H. vittatus* feed mainly on invertebrates and insects while adults feed mainly on fish and occasionally insects (Skelton, 2001). The species is distributed throughout southern Africa, but its distribution in South Africa is determined by various man-made structures such as weirs and dams as well as its temperature requirements (Van Loggerenberg, 1983; Steyn *et al.,* 1996). Because *H. vittatus* is a warm water fish, it occurs in warmer water in low altitude rivers where the water temperatures are more stable. In South Africa it occurs in the Phongolo River and its associated floodplain, in the Limpopo River System and the Incomati River system. It is also occurs in various rivers in the Kruger National Park, including the Letaba River, Olifants River, Sabie River, Luvuvho River and Crocodile River.

Hydrocynus vittatus is a highly valued angling species and is caught by recreational and sports anglers alike, which makes it an economically important species (Smit *et al.*, 2009). The Pongolapoort Dam generates a significant amount of money during the annual Tigerfish Bonanza, boosting the economy of the Jozini area. The indigenous people utilize this species in subsistence fisheries, but it is not a preferred species.

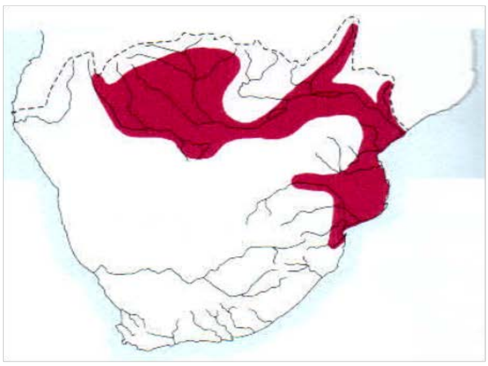

Figure 1.4: Distribution map of *Hydrocynus vittatus* in Southern Africa and an example of this species caught in Nyamiti Pan, Ndumo Game Reserve. *(Map adapted from Skelton, 2001)*

1.8 Aims of the study

Based on the concern raised by Ezemvelo Wildlife (KZN) and an extensive literature review on the fish from the Phongolo Floodplain, the following aims were identified in order to better understand the biology and ecology of various species in the floodplain and to assess the population structures and the health status of selected economically important species from a refuge area inside the Ndumo Game Reserve:

1. To determine the current community structure of fish in the Phongolo River and floodplain in order to evaluate the effect of irregular flood releases on the community structures based on historic data.
2. To compare the diversity and abundance of fish outside the Ndumo Game Reserve with that of the fish within the reserve.
3. To determine the population structure and health of selected fish species within Ndumo Game Reserve and to compare them to areas outside the game reserve.

The data from this study can be used to reassess the flood regime.

1.9 Objectives:

1.9.1 Objectives for Aim 1:

- Collecting historic data on flood releases of the Pongolapoort Dam.
- Resampling the sites used by Merron *et al.* (1993/1994) fish surveys using the same methods.
- Comparing historic data to new data.

1.9.2 Objectives for Aim 2:

- Selecting ecological similar sites within and outside Ndumo Game Reserve.
- Sampling for fish diversity and fish community structures within the selected sites.
- Comparing the community structures and abundance of the selected sites using applicable statistical analysis.

1.9.3 Objectives for Aim 3:

- Sampling for *Oreochromis mossambicus*, *Coptodon rendalli*, and *Hydrocynus vittatus*.
- Using ageing techniques to establish population structures.

- Determining the health status of these populations through histology and the Fish Health Assessment Index (FHAI)

1.10 Layout of dissertation

Chapter 1

This chapter provides a general introduction to the study, briefly discussing the main topics that will be focused on during the subsequent chapters. It includes the aims and objectives for the entire project

Chapter 2

Chapter Two is a detailed discussion of the study area and the selected sites for this study. A general outline of the different sampling surveys is given in this chapter. This chapter will also include the general methodology used to collect fish. The methodology regarding the Fish Health Assessment Index and the Fish Response Assessment Index are also discussed.

Chapter 3

Chapter Three focuses on the effects of flood releases on the fish community structure and biodiversity. This includes a complete literature review on the natural flow regime before the Pongolapoort Dam was built and the intended simulation of the natural flow after the dam was built. Recent data was compared to historical data from a comprehensive study done in the early 1990s in order to assess if the community structure and biodiversity have changed during the past twenty years.

Chapter 4

Chapter Four focuses on the biodiversity of fish outside Ndumo Game Reserve compared to inside the reserve during low flow and high flows. Extensive sampling was done at the two selected sites and compared using the Fish Response Assessment Index. The aim of this chapter is to determine whether the Game Reserve serves as a possible refuge area.

Chapter 5

Chapter Five discusses the health status and population structure of selected species from Nyamiti Pan, a possible refuge area for these species. A microscopic histology-based health assessment and a macroscopic health assessment were carried out to determine the current health status of these species. The population structure was investigated by removing otoliths for age determination studies.

Chapter 6

Chapter 6 is the concluding chapter of this dissertation and revisits its aims and objectives. Recommendations on flow and the flooding regime are also included in this chapter.