The Ecology of Nile Crocodile (*Crocodylus niloticus*) in Pongolapoort Dam, Northern KwaZulu-Natal, South Africa

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ABSTRACT

In general Nile Crocodile *Crocodylus niloticus* numbers in South Africa appeared to have recovered after persecution and eradication attempts during the last century. Within the last decade, however, the future of South Africa's Nile Crocodiles seems ominous yet again, as they are faced with renewed threats including habitat destruction and/or degradation. The primary Nile Crocodile populations in South Africa, Kruger National Park, Lake St Lucia and Ndumo Game Reserve are all currently threatened as a result of anthropogenic actions. The vulnerability of South Africa's major Nile Crocodile populations has highlighted the need for further studies on and assessment of other populations in the country.

This study was conducted from April 2009 to July 2010 on the Nile Crocodile population found in Pongolapoort Dam. The aim of the study was to obtain baseline data on the ecology of this previously unstudied population, which included obtaining an estimate of population size and structure, the reproductive dynamics and success of the population, general distribution of the population in the dam and seasonal changes in their distribution. The impact of the impoundment on this population was also discussed.

Initial surveys from 1981 and 1989 described few crocodiles in the system. Currently Pongolapoort Dam contains a significant Nile Crocodile population that was previously not considered as substantial. A conservative estimate of 273 Nile Crocodiles was determined for Pongolapoort Dam in 2009-2010. A combination of survey methods allowed for a population structure to be gauged and identified as having 116 juveniles (< 1.2 m), 75 sub-adults (1.2 - 2.5 m), and 82 adults (> 2.5 m). Currently the population has a high percentage of juveniles (42 %),

suggesting a growing population, with the proportion of adults (30 %) able to sustain a viable population into the future.

From the construction of the Pongolapoort impoundment in 1972 the water level has fluctuated and the surrounding landscape has been altered. As a result the Nile Crocodiles residing in the area had to adapt to the ever changing environment. Their general distribution changed after dam wall completion, when the dam began to fill. First distributional change was a movement out of the gorge section into the newly flooded areas. After the Domoina floods (1983) the dam level rose by over 70 % and the crocodiles moved into the current inlet section. The majority of the crocodile population is now found in the inlet section of the Pongolapoort Dam, utilizing the Phongola River in summer months and residing in the inlet section as historical basking sites during the winter months.

Investigating reproductive ecology is essential in order to access the population dynamics of an unstudied population, as reproductive output can be a measure of population health. Reproduction and nesting of Nile Crocodiles in Pongolapoort Dam, and in particular determining the effects of the impoundment on these were investigated. No previous reproductive effort had been documented prior to this study. Crocodiles congregated at a major basking site, where the Phongola River entered the dam, during August 2009 with a 576 % increase in numbers. This signalled the commencement of the breeding season. Females with transmitters made short trips upstream during this time. In November, with the first rains, the river rose and the majority of crocodiles moved up the inlet, and females established nests. Three major nesting areas were identified, two of which were located in the river inlet to the dam. Approximately 30 nesting females were identified during the 2009/2010 nesting season. All nesting areas identified had been used in prior nesting seasons. Nests were located on a variety of substrate types, from clay formed through culluvial and fluvial deposits to course river sand. Several of the nests were predated by Water Monitor (*Varanus niloticus*). Although the number of nesting females was greater than expected, during the study period there was a total recruitment failure of nests along the river due to a flash flood of the Phongola River in January 2010, destroying all nests prior to hatching. As several juvenile crocodiles were found during surveys, this preliminary study suggests that the Pongolapoort Dam Nile Crocodile population has a relatively high potential reproductive out-put, although their annual successes may vary greatly because of loss of nesting sites because of water level fluctuations and predation. It appears that the impoundment has generally had a positive impact on this Nile Crocodile population recruitment although suitable nesting sites may become limited.

There appear to be no current threats to the Nile Crocodile Pongolapoort Dam population, however illegal gill-netting and poaching on the dam and surrounding reserves is on the rise and if not prohibited can result in future problems. A second concern is the high abundance of alien invasive plants that dominate the area, most notably in the river inlet section, the Nile Crocodiles main nesting area. The water quality entering the system is unknown at present and should be tested in future studies to assess whether there may be any reason for concern.

In general the Nile Crocodile population in Pongolapoort Dam appears to be one of the least vulnerable and most reproductively successful in South Africa at present. The population has increased dramatically as a result of successful reproductive output even with the ecosystem changes as a result of the impoundment of the Phongola River. It is unlikely that the population increase was as a result of immigration from surrounding areas as the dam wall is a substantial barrier between the dam and the lower crocodile population of Ndumo Game Reserve some 70 km downstream. The high number of crocodiles found through all size classes, juveniles to large adults, also suggests that this population has been stably increasing for a number of years and has a sustainable breeding population.

PREFACE

The data described in this thesis were collected in the Republic of South Africa from February 2009 to December 2010. Experimental work was carried out while registered at the School of Biological and Conservation Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Professor Colleen T. Downs.

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

………………………….

Garreth Champion

December 2010

I certify that the above statement is correct…

…………………………..

Professor Colleen T. Downs

Supervisor

December 2010

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DECLARATION 1 - PLAGIARISM

I, Garreth Champion, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

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DECLARATION 2 - PUBLICATIONS

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

Publication 1

Champion, G & CT Downs. Minimum population number and the effect of impoundment on Nile Crocodile (*Crocodylus niloticus*) in Pongolapoort Dam

Author contributions:

GC conceived paper with CTD. GC collected and analysed data, and wrote the paper. CTD contributed valuable comments to the manuscript.

Publication 2

Champion, G & CT Downs. Spatial distribution responses of the Nile Crocodile (*Crocodylus niloticus*) to temporal habitat changes in Pongolapoort Dam, KwaZulu-Natal.

Author contributions:

GC conceived paper with CTD. GC collected and analysed data, and wrote the paper. CTD contributed valuable comments to the manuscript.

Publication 3

Champion, G & CT Downs. Reproductive and nesting dynamics of the Pongolapoort Dam Nile Crocodile population: effects of impoundment

Author contributions:

GC conceived paper with CTD. GC collected and analysed data, and wrote the paper. CTD contributed valuable comments to the manuscript.

Signed: ………………………………………………

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CHAPTER 1
Introduction

General review on the status and previous scientific studies on the ecology of Nile Crocodile (*Crocodylus niloticus*)

Crocodilians are keystone species playing an important ecological role in their related aquatic habitats (Ross 1998, Leslie and Spotila 2001). These primary predators maintain ecosystem structure and function as they impact on lower trophic levels and recycle nutrients (Ross 1998). Of the three species of crocodilian naturally occurring in Africa, the Nile Crocodile (*Crocodylus niloticus*) is the largest and most widely distributed (Ross 1998). The Nile Crocodile is the largest semi-aquatic, freshwater predator in Africa, found in over 40 countries in sub-Saharan Africa (Leslie and Spotila 2001). A wide array of freshwater habitat types are used by the Nile Crocodile, including rivers, lakes, swamps, estuaries and other such wetlands (Combrink 2004). The general distribution of Nile Crocodile in Africa has contracted somewhat as a result of desertification, anthropogenic persecution and habitat degradation (Leslie 1997, Combrink et al. 2010). In the 1950's and 1960's wild Nile Crocodile populations were greatly reduced both as a result of unregulated killing, for the skin trade and in "vermin control", and habitat degradation or loss, as a result of human population expansion and agricultural development (Cott and Pooley 1971 , Pooley and Gans 1976, Pooley 1982, Jacobsen 1984, Blake and Jacobsen 1992, Leslie 1997, Combrink 2004, Botha 2005, Bourquin 2008). Since the legal protection of the Nile Crocodile in 1973, under the Appendix I of CITES (Convention of International Trade in Endangered Species of Wild Fauna and Flora), there has been a general recovery in many populations (Gans and Pooley 1976, Games et al. 1992, Leslie 1997). In 1996 the recovery of

Nile Crocodile numbers in South Africa was seen to be significant enough to shift their endangered status from CITES Appendix I to Appendix II, allowing permits to be issued for the commercial ranching of the Nile Crocodiles and regulated trade in crocodile products (Leslie 1997, Ross 1998).

Summaries of the general ecology of the Nile Crocodile have been well documented in previous studies. Preliminary ecological studies on Nile Crocodile began in the late half of the twentieth century. Initial studies on feeding ecology were done by Cott (1961) in Uganda and Rhodesia (now Zimbabwe). Cott (1961) noted that there is a dietary shift from predominantly insects and aquatic invertebrate prey during the juvenile life stage to larger vertebrate prey items in later life stages. Modha (1967), Pooley (1969) and Hutton (1987a,bc) described breeding and reproductive ecological components for populations in Kenya and South Africa respectively, including courtship, mating and nesting dynamics. Hutton (1989b) did studies in Zimbabwe, investigated movement dynamics, home range, dispersal and segregation of size classes of Nile Crocodile. Hutton and Woolhouse (1989) investigated different census methods in Zimbabwe. A number of surveys have been done to determine Nile Crocodile broad scale distribution in Africa (Kofron 1992), and in particular to identify major populations in South Africa, with monitoring programmes being set up to track trends in some major populations, including Kruger National Park and St. Lucia wetland populations (Cott and Pooley 1971 , Pooley 1982, Jacobsen 1984, Jacobsen 1991). Following many of these preliminary or broad scale studies a number of more detailed studies have followed, focusing on particular populations (Blomberg 1976, Leslie 1997, Swanepoel 1999, Combrink 2004, Botha 2005, Bourquin 2008, Botha 2010) or specific ecological components such as reproduction, feeding, movement or behavioural interaction (Cloudsley-Thompson 1964, Kofron 1989, Hartley 1990, Kofron 1990, 1991, 1993, Aulie and

Kanui 1995, Swanepoel et al. 2000, Downs et al. 2008, Wallace and Leslie 2008, Osthoff et al. 2009), as well as environmental or human based circumstances possibly affecting Nile Crocodile populations (Swanepoel 1999, Leslie and Spotila 2001, Almli et al. 2005, McGregor 2005, Steyn 2008, Aust 2009, Bishop et al. 2009, van Vuuren 2009a, Ashton 2010, Combrink et al. 2010, Botha et al. 2011). As Nile Crocodiles are commercially ranched for the production of skin products, this has also allowed for the detailed observation of rare or conspicuous behavioural dynamics, especially regarding breeding, nest laying, egg development and parental behaviour (Blake 1974, Magnusson 1979, Blake 1993a).

Current Status of Nile Crocodile

Crocodilian populations seem to have recovered from the extensive global exploitation and persecution during the mid twentieth century (Gans and Pooley 1976, Ashton 2010). The security of major Nile Crocodile populations in South Africa is however once again under threat as a result of anthropogenic activities (Combrink et al. 2010). South Africa was previously thought to have three main Nile Crocodile populations, Kruger National Park (KNP), St. Lucia Estuary and Ndumo Game Reserve (Pooley 1982, Jacobsen 1984, Jacobsen 1991, Leslie 1997, Swanepoel 1999, Combrink 2004, Botha 2005). All three of the mentioned populations are currently threatened (Steyn 2008, van Vuuren 2009a, Combrink et al. 2010, Botha et al. 2011). Habitat destruction or alteration has occurred in many cases as a result of agricultural and industrial development, human population expansion, disturbance to nesting sites by livestock, pollution infiltration or direct dumping into river systems (Leslie and Spotila 2001, Combrink et al. 2010, Botha et al. 2011). Crocodiles have been targeted directly, exploited for traditional medicine or killed as a result of their preserved danger (Combrink et al. 2010).

South Africa's Freshwater Dilemma

South Africa is a semi-arid, water poor country, with freshwater being a very limited and highly sought after resource (Steyn 2008). The quality of almost all riverine systems in South Africa has progressively worsened (Ashton 2010). The high demand for freshwater in social, industrial and agricultural development has resulted in a decrease in conserved freshwater ecosystems and a drastic decline in associated aquatic biota (Steyn 2008, Ashton 2010, Kingsford et al. 2011). The irony in the increased anthropogenic demand for water is that, not only has there been a reduction in available water, but the water that remains has been increasingly degraded, causing a negative feedback (Kingsford et al. 2011). This degradation and destruction of our freshwater has resulted through river alteration, regulation, water extraction, pollution, the introduction of alien species and general unsustainable use (Kingsford et al. 2011). The anthropogenic alterations and water extraction to South Africa's river systems has resulted in major hydrological changes in these systems (Zhai et al. 2010). These changes include the decrease in many rivers flow rate, with a number of historically perennial rivers now flowing only sporadically (Zhai et al. 2010). The continuous infiltration of contaminants into many minor waterways and tributaries is of further concern and has resulted in the build up of pollutants in many major rivers, with detrimental effects on these rivers aquatic biota (Nel et al. 2009).

The lack of freshwater ecosystems represented and their successful conservation in South Africa has only recently been highlighted (Roux et al. 2008, Nel et al. 2009). The major gaps in riverine ecosystem conservation have been shown in a number of cases. The effect of pollution on "protected" aquatic ecosystems can be seen in the current situation in KNP, a world renowned wildlife reserve, where river ecosystems within the park are being destroyed through human activities in the catchment area outside the park (Steyn 2008, Ashton 2010). The infiltration of contaminants from industry in the upper Olifants River catchment area has resulted in mass die-offs of fish species and Nile Crocodiles in the KNP (Steyn 2008, Ashton 2010, Botha 2010, Ferreira and Pienaar 2011). A large number of Nile Crocodile died as a result of the bioaccumulation of toxins/pollutants in the Olifants River, South Africa's largest crocodile population (Steyn 2008, van Vuuren 2009a, Ashton 2010). The die-offs of large numbers of Nile Crocodiles have also been experienced in smaller populations upstream of the KNP on the Olifants River, with records of such mortalities as far back as 1980's in Loskop Dam (Botha et al. 2011). The die-offs of the Olifants River's Nile Crocodiles, as a result of decades of pollutant build up, may indicate that the population's recovery is unlikely and even the re-introduction of crocodiles to the system may be pointless (Botha et al. 2011). Furthermore, there has been a reduction in available crocodile nesting sites in the Olifants Gorge due to flooding of historical nesting sites as a result of impoundment construction downstream (Ashton 2010). The combination of contaminant build up and the impoundment of the Olifants River exacerbate the problem, as the impoundment of the river considerably reduces the rivers flow rate, allowing for deposition of sediment and therefore an even higher level of contaminant accumulation (Ferreira and Pienaar 2011). A further concern and consequence is that this accumulation will occur at the largest known nesting community of Nile Crocodiles in South Africa (Ferreira and Pienaar 2011).

A further case of the negative consequences of riverine systems being anthropogenically altered is that of St Lucia estuary, a world heritage site (Combrink 2004). The diversion of the Mfolozi River, combined with the high water abstraction from the Mkuzi and Hluhluwe Rivers for agricultural purposes, has resulted in drastic changes in hydrological processes within the lake and estuary system (Whitfield and Taylor 2009). These resultant changes have had considerable negative effects on the local biota, with the local extinction of the African Skimmer (*Rynchops flavirostris*) and general environmental stress on estuary based species (Whitfield and Taylor 2009). The Nile Crocodile population found in the estuary is one such species that seems to be suffering as a result of the changes in hydrology and accentuated by the recent droughts (A.S. Combrink pers comm.). Lake St Lucia contains the second largest population of Nile Crocodiles in South Africa, with over 1500 individuals (Blake and Jacobsen 1992, Combrink 2004). The crocodiles appear to have a reduced amount of freshwater sources in the estuary, as a result of the decreased inflow. Furthermore, the environmental stress put on other species in the system may have resulted in reduced food sources for the crocodiles, such as the absence of the historical mullet run (R. Taylor pers. comm.). The significant number of emaciated crocodiles found around freshwater sources may suggest the location of these food sources and freshwater sources may be separated (A.S. Combrink pers comm.). This stress on the Lake St Lucia Nile Crocodile population appears to be responsible for the current apparent decline in population numbers (as per annual aerial surveys) and a reduced nesting effort (A.S. Combrink pers comm.). The reduction in crocodile nests in the system may be a combination of reduced fitness of crocodiles as a result of environmental stress and favourable nesting areas becoming distant from water as a result of lower water levels in the Lake (A.S. Combrink pers comm.). Further investigation is needed to tease apart and quantify the effects that the anthropogenic induced changes in hydrology are having on the Lake St Lucia system and its crocodile population.

Another major Nile Crocodile population found in South Africa is located in Ndumo Game Reserve (NGR), KwaZulu-Natal (Blake and Jacobsen 1992). In the 1980’s this population was estimated in excess of 1000 animals (Pooley 1982). NGR appears to currently have neither water quality or quantity problems (P. Calverley pers comm.). Although the construction of the Pongolapoort Dam, upstream of the reserve, has changed the floodplain dynamics on the Phongola, one of Ndumo's main rivers, this appears to have had little effect on the crocodile population, with ample food resources and available fresh water (P. Calverley pers comm.). The NGR crocodile population is, however, under threat as a result of human disturbance in nesting areas, poaching and habitat destruction (Calverley 2010). The poaching of Nile Crocodile in NGR is a result of the demand for various body parts to be used in traditional medicine (Combrink et al. 2010). As NGR is located on a nutrient rich flood plain, its soils are highly fertile and sought after by surrounding communities for agricultural purposes (Mwaka et al. 2003). This has resulted in the destruction of riverine habitat and the establishment of subsistence farms inside the reserve, causing high disturbance to a historical nesting area (Meer 2010, F. Myburgh pers. comm.). The nesting effort of NGR is seen as very low (1 – 6 %), as few nests have been found in the reserve relative to the number of potentially reproductive females (Calverley 2010). However, this may not be an accurate estimate as seasonal changes in numbers of crocodiles in the reserve suggest the NGR crocodiles move into neighbouring Mozambique to nest (Pooley 1969, Blake and Jacobsen 1992, Calverley 2010).

With the current status of many of South Africa's major wild Nile Crocodile populations being under threat, there is increased need to identify other viable populations in order to avert wide scale loss of the Nile Crocodile in South Africa. The resilience of the species in South Africa cannot rely on only a few large populations, which are threatened, but the species resilience must rely on as many individual populations as possible.

Aims and objectives

The aim of this study was to obtain baseline data on the ecology and assess the status of the Nile Crocodile population in Pongolapoort Dam, a previously unrecognised population. As Pongolapoort Dam is an impoundment the effects of this on the Nile Crocodile population were investigated and the status of the population determined. In order to construct a better understanding of the dynamics and status of this population, a number of key components must be known, and the objectives were to determine the following:

- Minimum population size and status
- Population size classes (age) and sex ratio
- Population distribution in the available habitat
- Evidence of courtship, and nesting, and recruitment dynamics
- Habitat use for basking, feeding and reproduction

The above components were investigated and the findings presented and discussed in chapters to follow. Each chapter is presented as a manuscript prepared for submission to an international peer-reviewed journal and so some repetition was unavoidable. The Journal format for these has common names and place names with the first letter in capitals.

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CHAPTER 2

Minimum population number and effect of impoundment on Nile Crocodile (*Crocodylus niloticus*) in Pongolapoort Dam

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Abstract

The present threats to the major Nile Crocodile (*Crocodylus niloticus*) populations in South Africa highlight the importance of identification and protection of other viable and unthreatened Nile Crocodile populations, imperative in the conservation of the species in the country. The effect of the impoundment of the Phongola River on the Nile Crocodile population numbers and status was investigated. Initial surveys from 1981 and 1989 described few crocodiles in the system. Currently Pongolapoort Dam contains a significant Nile Crocodile population that was previously not considered as substantial. A minimum population number of 273 Nile Crocodiles was determined for Pongolapoort Dam in 2009-2010 using a combination of large scale spotlight surveys. A combination of survey methods allowed for a population structure to be gauged and identified as having a minimum of 116 juveniles (< 1.2 m), 75 sub-adults (1.2 - 2.5 m), and 82 adults (> 2.5 m). Currently the population has a high percentage of juveniles (< 42 %), suggesting a reproductively active population, with the proportion of adults (30 %) able to sustain a viable population into the future. Continued monitoring of the Nile Crocodile

population in Pongolapoort Dam is required to determine if the impoundment continues to support a viable population and determine accurate and precise population estimates.

Introduction

South Africa is a semi-arid, water poor country, with freshwater being a very limited and highly sought after resource (Steyn 2008). The flow rates of Southern Africa's river systems are sporadic as a result of the semi-arid climate of the region (Jacobsen and Kleynhans 1993). Furthermore, river systems in South Africa have been and continue to be drastically degraded (Kingsford et al. 2011, Ferreira and Pienaar 2011). This is a result of impoundment, inter-basin transfers, catchment degradation, water abstraction, pollution and introduced species (O'Keefe et al. 1989). As a result of this and the increasing pressure for water resources, the impoundment of rivers in South Africa is often unavoidable in order to create permanent water supplies for anthropogenic use (Jacobsen and Kleynhans 1993). River impoundment by dams has great effect on downstream waterways, disrupting hydrological processes, effecting water quality, geomorphology, ecology and ecosystem services (Heath and Plater 2010). The degradation of South Africa's river systems and the associated riverine habitat has threatened many biota, which are dependent on these habitats (Roux et al. 2008). The designing of protected areas to conserve freshwater biodiversity has been seldom considered (Nel et al. 2009). The negative effects of such impoundments, lowering river ecological integrity, are undeniable (Zhai et al. 2010). However, despite this loss of riverine habitat, there is now a need to correctly manage the existing impoundments to conserve the freshwater species now threatened as result degradation of this habitat.

An example of the potential negative and positive effects of an impoundment on a riverine system in terms of conservation is Pongolapoort Dam, KwaZulu-Natal, South Africa. The formation of this dam has disturbed the natural functioning of the lower Phongola River flood plain, threatening a number of aquatic species found there (Mwaka et al. 2003). It has however also created a new stable fresh water habitat and sanctuary for a number of species. Such species include *Hippopotamus amphibious* (Common Hippopotamus), *Crocodylus niloticus* (Nile Crocodile) and *Hydrocynus vittatus* (Tiger Fish) all of which are listed on the IUCN red list of threatened species (Combrink et al. 2010). Although these species do occur downstream of the dam, those populations are currently at great risk as a result of over exploitation, poaching and habitat destruction (Calverley 2010).

Pongolapoort Dam is one of South Africa's largest man-made water bodies, and is surrounded by several game reserves that are either state or privately owned and managed. Pongolapoort Dam is relatively new, completed in 1972, however only first filled significantly in 1984 (13 to 86%), as a result of large scale floods during Cyclone Domoina (Rossouw 1985, van Vuuren 2009a). The exact number of crocodile contained in the Dam after construction is unknown as is the number of crocodiles that may have emigrated down from the upper Phongola River. Jacobsen (1991), however, did survey the upper Phongola River and the northern sections of the Pongolapoort Dam during 1981 and 1989, recording 11 and 16 crocodiles respectively. The Dam has, in recent years, been labelled a "white elephant" due to its relatively low economic use and has been steeped in controversy, as a result of its politically driven construction under the old apartheid government of South Africa (van Vuuren 2009a). Despite this, from a conservation point of view, it may now however have great purpose, potentially having one of the few unthreatened and viable Nile Crocodile populations in South Africa. In order to fulfil this conservation potential, however, it is imperative that knowledge on this crocodile population in terms of numbers and demography is obtained (Da Silveira et al. 1997). Knowing the size and structure of a population is typically seen as a prerequisite for effective management of a species (Chabreck 1966, Games et al. 1992, Caughley and Sinclair 2006). Changes in such populations should also be monitored in order to achieve successful dynamic management, with changes being accounted for by driving factors such as changes in habitat parameters (Primack 2000).

Literature describes South Africa as having three major Nile Crocodile populations, the Largest in Kruger National Park (KNP), followed by St. Lucia Estuary and then Ndumo Game Reserve (Pooley 1982, Jacobsen 1984, 1991, Leslie 1997, Swanepoel 1999, Combrink 2004, Botha 2005, Calverley 2010). At present all three of these populations are under threat, with some experiencing drastic drops in population numbers (Steyn 2008, van Vuuren 2009b, Combrink et al. 2010, Calverley 2010, Botha et al. 2011). Pollution, habitat alteration/destruction and poaching are all current threats to the historical chief Nile crocodile populations of South Africa (Steyn 2008, van Vuuren 2009a, Combrink et al. 2010, Calverley 2010, Botha et al. 2011, Ferreira and Pienaar 2011).

The effect of pollution on “protected” aquatic ecosystems can be seen in current situation in KNP, a world renowned wildlife reserve, where river ecosystems within the park are being destroyed through human activities in the above catchment area outside the park (Steyn 2008, Ashton 2010). Contaminants produced by industry have infiltrated into the upper Olifants River catchment has resulted in mass die-offs of fish and Nile Crocodiles in the KNP (Steyn 2008, Ashton 2010, Botha 2010, Ferreira and Pienaar 2011). In recent years a large number of Nile Crocodile died as a result of the bioaccumulation of toxins/pollutants in the Olifants River, South Africa’s largest crocodile population (Steyn 2008, van Vuuren 2009b, Ashton 2010). The die-offs of large numbers of Nile Crocodiles have also been experienced in smaller populations upstream of the KNP on the Olifants River, with records of such mortalities as far back as 1980's in Loskop Dam (Botha et al. 2011). The die-offs of the Olifants River's Nile Crocodiles, as a result of decades of pollutant build up, may indicate that the population's recovery is unlikely and even the re-introduction of crocodiles to the system may be fruitless (Botha et al. 2011). Furthermore, there has been a reduction in available crocodile nesting sites in the Olifants Gorge due to flooding of historical nesting sites as a result of impoundment construction downstream (Ashton 2010). The combination of contaminant build up and the impoundment of the Olifants River exacerbate the problem, as the impoundment of the river considerably reduces the rivers flow rate, allowing for deposition of sediment and therefore possibility of an even higher level of contaminant accumulation (Ferreira and Pienaar 2011). A further concern and consequence is that this accumulation will occur at the largest known nesting community of Nile Crocodiles in South Africa.

This study forms part of a broader study on the Nile Crocodile population in Pongolapoort Dam. The focus of this study was to obtain baseline data on the Nile Crocodile population in this relatively newly formed habitat, paying particular interest to the response of the population to impoundment. One of the objectives of this study was to determine a minimum population size and structure, and compare these findings with aerial counts done in 1981 and 1989. This is important as crocodiles are keystone species in freshwater ecosystems and prior to this study numbers of Nile Crocodiles currently in the Pongolapoort Dam were unknown. In addition, this would form the basis for continued monitoring of the Nile Crocodile population in Pongolapoort Dam to determine accurate and precise population estimates with time. Determining a preliminary sex ratio of the crocodile population in Pongolapoort Dam was also an objective. It was hypothesised that the Nile Crocodile population in Pongolapoort Dam had been affected by the impoundment. It was predicted that the establishment of the impoundment had had a positive effect with numbers of crocodiles increasing, and the proportion of juveniles to adult crocodiles reflecting successful recruitment.

Materials and methods

Study site

Pongolapoort Dam is located on the east flowing Phongola River, in northern KwaZulu-Natal (27°22’10.81” S 31°51’22.49” E to 27°31’23.74” S 31°59’48.84” E). The dam is located between the towns of Golela, Jozini and Mkuzi, running along the western side of the Lebombo Mountains (Fig. 1). The area has a sub-tropical climate, with summers months hot (24.5 °C average) and wet, whilst the winters months are mild (15.8 °C average) and dry, giving the area its sub-tropical climate (Heard and Whitley 2009), with most of the 600 mm mean annual rainfall falling between the months of November and March (Rutherford et al. 2006). The study on Nile Crocodile in Pongolapoort Dam began in April 2009 and continued to the end of June 2010. The total study area included the entire Pongolapoort Dam and a short section of the Phongola River inlet to the dam, up to the N2 highway bridge.

Study methods

A minimum population number approach was used rather than a population estimate or density estimate as this was a baseline study where the dynamics, particularly presence and abundance of Nile Crocodiles in Pongolapoort Dam, and the effects of water levels and season on these had not been previously documented. Precision and accuracy of determining reliable population estimates requires prolonged monitoring, and correction for the particular survey biases of the system as has been shown in other studies (Ferreira and Pienaar 2011). Furthermore, in the current study it was found that the comparability of surveys was affected by variation in conditions between surveys. Consequently each survey was treated as a separate count rather than a replication and a minimum total determined.

The Pongolapoort Dam system was perceived as a “closed system”. Any movements by Nile Crocodiles out of the dam, up the Phongola River past the N2 highway bridge, by crocodiles were presumed to be short-term movements during the rainy season, with crocodiles returning in the dry season when the river became unfavourable habitat (Jacobsen 1991).

In order to establish a minimum population number and structure of Nile Crocodile in Pongolapoort Dam, a combination of survey methods was used. In each method crocodiles were counted and recorded with an associated location and size classes. Size classes were categorised as juveniles (< 1.2 m), sub-adults (1.2 - 2.5 m), adults (> 2.5 m) and “eyes only” (unknown size class). In all surveys each crocodile sighted was recorded with an associated total length (TL) estimate and its location using a hand held Global Positioning System (Garmin, eTrex, Kansas, USA).

(i) Aerial surveys

An aerial count of the entire Pongolapoort Dam including the inlets (Fig. 1) was conducted on 22 August 2009 using a fixed-wing Cessna 210 aeroplane. The aim of the survey was to obtain baseline data of minimum number and for future estimates of total abundance of adult crocodiles (> 2.5 m), not including juveniles due to their associated visibility bias (Games 1994, Ferreira and Pienaar 2011). Timing of the aerial survey in winter and after 10h00 increased the likelihood of crocodile sightings as they generally bask then (Downs et al. 2008). The survey crew consisted of four people, two observers, a pilot and a scribe. The survey began at 10h00 at the southern most point of the dam. Weather during this survey was favourable, with little wind, clear skies and good visibility. The plane was flown at approximately 100 m above the ground and travelled at an average speed of 120 km h^{-1}. At this speed and height, observers found the ability to sight crocodiles acceptable. The survey continued northwards up the western shore of the main dam body (Pongola Game Reserve, Fig. 1), towards the inlet section. The entire shore line of the dam (Fig. 1) was followed in this clockwise direction. The survey included the entire shore line of the main dam, including the section into Swaziland. The narrower dam section in the north west, up to the railway bridge, was also included in the clockwise circumnavigation (Fig. 1). Each crocodile seen was noted together with its estimated size category and location (recorded on an aerial photograph of the dam for later transfer to an electronic map). Areas with high densities of crocodiles were on occasion circled in order to obtain a secondary, more conclusive count. A section of Dam not included in this survey was the gorge section leading to the dam wall (Fig. 1). This has high cliffs and little shoreline terrain, and it was decided that the area was both too dangerous to navigate at a height that observations would still be possible and there was unlikely to be any significant number of crocodiles in the gorge (Champion pers. obs. 2009). The aerial survey was concluded at 11h00, once the eastern shore line of the main dam body had been flown and the original starting position reached.

A second aerial survey of the north western section of Pongolapoort Dam (Fig. 2) took place during favourable weather conditions, on 23 November 2010, using an AS350 Ecureuil Helicopter. As this survey technique is extremely costly, the entire dam could not be included. Instead the inlet and river section was surveyed, where the majority of crocodiles were expected to occur (G. Champion pers obs. 2009, Chapter 3). The survey began at 09h00 and finished at 10h00, following a predetermined route. The survey crew consisted of 4 observers, including a pilot and a scribe. The survey route followed the Phongola River, starting from the N2 bridge going downstream towards the railway bridge. During this section (7 km) of the survey both sides of the river were surveyed simultaneously as the river was narrow and observers had a clear view of both banks. After reaching the railway bridge, denoting the beginning of the dam, the survey continued along the shoreline in an anti-clock wise direction, keeping the shore line on the left-hand side of the helicopter, including the exploration of bays (Fig. 2). During the survey, 7 km of the river, 11 km of western shoreline and 7 km on the opposite, eastern bank on return to the railway bridge were surveyed. Again during the survey, any crocodiles seen were recorded along with their size class and location.

(ii) Day and Night boat surveys

The whole dam could not be included in boat surveys due to logistical constraints and associated costs. However, based on the aerial survey and other feedback, the section of dam where the majority of the crocodiles resided was surveyed (current study, G. Champion pers. obs. 2009, Chapter 3). Consequently regular boat surveys were used to determine the minimum number of Nile Crocodiles in the northern section of the Pongolapoort Dam. This area was estimated to contain approximately 80% of the crocodile population in the dam (G. Champion pers obs. 2009, Chapter 3). In addition, the ratio of juvenile, sub-adult and adult crocodiles in the survey area was determined. Locations of observed crocodiles were also recorded for general crocodile distribution and habitat use for the various size classes (see Chapters 3 and 4). The northern section of Pongolapoort Dam was divided into five transects of approximately 15 km long (Fig.

2). Areas not covered in the north, including the Swaziland section (restricted) and the upper river inlet section depending on water levels.

A 4.5 m aluminium boat was used, powered by a 30 hp outboard Yamaha engine (Hamamatsu, Japan). A total of 80 h of boat surveys were done between May 2009 and July 2010. Surveys were conducted along shoreline routes both at night and during the day each month. With night-spotlight counts being identified as most accurate method for determining numbers of crocodiles and day counts were best used for determining ratios of size classes (Campos et al. 1995, Combrink 2004). On some occasions areas with known high densities of crocodiles were not reachable by boat, due to water depth or presence of aquatic weed (*Hydrilla verticillata*) and therefore these clusters could not be included directly in boat surveys.

During daylight surveys, the number of observers present varied from one to three. The shoreline was followed closely, travelling approximately 50 m from the shoreline, where conditions allowed. Once a crocodile was spotted the boat was stopped. The locality and size class of the crocodile was recorded, as well as the distance to nearest neighbouring crocodile and any other observational information recorded (including presence of identification tags, Chapter 3). These surveys usually lasted between 2 - 3 h, covering a number of transects on a particular day.

Large scale night-spotlight counts of the northern section of Pongolapoort Dam were done twice during the study period, on the 31 October 2009 and 12 June 2010. The surveys consisted of a number of survey teams sampling transect sections simultaneously using various motorised boats. Each survey team surveyed a predetermined route, with the combination of survey routes covering the entire northern half of the dam, except for few areas inaccessible by boat such as the upper river section or restricted Swaziland section (Fig. 2). Each survey team had a minimum of three crew members, a skipper, a spotlight operator and a scribe. Survey teams were briefed prior to survey in order to standardise survey methods'. The entire survey took approximately 3 h with all teams starting simultaneously at a predetermined time and ending with in 20 min of one another. Crocodiles were identified by eye-shine as a result of the presence of a reflective optic layer known as the tapetum lucidum (Leslie 1997). Each crocodile seen was recorded along with its location and estimated size class when possible. In cases where the crocodile became submerged prior to an accurate size estimate being made, the crocodile would be recorded as "eyes only" (E.O). Such recordings would aid in number estimates but would not be included in size class structure calculations. Location was mapped on a collection of detailed aerial photos of the dam shoreline. At the start and end of the survey environmental conditions were noted as these have been shown to influence survey with regard to the number of crocodiles observed (Campos et al. 1995).

A number of crocodiles were caught using three commonly used methods hand grabs (used for juveniles), pole-noosing at night with spotlights and a baited spring-trap (Chapter 3). These methods are widely used in crocodilian studies and are well documented (Webb and Messel 1978, Hutton 1989b, Blake 1993a, Campos et al. 1995, Kay 2004, Strauss 2008, Cherkiss et al. 2009). Sex determination was only done for crocodiles of adequate size (n= 15), using the cloacal probing technique (Leslie 1997). This field technique did not allow for the accurate sexing of juveniles or small sub-adult animals.

Results

Aerial count

The aerial count of the entire Pongolapoort Dam in winter 2010 recorded a total of 134 Nile Crocodiles (> 1.2 m) along the shoreline. The majority of crocodiles were found in the Northern half of the dam, with high densities in the narrow north western sections (Figs 1 and 2). A total of 27 crocodiles were observed on the south western bank of the main dam from the most southern point (27°31’28.85”S 31°59’47.22”E) of the dam to the start of transect 5, southern entrance to the narrow section (27°22’11.73”S 31°55’59.58”E), 94 crocodiles seen in the narrow section up to the Railway Bridge (27°22’11.73”S 31°55’59.58”E to 27°22’14.64 S 31°51’20.03” E), and 13 crocodiles seen in the Northern section of the main dam, including the Swaziland section (27°20’56.77”S 31°55’30.02”E to 27°17’43.69”S 31°57’02.83”E). During the survey of the entire eastern shore of the main dam no crocodiles were observed (27°17’43.69”S 31°57’02.83”E to 27°31’28.85”S 31°59’47.22”E).

The helicopter survey in November 2009 of the northern section of Pongolapoort Dam recorded 126 crocodiles, 17 juveniles, 25 sub-adults and 83 adults. Of these, 48 were observed in the upper inlet section of the river, between the N2 highway Bridge (27°23’40.24”S 31°49’36.29”E) over the Pholgola River up to and including Buffalo Bend (27°22’47.05”S 31°50’44.43”E, Chapter 4, Fig. 1). In the lower inlet section below Buffalo Bend to the Railway Bridge (27°22’10.81”S 31°51’22.49”E, Chapter 4, Fig. 1) 18 crocodiles were observed. A further 49 crocodiles were observed on the western bank of the narrow section between the Railway Bridge and Cliff End (27°21’45.81”S 31°53’40.16”E, Chapter 4, Fig. 1). After switching banks to Houseboat Bay (27°21'25.72"S 31° 53'15.34"E) and travelling back towards Railway Bridge (Fig. 2), another 11 crocodiles were recorded.

Spotlight survey

The large scale spotlight survey on 30 October 2009 recorded 170 crocodiles over three sections (Table 1, Fig. 3), 29 in section 1 (northern section in South Africa of main dam), 116 in section 3 (both banks between railway bridge and Inkwazi Lodge) and 25 in section 4 (southern bank from Inkwazi Lodge to southern exit of narrow section). Transects 2 (northern bank from Inkwazi Lodge to Ezemvelo KZN Wildlife camp site) and 5 (southern exit of narrow section to mid point on western bank of main dam 27°25'43.60"S 31°56'04.45"E) were not completed due to equipment failure and the apprehending of illegal gill-net fishermen, respectively. The inlet river section was also not included as it was inaccessible, too shallow to navigate by boat. During this survey 75 observed crocodiles were identified as juveniles (< 1.2 m), 4 as sub-adults (1.2 - 2.5 m) and 4 as adults (> 2.5 m) (Table 1). The remaining 87 observed crocodiles were recorded as "eyes only" (Table 1). The survey done on 12 June 2010 recorded 219 crocodiles (Table 2) over 6 transects, 60 crocodiles in the river section, 29 in section 1 , 39 in section 2, 66 in section 3, 12 in section 4 and 24 in section 5 (Table 2, Fig. 4). A total of 16 juveniles were recorded, 13 sub-adults and 31 adults (Table 2). The remaining 159 observations were recorded as "eyes only" (Table 2). On a smaller scale spotlight survey of section 3 on the 25 November 2009, 113 crocodiles were recorded (Fig 5). 43 juveniles (< 1.2 m), 31 sub-adults (1.2 - 2.5 m) and 24 adults (> 2.5 m) were identified. The remaining 15 crocodiles were recorded as "eyes only" (Fig. 5).

Day boat survey

A number of day boat surveys were done during the study period. The highest number of the juvenile size class was recorded during one of these surveys. The highest number of juveniles recorded was 116 on the 22 October 2009, during a 3 h survey including sections 2, 3, 4 and the river inlet up to Buffalo Bend (Fig. 1, Chapter 4). There had recently been the annual mass water releasing (late September 2009), dropping the water level and exposing an unvegetated, muddy shoreline. Juveniles were easily spotted, as they basked high up on the back (approximately 10 m from the water line) and could be seen fleeing to the water on approach. This unusual basking behaviour may have been a result of lower bank, covered in wet cold mud, not allowing crocodiles of small body size to efficiently attain the thermoregulatory requirements during basking. Smaller crocodiles would therefore travel further from the water's edge in search of drier land.

Survey compilations

The highest number of each size class of Nile Crocodile were recorded using different survey methods. The highest juvenile count (n = 116) was recorded using a day boat survey (22 November 2009), the highest sub-adult count (n = 31) was recorded during a spotlight survey (25 November 2009), and the highest number of adults counted (n = 82) was recorded during the helicopter survey (23 November 2009). The total population is therefore a minimum of 229 individuals. The exact number is most likely considerably higher as surveys under estimate numbers as a result of observer and visibility bias (Games 1994, Ferreira and Pienaar 2011).

Sex ratio

A total of 32 Nile Crocodiles were captured at Pongolapoort Dam during the study period; 4 using a baited spring-trap, 17 hand grabs and 11 crocodiles using a pole noose. 17 crocodiles were small juveniles (all "hand grabs") and of an insufficient size for sexing using the particular field method. The other 15 were large enough to sex. A total of 7 females and 8 males were confirmed, resulting in a sex ration of 0.88:1 females to males (n = 15). All crocodiles caught using baited traps were male (n = 4), 27% of total number of animals caught.

Discussion

No surveys had been conducted to assess the Nile Crocodile population size in Pongolapoort Dam as a whole prior to this study. In prior years portions of the dam (pre and post its establishment) were included in provincial large scale surveys as Pongolapoort Dam fell over two provincial borders, the former Transvaal (now Mpumalanga) accounted for the northern half of the dam and former Natal (now KwaZulu-Natal) which accounted for the southern half (Jacobsen 1991). As the dam crossed provincial boundaries, it also fell under two associated conservation agencies (former Transvaal Conservation Agency and Natal Parks Board) and therefore data on such provincial surveys only included a fraction of the dam on any one survey (D. K. Blake pers. comm.). No official records of crocodile numbers in the southern section (former Natal side) exist as the area was considered to only contain a low number of individual crocodiles, not seen as a self sustaining viable population (D. K. Blake pers. comm.). Former reports on survey results done by Jacobsen (1991) of the upper Phongola River (from Commondale to Pongolapoort Dam) and including the northern dam sections show considerably low numbers of crocodiles. Jacobsen (1991) did an aerial survey of 193 km along the Phongola

River in 1981 and in 1989 where he recorded a total of 11 (0.06 per km) and 16 (0.08 per km) crocodiles respectively. It must be noted that the apparent increase from 1980 to 1989 cannot, for a number of reasons, be interpreted as a true increase in crocodile population through reproductive recruitment. Firstly, the survey was done by aerial count and therefore has possibility of error (Games 1994, Ferreira and Pienaar 2011). Secondly, the dam level had changed dramatically between these two surveys (from < 13% in 1980 to 85% in 1989) (Heath and Plater 2010) which would have resulted in more areas being flooded in the northern sections of the dam, possibly allowing crocodiles residing in the dam on the southern (former Natal province) section to move into these newly available areas. Thirdly, as a result of these major increases in water levels it is unlikely that nesting areas would have survived flooding. Jacobsen (1991) described the Phongola River and Dam as generally disappointing with regards to number of crocodiles seen. Jacobsen (1991) also mentioned although his survey did not include crocodiles observed on the former Natal province side in their survey results, a number of larger crocodiles but these were also in low numbers. He also noted that the dam had created a new sanctuary for the potential establishment of a viable crocodile population (Jacobsen, 1991). During the present study the number of Nile Crocodiles on the upper Phongola River above the N2 bridge was not determined. There are a number of small weirs, private dams and farming reservoirs along this upper section which may provide potential refuge for crocodiles (G. Champion pers. obs.). These numbers are, however, likely to be low and comprised of sparsely scattered individuals, not representative of a self-sustainable population (various pers. comm.).

Detailed interpretation of survey results on crocodilian populations is often difficult because of the number of factors that affect the precision and accuracy of methods used and the dynamics of populations in terms of season and habitat use (Campos et al. 1995, Ferreira and

Pienaar 2011). In the current study a minimum total number of Nile Crocodiles was determined as a baseline for further surveys and population estimates. This was a consequence of the lack of historical data available, length of the current study and the dynamics of determining crocodile abundance. Estimates of crocodile abundance can vary significantly with time as a result of several reasons (Ferreira and Pienaar 2011) highlighting the importance of ongoing surveys and the determination of correction factors for improved precision and accuracy of estimates. Although the use of standard correction factors for the various survey techniques used to determine crocodile population estimates, it is now understood that each environment and associated population needs its own correction factors calculated (Combrink pers. comm.). The use of a standard correction factor derived from a separate survey site may lead to greatly biased estimates (Ferreira and Pienaar 2011). There has been a significant increase in the number of Nile Crocodiles in Pongolapoort Dam currently compared with the aerial survey results of 1980 (11 crocodiles) and 1989 (16 crocodiles) of the entire upper Phongola River (193 km) including the northern section Pongolapoort Dam. In comparison in 2009, 134 crocodiles (94 recorded in the northern section) were observed in an aerial survey of Pongolapoort Dam alone. The presence of a range of size classes from 50cm to 4.6 m observed during this 2009/2010 study suggests a healthy population structure. Identification of over 30 nesting sites (Chapter 4) during the 2009/2010 further supports the current presence of a viable Nile Crocodile population in Pongolapoort Dam.

Other impoundments previously identified to have viable Nile Crocodile populations in South Africa, include Loskop Dam and Flag Boshielo Dam (Jacobsen 1991). Both of these impoundments are located on the Olifants River, a river system that contains the highest number of Nile Crocodiles in the country (Ashton 2010). Both of these populations of Nile crocodiles found in these impoundments have been studied, with focus on population trends, movement dynamics and reproductive output (Botha 2005, Botha et al. 2011).

Botha's (2005) study of Flag Boshielo Dam showed a viable population (> 210 individuals), with a similar population structure to the current Pongolapoort Dam population structure with a high percentage of juveniles and sub-adults (> 50 %). The reproductive effort of the Flag Boshielo population was low in comparison to other South African populations, with 5.3 mean annual nests found in the system (13 % reproductive effort).

Loskop Dam had an estimated Nile Crocodile population of 32 individuals in 1979 (Botha et al. 2011). Concerns of the decline of crocodile numbers in Loskop Dam were raised in the 1980's (Jacobsen 1984). Spotlight counts in 2010 estimated that only 4 crocodiles remained in the dam (Botha et al. 2011). Two hypotheses have been given for the notable decline of the Loskop Nile Crocodile population (Botha et al. 2011). The first suggested that crocodiles were dying as a result of pollution entering the upper catchment area, directly effecting crocodile health as well as poisoning food resources (Ashton 2010, Botha et al. 2011). The second suggested habitat alteration, as a result of raising the dam wall, inundated historically important nesting areas and reducing recruitment (Botha et al. 2011). The inundation of basking sites was also suggested to have possibly decreased the general suitability of the dam for crocodiles and may have also have resulted in individuals moving out of the dam and into the river system (Botha et al. 2011). The current situation in both Loskop and Flag Boshielo Dams is of great concern, with surveys showing continued decreases in population size and reproductive output (Ashton 2010, Botha et al. 2011). The combination of continued environmental stress and contaminant build up in the aquatic food web, resulting in the decline of crocodile numbers in these two impoundments, appears to be a commonality across all populations found in the

Olifants drainage system (Jacobsen 1984, Ashton 2010, van Vuuren 2010, Botha et al. 2011, Ferreira and Pienaar 2011). The trends seen in Nile Crocodile populations in these impoundments along the Olifants river underlines the lack of protection our aquatic habitats have and further highlights the importance of conserving Nile Crocodile Populations which appear to be in less threatened or degraded environments, such as Pongolapoort Dam.

The preliminary data on sex ratios of 0.88 females to males in Pongolapoort Dam is not representative of the entire population sex ratio. Sample size was inadequate as a result of difficulties in catching adult crocodiles, and the need for physical examination for sex determination. There is also a gender bias in one catching technique used with baited spring-traps often favouring large male crocodiles (M. Robertson pers. comm.). Similarly at Pongolapoort Dam all crocodiles caught using baited traps were male, 27% of total number of animals caught. It is therefore suggested that future studies should focus on determining more accurate sex ratio's by significantly increasing sample size and thereby reducing any bias effect. Studies with significant sample sizes for sex ratios of other nearby populations of Nile crocodile in St. Lucia Estuary and NGR have shown a very near 1:1 ratio of males to females (Calverley 2010, A. S. Combrink pers. comm.).

In conclusion, the Nile Crocodile population in Pongolapoort Dam following the impoundment of the Phongola River appears to have increased based on minimum total numbers counted and number of juveniles, both suggesting successful reproductive recruitment and population viability. It is unlikely that the population increase was as a result of immigration from surrounding areas as the dam wall is a substantial barrier between the dam and the lower crocodile population of NGR some 70 km downstream. The high number of crocodiles found through all size classes, juveniles to large adults, also suggests that this population has been increasing for a number of years and has a sustainable breeding population (Chapter 4). Future studies should aim at determining a population index, in order to monitor any changes in the Pongolapoort Dam Nile Crocodile population and allow comparison with other populations (Ferreira and Pienaar 2011). The positive status of this population is of great importance as many other populations in South Africa are currently under threat as a result of habitat degradation through pollution. Continued monitoring of the Nile Crocodile population in Pongolapoort Dam is required to determine if the impoundment continues to support a viable population and determine accurate and precise population estimates.

Acknowledgements

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Legends for Figures

Figure 1. Location of Pongolapoort Dam in South Africa.

Figure 2. Transect routes for the Northern sections of Pongolapoort Dam (1-2 trans 1; 2-3A trans 2; 3A-3B-4 trans 3; 4-5 trans 4; 5-6 trans5).

Figure 3. Distribution of Nile Crocodile observed during a spotlight survey of northern sections of Pongolapoort Dam, 30 October 2009 (n = 170).

Figure 4. Distribution of Nile Crocodile observed during a spotlight survey of northern sections of Pongolapoort Dam, 12 June 2010 (n = 219).

Figure 5. Distribution of Nile Crocodile observed during a spotlight survey of section 3 of Pongolapoort Dam, 25 November 2009 (green – Juvenile; purple- Sub-adult; yellow- Adult; white- Eyes only; n = 113).

Table 1. Summary of the night survey of Nile Crocodile distribution in northern sections of Pongolapoort Dam, 30 October 2009 (IA- inaccessible, F-Failure to complete)

Table 2. Summary of the night survey of Nile Crocodile distribution in northern sections of Pongolapoort Dam, 12 June 2010.

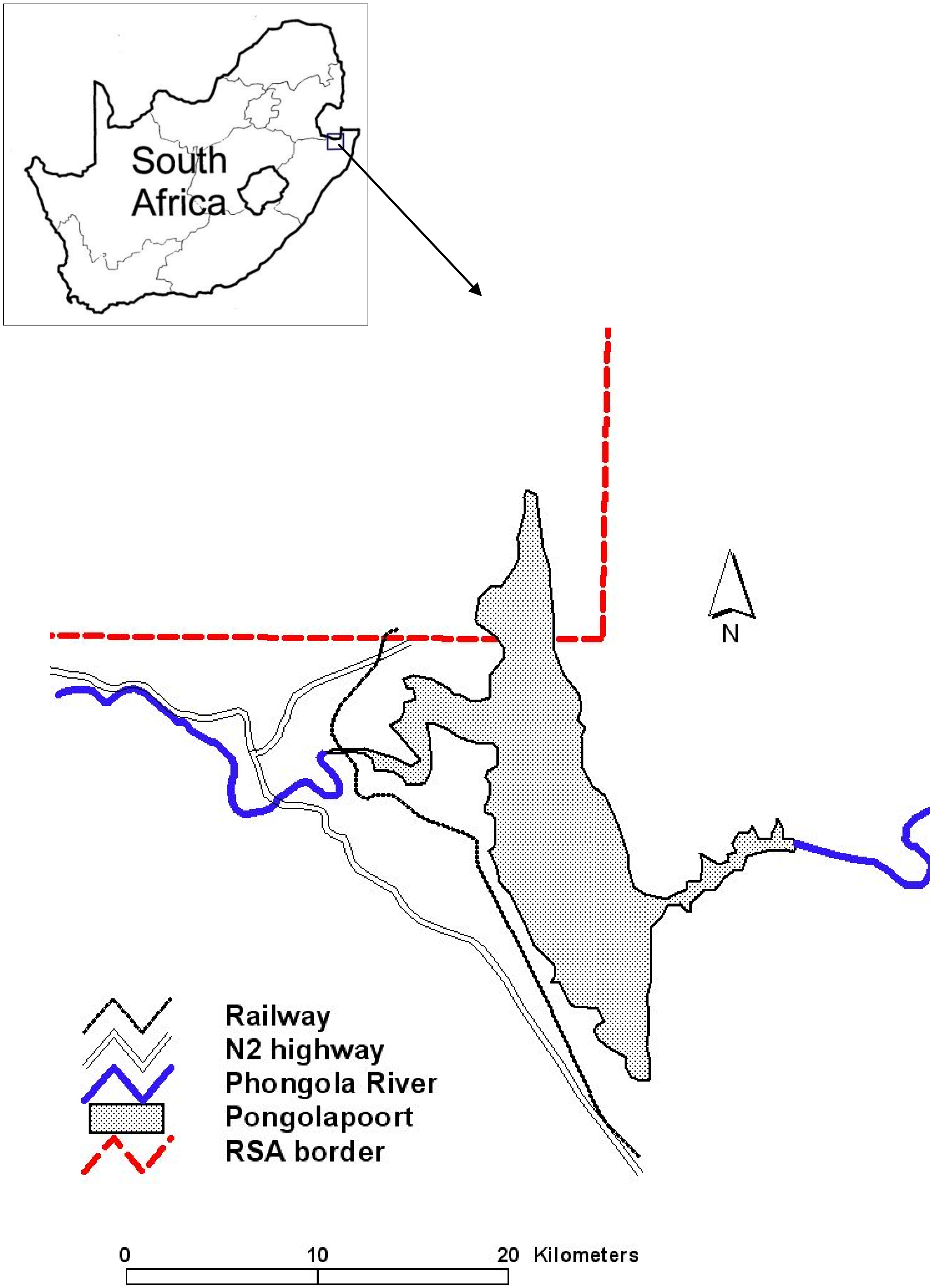

Figure 1. Location of Pongolapoort Dam in South Africa

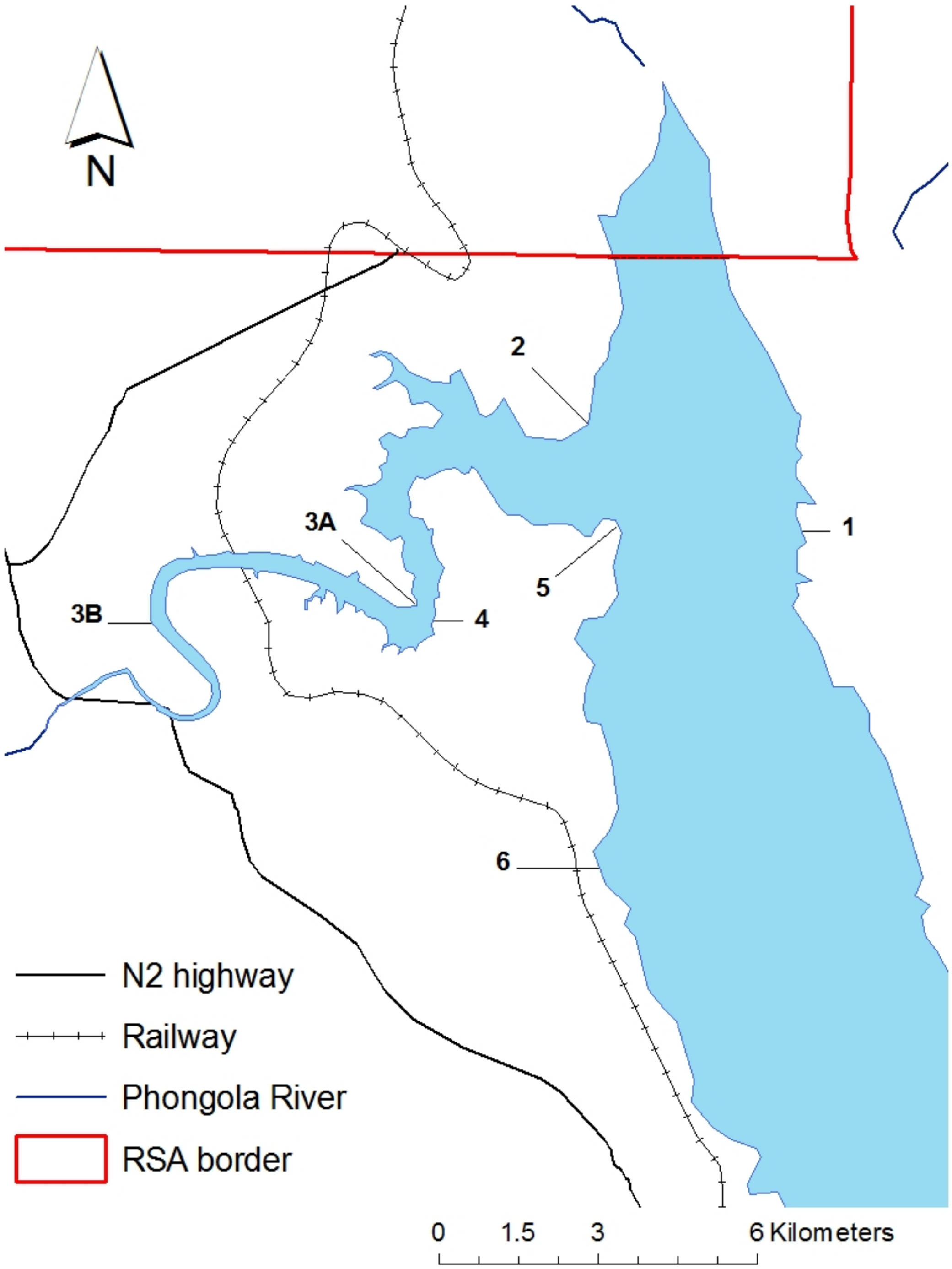

Figure 2. Transect routes for the Northern sections of Pongolapoort Dam (1-2 trans 1; 2-3A trans 2; 3A-3B-4 trans 3; 4-5 trans 4; 5-6 trans5).

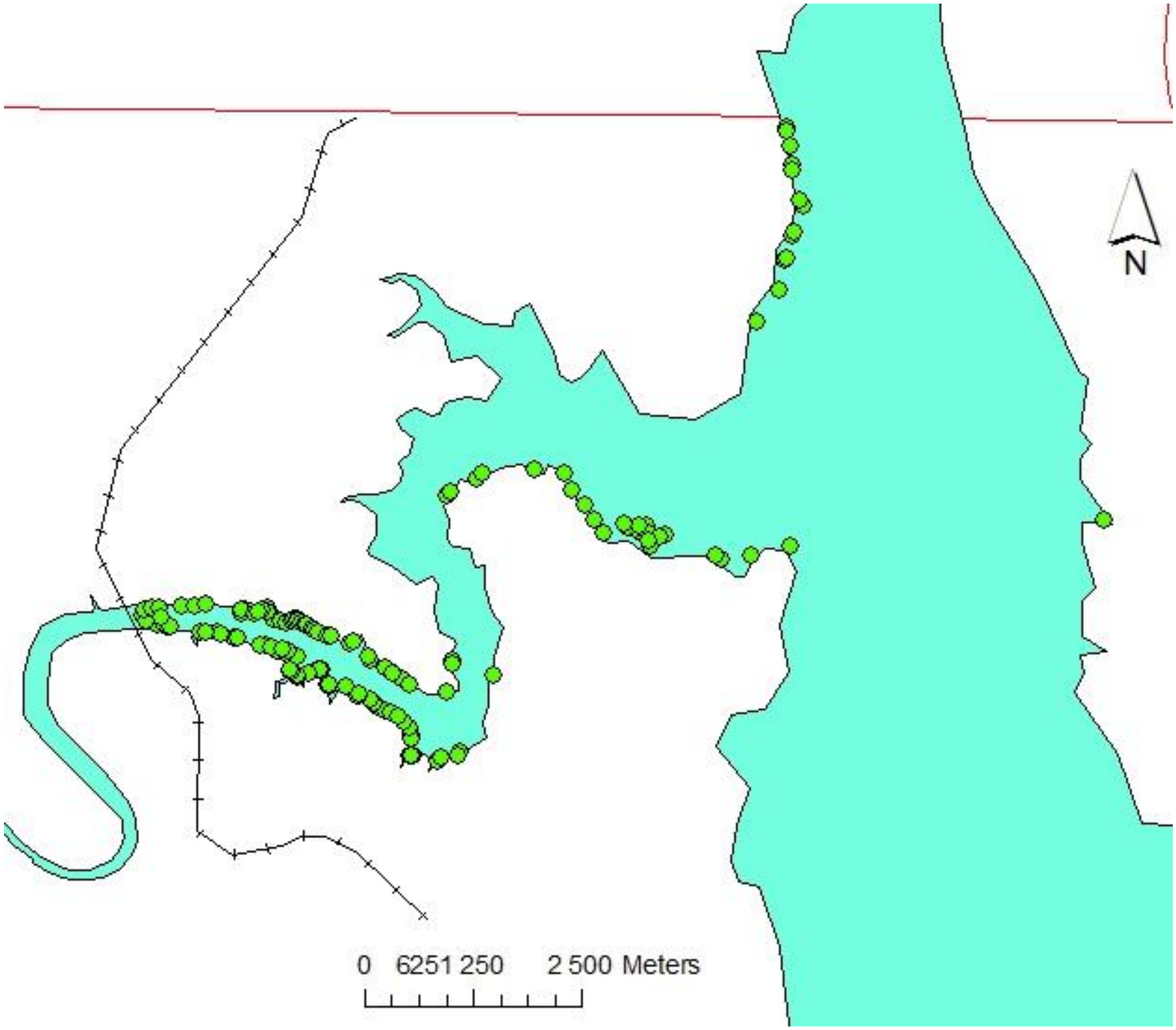

Figure 3. Distribution of Nile Crocodile observed during a spotlight survey of northern sections of Pongolapoort Dam, 30 October 2009 (n = 170).

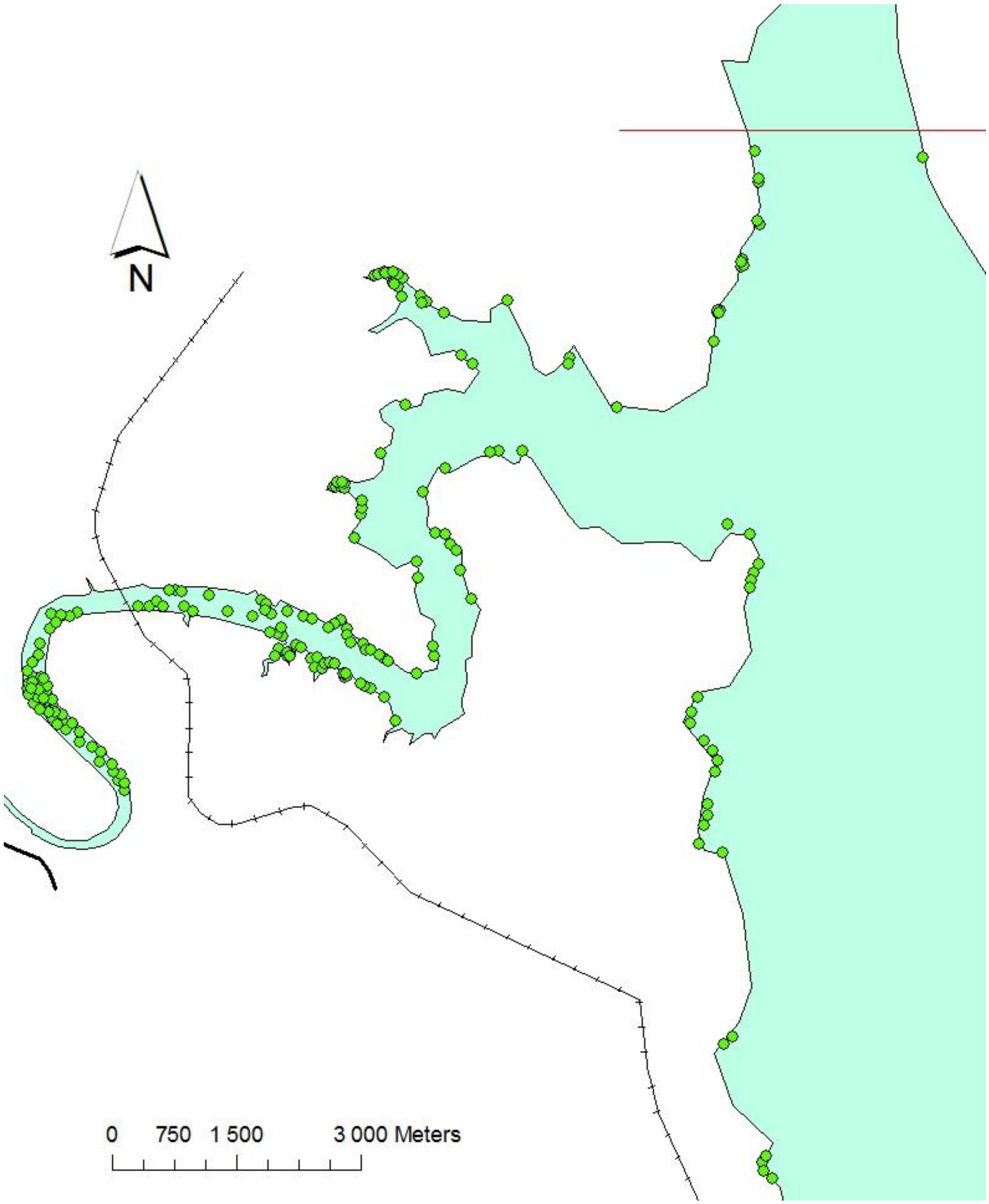

Figure 4. . Distribution of Nile Crocodile observed during a spotlight survey of northern sections of Pongolapoort Dam, 12 June 2010 (n = 219).

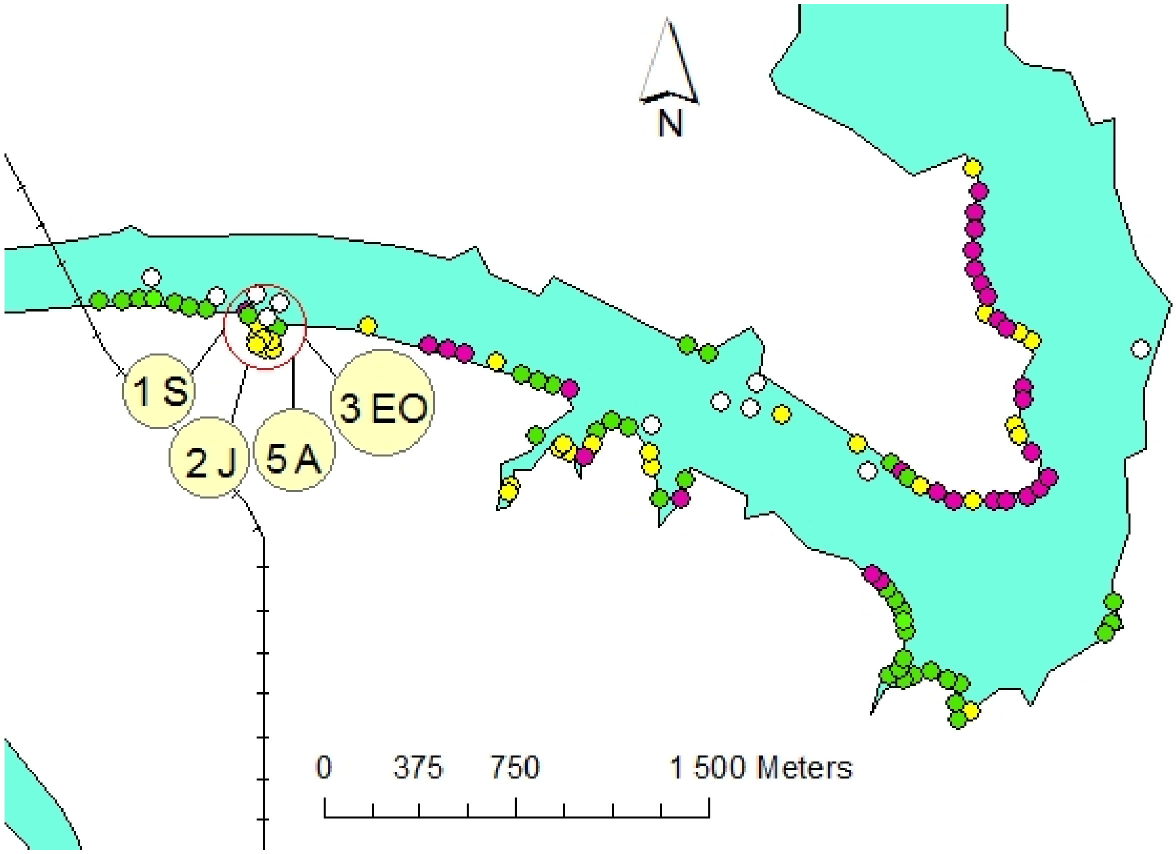

Figure 5: Distribution of Nile Crocodile observed during a spotlight survey of section 3 of Pongolapoort Dam, 25 November 2009 (green – Juvenile; purple- Sub-adult; yellow- Adult; white- Eyes only; n = 113).

Table 1. Summary of the night survey of Nile Crocodile distribution in northern sections of Pongolapoort Dam, 30 October 2009 (IA- inaccessible, F-Failure to complete)

Section	River	1	2	3	4	5	Total
Adult		4		71	0		75
Sub-adult		1		1	2		4
Juvenile		4		0	0		4
Eyes only		20		44	23		87
Total	**IA**	**29**	**F**	**116**	**25**	**F**	**170**

Table 2. Summary of the night survey of Nile Crocodile distribution in northern sections of Pongolapoort Dam, 12 June 2010.

Section	River	1	2	3	4	5	Total
Adult	27	6	4	0	0	0	37
Sub-adult	0	1	10	1	0	0	12
Juvenile	0	0	9	0	1	0	10
Eyes only	33	11	16	65	11	24	160
Total	**60**	**18**	**39**	**66**	**12**	**24**	**219**

CHAPTER 3

Spatial distribution responses of the Nile Crocodile (*Crocodylus niloticus*) to temporal habitat changes in Pongolapoort Dam, KwaZulu-Natal

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Abstract

Spatial distribution and use of habitat by Nile Crocodile (*Crocodylus niloticus*) in an impoundment, the Pongolapoort Dam, were investigated. The historical and seasonal changes of Pongolapoort Dam and the response of Nile crocodile distribution were reviewed and determined. From the construction of the Pongolapoort impoundment in 1972, the water level has fluctuated and the surrounding landscape has been altered. As a result the Nile Crocodiles residing in the area had to adapt to this changing environment. The first general distribution changed after dam wall completion, when the dam began to fill. First distributional change was a movement out of the Phongola River gorge section into the newly flooded areas. After the Domoina floods in the 1980s the dam level rose by over 70 %, and the crocodiles appear to have moved to the current inlet section. Although dam levels have fluctuated greatly within and between years, the crocodiles appear to have adapted successfully here. The majority of the crocodile population is now found concentrated in the inlet section of the Pongolapoort Dam,

utilizing the Phongola River in summer months and residing in the inlet section as historical basking sites during the winter months.

Introduction

The identification of quality and suitable habitat in the conservation and management of a species is imperative (Pedrini and Sergio 2002). In order to conserve a species, not only must its habitat preference be known but an understanding of how the species uses available landscape mosaic is crucial (Hutton 1989). Landscapes are usually both spatially and temporally variable, creating a heterogeneity of habitats, with gradients of habitat quality and suitability (Pedrini and Sergio 2002). Limnetic landscapes are one such example of heterogeneity (Kingsford et al. 2010). Such landscapes form a spatial mosaic of habitat types that are temporally variable, with expansion and contraction cycles and changing management paradigms creating a dynamic environment (Robinson et al. 2002). The temporal heterogeneity of the landscape mosaic results in spatial changes in the quantity and distribution of quality or preferable habitats (Ward 1998). These spatial changes over time, whether cyclic or transitional, are often responsible for observed movement dynamics and distributional shifts within species found in these systems (Robinson et al. 2002).

In order to assess the habitat use and the habitat preference of a species or population, one must first define the meaning of “habitat”. The term “habitat” has been used loosely in landscape ecological studies, with habitat parameters being subjectively defined using any number of environmental parameters (Lindenmayer et al. 2003). Habitat outlines may however be better determined by species-specific parameters rather than preselected environmental parameters (Dover and Settele 2009). With carnivore species globally threatened as a result of exploitation, habitat loss and fragmentation, we still know very little about the habitat requirements and the use of habitat types by many of these species (Conde et al. 2010). With rapidly diminishing wild aquatic habitats around the world, crocodile species are particularly threatened and understudied with regard to habitat use (Kofron 1993, Brien 2008, Strauss 2008). One of these is the Nile Crocodile (*Crocodylus niloticus*). Understanding the habitat requirements and habitat use of a specific Nile Crocodile population requires a combination of understanding the specific landscape mosaic dynamics that the population is found in and the resource requirements of the selected Nile Crocodile.

On a habitat scale, Nile Crocodile distribution and abundance may be dependent on localised environmental resources such as food availability, preferred basking areas, level of disturbance (including anthropogenic), availability of suitable nesting area and presence of competing individuals (Combrink 2004). The distribution and abundance of the Nile crocodile may also change as a result of temporal changes and spatial variations in habitat suitability and quality (Botha et al. 2011). The Nile crocodile has a coarse-grained use of habitat subsets, whereby the use of each available subset is not related to the proportion of that subset in the habitat, making certain, possibly rarer habitat types such as nesting areas, key for population viability (Morris 1987). One can therefore hypothesis that an increase in local favourable habitat type or habitat subset would result in an increase in abundance and a shift in spatial location of said habitat would result in a responding shift in crocodile distribution.

This was a preliminary study investigating the perception of habitat suitability and associated population dynamics of the Nile Crocodile population in Pongolapoort Dam. The study reviewed and investigated both the spatial and temporal habitat changes and resultant responses in abundance and distribution of the Nile Crocodile population. The aim of this facet was to obtain preliminary data on the habitat use and preference of the Pongolapoort Dam crocodile population. Objectives included determining response of the population to the impoundment, and seasonal shifts in general distribution patterns and habitat type selected for by different size classes of crocodiles. Suggestions on driving factors responsible for these movement dynamics were also made. In addition, on an individual movement scale, nine crocodiles were fitted with VHF radio transmitters, in an attempt to determine seasonal home range size and use for crocodiles of different sizes and gender.

Materials and methods

Study site

The study took place on Pongolapoort dam (27°22'10.81" S 31°51'22.49" E to 27°31'23.74" S 31°59'48.84" E), Northern KwaZulu-Natal. Construction of Pongolapoort Dam was completed in 1972. This impoundment on the Phongola River is the third largest, by volume (2 500 million m^3), in South Africa (van Vuuren 2009). The region experiences a sub-tropical climate, with hot, wet summers and dry moderate winters (Rutherford et al. 2006). The area has an average annual precipitation of 600mm, falling predominantly over the summer months (November to March). Water level data for the dam from 1972 to 2010 was sourced from Department of Water Affairs, Howick, KwaZulu-Natal.

Due to the large size of Pongolapoort Dam, the entire dam could not be included in all facets of this study as a result of logistical and financial constraints. The focal area of the study was the northern half of the dam, with special attention to the narrow western section. The narrow western section, where the inlet enters, was focused on as this contained the highest number of crocodiles (approximately 80% of total population- Chapter 2).

Crocodile capture

From April 2009 to November 2009, Nile Crocodiles (> 2 m) were captured in the northern section of the dam, using previously described techniques (Blake 1993b, Kofron 1993, Cherkiss et al. 2009).

Active capture took place at night, preferable on or near new moon phase, using a 4.5 m aluminium boat. A minimum of three crew members were required for such operations, including a skipper (boat navigation) and spotlight operator for crocodile detection and a person responsible for snaring the crocodile. Crocodiles were identified by their eye shine in the spotlight. Once the capture team had selected a particular crocodile, the boat was driven towards it with the spotlight focused on the animal. When close enough, a 3 m pole was used to slide an attached standard self-locking 3S-72” Thompson steel snare over the crocodile’s head and then closed around its neck. The snare was attached to 50 m of rope and the crocodile was given rope to fight, away from the boat. After the initial fight, the team would find a suitable place on the shore to beach the boat and pull the crocodile onto land. The crocodile was pulled up the bank, far enough from the water for other crocodiles not to be a major threat to the capture crew. The crocodile’s eyes were then covered with a towel to calm the animal, and the jaws were cable tied shut as a precaution. Two team members then simultaneously sat on the crocodiles back, subduing it. The jaws were then taped closed using duct-tape as the primary jaw restraint. Capture location and time was recorded. The animal was then assessed including morphometric measurements, gender determination, scute clipping (Leslie 1997), tagging and possibly transmitter attachment. The crocodile were sexed through cloacal cavity examination. The VHF radio transmitters were attached to the four major nuchal scutes of the neck. A 5 mm hole was drilled through the ridge of each nuchal scute and the transmitter was attached using cable-ties and Vortex dental acrylic. Transmitters were encased in plastic casings (50 mm x 20 mm x 80 mm) for protection, with a 250 mm aerial protruding out the back of the box. The tracking of the crocodiles fitted with transmitters was done using a Yogi directional antenna and Alinco wide band receiver (DJ-X10, Japan).

A spring trap was used to target very large male crocodiles that were too wary to catch using the active capture snaring method. The trap was set up on the water edge, and consisted of a "T" piece base, with an attached spring made of three vehicle feather springs attached end to end. One end of the spring was attached to the "T" piece, with the other end had a large sliding noose attached. The sliding noose was tied using 50 mm dynamic climbing rope. The spring was bent over and held in place by a trigger mechanism. The trigger mechanism was attached, using nylon rope, to a bait ball at the base of the "T" piece frame. The sliding noose would be held open across the access point to the bait ball using collected tree branches. Thorny vegetation was then packed around the trap structure to prevent other scavengers from accessing the bait and triggering the trap prematurely. The rope forming the sliding noose was anchored independently of the trap to a fixed structure such as a large tree. The crocodile would enter through the open access point, taking hold of the bait ball and attempting to drag the bait back to the water would spring the trap. As the trap was sprung the sliding noose would tighten around the crocodile's midriff, just behind the front legs. The spring would ensure the rope and noose remained taught, not allowing the crocodile to escape. Traps were usually set up early in the morning, as fast as possible in order to minimize human presence in the area and the associated disturbance. The trap would be checked, from a distance using binoculars, twice daily for captured crocodiles or the premature springing of the trap. Once a crocodile was captured, the capture team would pull the crocodile up onto the bank using the already attached climbing rope. The crocodile would then be subdued and processes as with active captured crocodiles (as above).

Broad scale distribution patterns

Boat surveys mapping the distribution and related habitat used by different size classes of crocodiles in the northern section of the dam were done during the morning hours, on days when weather conditions promoted basking (Chapter 2). A total of 80 h of boat surveys were completed between May 2009 and July 2010, using a 4.5 m aluminium boat powered by a 30 hp outboard motor (Hamamatsu, Japan). Surveys were conducted along predetermined routes of approximately 15 km. The survey boat would travel close to the shore line where ever possible (50 m) at approximately 25 $km.h^{-1}$. Accessibility to a number of areas was occasionally limited, dependent on water level of the dam or the presence of aquatic weed (*Hydrilla verticiiata*). With certain areas not being possible to survey, the use of these areas by each crocodile size class could not be determined, however suggestions were made about the probable use of these areas. During surveys, once a crocodile was sighted the boat would be slowed down or stopped if need be and the size class, location and distance to nearest neighbouring crocodile noted. Size class allocation was related to probable life stage, such as juvenile (> 1.2 m), sub-adult (1.2 - 2.5 m) and adult (> 2.5 m).

Results and Discussion

Review of historical environmental changes in Pongolapoort Dam

There have been major changes, in the last half century, in the region now covered by the Pongolapoort Dam. These changes in ecosystem structure and habitat mosaic have resultantly effected the Nile Crocodile population of the area. Prior to the impoundment of the Phongola River, the river was mostly shallow and swift flowing with only occasional seasonal pools, having relatively few crocodiles (Jacobsen 1991). The gorge or “poort” section, site selected for the construction of the dam wall, contained most of the adult crocodiles which resided in the deeper perennial pools (K. Landman pers. comm.).

The construction of the Pongolapoort Dam wall resulted in a high disturbance level in this previously isolated and undisturbed gorge (van Vuuren 2009). Once the dam wall construction was completed in 1972, any crocodiles upstream of the wall would have been isolated from the lower, substantial Nile Crocodile population found in Ndumo Game Reserve. The wall also significantly changed the river ecosystem by modifying hydrology, morphology and habitat structure as in other impoundments (Zhai et al. 2010). Similarly the impoundment of the Phongola River altered the physical characteristics of the habitats, including continuity, flow distribution organic matter and water temperature as in other impoundments (Zhai et al. 2010). This would have altered the bio-ecological processes of the system further effecting resident animal populations (Heath and Plater 2010), such as the Nile Crocodile population. For example these habitat changes, particularly changing water levels, would result in resource changes that may affect the ecology of Nile Crocodiles, including reproduction. Nile Crocodile populations have been shown to establish specific nesting areas, reusing these areas for consecutive years (Pooley 1969, Kofron 1989, Hartley 1990). Fluctuating water levels may result in reproductive failure, either as a result of low water levels, increasing distance from nest to water line decreasing the survivability of nests or as a result of high water levels, flooding nests (Pooley 1969, Botha et al. 2011).

The Pongolapoort Dam level for the 12 years after construction remained very low (Fig. 1a,b), fluctuating from 1.5 % capacity in 1972, up to 21 % capacity in 1975, a 23 m difference in height (van Vuuren 2009, DWAF 2010). This minor water impoundment would still have dramatically altered the environment, changing available basking areas and flooding any previous used nest sites. The fluctuations in dam surface area from 500 ha at 1.5 % capacity to 4 800 ha at 21 % capacity, resulted in changes in shoreline characteristics and would also have forced changes in distribution of any crocodiles still present in the gorge (Fig. 1b,c).

In early summer of 1983/84 the Pongolapoort Dam was at 8.5 % capacity (Fig. 1b). In January 1984 a large scale flood occurred as a result of Cyclone Domoina (Rossouw 1985). The flooding resulted in record level peak flow (1600 $m^3.s^{-1}$) of the Phongola River, with 700 mm of rainfall falling over the catchment area, above the dam (van Vuuren 2009a). The dam level rose from 8.5 % capacity in January 1984 to 82.1 % capacity by February of the same year (DWAF 2010). This equated to a surface area increase of the impoundment from 2 800 ha to 11 800 ha, resulting in hundreds of hectares of previously un-flooded land becoming submerged. This was the second and most extreme major habitat disturbance experienced by the Nile Crocodiles in the system after the dam construction. The rapid landscape remodelling would have affected resident crocodiles with changing dynamics and increased habitat availability with changing resource distribution and density. This would have once again have changed available basking sites and potential nesting sites (Jacobsen 1991).

Jacobsen (1991), during surveys of the upper Phongola River in 1981 and 1989, described the upper Phongola River as generally disappointing with regards to crocodile numbers but mentioned that the impoundment and resultant flooding of surrounding areas post-Domoina, appeared to create a favourable habitat for the establishment of a viable crocodile population.

After the Domoina floods, the impoundment maintained a more stable water level, between 1984 and 1991 (Fig. 1a). From 1991 (75 % capacity) the area experienced drought conditions and the dam level dropped to 30 % capacity in 1993, a resultant drop of 15 m in height (Fig. 1a,b). The large drop in water level would have resulted in a substantial retraction of water line, exposing previously submerged ground, which would almost definitely resulted in changes in shoreline dynamics with regard to crocodile food resources, basking site availability and possibly distribution of favourable habitat types. This would also have disturbed the reproductive ecology of the resident Nile Crocodiles, with any previously used nesting areas prior to the drought being a great distance from the water.

The drought period ended in late 1995, when another flood event occurred, raising the dam level from 38 % early December 1995 to 90 % in January 1996, a 12 m increase in height (Fig. 1a and 1b). The timing of this flood, post nest laying and pre-hatching would most likely have resulted in the flooding of any established nest sites. The sudden and substantial shift of shoreline would once again have changed the dynamics of associated microhabitats.

Annual variations in water height from 1996 to 2002 were relatively stable in comparison with earlier years, with less than 4 m fluctuation in mean annual water height (Fig. 1a). These years remain the highest maintained level in the dam's history thus far, with percentage capacity maintained above 90 % (Fig. 1b). In the summer of 2001 large scale flooding occurred over most of the eastern regions of southern Africa (Mwaka et al. 2003). This was the first time that the dam reached and exceeded 100 % capacity (Fig. 1b). As a result of the already high capacity of the Pongolapoort (> 90 %) prior to this flooding, there was minimal change in water level in meters, > 2 m change in annual mean water level (Fig. 1a). This would therefore have had less of an impact on the changing shoreline locality or possible dynamics of shoreline around the entire dam, such as previous flood events. The impact on the river inlet was however substantial, with the Phongola River bursting its banks, flooding all areas identified as nesting sites in 2009 and 2010 (Fig. 2c, Rippon pers. comm.). The flooding also greatly changed the shape of the inlet channel and its banks, as well as changing the shape of the dam where the inlet enters the dam (C. Rippon pers. comm.). During this period this area was already seen to contain the majority of Pongolapoort Dams Nile Crocodile population and contained nesting sites (M. Thomas pers. comm.). The bursting of the Phongola River banks in 2001 would therefore most likely destroyed the majority if not all nesting sites located in these sections, as was seen in 2009/2010 nesting season (G. Champion pers. obs. 2010, Chapter 4)

In 2002 the mean annual percent capacity of Pongolapoort Dam was dropped as a result of management decisions (Mwaka et al. 2003). The flooding and over-flow from the dam in 2001 has caused substantial damage downstream, most noticeable in Mozambique (Mwaka et al. 2003).

The water management policy of the Pongolapoort Dam has since attempted to ensure minimal unplanned flood damage to areas below the Pongolapoort Dam, maintaining dam levels around 75 % capacity (Heard and Whitley 2009). In order to simulate natural seasonal flooding, which drive numerous ecological processes in the lower Phongola flood plain, there is an annual controlled mass release of water from the Pongolapoort Dam each September (Dickens et al. 2008). This release results in an approximate 2m drop in water level (Fig. 2a). This pre-rain season release ensures that the effects of summer floods on areas below the dam can be controlled or at least reduced (Dickens et al. 2008). The current water management plan of Pongolapoort Dam results in a more predictable and less extreme fluctuation of seasonal water level than experienced in the earlier years after dam construction. This management plan has, however, no control on water inlet, with river flow rate and water volume entering the dam determined by rainfall in the above catchment area of the upper Phongola River. This therefore results in this area still being susceptible to natural flood disturbances, which continue to alter and change the inlet section. As this area is greatly utilized by the Nile Crocodiles in Pongolapoort Dam, notably for breeding (Chapters 2 and 4), the natural environmental disturbances still have a significant effect on their population dynamics (see below).

A further environmental change which has occurred was as a result of the introduction of an alien invasive aquatic weed, *Hydrilla verticillata* in Pongolapoort Dam. This was the first water body in South Africa where this submersed macrophyte was identified (Madeira et al. 2007). First identified in February 2006, it has since become a dominant species along the inlet section and western shoreline of the main dam. Although the weed has been shown to have the potential for economic and environmental damage, there is little evidence of it showing major environmental problems in Pongolapoort Dam as of yet (Madeira et al. 2007). The weed has created thick mats near the shoreline, which become impenetrable by motor boats, clogging up their propellers. The weed appears to be favoured by many fish species as a protective nursery (C. Rippon pers. comm.). The seasonal changes in water level prevent the weed from maintaining mats near the water's edge. Instead these mats are found a number of meters off shore, dependent on water depth (Fig. 3). This creates a channel of weed free water between the bank and the mat which may create an important habitat component for small crocodiles (see below).

The adaptability of the Nile crocodile as a species is shown in the way the population of Pongolapoort Dam, has not only survived through large scale environmental disturbances and habitat alterations but the population has expanded and formed one of South Africa's significant populations both in size and reproductive success (Chapter 2 and 4). The high frequency of natural disturbances in riverine ecosystems has likely aided in the adaptability of the aquatic biota in larger scale, anthropogenic caused habitat alterations. Although Pongolapoort Dam levels fluctuated greatly within and between years, the Nile Crocodiles appear to adjust to these changes and successfully persist here. The majority of the crocodiles were concentrated in the north-west section of the dam, moving upstream and utilizing the Phongola River in summer months while residing in the inlet section during the winter months where there are historical basking sites (Fig. 4 a. and b).

Seasonal distribution patterns and associated broad habitat use

The shoreline of Pongolapoort Dam was highly variable as a result of the current water management strategy. Pongolapoort Dam experienced seasonal changes in habitat traits as a result of changes in water level through the year (Fig. 2a,b,c). Fluctuation in water levels causes dynamic changes in the shoreline vegetation species and structure (Peintinger et al. 2007), and shoreline topography. In brief areas of Pongolapoort Dam shoreline not seasonally flooded were well grazed by game species, leaving a grazing lawn along most of the dam shoreline (Fig. 3). As the water level dropped (late September), a newly exposed lower shore line developed which had thick, muddy banks with little or no vegetation (Fig. 5). As these banks dried out a number of plant species colonized the sediment deposit and a successional shift took place, with taller grass species later dominating the banks until the water level rose once more raising the shoreline (Fig. 6). This resultant dynamic change in shoreline changed habitat characteristics temporally, which in effect affected changes in crocodile distribution and abundance.

The general distributional pattern of the Nile Crocodiles in Pongolapoort Dam appeared to be driven by two key factors. Firstly, a rank of their ecological objectives was a key factor which changed temporally. These included mating, nesting, feeding, survival or basking. The ranking of these objectives were dynamic, changing as certain objectives become more important and others less. These ecological objectives affected not only distribution but the density at which crocodiles congregated (Kofron 1993). Secondly, the spatial locality of these congregations was a key factor and was determined by habitat/locality which provided for the successful completion of the respective ecological objective concerned. The ranking of ecological objectives and related responses, and consequently changing distribution and habitat use of crocodiles also appeared to differ between different size classes of crocodile (Chapter 2, Fig 3). This should be expected as size classes differ greatly in diet, risk of predation, degree of inter-specific competition, or drive to reproduce (Hutton 1987, 1989, Kofron 1990, Wallace and Leslie 2008). The resultant spatial separation of size classes appears to be due to the differences in the ranking of ecological objectives and therefore a difference in perception of what defines a favourable habitat. However, the threat of cannibalism to smaller individuals may also add to the size class separation (Hutton 1989).

In Pongolapoort Dam, juvenile Nile Crocodiles were seen to be predominantly solitary, with no communal basking groups of juveniles identified. Juveniles were most common along well vegetated banks and areas with high densities of aquatic weed, which appeared to provided safe refuge. In addition, these weed beds appear to provide a wide array of food sources, catering to the diverse diet of juvenile crocodiles, such as various invertebrate, amphibians, gastropod, crustacean and small fish species (Wallace and Leslie 2008). Juveniles and sub-adults were often seen in the shallows hunting during dusk. Basking sites of juveniles and sub-adults appeared to be informal with any structure or opening in vegetation being used including small sand patches (< 1 m), exposed logs and weed mats (Fig. 6). Sub-adults crocodiles appeared in a wide array of habitats, with no apparent preference. Sub-adults appeared to have a shifting habitat preference as they increased in size, with smaller individuals mostly solitary and inconspicuous preferring vegetated habitats, similar to juveniles. This may have been a result of their diverse diets and that they could access food in most habitat types (Hutton 1987). The larger sub-adults (> 2 m) were seen basking in clusters on open banks, occasionally with a single larger crocodile present. Definitive movement patterns could not be determined for either juvenile or sub-adult size classes as they favoured vegetated habitats and therefore the ability to spot individuals and accurately survey distributional trends varied seasonally. Hutton (1989) found that smaller size classes have relatively small home range distributions, with the larger sub-adults having the greatest dispersal tendencies.

Adult Nile Crocodiles in Pongolapoort Dam were often found to have preferred basking sites, characterised by low vegetated banks with high sun exposure and a nearby deep water channel as an escape route (Fig. 7). A definite seasonal change in distributional pattern was observed during the study period. During the winter months (May-July) the majority of adult crocodiles were observed between Buffalo Bend and Inkwazi Lodge (Fig. 4a). Major basking clusters were located in most major bays, including Croc Bay and Hissing Bay. In August, the onset of the breeding season there was a mass movement of crocodiles into the inlet section, with the highest density of crocodiles located at Buffalo Bend (Fig. 4a). At the end of the September 2009, the Tiger Fish Bonanza was held, the largest Tiger fishing competition in the southern hemisphere. During this time of high disturbance crocodiles still present in the dam sections, became very shy and wary. It is expected that the crocodiles remained in hidden, highly vegetated areas. After the fish competition, the mass water release from Pongolapoort Dam took place, dropping the water level by 2 m within a week. The inlet section became shallow, with few deep channels and a number of exposed mud flats on which adult crocodiles congregated (Fig. 6). A large number of adult crocodiles still congregated at Buffalo Bend during this time. In November the first summer rains raised the river level, changing the water colour and basking site availability for adult crocodiles. Most of the crocodiles migrated upstream of Buffalo Bend with only a few remaining behind (Fig. 4a). The crocodiles that moved upstream spent the remainder of the summer months there basking on open sandy banks. Some females selected nesting sites here and guarded their nests (Chapter 4). Movement of crocodiles upstream of inlets during months of high water appears to be a common occurrence, especially with respect to impoundment based populations (Hutton 1989, Jacobsen 1991, Jacobsen and Kleynhans 1993, Kofron 1993, Swanepoel 1999, Botha 2005).

Crocodiles fitted with VHF radio transmitters

Due to logistic difficulties capture of Nile Crocodiles and attachment of transmitters at Pongolapoort Dam was delayed. However, 9 crocodiles were eventually captured and fitted with transmitters, ranging in size from 2.12 - 4.3 m. 5 of the 9 transmitter crocodiles were females (2.81 - 3.06 m), of which 4 were observed at Buffalo Bend during breeding period (Fig.9 d, e, f and h) and one was later identified on a nest at the Causeway Bend (Fig. 9 c). The 4 males fitted with transmitters (2.12 – 4.3 m) showed varying degrees of movement (Fig. 9 a, b, g, and i), with the larger crocodiles moving less both in frequency and distance (Table 2). The largest of the transmitter crocodiles, a 4.3 m male, was the last fitted with a transmitter and moved from Hissing Bay (capture site) to the Buffalo Bend, where he remained for the duration of the breeding season (Fig. 9b). During this time all transmitters became detached, with the longest attachment lasting nearly 4 months and the shortest only 6 weeks (mean $\pm$ SE attachment days 76.9 $\pm$ 26.4 days). Transmitter attachment method and resultant longevity has been a problem when studying movement dynamics of crocodilians, with similar results seen in Flag Boshielo Dam and Ndumo Game Reserve (Strauss 2008, Calverley 2010).

The tracking of the nine crocodiles fitted with radio transmitters did not give rise to viable home range or territory predictions. The tracking period had a number of factors affecting the movement and location of captured crocodiles which prevented any accurate predictions to be made. One such factor included the disturbance effect of the capture event. This could not be quantified and therefore the early movements of the crocodile away from the capture site may merely have been a response to the stress experienced during the capture procedure, rather than the movement within a home range or territory. Soon after the fitment of the transmitters was the commencement of the breeding season, which may show movement between two seasonal home ranges or preferred habitats rather than within in a single home range.

Conclusions

Although Pongolapoort Dam levels fluctuated greatly within and between years, the Nile Crocodiles appear to adjust to these changes and successfully persist here. The majority of the crocodiles were concentrated in the north-west section of the dam, moving upstream and utilizing the Phongola River in summer months while residing in the inlet section during the winter months where there are historical basking sites. The current management of water levels by the Department of Water Affairs and Forestry appears to have no noticeable negative effects on the Nile Crocodile population in Pongolapoort Dam. The maintenance of this water level management paradigm may promote further nesting in the dam itself as levels are perceived as more predictable, however this may not be the case. However, infrequent flooding of the inlet river affects nesting of crocodiles (Chapter 4).

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Legends for Figures and Tables

Figure 1. The historical fluctuations in a. water height (m), b. percentage capacity (%), and c. surface area (ha) measured at the Pongolapoort Dam wall from 1970 to 2009.

Figure 2. The monthly mean (± SE) fluctuations in a. water height (m), b. percentage capacity (%), and c. surface area (ha) measured at the Pongolapoort Dam wall during 2009 from January to December.

Figure 3. Aerial photo showing the *Hydrilla verticillata* weed mats found a number of meters off shore, creating a channel of weed free water between the bank and the mat which may create an important habitat component for small crocodiles.

Figure 4.a. Distribution of adult Nile Crocodile (> 2.5 m total length) observed during a day survey of sections 2, 3 and the river, of Pongolapoort Dam, (a) 26 November 2009 (n = 64) and (b) 25 July 2009 (n = 71).

Figure 5. Aerial photograph showing the muddy, unvegetated banks exposed after the drop in water level as a result of the annual water release in Pongolapoort Dam.

Figure 6. Photograph showing the colonisation of newly exposed shoreline by plant species in Pongolapoort Dam.

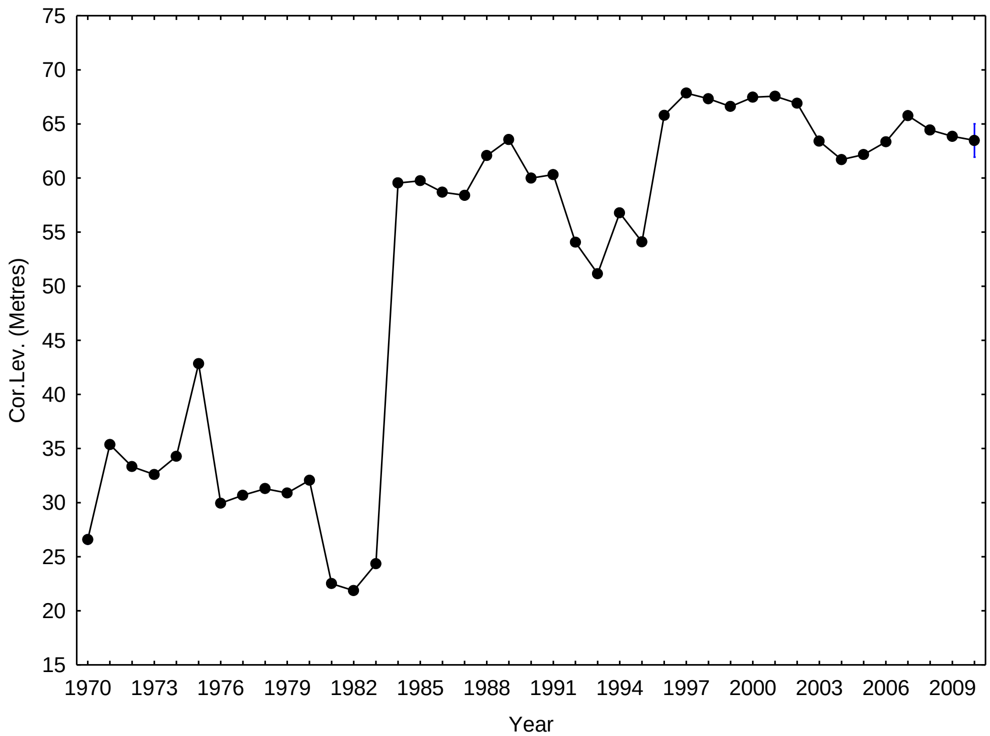
Figure 7. Photograph of an example of a preferred basking site of adult Nile Crocodiles at Pongolapoort Dam.

Figure 8. Tracked locations of Nile Crocodiles in Pongolapoort Dam where the individual crocodiles are shown as follows: a. 150.375, b. 151.017, c. 150.437, d. 150.295, e. 150.255, f. 151.225, g. 150.475, h. 151.315, and i. 150.344. Note symbols for dates of tracking locations are as follows: Target capture; Triangle 08/07/2009; Circle 13/08/2009; Square19/08/2009; Star

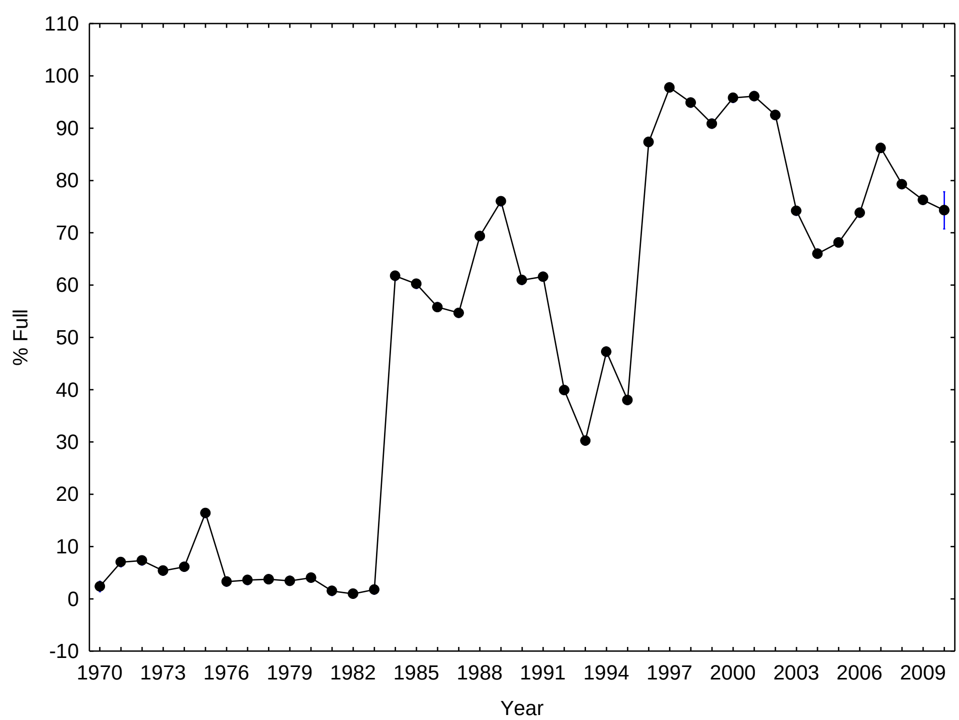
25/08/2009; Cross 01/09/2009; Diamond 23/09/2009; Bolt 02/10/2009; Asterisk 08/10/2009; Tick 09/10/2009; Pentagon 14/10/2009; Flag 23/10/2009.

Table 1. Summary of frequency, sex, total length, capture method and attachment duration of tracked Nile Crocodile.

a.


Cor.Lev. (Metres)
75
70
65
60
55
50
45
40
35
30
25
20
15
1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006 2009
Year

b.


% Full
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100
90
80
70
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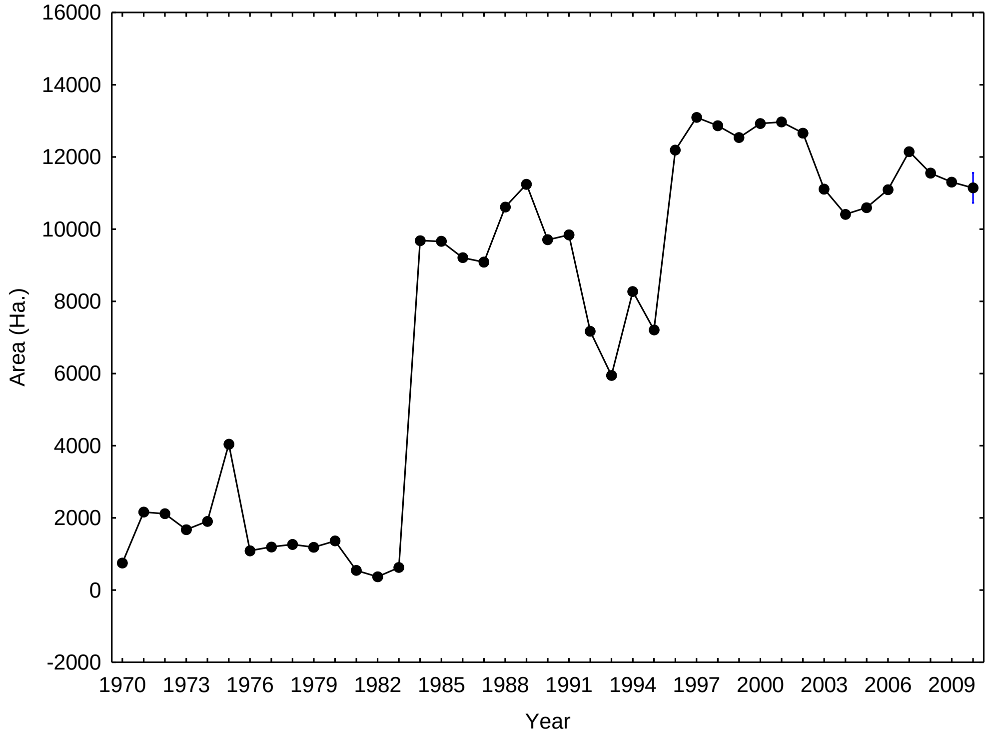
10
0
-10
1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006 2009
Year

c.



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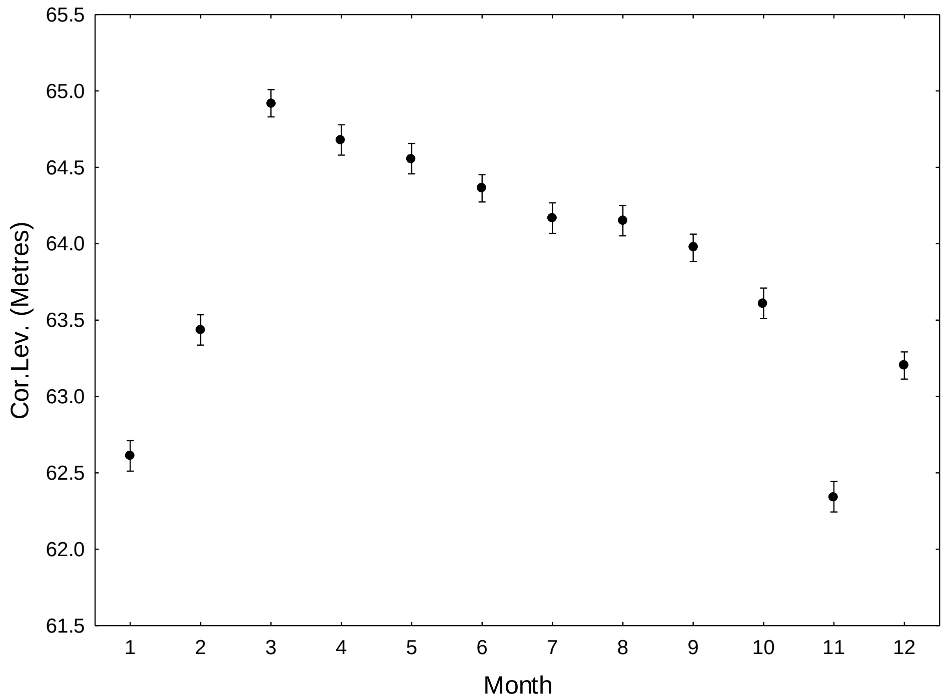
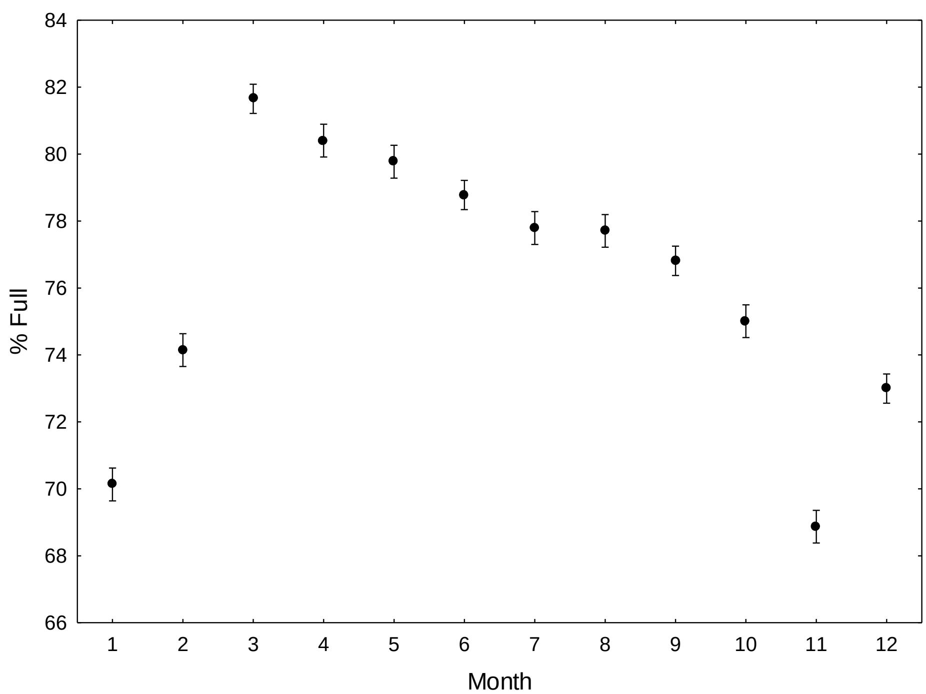
a.


65.5
65.0
64.5
64.0
63.5
63.0
62.5
62.0
61.5
Cor.Lev. (Metres)
1
2
3
4
5
6
7
8
9
10
11
12
Month

b.


84
82
80
78
76
74
72
70
68
66
% Full
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2
3
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5
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7
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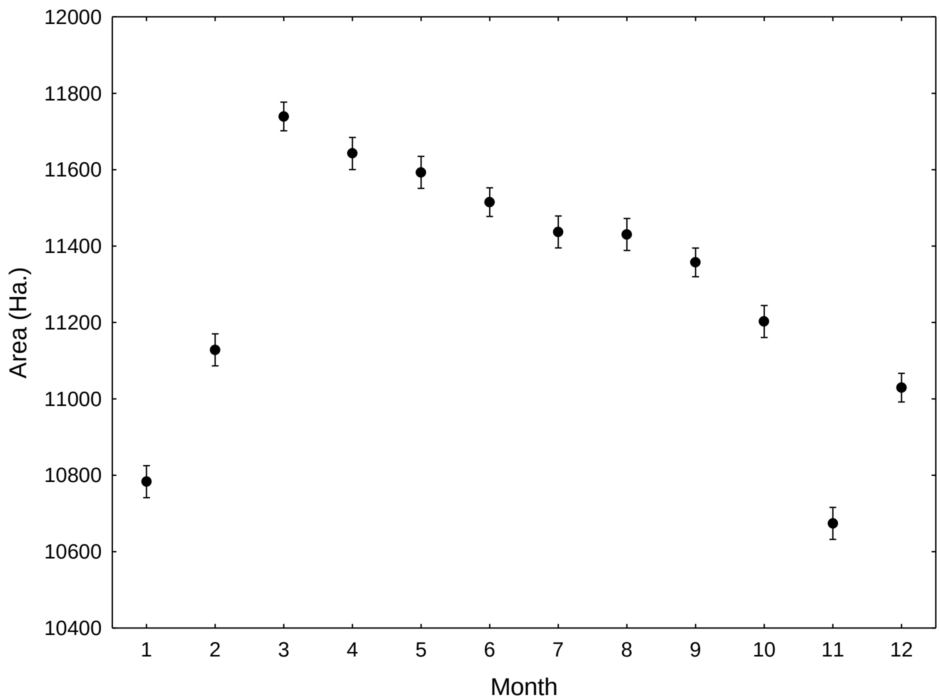
11
12
Month

c.



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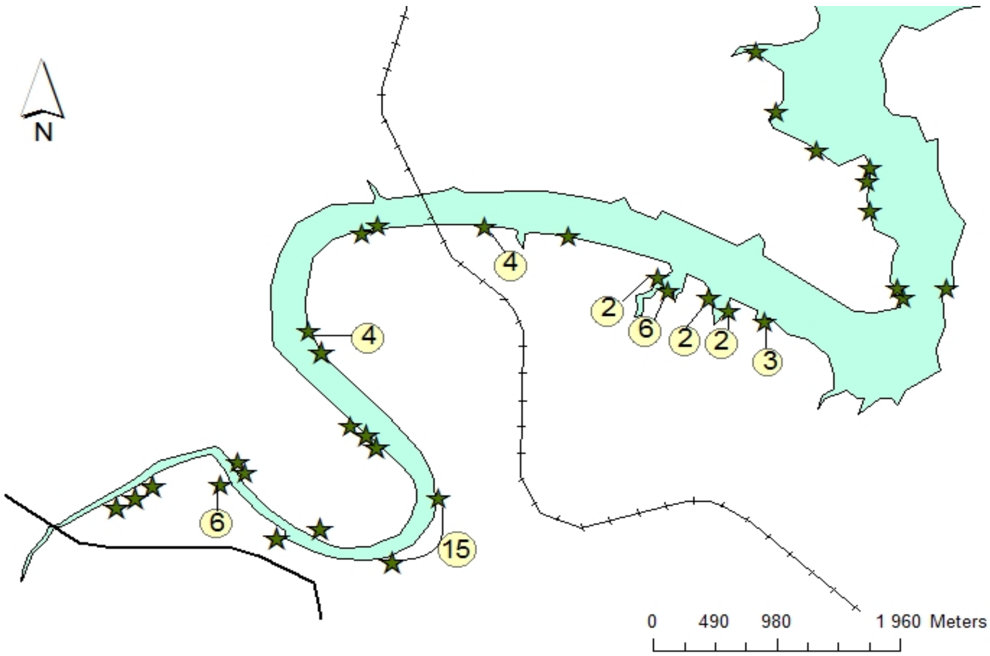

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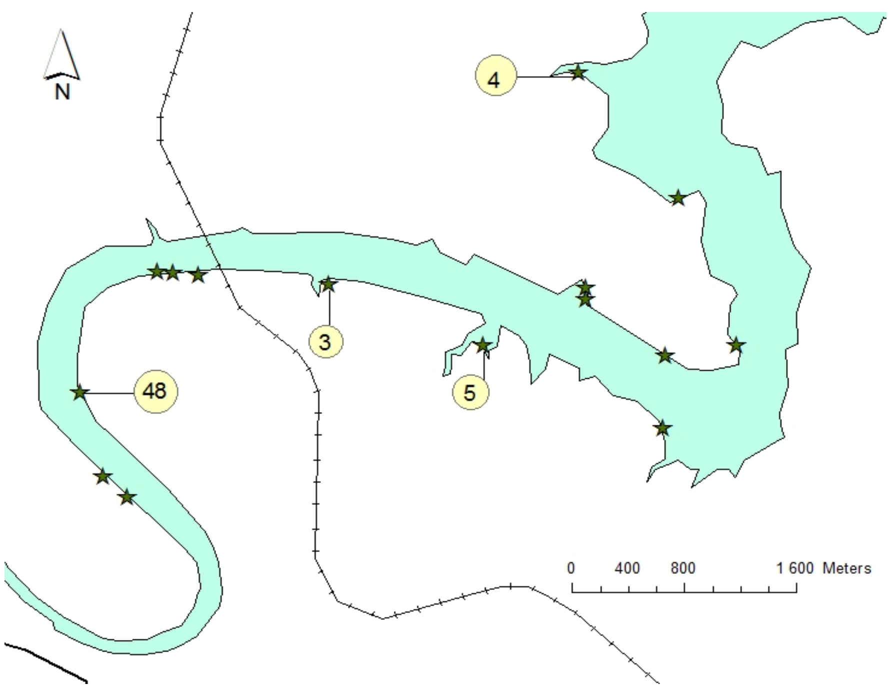

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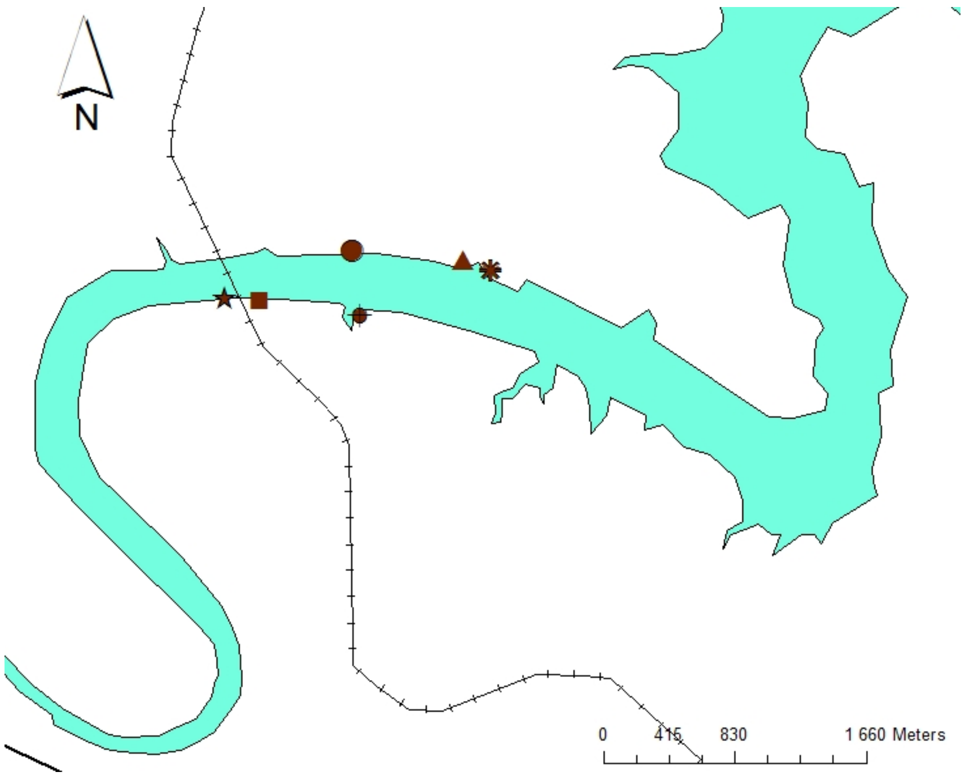
a.



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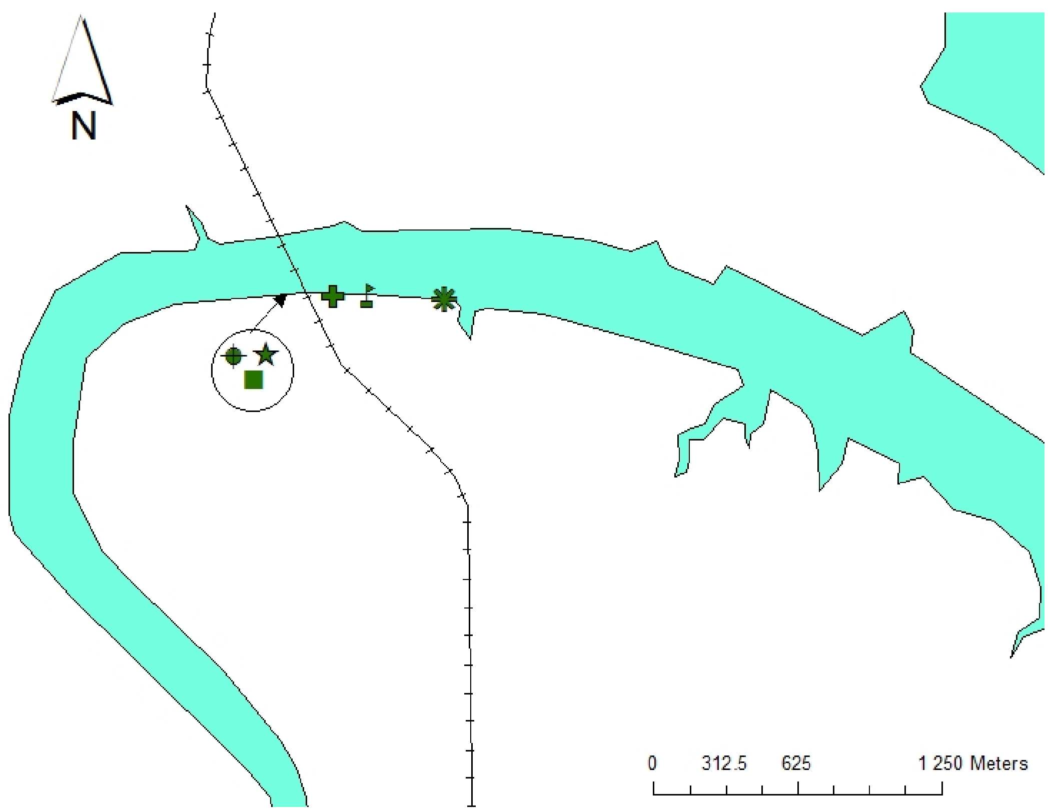
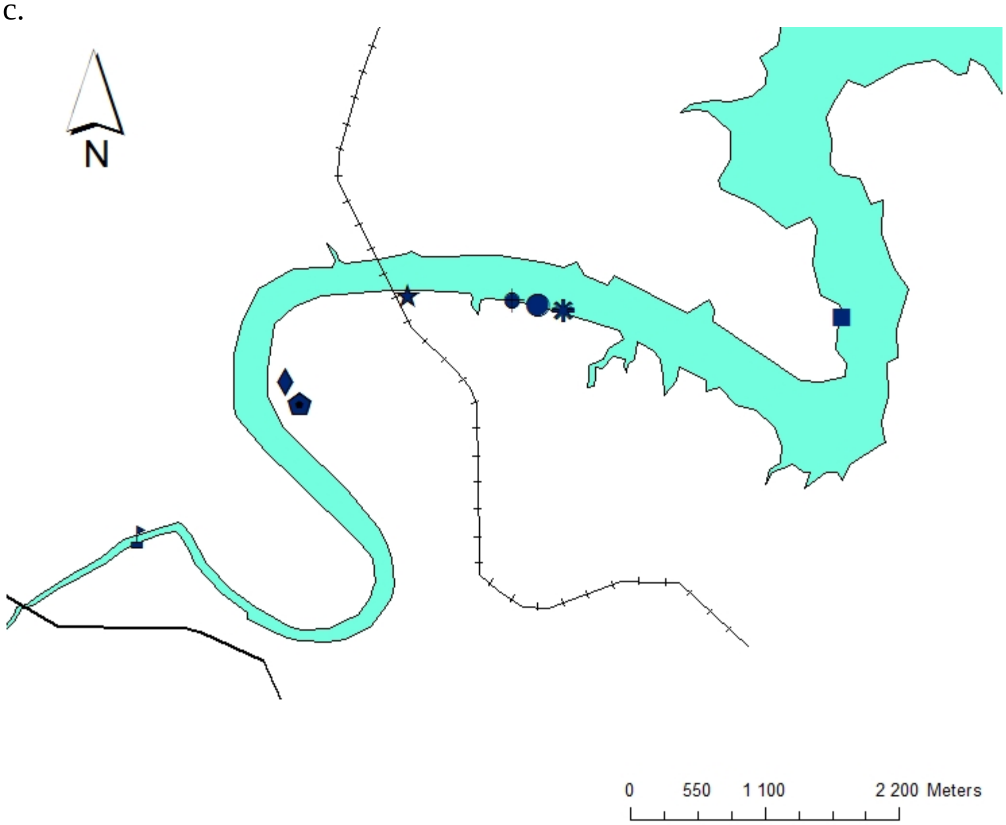
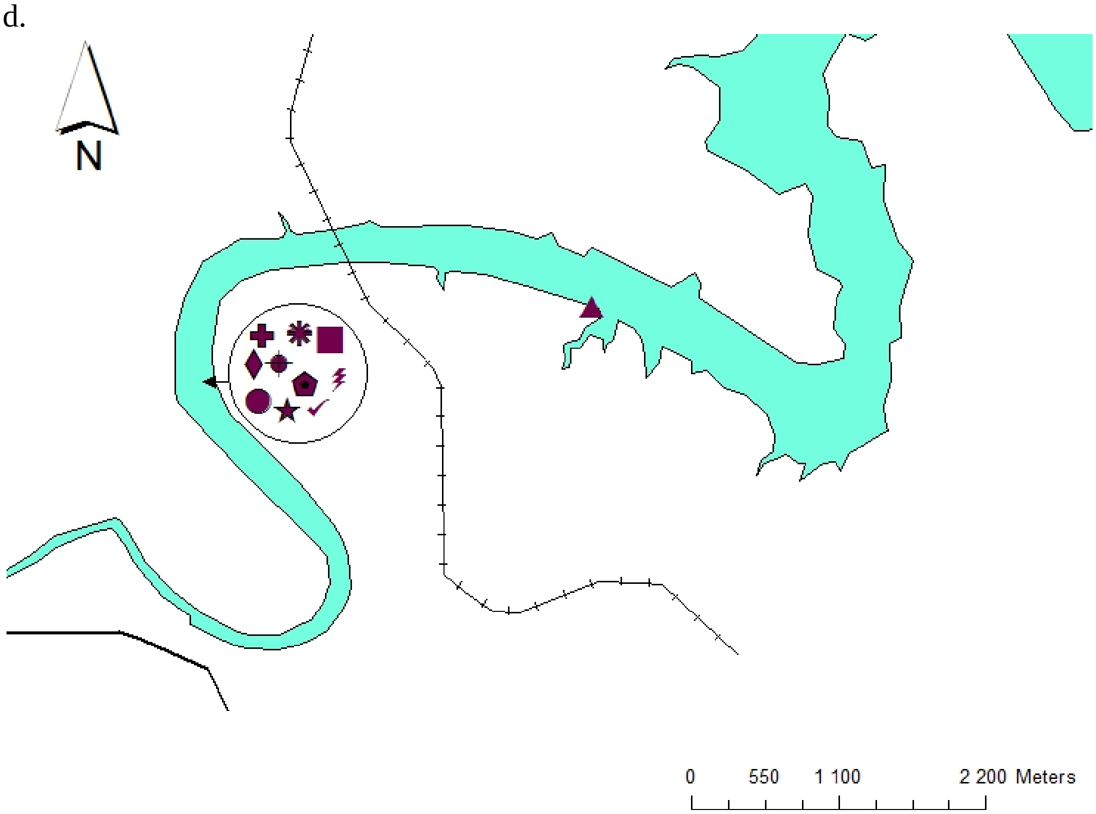


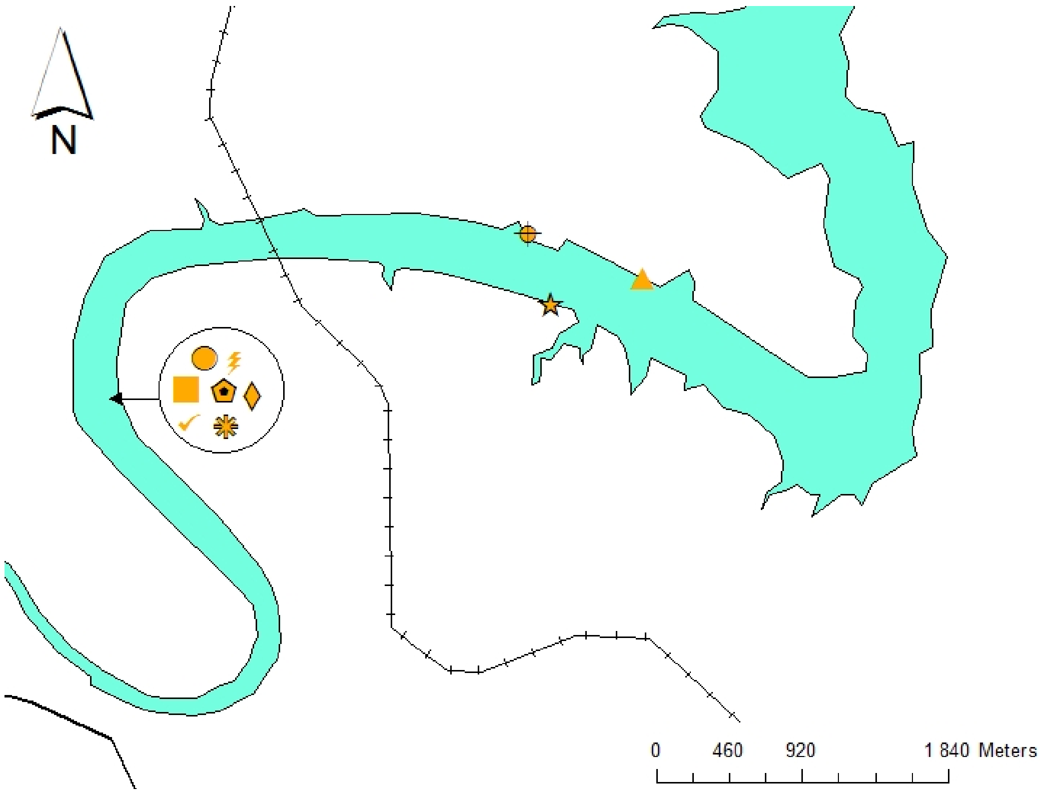
c.



d.



e.



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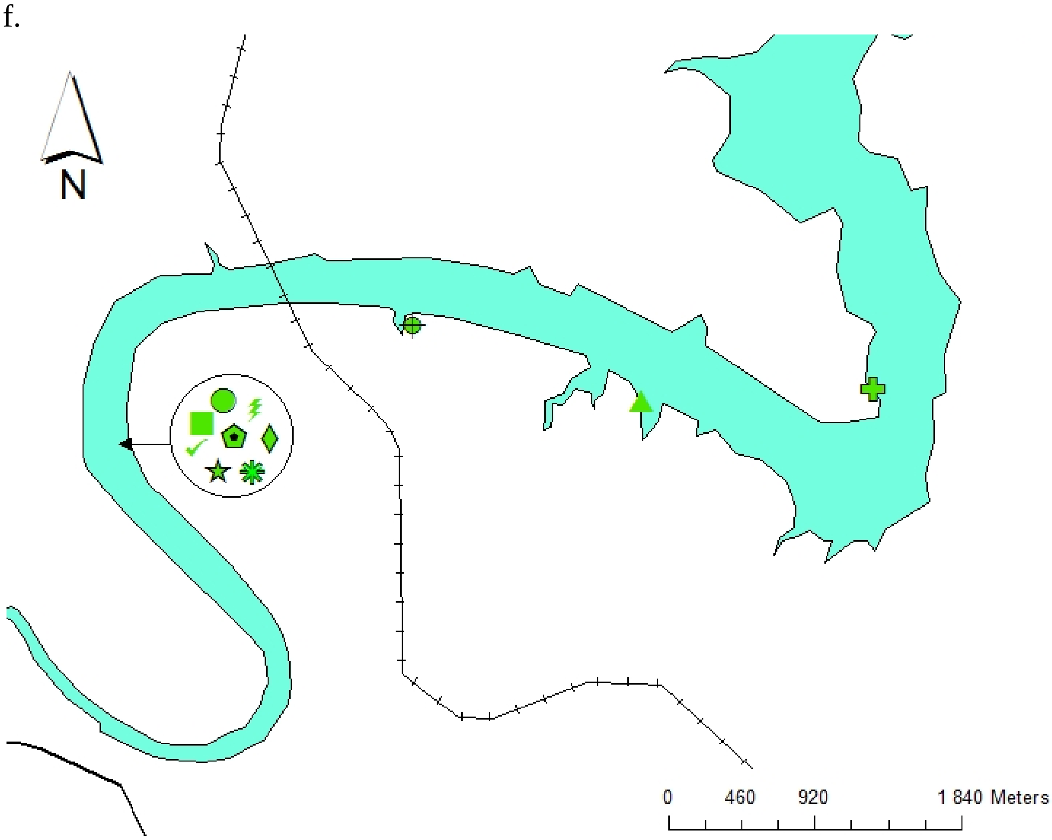
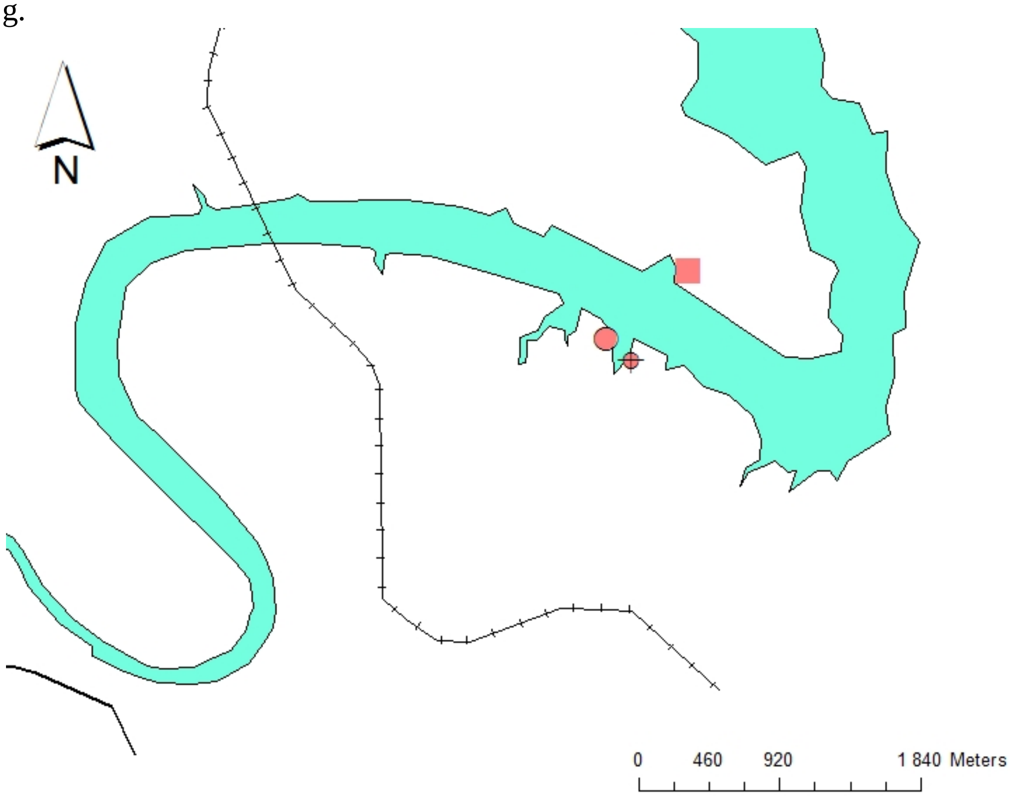
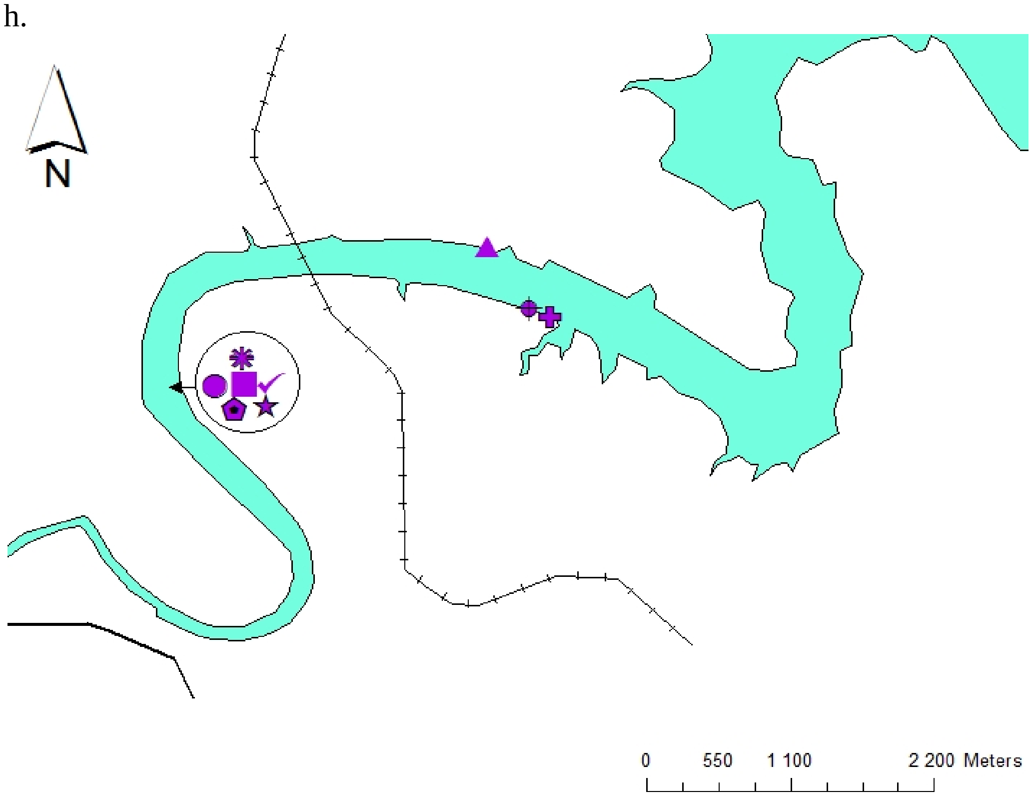


g.



h.



i.

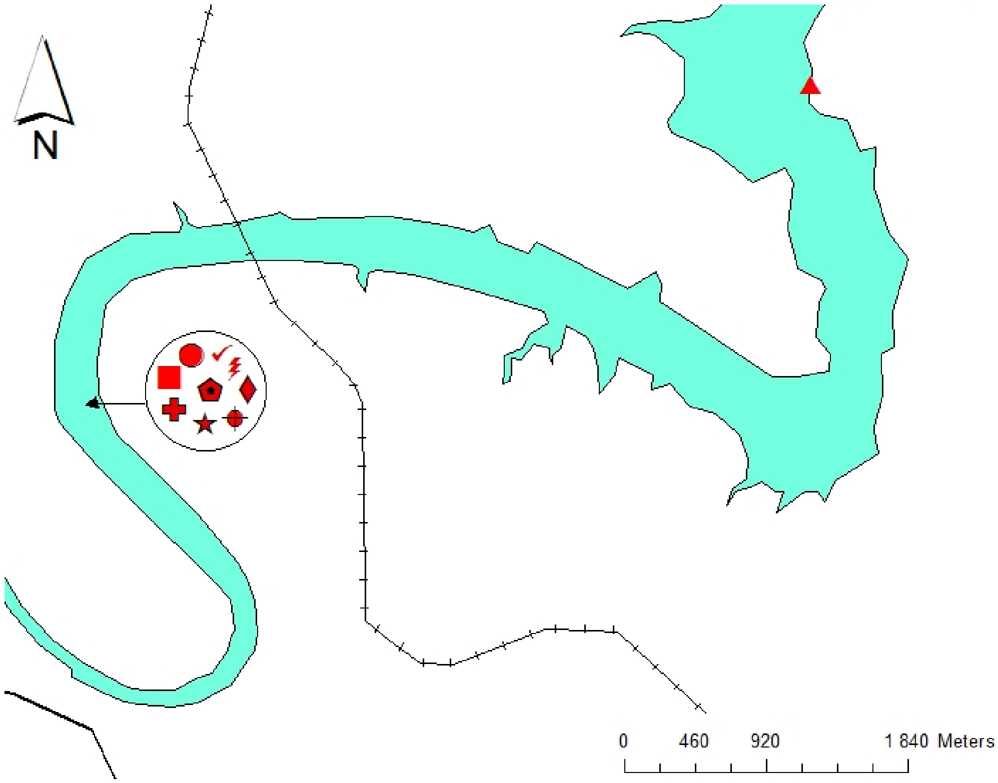


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Table 1. . Summary of frequency, sex, total length, capture method and attachment duration of tracked Nile Crocodile at Pongolapoort Dam during 2009.

Transmitter frequency	Sex	Total length (cm)	Capture type	Attachment duration (Days)
150.375	male	353	Trap	98
151.017	male	430	Trap	98
150.437	female	303	Noosing	98
150.295	female	287	Noosing	42
150.215	female	292	Noosing	42
150.255	female	306	Noosing	42
150.475	male	299	Noosing	92
151.315	female	281	Noosing	93
150.344	male	254	Noosing	87

CHAPTER 4

Reproductive and nesting dynamics of the Pongolapoort Dam Nile Crocodile population: effects of the impoundment

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Abstract

Investigating reproductive ecology is essential in order to access the population dynamics, particularly of an unstudied population. Reproductive output can be a measure of population health. Reproduction and nesting of Nile Crocodiles (*Crocodylus niloticus*) in Pongolapoort Dam, and in particular determine the effects of the impoundment on these were investigated. No previous reproductive effort had been documented prior to this study. Crocodiles congregated at a major basking site where the main tributary entered the dam during August 2009 with a 576 % increase in numbers. This signalled the commencement of the breeding season. Females with transmitters made short trips upstream during this time. In November, with the first rains, the river rose and the majority of crocodiles moved up the inlet, and females established nests. Three major nesting areas were identified, two of which were located on the river inlet to the dam. Approximately 30 nesting females were identified during the 2009/2010 nesting season. All nesting areas identified had been used in prior nesting seasons by the presence of old shell fragments. Nests were located on a variety of substrate types, from clay formed through culluvial and fluvial deposits to course river sand. Several of the nests were predated by Water Monitor (*Varanus niloticus*). Although the number of nesting females was greater than expected, during

the study period there was a total recruitment failure of nests along the river due to a flash flood of the Phongola River in January 2010, destroying all nests prior to hatching. As several juvenile crocodiles were found during surveys, this preliminary study suggests that the Pongolapoort Dam Nile Crocodile population has a relatively high potential reproductive out-put although their annual successes may vary greatly because of loss of nesting sites as a result of water level fluctuations and predation. It appears that the impoundment has generally had a positive impact on this Nile Crocodile population recruitment although suitable nesting sites may become limited.

Introduction

In order to effectively conserve a species, the various contributing populations must be understood and managed to their individual needs (Jacobsen 1991). The Nile Crocodile (*Crocodylus niloticus*) is currently listed as a vulnerable species (Ross 1998, Hutton 2001, Ashton 2010), with the major wild populations appearing to be extremely threatened at present. The three major populations in South Africa, Kruger National Park, St. Lucia Estuary and Ndumo Game Reserve, are all threatened by anthropogenic disturbances such as pollution, poaching and habitat alteration/destruction (Leslie 1997, Combrink 2004, Ashton 2010). This general trend of vulnerability has underlined the lack of knowledge about the state of the systems crocodiles inhabit in South Africa. It is therefore imperative that further knowledge of South Africa's various other wild crocodile populations is obtained in order to identify potential threats and respond to them accordingly. Increased knowledge of these other smaller populations will aid in identifying threats to a specific population and identify general threats to South Africa's Nile Crocodile population as a whole. This will assist in management of all sub-populations to their specific needs. Consequently it is hoped that this will promote conservation and improved status of the Nile Crocodile in South Africa.

The Nile Crocodile was once widely distributed and prominent on the eastern half of southern Africa, but their distribution has been greatly reduced with local extinctions in extended parts of their range (Blake and Jacobsen 1992, Ross 1998, Ashton 2010). The contraction of their range and abundance has been a consequence of human pressure, both directly through extermination and indirectly through habitat alteration, pollution and other such disturbances (Cott and Pooley 1971 , Kyle 1999, Kingsford et al. 2010). Generally Dam construction will lower the associated rivers ecosystem integrity (Zhai et al. 2010). Although these disturbances and alterations made on river systems in which Nile Crocodiles reside have generally had negative impacts, in a few instances they have increased numbers of crocodiles (Jacobsen and Kleynhans 1993). Water impoundments on rivers such as dams have created major problems in regard to hydrological aspects in South Africa's river systems, however these impoundments have created permanent refugia for many species including the Nile Crocodile (Jacobsen and Kleynhans 1993). Other systems that have seen a positive effect of impoundment includes Pong Dam (India) where there was a dramatic increase in both abundance and diversity of water associated avian species as a result of the creation and expansion of new habitats (Pandey 1993). Systems such as these require management with the conservation of these species focused on, particularly if the species are threatened elsewhere in their range.

A number of research projects have been completed in the last decade, focusing on specific Nile crocodile populations in South Africa (Swanepoel 1999, Combrink 2004, Botha 2005). Such studies are critical for the successful management of these individual populations and conservation of the species as a whole. Unfortunately a large proportion of these populations have crashed since these studies. Botha (2005) estimated a total population of 211 Nile crocodiles in Flag Boshielo Dam, whilst the latest surveys show a total of only 98 in 2009 (Ashton 2010). Loskop Dam has gone from a total of 30 in 1984 to a total of 8 in 2009, all of which were juveniles (Ashton 2010). The Lake Sabiya crocodile population has shown a dramatic 93% drop to 7 individuals from 1990 to 2009 (Combrink et al. 2010).

The Pongolapoort Dam is South Africa's third largest dam by volume, with a holding capacity of 2 500 million m^3 of water (van Vuuren 2009b). Although large, about 45 % of the dam perimeter has little suitable habitat for Nile Crocodiles (Chapter 3). The dam is relatively new, completed in 1972 but only first filled significantly in 1984, as a result of large scale floods during Cyclone Domoina (Mkwaka et al. 2003). The Pongolapoort Dam was completed on the Phongola River and this section of river supported a relatively low, however unquantified, number of Nile Crocodiles prior to dam completion (Jacobsen 1991). In addition the majority of the crocodiles occurred in the gorge section prior to impoundment (K. Landman pers. comm.). The current study was part of a broader study on the Nile Crocodile population in Pongolapoort Dam, KwaZulu-Natal, South Africa. This population is of particular interest as it is relatively newly established and the ecology and growth of populations found in impoundments are poorly documented. The objective of this facet of the study was to document reproduction and nesting of Nile Crocodiles in Pongolapoort Dam, and in particular to determine the effects of the impoundment on these. Accessing reproductive output can help gauge the health of a population (Guillette and Edwards 2008). It was hypothesised that the formation of the dam has affected potential nesting sites and reproductive potential. It was predicted that there were increased nesting sites and increased survival and recruitment. In addition comparison was made with preliminary observations of this population in the 1980s prior to it filling.

Materials and methods

Pongolapoort Dam (27°22’10.81” S 31°51’22.49” E to 27°31’23.74” S 31°59’48.84” E) is located on the east flowing Phongola River, in northern KwaZulu-Natal. The dam runs from north to south, along the western side of the Lebombo Mountains, between the towns of Golela and Mkuzi. The area has a sub-tropical climate (Rutherford et al. 2006). The summers months are usually hot and wet (24.5 °C average), whilst the winters months are mild (15.8 °C average) (Heard and Whitley 2009). With most of the 600 mm mean annual rainfall falling between the months of November and March (Rutherford et al. 2006). The dam is found at 110 m.a.s.l The maximum surface area of the Pongolapoort dam is 12 470 ha with a maximum capacity of 2 500 m^3 (Heard and Whitley 2009). The Phongola River is the only perennial river flowing into the Pongolapoort Dam (Heard and Whitley 2009).

Data were collected from April 2009 until the end of June 2010. As Pongolapoort Dam is so large, it was, on a logistic scale, impossible to observe all Nile Crocodile clusters/ aggregations around the dam in this study. After surveys of the dam for presence and abundance of crocodiles (Chapter 2), a section of the dam from Buffalo Bay (Phongola River inlet) (27.380225 S, 31.84549 E) to the Pongola Nature Reserve camp site (27.34315 S, 31.90530 E), was selected. Here the greatest number of crocodiles was concentrated (Chapter 2). This area was the north-eastern section of the dam and included the main river inlet (Fig. 1). The clusters/ aggregations of crocodiles outside of this area were however included in aerial surveys to locate crocodiles and possible nesting sites.

No previous documentation of number Nile Crocodile nesting females or nest site localities at Pongolapoort Dam was available. As a result surveys were carried out to identify general nesting areas. After the nesting areas were identified, detailed information on actual number of current nests, as well as size classes of nesting females and environmental parameters associated with individual nest site selection were obtained. A number of surveys were conducted each month from August 2009 to February 2010, using a combination of methods to achieve these objectives.

A single aerial survey of the north western section of Pongolapoort Dam was conducted on the morning of 23 November 2010, during favourable weather conditions, using a AS350 Ecureuil Helicopter (Squirrel). This survey team consisted of 4 observers, including the pilot and a scribe. The survey commenced at 10h00 and finished at 11h00, covering 25 km. During this survey a total crocodile count was obtained (Chapter 2), noting distribution, size classes and probability of nesting sites. Probable nesting sites/areas were identified by either atypical basking behaviour, such as unusual basking site selection or odd diffuse basking clusters, or by visuals of nesting depressions or actual eggs of only partially covered nests. The survey route included the river inlet (N2 road Highway Bridge to Railway Bridge), as well as the dam sections 3 and 4 as described elsewhere (Chapter 2). The remaining sections, including the main body of the dam (sections 1, 5-17) were not surveyed due to the high financial cost associated with this method of survey and the low likelihood of nest sites in these sections with unsuitable habitat (Chapter 3). Once a possible nesting area was identified from the air and its geographical location noted using a global positioning system (GPS, Etrex, Kansas, USA), it was later confirmed by a follow-up foot survey (see below).

Foot surveys to determine numbers and localities of Nile Crocodile nest sites consisted of 2-3 observers who walked along the water-line as closely as possible, however some water-line areas were inaccessible and had to be circumnavigated. En route any paths possibly created or used by crocodiles were investigated. Areas around well known basking sites or possible historical nesting sites (various pers. comm.) were more intensively examined for evidence of nesting sites and number of nests within these areas determined by walking them extensively while on a foot survey. When searching for individual nests, a nest's presence was often made known by a fleeing crocodile with observers approach. The exact nest site was often identified by an indent or signs of soil disturbance, accompanied by imprints where the crocodile had been laying near/on the nest. The geographical position of nests was obtained using a GPS.

In order to minimize disturbance at the crocodile nesting areas, minimal time was spent there, with the aim to merely confirm the number of nests, their locations and if possible the size class of the nesting females. Historical nesting sites from prior breeding seasons were also noted if discovered. These were usually identified by the presence of old egg fragments which may take a number of years to decompose fully (Leslie 1997). Female crocodiles were occasionally observed on nests from a distant vantage point with minimal, if any, disturbance. This allowed for a non-bias opportunity to observe the nesting females presence and behaviour at the nest. Each area was not intensively walked more than twice during the breeding season to minimize disturbance. Further measurements and recordings were delayed and only taken at the end of the nesting season (post-hatching) to further minimize disturbance. All parameters measured at each nest were environmental (approach distance from water, exit distance to water, height above water, substrate type, distance to nearest neighbouring nest and vegetation cover). Each nest was assigned a disturbance rank where 0/3 was very low, 1/3 was low, 2/3 was moderate and 3/3 was frequently disturbed. In addition, the probability of discovering previously overlooked nests was expected to be greater after hatching. During these post-hatching measurements attempts were made to estimate hatching success and determine levels of predation at various nesting areas.

Due to the flash flooding and resultant destruction of all nests along the river sections and alteration of the river banks, some environmental parameters for some of the nests were approximations made from photographic records. A commonly included parameter in many past studies was height above water. However, in this study it was not included, as the river level fluctuated dramatically with sporadic summer rains and the dam level constantly rose with the onset of summer rains in the upstream catchment area.

As some of the dam's Nile Crocodiles had been caught, tagged for unique identification and fitted with radio-transmitters (Chapter 3), these were monitored hourly for 24 h each month for several months and any reproduction related data collected presented here. Other crocodiles had been previously caught and were uniquely identifiable from their individual colour-coded tail scute tags assisted in determining presence of males and or females at the respective breeding areas.

A number of opportunistic observations of Nile Crocodile reproduction were made and recorded during surveys and visits to the respective breeding areas and in particular from various vantage points overlooking these during the breeding season (August-February). A number of mass basking areas were identified as been used year round, however at only one was opportunistic observations made on courtship and mating events. This mass basking area was referred to as Buffalo Bend (27°22'47.05" S, 31°50'44.43" E). A second area identified as a "communal" nesting site and referred to a Causeway Bend (27°23'22.74" S, 31°50'25.10" E) was also monitored regularly. At all these, observations were made and any mating and/or courtship behaviour, as well as threat displays and aggressive interactions between Nile Crocodiles recorded.

Results

Mating and courtship

The Buffalo Bend basking area (Fig. 1) for crocodiles was a large island located on the inner corner of a river bend at the dam inlet of the Phongola River. The 2009 Nile Crocodile mating season commenced during August, when numbers of crocodiles using this basking area increased from 13 (observation July) to 75 (observation August) i.e. a 577 % increase in numbers. These crocodiles were mainly in the 3 - 4 m size class (85 %) with a single large dominant male of 4.5 m present (Chapter 3). This male was the only one observed mating during repeated surveys at this time. He was observed performing aggressive displays towards other crocodiles in the water as well as occasionally chasing a number of smaller crocodiles of unknown genders from the basking site. Presence of a number of tagged crocodiles with unique colour-coded tags attached to their tail scutes (Chapter 3) confirmed that although the largest male appeared dominant, there were a number of other smaller males present, included two tagged males of 3.4 m and 3.0 m. During this period there were also a number of previously tagged adult females present at the basking area, some of which had travelled from their usual basking areas to Buffalo Bend (Chapter 3). While others of these were commonly found in the area prior to the mass congregation/aggregation in August 2009.

Two tagged adult females with VHF radio transmitters attached (Chapter 3) arrived at Buffalo Bend during this period. These females, both 3 m in length, were observed during 24 hour observational sessions, moving further up river periodically at night and returning before morning to this basking area. At this time of year the water was clear and the river above Buffalo Bend was still very shallow (< 30 cm), except for a very thin channel along the outer edge which was slightly deeper (approximately 1 m). With the arrival of the first rains in early November, the river rose considerably and water colour changed dramatically to brown as a result of sediment run-off into the river. With the resulting rise in river level, Buffalo Bend basking area was greatly reduced in size and the once large long island was reduced to a number of small islands. Within two days of the dramatic change, the large numbers of crocodiles previously based there dispersed. The majority of these crocodiles moved upstream from Buffalo Bend, some being re-sighted, during the helicopter survey (23 November 2009), as high as the N2 road highway bridge that crosses the Phongola River 7 km upriver from Buffalo Bend in an area previously unpopulated by adult crocodiles during the winter months (Chapter 2).

Nest Sites and nesting

Three general communal nesting areas were identified in the 2009/2010 breeding season. These areas are referred to as "Croc Bay" (27°22'42.90" S 31°52'27.93" E), "Cliff Ledges" (27°23'33.19" S 31°51'26.58" E) and "Causeway Bend" (27°23'22.74" S, 31°50'25.10" E) (Fig. 1). The reproductive index, proportion of actual females nesting to the total females with the potential to reproduce, of 0.73 was high in relation to other large populations in South Africa.

Croc Bay

Croc Bay was located in Section 3 of the dam, on the southern bank between Inkwazi lodge and the railway bridge (Fig. 1). This was the largest bay in the section and was well protected against wind. The bay consisted of a large bowl bay, with a second narrow curved bay extending off the back of the larger bay. The small narrow bay has steep banks and clay substrate with a high gravel load. Here a number of old nesting depressions were located, scattered with degrading egg fragments, suggesting that the area had been used in prior breeding seasons for nesting. Only two nests (7% of total nests found) were identified here during the 2009/2010 season, one located on a well used animal path and another at the base of a cliff, very near the water edge (Fig. 2a, Table 1).

The nest located on the game path was approximately 8 m from the water edge and 3 m above the water surface, at about the 100% full capacity mark of the dam. The associated female was an estimated 3 m long. The nest site had no nearby shade for the female to rest in during the heat of the day. The nest site was on bare soil, but surrounded by weeds of approximately 50 cm in height, with *Parthenium hysterophorus,* the alien invasive plant, being the dominant species (Table 1). As the nest was located only just off a well used game path, it was allocated a disturbance level of “3/3” (very frequent). This path was used daily by a number of game species as a water access route. On 12 December 2009 at 10h00, a large monitor lizard (*Varanus niloticus*) was observed digging up the nest, stealing an egg and fleeing to a nearby shrub thicket. Once the egg was consumed, the lizard would return and steal another. Predation on the nest continued for a number of days until the nest was completely raided with no eggs remaining. It is uncertain whether the initial lizard, responsible for opening the nest, consumed all the eggs or whether a number of lizards were responsible for raiding the complete clutch. At no time during this period was the nesting female present during the nest raids and once the nest had been opened, no attempt to recover it was made by the female. After the nest was predated, the nesting female was not seen at the nest site again.

The nest site at the base of the cliff (Fig. 2a; 27°22’42.90” S 31°52’27.93” E) was on shallow, hard soil, which appeared to only form as a result of sediment wash off down the cliff face. It was 2 m from the water edge and only 0.5 m above the water surface on a small ledge. It was considerably below the dam’s 100% full capacity mark. The nest was not observed prior to predation and it is assumed that predation happened soon after the eggs were laid, as the eggs were not covered sufficiently with soil once laid. The nesting female associated with this nest was the smallest of the observed breeding females during the 2009/2010 breeding season, estimated at 2.8 m. The site had no nearby shade but was very near the water, which would offer protection during the heat of the day. Due to this site's locality it was only accessible by water and therefore was allocated a "0/3" (very low) disturbance value, as no large game or people could reach it. However, this female abandoned the nest soon after it had been predated and few observations were made regarding her behaviour around the nest.

These two nest sites were approximately 30 m from one another. No interactions between the two nesting females were witnessed, nor were any other Nile Crocodiles seen in the inner bay during this time, even though the large outer bay was used year round as an established basking site, with a number of crocodiles residing there (Chapter 2). Consequently both nest sites at Croc Bay failed early in the season as a result of predation by monitor lizards (*Varanus niloticus*) (Fig. 5).

Cliff Ledges

The Cliff Ledges nesting area (27°23'33.19" S 31°51'26.58" E, Fig. 1, Fig. 2b) was located along the inlet section of the river, 500 m upstream of the favoured basking and courtship site "Buffalo Bend". A high proportion of the ledges were inaccessible as the site backed onto high cliffs, with a number of rock protrusions which extended out of the cliff face, into the river creating wall like obstructions from either side. This area was only accessible from the water or an arduous climb down a cliff face. This protected area was given a disturbance level of 0/3 (very low). The soils on the ledges appear to have accumulated as a result of the both culluvial and fluvial deposits, resulting in shallow clay sediment, with varying gravel loads (Table 1). The area contained the highest number of identified nest sites, with a total of 19 sites (68% of total nests found) identified during an aerial survey by helicopter. The nests were all located on the outer bend of the river. Nine sites were visited during a later foot survey. The remaining ten sites were either inaccessible or unfound during the foot survey. Four of the nine nests visited (during the foot survey) fell outside the inaccessible ledge area and could be easily accessed by following the bank alongside the river. Two of these nests were down-stream of the cliffs and two upstream. The locality of the nests outside the protected ledges resulted in easier access and a higher disturbance frequency, allocated a 2/3 (moderate disturbance) as large game, especially African Elephant (*Loxodonta africana*), frequented the area whilst feeding on riverside vegetation and accessing water.

Although, during the helicopter survey, a high number of nests were found along the less accessible ledges only five nests were reached and verified by foot. During the aerial survey, on approaching the cliffs, a high number of crocodiles were seen fleeing off the ledges into the river. These ledges seemed noticeably atypical with regards to areas usually selected for basking, both with respect to the ledge's physical characteristics and the diffuse basking pattern observed (Fig. 3). On closer observation a number of nesting sites were identified, some already opened and predated, others visible as they were inadequately covered. During the aerial survey just after 10h00 a 3 m female crocodile was seen dropping her entire clutch of eggs, with no attempt to excavate or clear a nesting area (Fig. 4, croc "X"). The over 45 eggs were dropped directly onto a patch of flattened grass. On the helicopters approach the female made no attempt to flee into the water, but remained next to the mound of eggs. She showed no response to the helicopter presence, even with the wind and sound disturbance the helicopter created whilst hovering over the site. Later a foot patrol found the site, where all eggs had been destroyed by predators including monitor lizards (*Varanus niloticus*). The various ledges were separated by the rock protrusions, each ledge accommodating a various number of nests. Nests along the ledges were in close relation to one another, with the mean distance between nearest neighbouring nests being 5 ± 2.4 m (n = 9). Mean length of female crocodiles nesting on the ledge was 3.1 ± 0.1 m (n = 9).

A network of pathways was visible from the air, leading from less demanding access points from the water, up onto the ledges towards apparent nesting sites. Return pathways (escape routes) into the water, ran straight towards the water, directly off the steep banks, making clear slide marks. These pathways showed a definite circular pathway to and from the nest sites, with the approach path usually being considerably longer than the departure. Distance from nest to water varied from 3 to 40 m, with a mean direct distance from nest to water of 9.8 ± 12.0 m (n = 9).

Of concern was the high abundance of alien invasive plants along the ledges where the Nile Crocodile nests were. The two main dominant species included *Parthenium hysterophorus*, which surrounded seven of the eight nests along this area and *Chromolaena odorata*, which created a number of dense thickets along the foot of the cliff and was in close proximity of five of the nine nests. It was however noted that these *Chromolaena odorata* thickets were used as shade refuge by a number of crocodiles nesting on the ledges. The shading effect of surrounding vegetation on nests was not quantified in this study.

Causeway Bend

The Causeway Bend nesting area (Fig. 1) was just below a washed out causeway, located 500 m downstream of the N2 road highway bridge, where it crosses the Phongola River and 1.5 km upstream of the dam. This crocodile nesting area, with 7 nests (25% of total nests found), was the furthest up the inlet from the dam of the three identified nesting sites (Fig 2c, Table 1). However, it must be noted that crocodiles were seen above this point. The area above the highway was however not surveyed for nests because of logistic constraints. Nest sites were identified on both sides of the river (Fig. 2c) at Causeway Bend, five on the inner bank of the bend (river left) and two on the outer bend (river right). Inner and outer banks were dissimilar to each other in environmental characteristics (Table 1).

The outer bank was similar to the Cliff Ledge crocodile nesting area, with a ledge backing onto a cliff and inaccessible except by water. These nests here were therefore allocated a disturbance level of 0/3 (very low). The soils were shallow, formed through colluvial and fluvial deposits. Both weeds *Parthenium hysterophorus* and *Chromolaena odorata* were dominant plant species surrounding the site. In contrast, the inner bank consisted of a large sandy beach, surrounded by *Phragmites australis* reed beds. Here the soil substrate was uniform river sand, with a very low gravel load. This area had few alien invasive plant species, and no *Parthenium hysterophorus* or *Chromolaena odorata* evident (Table 1). As a consequence of its isolation and infrequent visitation by other animals or humans and the surrounding reed bed which formed a protective barrier around, this nesting area was allocated a disturbance level of 1/3 (low). Nests were in close proximity to one another with mean distance to nearest neighbouring nest 5.7 $\pm$ 1.7 m (n = 7). Distance to water from each nest varied considerable though, as nests were scattered in a circular fashion. The two nests on the outer bank were near the water, both 3m from the ledge edge. The inner nests were all further, with a mean distance of 14.6 ± 10.9 m (n = 5). Mean length of nesting females was higher than the mean length of nesting females at the other nesting areas. These females were also observed spending a large proportion of time at their nest sites. The nesting area had a number of shade refuges that females would use during the heat of the day. Nests on the outer bank were not visited and could only be observed during the aerial survey. Therefore very little observational data was obtained for these sites. The inner bank nesting sites however were visited on two occasions by foot survey and easily viewed on a number of occasions from a high vantage point, which created no disturbance for the nesting females during observations. All of the nests on the inner bank were well buried and no form of predation was apparent at any of these nesting sites. During one of the foot surveys to the inner this site, a number of nest sites from prior breeding seasons were identified by the presence of old degrading egg fragments.

On 10 January 2010 the Phongola River had a major flash flooding, with highest river levels recorded since the 2000 floods. The flash flood resulted from major rainfall over the entire catchment area above the Pongolapoort Dam, flooding all tributaries and the Phongola River itself. The Phongola River burst its banks and flooded all nest sites along the inlet section (i.e. all nest sites described above). The flood waters transformed and reshaped the whole inlet section of the river into the dam, erasing past basking areas and creating others in new areas. The recruitment for the 2009/2010 breeding season was estimated to be zero. However, there were unverified reports of a few hatchlings being spotted in the inlet section during February 2010 either suggesting the possibility of a nest hatching prior to the flooding or a nest site in another area being successful.

Despite the apparently low recruitment in the 2009-2010 breeding season numbers of juvenile crocodiles were observed (Chapter 2) showing that the Nile Crocodiles are having reproductive success, all be it annually variable.

Discussion

As mentioned Pongolapoort Dam was completed in 1972 on the Phongola River. The section of river incorporated into the dam supported a relatively low number of crocodiles prior to dam completion (Jacobsen 1984) and these were mainly found in the gorge section prior to impoundment. The construction of the dam resulted in a complete habitat change, as rising dam levels flooded areas previously used by crocodiles and made new areas available (Chapters 2 and 3). Such drastic habitat change may be equated to the relocation of the crocodile population. The impoundment changed food availability and distribution patterns (Ward 1998), as well as shifting available basking and nesting areas. Consequently Nile Crocodile home range and territory parameters, communal courtship sites and available nesting areas were affected (Botha 2010). Since the establishment of the dam in 1972, its water level has fluctuated drastically, between 12 to 107% capacity (60 m fluctuation in height at the dam wall), as a result of floods, droughts and changes in management strategies (van Vuuren 2009b). The results of this study may therefore only be relevant for this specific combination of range of water levels and the water management strategy being followed at the time of the study. However, the results will allow for future studies to explore the changes in population dynamics of the Pongolapoort Dam Nile Crocodile population in response to changes in the characteristics of the water body they inhabit.

Mating and Courtship

During this study dam water level fluctuated (68 - 81%) with an approximate 2 m vertical difference in water level (Chapter 3). The observed aggregation and increase in number of Nile Crocodiles present at Buffalo Bend during the mating season was most likely due to its locality. As this basking site is the last "deep" water, after which the river upstream became shallow and did not appear to offer adequate depth as refuge to large crocodiles. Aggregations of Nile Crocodiles during the mating season have been previously documented (K. Landman pers comm.). Presence of a number of adult males at Buffalo Bend suggested no strict territorial structure, particularly during the mating season. However, the apparent dominance of a single large male suggested a hierarchical system. Smaller males present were not observed mating, however they may have done so opportunistically when the larger male was not present to assert dominance. Movement of some females upriver during night at this time is likely explained as preliminary visits to potential nest sites, as described by Blake and Loveridge (1987). Their movement upstream at night was most likely due the darkness being perceived as a safe time to traverse the shallow river.

Nest site selection

Croc Bay (Fig. 1) appeared to be a previously well used historical Nile Crocodile nesting site, at a time when the dam level was maintained at a far higher level (1996-1998) (C. Rippon pers comm.). During these years there appeared to a high number of nesting females at this site (C. Rippon pers comm.). Previously as a result of the higher water levels, the cliffs that are now present were mere ledges, allowing for more nesting sites with close proximity to the water. The disturbance level was much lower, as at high levels the nearby road was unused and game accessed water using different game trails (various pers comm.). The reason for continued use of this area during the 2009/2010 season despite its current unsuitability is unknown and may be related to inexperience or their inability to adapt to unpredictable water levels.

Location of Nile Crocodile nest sites in the inlet section of the main river entering the dam appear to escape the effect of dam level fluctuations and anthropogenic disturbance. These sites appeared to experience conditions similar to nesting sites in other river systems (Graham 1968, Pooley 1982, Leslie 1997, Swanepoel 1999, Botha 2005, Borquin 2008). Similarly observations made during the 2009/2010 breeding season had similarities with other studies of Nile Crocodile populations in other systems, including open river systems. In particular, congregation in deep pools during the dry season where mating takes place has been documented in some studies of river-based crocodile populations (Kofron 1993, Swanepoel 1999). This can be likened to the use of Buffalo Bend as a mating area, as it was the last deep water before the river became shallow further upstream away from the dam (Chapter 3). Commencement of nesting with the onset of first summer rains has also been documented in other systems, including the major crocodile population at Ndumo Game Reserve, also on the Phongola River (Pooley 1969). Botha (2005) showed a similar preference of a dam-based Nile Crocodile population to nest in the dam inlet section rather than in the main dam body.

With regard to the great variability in nest site selection, Pooley (1969) and Hartley (1990) also recorded variation in soil substrate chosen for nesting, the distance from water, surrounding vegetation cover and distance to neighbouring nests. Pooley (1969) and Kofron (1989) also found that nest depth varied according to substrate type, with coarse river sand allowing for the deeper nests. It is unsure whether the predatory level is related to the depth at which the eggs are buried, with shallower nests possibly being more easily detected through higher levels of scent (from the egg chamber) escaping through the soil. This may explain the high predation level at the Cliff Ledge nesting site while no nests were predated at Causeway Bend. Observations of only partially covered eggs along the Cliff Ledge suggest this may be the case.

Annual recruitment of Nile Crocodiles varies as a result of environmental variability between seasons (Pooley 1969, Kofron 1989, Swanepoel et al. 2000). Total recruitment failure due to flooding is not uncommon and has been documented in a number of studies at various localities (Pooley 1969, Kofron 1989, Swanepoel et al. 2000). Noting the delay of laying in anticipation of the first rains, it is evident that drought periods affect recruitment as well. In the current study fluctuating river levels affected Nile Crocodile recruitment adversely. However, despite the apparently low recruitment in the 2009-2010 breeding season, high numbers of juvenile crocodiles, from prior seasons, were observed (Chapter 2) showing that the Nile Crocodiles were having reproductive success. From the number of nests found in 2009-2010 at Pongolapoort Dam it appears that the Nile Crocodile population has a relatively high potential reproductive out-put although their annual successes may vary greatly because of loss of nests to predation and fluctuating water levels, particularly river inlet. Thus far the population appears to have a high reproductive index of 0.76, when compared with other major crocodile populations in South Africa, such as Ndumo Game Reserve (0.2, Calverley 2010) and St. Lucia (0.3, A. S. Combrink pers comm.). However, it appears that there is a paucity of suitable nesting areas with crocodiles sometimes using unsuitable cliff ledges. A further concern is the degree of alien invasive vegetation at several of the nesting areas and its potential negative impact. However with the observation of reproductive effort and high number of juveniles, preliminary assessment currently suggests a healthy population.

Conclusion

As a result of human encroachment and habitat destruction there has been a great decrease in suitable Nile Crocodile breeding grounds in general (Pooley 1969, Combrink 2004). Despite the generally negative effects of river impoundments, the Pongolapoort Dam has resulted in the establishment of a relatively large Nile Crocodile population, with a considerable reproductive potential. However, the latter is affected by changing water levels and predation. This underlines the importance of ensuring the consideration of Nile Crocodiles and their breeding grounds in Pongolapoort Dam management plans. Further studies are recommended, specifically focusing on nesting dynamics and seasonal changes in the success of nesting effort, as well as any changes in areas used for nesting.

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Legends for Figures and Table

Figure 1. North Western section of Pongolapoort Dam and inlet section.

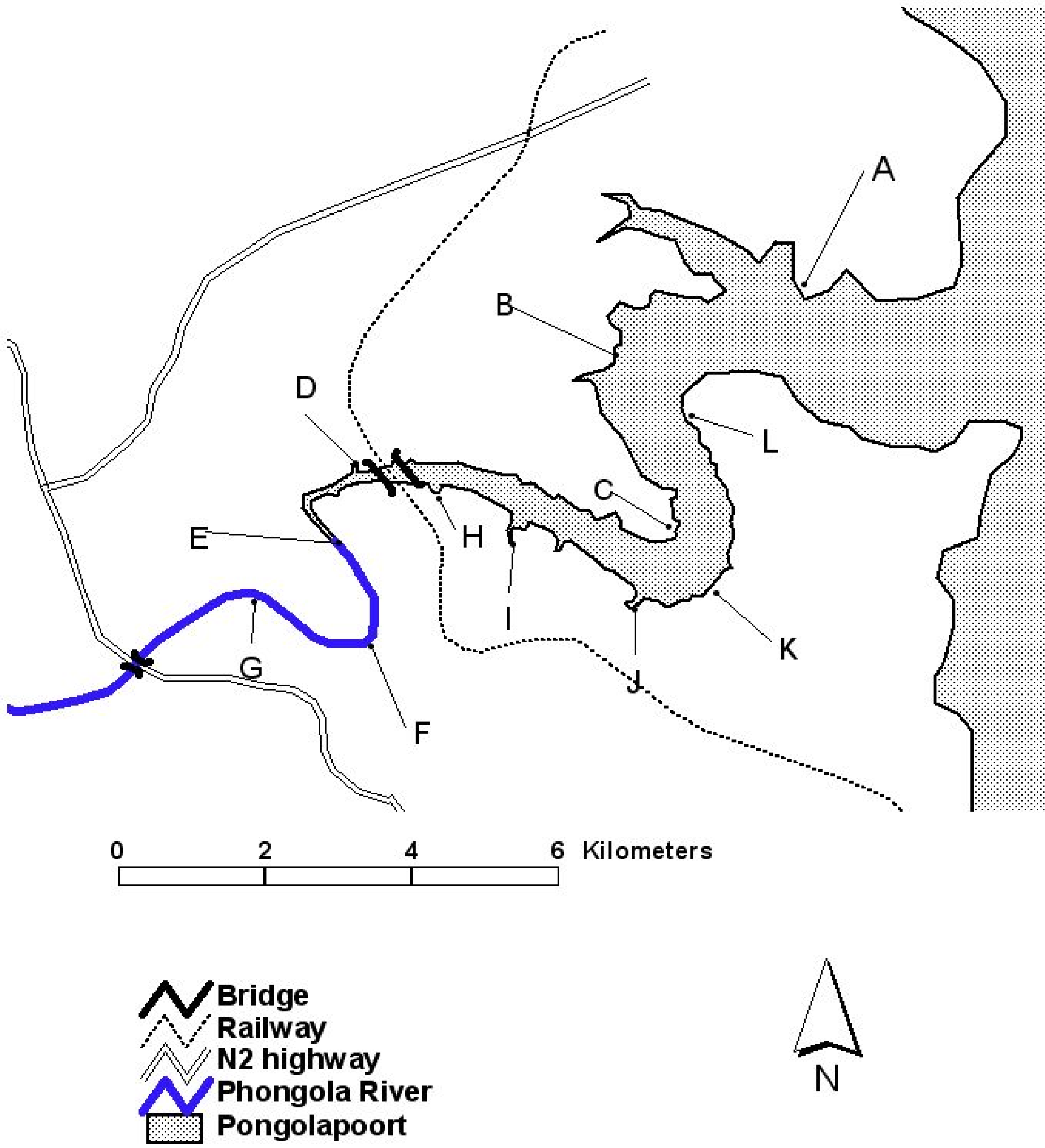
Figure 2. Localities of nest sites in the three identified nesting areas of Pongolapoort Dam in the 2009 nesting season, **a**- Croc Bay, **b**- Cliffs and **c**- Causeway Bend.

Figure 3. Nile Crocodile nest sites on cliff ledges along the inlet to the Pongolapoort Dam.

Figure 4. Female Nile Crocodile seen on the cliff ledges, laying a clutch of eggs, with no apparent attempt to dig a nest or cover the eggs after laying.

Figure 5. Raided Nile Crocodile nest by monitor lizards at Croc Bay.

Table 1. Summary of Nile Crocodile nest site characteristics at Pongolapoort Dam in 2009.



A	KZN Wildlife Camp Site	G	Causeway Bend
B	Houseboat Jetty	H	Hissing Bay
C	KZN Point	I	Croc Bay
D	Mvubu Jetty	J	Mpalane Jetty
E	Buffalo Bend	K	Inkwazi Lodge
F	Cliff Ledges	L	Cliffs End

Figure 1. North Western section of Pongolapoort Dam and inlet section.

2a.

2b

2c

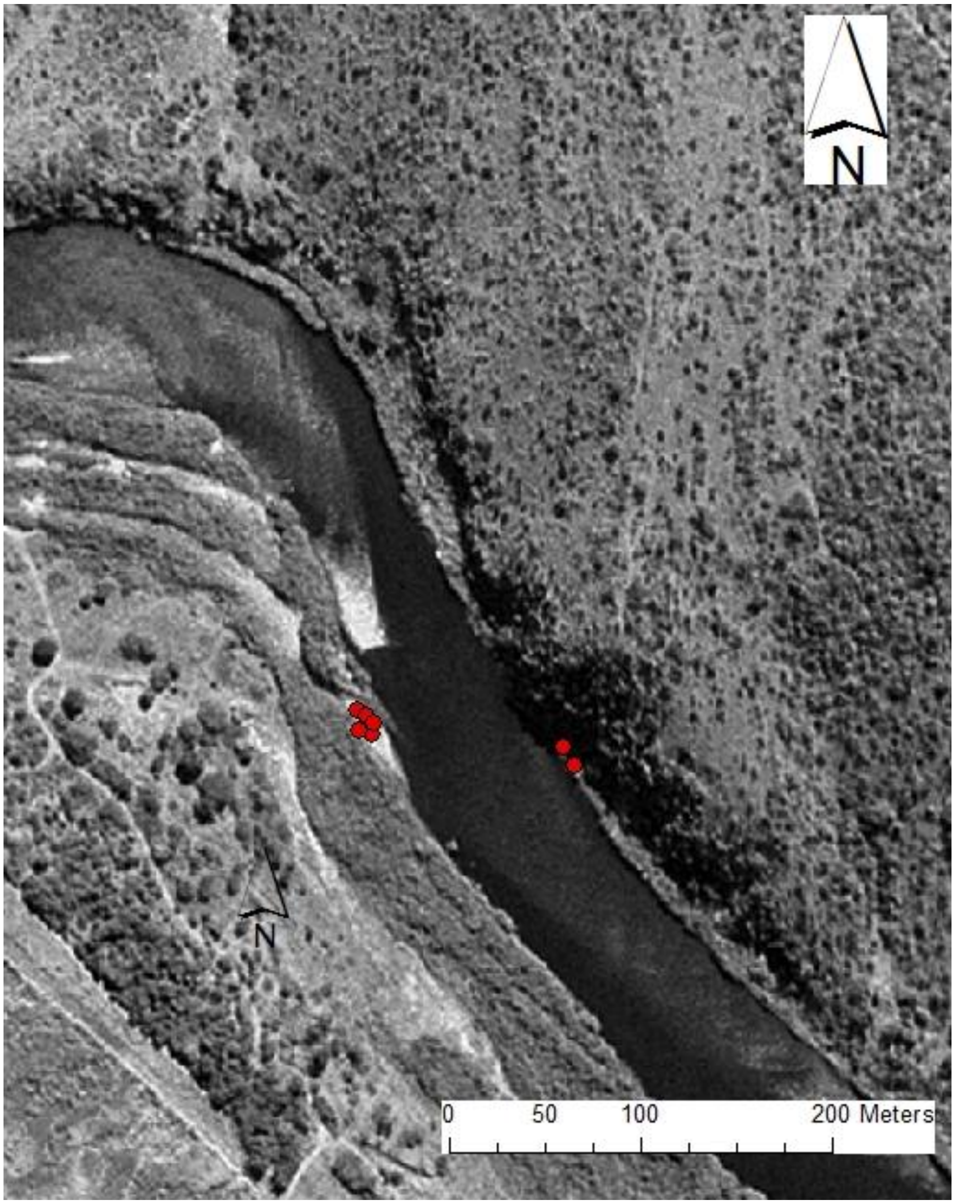


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Figure 5. Raided Nile Crocodile nest by monitor lizards at Croc Bay

Table 1. Summary of Nile Crocodile nest site characteristics at Pongolapoort Dam in 2009.

Location	Estimated female TL (m)	Distance to water (m)	Distance to nearest Crocodile (m)	Substrate	Predation prior to flooding	Presence of *Parthenium*	Presence of *Chromolaena*
Causeway Bend	3.4	6	6	Sand	No	No	No
Causeway Bend	3.2	6	4	Sand	No	No	No
Causeway Bend	3	8	4	Sand	No	No	No
Causeway Bend	3.4	25	5	Sand	No	No	No
Causeway Bend	3	28	5	Sand	No	No	No
Causeway Bend	3	3	8	Clay	?	Yes	Yes
Causeway Bend	3.1	3	8	Clay	?	Yes	Yes
Cliff Ledge	3	50	?	Clay	No	Yes	Yes
Cliff Ledge	3	4	?	Clay	?	Yes	Yes
Cliff Ledge	3.1	4	?	Clay	?	Yes	Yes
Cliff Ledge	3.3	3	4	Clay	Yes	No	No
Cliff Ledge	3.2	4	4	Clay	?	Yes	Yes
Cliff Ledge	3	4	2	Clay	Yes	Yes	Yes
Cliff Ledge	?	5	2	Clay	Yes	Yes	No
Cliff Ledge	3.2	10	8	Clay	No	Yes	No
Cliff Ledge	3	15	8	Clay	No	Yes	No
Croc Bay	3	8	30	Shale	Yes	Yes	No
Croc Bay	2.8	2	30	Shale	Yes	No	No

CHAPTER 5

Summary and Future Considerations

A number of studies have been done investigating the ecology of South Africa's major Nile Crocodile populations and assessing their current conservation status (Pooley 1969, Jacobsen 1984, Leslie 1997, Swanepoel 1999, Combrink 2004, Botha 2005). In general Nile Crocodile numbers were seen to have recovered after persecution and eradication attempts in the mid twentieth century (Ross 1998). The first decade of the twenty-first century appears gloomy for South Africa's Nile crocodiles, as they are faced with a new threat, habitat destruction. The three historically major Nile crocodile populations in South Africa, Kruger National Park, St Lucia and Ndumo Game Reserve are all currently threatened (Ashton 2010, Combrink et al. 2010, Botha et al. 2011).

Unlike the past threats of extermination through eradication programs, the current threats are somewhat more subtle and long lasting. As the water quality in the Olifants River deteriorates, as a result of pollution in the upper catchment area, there has been a crash in the aquatic ecosystem functioning with associated fish, bird and crocodile mass deaths (Steyn 2008, van Vuuren 2009a, Ashton 2010, van Vuuren 2010). This threat to South Africa's largest crocodile population has been a slow gradual build up over time and appears to have passed a threshold of recovery unless drastic measures are taken to reduce the impact that industries are having in the catchment areas. As industry on the upper Olifants catchment forms an integral part of South Africa's economy, it is very unlikely that the pollution in what is now seen as the "hardest working" river in the country will stop (Ashton 2010).

In the Isimangliso Wetland Park (including Lake St Lucia) there has been an anthropogenically forced change to the hydrology of the system. These changes in hydrology are a result of river divergence and water abstraction, with the major water source of Lake St Lucia, the Mfolozi River, now flowing directly into the sea and other feeding rivers being highly utilized by surrounding communities for agriculture, the Lake system has been placed in an artificial state of drought, with limited fresh water availability (Whitfield & Taylor 2009). This environmental stress appears to have effected both the health and reproductive potential of the St Lucia crocodile population, with studies showing a decline in nesting effort and an increase in number of emaciated crocodiles in the system (Combrink et al. 2010). The resolving of the water crisis in St Lucia seems unlikely as once again, reverting the impacts of man on the system would prove to be very costly and an inconvenience to the surrounding farming and rural communities.

Ndumo Game Reserve shows little, if any sign of reduced water quality and appears rich in natural resources. It is however these resources that appear to be threatened as the local Mbangweni community have torn down the eastern fence of NGR and taken forced occupation in the reserve (Meer 2010). This has resulted in the clearing and burning of indigenous vegetation for agricultural purposes and a significant increase in illegal poaching and gillnetting (per obs.). This disturbance in the eastern flood plain and increase in poaching is of concern, as this has resulted in a disturbance to historical nesting grounds of crocodiles with no nests recorded in this area after illegal occupation of the reserve (Calverley 2010). There has also been a significant increase in the number of crocodiles killed for traditional medicine and black magic uses (Calverley 2010). Although this situation threatens the Ndumo Game Reserve Nile

Crocodile population, it can be resolved in relatively short time, if the authorities intervene, and the system is likely to recover, unlike that of the Olifants (Calverley 2010).

In the current study the Pongolapoort Dam Nile Crocodile population was found to be well established, with a high nesting effort (Chapters 2-4). This is a significant finding when considering South Africa's current situation regarding its major Nile Crocodile populations. With a minimum population count of 273 (116 juveniles, 75 sub-adults and 82 adults, Chapter 2), the population has increased considerably after river impoundment. The impoundment also appears to have shifted the general distribution of Nile Crocodiles, with the majority of the population found in the northern and inlet sections (Chapter 3). The Phongola River which feeds into Pongolapoort Dam is used by adult crocodiles in summer, when the water level of the river rises considerably (Chapter 3). The river section also contained the main nesting areas, where some 25 nests were identified (Chapter 4). These nest sites are, however, at risk of flooding particularly infrequent flooding of the river section, as seen in 2009 which resulted in total recruitment failure (Chapter 4). The site selection of Nile Crocodile nests was also unexpected as these were found in areas seen as atypical or unfavourable nest sites, with the majority being laid in shallow clay soil (Cliff Ledges) and only 5 nests found in typical deep sandy sediment (Causeway Bend, Chapter 4). The annual fluctuation of water levels in the dam appears to be a major driving factor in many of the resident's species movement dynamics (Chapter 3). The Nile Crocodile population in Pongolapoort Dam appears to have no major threats currently (C. Rippon pers. comm., pers. obs.) and has been reproductively successful (Chapter 4). The population has increased significantly even with the ecosystem changes as a result of the impoundment of the Phongola River (Chapters 2 and 3). It appears that the Pongolapoort population has no feeder population, but the degree of movement of individual crocodiles upstream of the dam is unknown. It is important that further studies on the Pongolapoort Nile Crocodiles be conducted in order to better document their ecological dynamics and interactions with their changing environment, as well as attempted to determine any future threats to the crocodile population. There are a number of areas of concern regarding Nile Crocodiles at Pongolapoort Dam that this study identified, but was not able to investigate further and consequently recommends ongoing research..

Future considerations

Illegal gill-netting in the Pongolapoort Dam appears to be on the rise, with syndicates operating out of Jozini town (C. Rippon pers. comm.). Young men are hired to set gill-nets throughout the dam, targeting mainly bream species (*Tilapia rendally* and *Oreochromisis mozambiques*), which are then sold to communities throughout Northern Zululand (per obs.). This has not yet shown any direct negative effects on the Nile Crocodile population, however illegal operations such as this must be controlled and removed, as they run the risk of over exploiting fish stocks which can upset the ecosystem food web and ecological functioning of the dam (Kyle 1999). High densities of gill-nets have also been shown to be a direct threat to smaller crocodiles, where they can become trapped and drown (Kyle 1999). The increase in illegal activity on the dam can also result in the exploitation of other species, such the poaching of game on surrounding game farms and the killing of crocodiles for traditional medicine and black magic (McGregor 2005). Currently there are a number of police officers, local landowners and Ezemvelo KZN Wildlife honorary rangers that do regular night patrols in an attempt to intercept boats setting gill-nets, however this does not resolve the issue as the syndicate is not closed down.

A second concern and a potential threat to the Pongolapoort Dam Nile Crocodile population are the high amounts of alien invasive plant species in the system, most concerning in the major nesting areas along the inlet (Chapter 4). Species such as *Chromolaena odorata*, *Lantana camara*, and *Parthenium hysterophorus* were abundant at nesting sites and pose a threat in reducing favourable nest sites as well as potentially effecting nesting success (Chapter 4, Leslie and Spotila 2001). The exact impact of these plants on the crocodile reproductive success was not assessed and should be an aim in future studies. An additional alien invasive plant species that is prevalent in the Pongolapoort Dam is the aquatic weed *Hydrilla verticillata,* which has been a major problem plant in the United States (Madeira et al. 2007*)*. This weed appears to be a significant component shaping habitat structure and is highly utilized by fish as nursery protection (C. Rippon pers. comm.). As these weed beds appear to be a favoured habitat for smaller crocodiles (Chapter 3) further studies should investigate this and the role *Hydrilla verticillata* plays as an ecosystem component.

A country wide concern is the quality of South Africa's fresh water (Ashton 2010). Although the Phongloa River has very little industry within its catchment, there is a large amount of agricultural activity along its banks, which may be a source of pesticides and fertilizers with the potential to contaminate the river (pers. obs.). A number of fish (mainly bream) were found with an unknown skin disease, and some died, during the study (pers. obs.). However no connection was made between these observations and a potential pollutant problem. This should however be investigated further, with sediment and fish samples taken to assess the probability of bioaccumulation or contaminant build up in the system.

Objectives of future studies should also include a more detailed study into the individual movement dynamics of Nile Crocodiles in Pongolapoort Dam, focusing on various size classes, as that objective was not successful in this study. The home range and territoriality of different size classes also requires further investigation, with particular focus on the interactions at Buffalo Bend during breeding season, when crocodiles of both sex are at high densities and competing for breeding opportunities. The nest site selection and nesting female's behaviour should also be investigated with particular emphasis on the survivability of nests in a non-flood year. This will also aid in creating a more effect population viability model, able to estimate future trend in the Pongolapoort crocodile population. A more thorough survey of the main dam body should also be done, to determine whether there were any substantial clusters of crocodiles or breeding groups overlooked during this study. Aerial surveys should also be done more frequently, predominantly during the nesting season to ensure that any previously unfound nesting sites may be located. Lastly, as the crocodile population of Pongolapoort Dam appears to have developed from a relatively few individuals, genetic tests should be done, focusing on the younger animals in order to assess genetic diversity in the population. This may give insight to the connectivity of the population to other crocodile populations, such as the crocodiles found in Itala Game Reserve, upstream.

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Oil

Microwave Sample Preparation Note: XprOP-1 Rev. Date: 6/04
Category: Oils

Sample Type: Oil
Application Type: Acid Digestion
Vessel Type: 55 mL
Number of Vessels: 12
Reagents: Nitric Acid (70%)
Method Sample Type: Organic
Sample Weight: 0.5 gram

Step 1:

Acid Type	Volume
Nitric	10 mL

Heating Program: Ramp to Temperature Control

Stage	Max. Power	% Power	Ramp (min.)	Pressure (psi)	Temperature (°C)	Hold (min.)
(1)	1200 W	75	15:00	-	200	15:00

NOTE A: This procedure is a reference point for sample digestion using the CEM Microwave Sample Preparation System and may need to be modified or changed to obtain the required results on your sample.
NOTE B: Manual venting of CEM closed vessels should only be performed when wearing hand, eye and body protection and only when the vessel contents are at or below room temperature to avoid the potential for chemical burns. Always point the vent hole away from the operator and toward the back of a fume hood.
NOTE C: Power should be adjusted up or down with respect to the number of vessels. General guidelines are as follows: 8-12 vessels (50% power), 13-20 vessels (75% power), >20 vessels (100% power).
NOTE D: "Organic Method Sample Type" should be used for most sample types. Choose "Inorganic" for samples with more than 1 gram of solid material remaining at the bottom of the vessel at the end of the digest (ex leach methods). Choose "Water" for samples that are largely aqueous prior to digestion.