The distribution, conservation status and blood biochemistry of Nile crocodiles in the Olifants river system, Mpumalanga, South Africa

by

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Submitted in fulfilment of the requirements for the degree of

Philosophiae Doctor (Wildlife Management)

at the

Centre for Wildlife Management

Department of Animal and Wildlife Sciences

Faculty of Natural and Agricultural Sciences

University of Pretoria

Pretoria

November 2010

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DECLARATION

I, Petrus Johannes Botha declare that the thesis, which I hereby submit for the degree Philosophiae Doctor (Wildlife Management) at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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This work is dedicated to the people who had a special influence on my life and my work:

My wife Joyce and daughter Elzahn, the stability and support you both provided, the interest you took in my work and the encouragement to carry on every time I encountered a setback inspired me to complete this work. Thank you for understanding my passion for Nile crocodiles and allowing me the freedom and personal space to follow the direction that my life took and especially thank you for all the times you remained behind at home to ensure that life at home carried on normally while I was away doing fieldwork. Joyce, thank you for all the times you had to handle the many household emergencies from the dog being spat in the eyes by a Moçambique Spitting Cobra, to fixing household appliances, fixing the car, changing tyres on your own, but your willingness to step in on my behalf allowed me to concentrate on the work at hand with success. Elzahn, thank you for understanding, at your young age, the importance of this work to me and thank you for supporting your mother at home during all the times I was away doing fieldwork, being able to rely on you meant that I could successfully concentrate on what became a life absorbing project.

Dad, I wish I could have shared this incredible last ten years with you, but I know you know my achievements.

Mom, thank you for teaching me to always do my best and always to complete everything that I started, this gave me the determination to keep going until I had reached my goal.

I also dedicate this work to the late Douw "Swannie" Swanepoel my mentor and source of inspiration to study crocodiles. Swannie was one of the last true South African "crocodile men" who unfortunately could not finish his life's work, but his life inspired me to complete this work. Thank you Swannie.

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ABSTRACT

The outlook for Nile crocodiles in the Olifants River does not look optimistic. Since the increase in capacity of the Loskop and Flag Boshielo Dams, the crocodile population was left with no basking or nesting sites and has declined over the past 30 years. Shortly after the

Massingire Dam in Moçambique filled to full capacity an estimated 160 crocodiles died in the Olifants River Gorge, a couple of kilometres upstream from the dam. The Olifants River is acknowledged by many experts as one of the most polluted rivers in South Africa and acid mine drainage, industrial pollution and untreated sewage in the river are all contributing to the poor water quality of the river. Further, the Department of Water Affairs and Forestry acknowledge that water demand already exceeds their capacity to supply and that the situation will worsen considerably in the near future.

Aerial surveys of Nile crocodiles in the Olifants River was carried out during December 2005 and November 2009. An average total population of 714 Nile crocodiles were counted and corrected to an estimated 1140 individual crocodiles to eliminate the effects of undercounting. The Kruger National Park and specifically the area of the Olifants River Gorge was found to be one of the preferred habitat areas for crocodiles in the Olifants River as was the Flag Boshielo Dam, the area between the Blyde River and the western boundary of the Kruger National Park and the Olifants River between the Loskop Dam and the Flag Boshielo Dam. Repeated nesting in areas such as the Kruger National Park, the Flag Boshielo Dam and the Olifants River between the Loskop Dam and the Flag Boshielo Dam confirmed that these areas are critically important to the nesting success of Nile crocodiles in the Olifants River. The Elands River was confirmed as an important refuge area for Nile crocodiles in the Groblersdal-Flag Boshielo Dam area of the Olifants River. Surveys revealed an estimated total of only 15 crocodiles in the Loskop Dam and confirmed that no

crocodiles in the large (2.1 - 4.0m TL) and very large size class (>4.0m TL) are currently present in the population. Blood biochemistry results indicate that the Olifants River Nile crocodile population probably suffers from chronic inflammation (especially in the Loskop Dam and Olifants River Gorge populations), infectious disease (particularly in the Loskop Dam population but all other sites also showed elevated values), possible inadequate diet and malnutrition (especially during the pansteatitis outbreak of August/September 2008) and are suffering serious immune problems in the Olifants River Gorge. A conservation and management plan is suggested which identifies threats to the continued existence of a viable Nile crocodile population in the Olifants River.

Finally, it is suggested that the conservation status and risk of extinction of Nile crocodiles in the Olifants River be upgraded to the **Endangered** category since it currently complies to the following criteria; EN A2abce; C2a(i) published in the IUCN Red List Categories and Criteria Version 3.1 (IUCN, 2001).

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ACKNOWLEDGEMENTS

I wish to acknowledge and thank the following persons and organisations whose involvement made this research project possible:

- My wife Joyce and daughter Elzahn;
- Prof Wouter van Hoven (Centre for Wildlife Management, University of Pretoria);
- Prof Louis Guillette Jr. (Department of Zoology, University of Florida);
- Mrs Liset Swanepoel (Centre for Wildlife Management, University of Pretoria);
- Mr Kelvin Legge (Department of Water Affairs and Forestry);
- Dr Jan Myburgh (Veterinary Faculty, University of Pretoria);
- Mr Johan Eksteen (Mpumalanga Tourism and Parks Agency);
- Mr Koos de Wet (Mpumalanga Tourism and Parks Agency);
- Mr André Hoffman (Mpumalanga Tourism and Parks Agency)
- Dr Brady Barr (National Geographic Television);
- Mr Charles Oosthuizen (GIMS (Pty) Ltd);
- Dr Freek Venter (South African National Parks);
- Mr Danie Pienaar (South African National Parks);
- University of Pretoria (Post graduate bursary);
- The Koos du Plessis Bursary Fund;
- The May and Stanley Smith Bursary Fund;

- Department of Water and Environmental Affairs;
- Mpumalanga Tourism and Parks Agency;
- André Coetzee (Henley Air);
- Ané du Preez (Henley Air);
- Hein Neser (Henley Air);
- Brett Hesketh (Henley Air).

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CHAPTER 1

THE IMPORTANCE OF CROCODILIANS IN THE ECOSYSTEM

According to King and Burke (1997) the term crocodilian refers to the 23 living species of crocodile-like animals (e.g. alligators, caimans, crocodiles, gharials and false gharials) comprising the order Crocodylia. The order Crocodylia is currently arranged in three families i.e. Alligatoridae, Crocodylidae and Gavialidae (Appendix II) (King and Burke, 1997; Ross, 1998). Brochu (2003) comments that crocodilian phylogeny reveal a more complex history and that phylogenetic relationships and time of divergence of the two living gharials, the relationship among living true crocodiles and the relationships among caimans must be considered by phylogeneticists in future. The Nile crocodile is among the largest and best known of all crocodilians. It is the most widespread crocodilian of the African continent (Figure 1) and is found throughout tropical and southern Africa and Madagascar (Ross and Magnusson, 1990). African countries within its range include: Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo, Côte d'Ivoire, Democratic Republic of Congo, Egypt, Ethiopia, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Liberia, Madagascar, Malawi, Mali, Mozambique, Mauritania, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia and Zimbabwe (Ross, 1998). The historical distribution of the Nile crocodile included the Nile River delta and the Mediterranean coast from Tunisia to Syria while isolated populations are known to have existed in lakes and waterholes in the interior of Mauritania, south-eastern Algeria and north-eastern Chad in the Sahara desert (Ross and Magnusson, 1990). Two other species of crocodilian occur in Africa. They are the slender-snouted crocodile (*Crocodylus cataphractus*) and the dwarf crocodile (*Osteolaemus tetraspis*) but neither of these two species occurs in southern Africa.

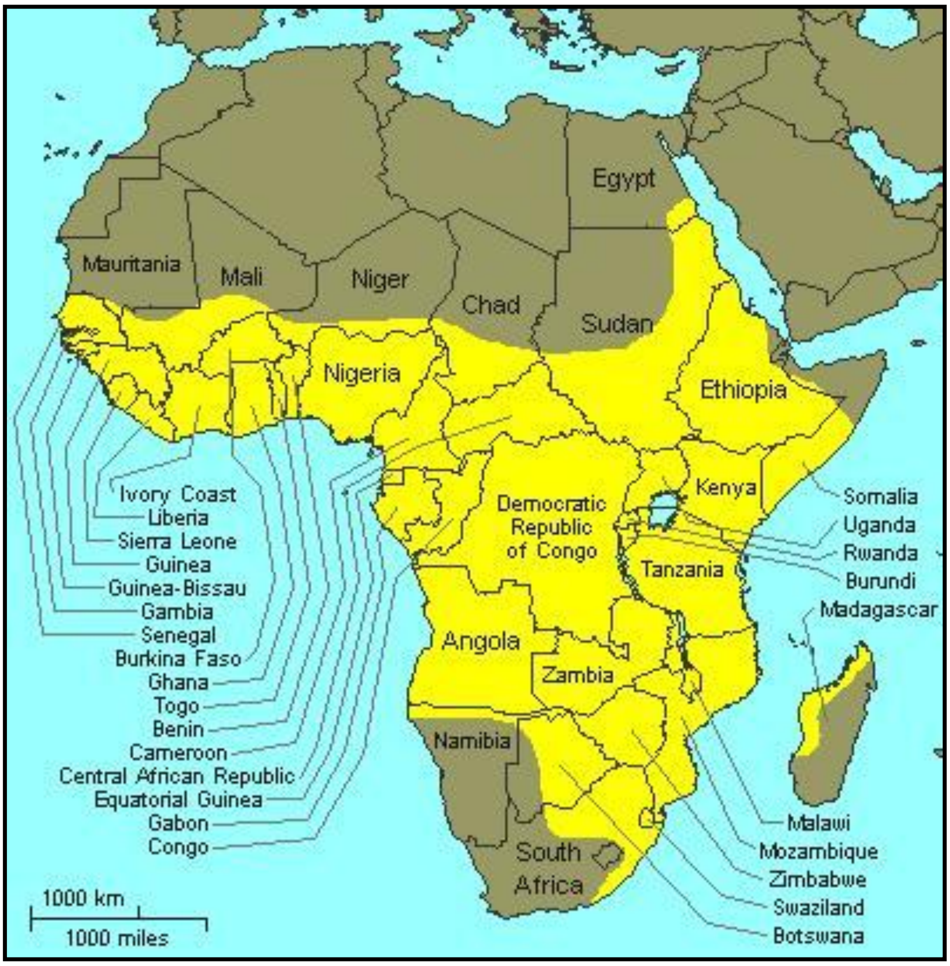

Figure 1: Distribution (in yellow) of *Crocodylus niloticus* in Africa (Britton, 2007).

The distribution of Nile crocodiles in South Africa is limited to the north-eastern parts of the country. Here they occur in the area of the former Transvaal province (now North West province, Limpopo province and Mpumalanga province) from the towns of Brits and Rust de

Winter northwards and eastwards extending into Natal (now KwaZulu-Natal province) as far as the Tugela River (Jacobsen, 1988) (Figure 2). However, the historical distribution of Nile crocodiles in South Africa occurred over a much larger area which extended as far southwards as the Transkei and the Great Fish River in the Eastern Cape (now Eastern Cape province) (Jacobsen, 1988).

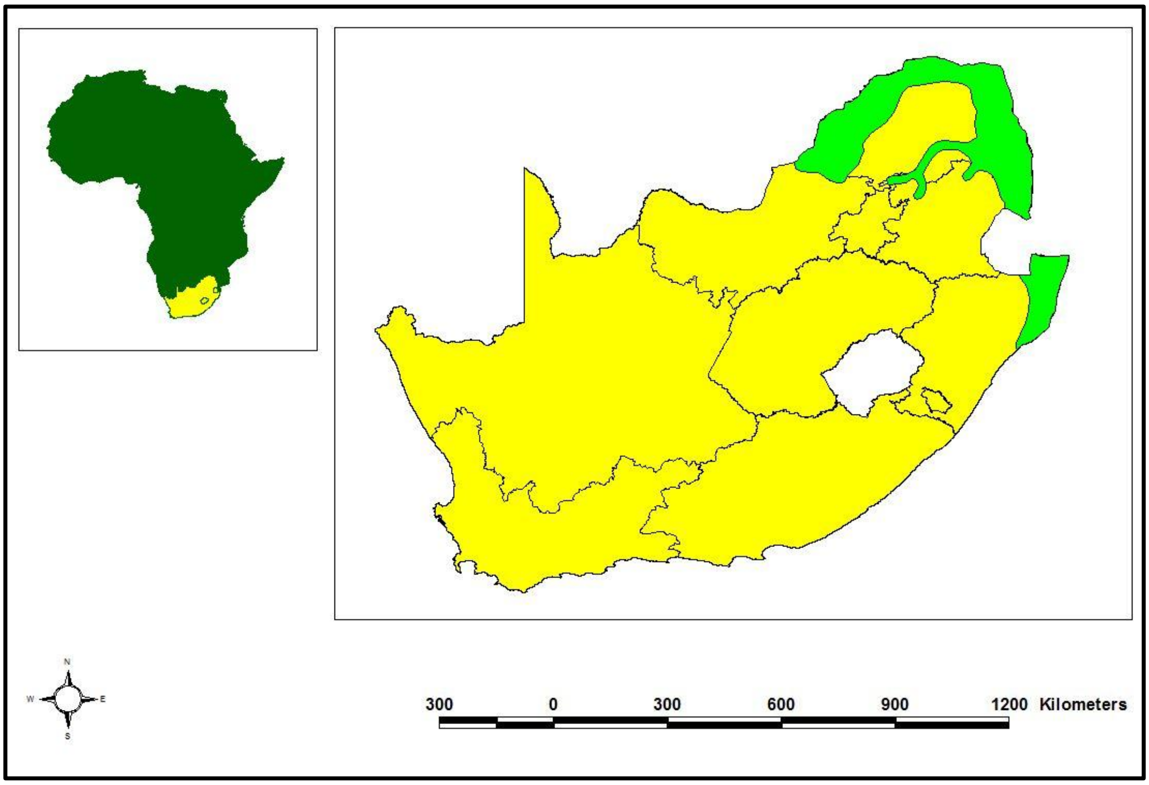

Figure 2: The distribution (in green) of *Crocodylus niloticus* in South Africa based on a map published by Jacobsen in 1988.

Crocodilians are of great antiquity with hundreds of fossil forms and three major radiations (Ross, 1998). Despite their antiquity, it is quite inappropriate to treat crocodilians as "living fossils" whose "inferiority" forced them into a marginal ecological role as amphibious predators in a world now dominated by mammals (Sues, 1990; Brochu 2003). In fact, they are highly specialized for their particular mode of life and during their long evolutionary history that spans more than 200 million years, they have undergone considerable changes (Sues, 1990).

Crocodiles have always represented the power and virility of nature to many ancient cultures from the Egyptians and Mayans to the aboriginals of Australia and New Guinea. There were, however, others to whom crocodilians were all that were terrible about nature and nothing more than a dangerous nuisance to be eliminated. Over many centuries, crocodile skin have been used by the Egyptians, the Romans, native people from Africa, America and Asia but in the late 19th and early 20th centuries crocodile skin became not only functional but also fashionable. After World War II the demand for crocodile skin sky-rocketed and several species of crocodilian almost became extinct because to most people the only good crocodile was a dead one. Many crocodilians experienced uncontrolled exploitation where sub-adult and adult crocodiles were hooked, speared, shot or otherwise killed for their skins for international trade. Many crocodile species around the world suffered serious declines in their numbers with only those species with difficult to tan skins, escaping relatively unmolested. During the 1970's once the harm caused by uncontrolled exploitation had been realised, scientists and even former hunters began to advocate harvest restrictions as a protective measure before it was too late. Improved protection and tightly controlled exploitation rescued many crocodilian populations from continued decline. Saltwater crocodiles in the Northern Territory of Australia recovered from an estimated 3000 animals in 1971 to an estimated 80 000 animals thirty years after their initial protection began (Britton, 2008). Scientists and conservationists realised that something had to be done to prevent the problem of declining crocodile populations due to harvesting pressure, repeating itself. The challenge was to change people's attitudes towards crocodiles; simply telling people that crocodiles are great for the environment was not going to be enough. Despite efforts to educate people that crocodiles are dangerous and should be treated with caution and respect, conservation efforts suffer a severe setback every time another crocodile attack on a person is reported. The removal of problem crocodiles from public and other areas where there is conflict with humans becomes the best option for conservation authorities. The reasoning behind this being that it is worth the effort to relocate ten or twenty crocodiles in order to avoid one human death, which in turn could lead to public pressure demanding the culling of a hundred (or a thousand) crocodiles.

The establishment of hundreds of crocodilian farms worldwide during the last quarter of the 20^{th} century was responsible for a fundamental change in the production of crocodilian skin (Luxmoore, 1992). Crocodile farming is defined as the rearing of crocodilians in captivity for commercial production of skins and other products or live animal sales (Luxmoore, 1992). The term "crocodile farming" encapsulates two fundamentally different activities namely "captive breeding" and "ranching". The term "captive breeding" refers to the raising in captivity of crocodilians, which originate from eggs produced by captive adults while "ranching" refers to the raising in captivity of crocodilians, which originate from wild-harvested eggs or hatchlings (MacGregor, 2006).

The shift from hunting crocodiles for their skins to captive breeding has some important impacts on the conservation of crocodilians. The first impact on the conservation of crocodilians is that captive breeding operations are likely to have limited interest in wild crocodilians because they operate as closed systems and can therefore have a particularly erosive effect on *in-situ* conservation plans (Ross, 2001). The re-investment in wild crocodilians is particularly unsupported in practise by captive breeding operations because in commercially successful operations, re-investment in wild crocodilian populations is simply not undertaken (Hutton *et al*., 2001; MacGregor, 2001, 2002; Moyle, 2003). Sustainable use of wild crocodilians is likely to be of reduced interest to successful captive breeding operations as the relative returns from crocodile habitat are much lower than those from alternative forms of land use (e.g. forestry, livestock) (Woodward, 1998; Thorbjarnarson and Velasco, 1998; Thorbjarnarson, 1999). Therefore, local farmers and landholders are much less likely to tolerate the proximity of wild crocodilians and the risks they pose to humans and livestock without some form of compensation. As a result, they are therefore much more likely to respond to incentives to transform crocodilian habitat (MacGregor, 2006) and less likely to be concerned with the conservation of crocodile habitat and restocking of dwindling wild populations. It makes sense then that without the conservation of nesting habitat, crocodile conservation will have severe difficulty in succeeding.

The second more important impact is that that countries relying primarily on captive breeding of crocodilians for production, as opposed to ranching or wild harvest, are more often than not associated with poorly known, depleted wild crocodilian populations (Luxmoore *et al.*, 1985; Ross 2001). Both the studies of Luxmoore *et al.* (1985) and Ross (2001), done more than 15 years apart, confirmed that this state of affair follows because of the poor ties these countries (e.g. Columbia, South Africa, Thailand and Mexico) often maintain with the wild resource. It is my opinion that South Africa and more specifically the northern provinces fall into exactly this category because none of the official conservation departments or parks boards in the North West province, Limpopo province or Mpumalanga province currently employ a crocodile expert specifically to monitor wild crocodile populations.

Poaching for hides is no longer regarded as a threat (Blake and Jacobsen, 1992) and the status of the Nile crocodile is relatively secure and abundant in southern and eastern Africa, where it is regarded as a species with a moderate need for the recovery of the wild population (Ross, 1998). However, Pooley warned as long ago as 1969 that crocodilians are not only threatened by over exploitation but also significantly by other human activities such as destruction or alteration of their wild habitat. Since then, Nile crocodile populations have been severely depleted especially in recent years primarily due to the reduction of riverine habitat caused by the construction of dams, weirs and irrigation schemes (Jacobsen, 1988). This, along with the flooding of nesting banks, pollution of rivers and persecution by man due to incompatibility with livestock farming has led to the fragmentation of breeding populations and a subsequent decrease in hatchling numbers (Jacobsen, 1988). It is estimated that less than 150 Chinese alligators (*Alligator sinensis*) currently exists in a tiny fraction of their former range (Britton, 2008). This drastic reduction in numbers is the direct result of thousands of hectares of former alligator habitat being converted into agricultural land needed to feed and house thousands of people (Britton, 2008). South Africa currently finds itself in a similar situation where large tracts of land are needed to feed and house thousands of people. In their efforts to survive, crocodilians destroy irrigation canals and kill valuable livestock leading to their own indiscriminate destruction.

Gardenfors *et al.* (2001) states that when the population as a whole is considered, a taxon may not have a high risk of extinction but that the probability of local extinction is generally higher in smaller populations. Similarly I believe that while Nile crocodiles are currently regarded as "vulnerable" in South Africa, local populations, such as the Olifants River population, on their own may very well be worse off especially when one takes into account that the Olifants River is one of the most polluted and threatened rivers in South Africa (Myburgh, 1999; Water Research Commission 2001; Driver *et al.*, 2004). A recent survey by Driver *et al*. (2004) has shown that 82% of all rivers in South Africa are threatened while 44% of all South African rivers are critically endangered compared to 5% critically endangered terrestrial ecosystems. Jacobsen warned in 1988 that unless the utilisation of water from rivers is rationalised the situation would become detrimental to the survival of crocodiles. Britton (2008) expresses the opinion that people who live around crocodilians need to see advantages in conserving these reptiles. He suggested that it would be difficult for these people to support conservation efforts if crocodilians have no intrinsic, aesthetic, environmental, economic, social or cultural value to them. Therefore the important question becomes what exactly is the worth of crocodiles? Leading crocodile and alligator experts feel that crocodiles express their worth to their environment in the following important ways.

1. Crocodiles maintain biodiversity of wetlands by opening up trails and maintaining deeper pools of open water which is also used by fish, other reptiles, amphibians, birds and even some mammals (Alcala and Dy-Liacco, 1990). They deepen waterholes during drought and provide microhabitats for smaller aquatic organisms (Alcala and Dy-Liacco, 1990).

2. Crocodiles encourage biodiversity by preying on the most abundant species thereby increasing resources for less abundant species. For example, crocodiles keep the Sharptooth catfish (*Clarias gariepinus*) populations under control allowing smaller fish species such as tilapia and yellow fish populations to survive (Alcala and Dy-Liacco, 1990). By preying on what is considered to be a commercially worthless fish species, crocodilians eliminate the predator of an important human economic resource (Alcala and Dy-Liacco, 1990). It is conceivable that this balance could be essential for the health of both the environment and the human population living near wetlands, rivers

and streams. A number of water borne diseases are vectored by mosquitoes and healthy fish populations that include small fish preying on mosquito larvae could have a profound influence on the spread of these diseases. Over population of an aquatic system with predatory fish like Sharptooth catfish (*C. gariepinus*) could alter the balance in the system, potentially leading to greater numbers of disease bearing mosquitoes. In terms of maintaining high species diversity and healthy ecosystems essential to human health, crocodilians are a powerful and keystone species in tropical ecosystems (Craighead, 1968; King, 1988, Alcala and Dy-Liacco, 1990; Mazotti *et al.,* 2008).

3. Crocodiles are an environmental indicator species and monitoring contaminant levels in crocodiles can provide a good indication of the level of contaminants in the aquatic ecosystem (Crain and Guillette, 1998; Guillette and Iguchi, 2003; Milnes and Guillette, 2008).

4. Crocodiles have aesthetic value and people are fascinated with these huge and powerful predators. They form part of the traditional "wildlife of Africa" which people travel around the world to see, photograph or hunt. Newsome *et al.* (2005) came to the conclusion that the crocodile has become an iconic image of visitor experience. According to the South African Tourism website, between 20 and 27% of international tourists who visited South Africa during the first three quarters of 2008 undertook natural or wildlife related activities (South African Tourism, 2008a; South African

Tourism, 2008b; South African Tourism, 2008c).

5. Crocodiles are economically important, with assets on a single well managed crocodile farm such as the Renishaw Farm on the KwaZulu-Natal south coast being worth as much as R 5 724 000 (Crookes Brothers Limited, 2008). Products such as skins and meat can generate a profit of around R 1 575 000 per year on a single well managed crocodile farm per year (Crookes Brothers Limited, 2008). Studies in Botswana have shown that the financial return on investment in crocodile farming is in fact higher than the mean economic rates of return (Barnes, 2001)

6. Crocodilians are apex predators in their habitats where they have virtually no predators of their own and reside at the top of their food chain. Food chains transfer energy, in the form of food from its source in plants to herbivores and on to carnivores and omnivores. In tropical areas, nutrients are recycled rapidly following decomposition, leaving streams and lakes nutrient poor. Research proved that crocodilians feeding on adult fish nearly doubled the amounts of calcium, magnesium phosphorus, potassium and sodium in these nutrient poor streams and lakes making it a much more productive system for hatching fish and other aquatic organisms (Alcala and Dy-Liacco, 1990; Vitt and Caldwell, 2009).

Sustainable use strategies work in some areas but the question is whether they will continue to work in the long term, especially in the unstable political climates of African states. One undeniable factor is that conservation is expensive and effective action without sufficient resources is impossible. Management programs need further development if they are to help the remaining endangered and vulnerable crocodilian populations.

The primary objective of this study is to determine the distribution, status (numbers and population structure), vulnerability (conservation status) and the extent of any population changes in wild populations of Nile crocodiles occurring in the Olifants River its tributaries and impoundments. This should give an indication of the stability of the crocodile population in the Olifants River system.

The second objective of the study is to determine whether there is any change in the general health of crocodiles, based on the levels of certain parameters in their blood biochemistry, over the gradient of the Olifants River and particularly those crocodile populations occurring in the Loskop Dam, Flag Boshielo Dam, Olifants River Gorge and the Blyderivierspoort Dam. These four populations have been chosen as research sites because they represent populations in the upper, middle and lower Olifants River with the Blyderivierspoort Dam used as control population since it is situated in a tributary of which the catchment is situated in a protected area and is therefore not subjected to the same levels of abuse as the rest of the Olifants River is.

It is known that external factors such as environmental conditions influence the normal physiology and health of ectothermic vertebrates (Campbell, 2006). Blood biochemistry profiles therefore are often used to assess the physiologic status of reptilians (Campbell, 2006). However, reptilian clinical chemistry has not achieved the same degree of critical evaluation as seen in mammals and because of the difficulty in obtaining meaningful reference intervals for each species of reptile decision levels are often used when assessing reptilians (Campbell, 2006). Due to this lack of meaningful blood biochemistry reference intervals for reptiles and Nile crocodiles in particular, studies contributing to this knowledge is of great value.

Blood samples has been analysed for: Total Serum Protein (TSP), Albumin, Globulin, Albumin/Globulin Ratio, Alanine transaminase (ALT), Alkaline phosphatise (ALP), Aspartate aminotransferase (AST), Glucose, Sodium (Na), Potassium (K), Calcium (Ca^{2+}), Total Calcium (Ca^{Total}), Magnesium (Mg), Cholesterol, Creatinine, Chloride (Cl), Uric Acid, Serum Inorganic Phosphate (SIP), Triglycyrides, Vitamin A and Vitamin E since these are the blood biochemical tests that appear to be the most useful in reptilian diagnostics (Campbell, 2006).

Results from tests of these parameters should indicate the general health of crocodiles in these populations and thus allow speculation regarding the overall health of crocodile populations in the Olifants River.

The third objective of the study is to suggest a management program/plan to guide future development of the Olifants River, utilisation of the aquatic resource, crocodile nesting and basking habitat, identify possible sustainable use programs and suggest measures to protect the wild crocodile population in the Olifants River system of South Africa.

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CHAPTER 2

DETAILED OVERVIEW OF THE OLIFANTS RIVER BASIN

LOCATION OF THE OLIFANTS RIVER

The Olifants River has its origin near the town of Breyten on the Highveld Grasslands of the Mpumalanga province in South Africa (Figure 3). The upper reaches of the river flows through the industrial and mining area near the towns of Witbank and Middelburg in Mpumalanga before it cuts through the mountains to the Loskop Dam. From here, the Olifants River meanders through the Springbok flats; passes the Strydpoort Mountains and carries on through the Drakensberg Mountains to descend over the escarpment. Finally, the Olifants River flows through the Lowveld and the Kruger National Park. Crossing the international border, the river flows into the Massingire Dam in Moçambique and eventually on to the Indian Ocean.

The Olifants River catchment covers approximately 54 570 km^2 and is subdivided in nine secondary catchments (Water Research Commission, 2001). The area covered by the catchment is equal to 4.3% of the total surface area of the whole of South Africa and 18.9% of the former Transvaal province (Kleynhans, 1992). A total run-off of approximately 1 861 million m^3 is recorded annually in the Olifants River catchment (Kleynhans, 1992). This run-off is equal to 4.1% of the annual run-off recorded for the entire South Africa (O'

Keeffe, 1986). According to the Department of Water Affairs and Forestry (2008), the total length of the Olifants River from its origin to the mouth near the town of Xai-Xai on the Indian Ocean coast of Moçambique is approximately 954.9 km.

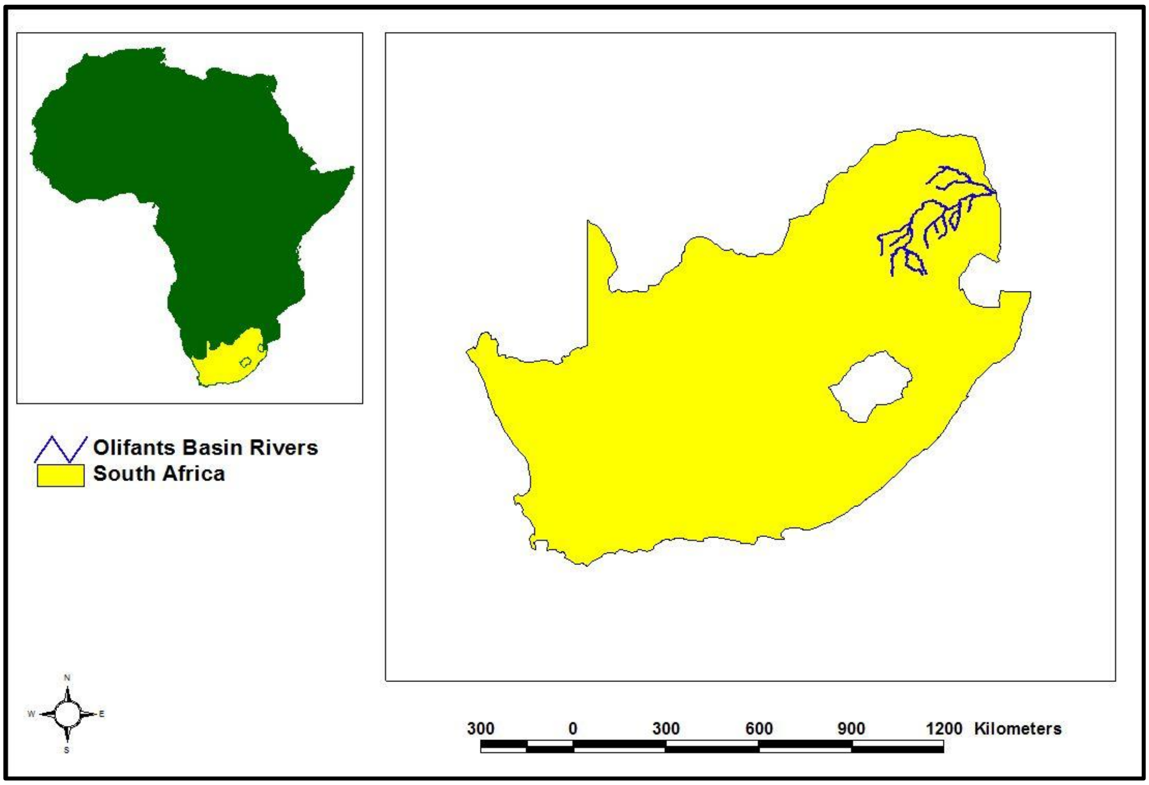

Figure 3: Locality of the Olifants River basin in South Africa.

According to Havenga (2007) of the Department of Water Affairs and Forestry, the Olifants River is currently one of the most stressed catchments in South Africa. It is estimated that the Olifants River cannot supply enough water to meet the current and future water demand from industry, residential developments, agriculture, forestry, mining and the environment. According to Havenga (2007), the river already exhibited a negative water balance in 2004 (i.e. more water was being abstracted from the river than was available) and that this negative water balance is estimated to be a staggering -242 million m^3/a in the year 2025 (Table 1).

Table 1: The calculated water balance of the Olifants River for 2004 and the projected water balance of the Olifants River for 2025 (Basson and Rossouw, 2003).

Water demand	Year 2004	Year 2025
Water available in the river	609 million m^3 L/a	630 million m^3 L/a
Water required by users	965 million m^3 L/a	1074 million m^3 L/a
Balance before water transfers	**-356 million m^3 L/a**	**-444 million m^3 L/a**
Water transferred in	172 million m^3 L/a	210 million m^3 L/a
Water transferred out	8 million m^3 L/a	7 million m^3 L/a
Balance remaining	**-192 million m^3 L/a**	**-241 million m^3 L/a**

There are more than 2500 dams in the Olifants River catchment, of which more than 90% have a volume of less than 20 000 m^3 and 30 major dams with capacities of more than 2 000 000 m^3 (Swanepoel, 1999). The Department of Water Affairs and Forestry (Basson and Rossouw, 2003) have determined that irrigation (agriculture) alone uses 58% of the available water in the Olifants River. Table 2 shows the extent and requirements of current and projected water use in the Olifants River catchment area although the figure of 3 million m^3/a in 2004 given for the forestry industry seem very low when compared to 1987 and the expected 2010 need. This could be a calculation mistake by the original author.

Table 2: Major water users in the Olifants River and projected needs for 2010 (Theron *et al.*, 1991; Basson and Rossouw, 2003).

Water users	Percentage use 2004	1987 (million m^3 L/a)	2000 (million m^3 L/a)	2010 (million m^3 L/a)
Power generation	18.76	208	181	208
Irrigation	57.72	538	557	640
Forestry	0.31	56	3	63
Domestic & Industrial	13.58	90	131	180
Mining	9.64	80	93	100
Total	**100**	**972**	**965**	**1191**

According to the Water Research Commission (2001), the Olifants River experiences extreme demand for natural resources, with associated land modification and pollution. Thus, the river ecosystems of the Olifants River are currently classified as moderately to largely modified. In the upper parts of the catchment, mining related disturbances are the main causes of impairment of river health (Water Research Commission, 2001). There is also extensive invasion by alien vegetation and alien fauna. Ecologically insensitive releases of water and sediment from storage dams are another major cause of environmental degradation downstream (Water Research Commission, 2001). This is particularly relevant in the middle and lower parts of the catchment. The Olifants River was historically a perennial river but is currently so over utilised that large parts of the river north of the Flag Boshielo Dam is currently characterised by large pools connected by narrow flows during the dry season.

The study area is defined as the Olifants River from the confluence of the Wilge River above the Loskop Dam downstream past the town of Groblersdal, on to the Flag Boshielo Dam, then past Penge and Burgersfort, onward past the confluence of the Blyde River into the Kruger National Park ending at the RSA/Moçambique international border (Figure 4).

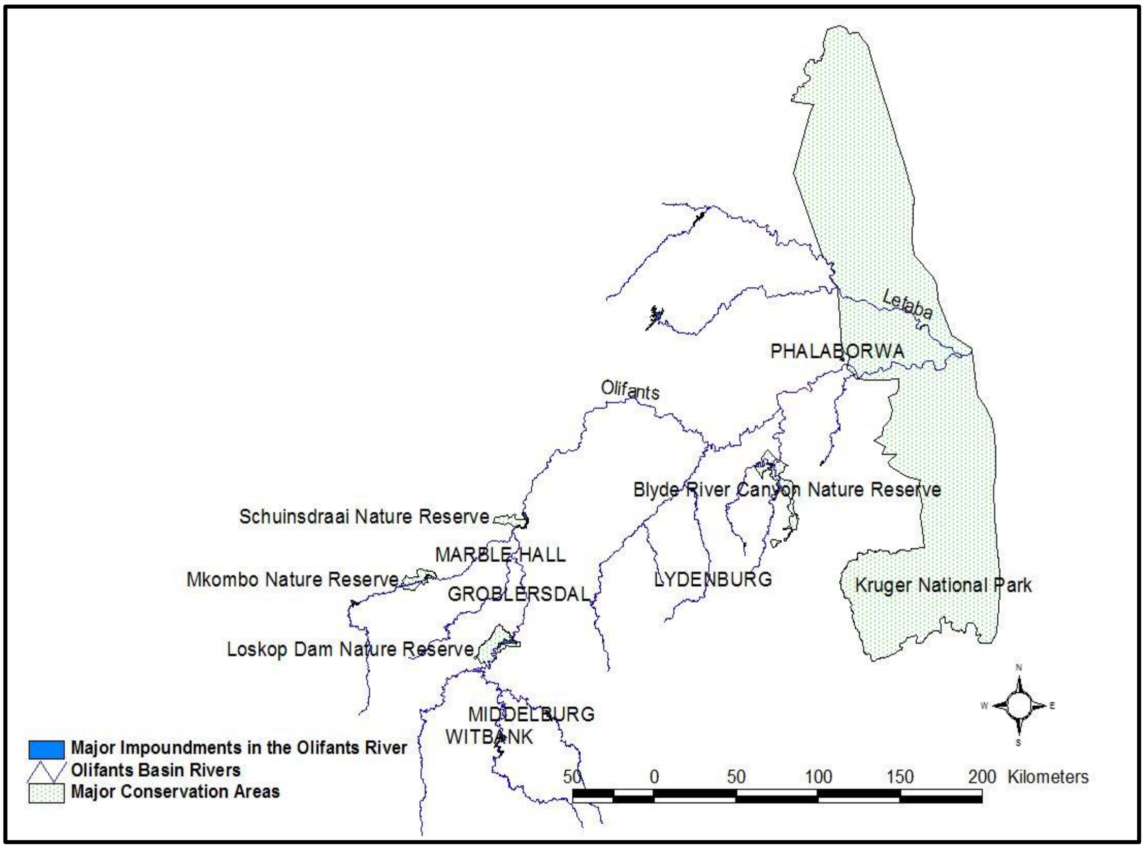

Figure 4: The Olifants River and its major tributaries in relation to major towns and conservation areas in the region.

In terms of the aerial survey, the following tributaries were included in the study area: the Steelpoort River from its confluence with the Olifants to the general area near Roossenekal, the Ohrigstad River from the town to its confluence with the Blyde River and the Blyde River from the Blyderivierspoort Dam (Swadini) to its confluence with the Olifants River. Also surveyed was the Elands River from the Flag Boshielo Dam to the Rust der Winter Dam and short distance of the Wilge River from its confluence with the Olifants River (just before the Loskop Dam). The Loskop Dam, Flag Boshielo Dam, Blyderivierspoort Dam, Rhenosterkop Dam, Rust der Winter Dam were surveyed as part of the aerial survey. It is important to note that the entire length of some of the rivers (e.g. Wilge River) was not surveyed due to the habitat clearly being unsuitable for Nile crocodiles.

Blood and urine samples of selected Nile crocodiles inhabiting the Loskop Dam, Flag Boshielo Dam and the Blyderivierspoort Dam were also collected. These three populations have been chosen as research sites because they represent populations in the upper, middle and lower Olifants River.

In 1992, Kleynhans wrote: *"There was a river ... The Olifants River. This name recalls a vision of untouched Africa with large herds of game on vast plains drinking from a huge river. Unfortunately, this idyllic vision has become only a vague dream to be replaced by a nightmarish reality."*

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TOPOGRAPHY OF THE OLIFANTS RIVER BASIN

Myburgh (1999) describes the topography of the catchment as varying from approximately 2300 metres above mean sea level in the Drakensberg, to less than 300 metres above sea level in the Lowveld of the Kruger National Park. However, in their detailed description the Water Research Commission (2001) divided the Olifants River Catchment into five ecoregions namely: Highveld, Central Highlands, Bushveld Basin, Great Escarp Mountains and Lowveld. Ecoregions will be used as the unit for comparison when discussing topography, geology, present ecological state and land-use. Biomes, bioregions and vegetation are discussed in terms of broad vegetation types.

Highveld Ecoregion:

The Olifants River originates on the Highveld Grasslands which is characterised by flat grasslands and rolling rocky zones on top of the escarpment (1500 to 1750 m above mean sea level). In this region, the river structure varies from a narrow channel with no definite riparian zone to a 20-30 m wide channel with well developed riparian habitat.

Central Highlands:

From the confluence of the Olifants and Klein-Olifants Rivers the river decreases in altitude from 1500 to 1000 m above mean sea level while it flows in a north-westerly direction until the Wilge River joins up with it upstream of the Loskop Dam. Here the river varies from a single channel to multiple channels with afforested islands and steep river banks with narrow floodplains in some areas. Rapids and pools are common as are boulders and large rocks in the riverbed. The central highlands ecoregion is also present where the Olifants River passes south of the Strydpoort Mountains foothills.

Bushveld Basin:

From the Loskop Dam the Olifants River flows through relatively flat landscape of the Bushveld Basin Ecoregion past the towns of Groblersdal and Marble Hall to the Flag Boshielo Dam (1500 to 800 m above mean sea level). The river is steep with many riffles in this ecoregion, becoming gentler with a sandy bed due to alluvial deposits.

Great Escarpment Mountains:

In this area, the Olifants River passes through the upper slopes of the Drakensberg Mountains where it meanders through the landscape at an altitude of 1000 to 2000 m above mean sea level. The riverbed is stony and between 50 and 80 m wide with deep alluvial sand and silt deposits. In some areas the river forms secondary channels, floodplains and woody islands.

Lowveld:

The Olifants and the Blyde River meanders through the Drakensberg and enters the Lowveld just before the confluence of the two rivers. This region is characterised as a lowland area with rolling plains and has a mean altitude of 200 - 600 m above mean sea level where the river flows eastward through the Kruger National Park. In the Lowveld Ecoregion, the river is a broad sandy channel changing to several channels with permanent reed-grown islands, sand banks and floodplains. Floodplains are usually elevated in relation to the riverbed.

Lebombo Uplands:

The Letaba River joins the Olifants River west of the Olifants Rest Camp in the Kruger National Park. Here a narrow gorge with towering stone walls form where the Olifants River flows through the Lebombo Mountains before it crosses the international border with Moçambique. The river is characterised in this area by an abundance of big rocks, stones and pebbles while the riparian zone alternates between narrow zones close to the stream to broader zones with sand banks.

GEOLOGY OF THE OLIFANTS RIVER BASIN (FIGURE 5)

Various authors (Louw, 1951; Kruger, 1971; van Wyk, 1983) have shown that geology has an important influence in the determination of plant communities. Although geology does play an important role in the distribution of riverine vegetation, there are several other factors that have a direct influence on the occurrence and distribution of plant species in the riparian habitat (Myburgh, 1999). Geomorphology with its associated hydrological processes such as floods, siltation, erosion, groundwater movement, fluctuations of the water table all play a critical role in the occurrence and distribution of plant species associated with the riparian zones of rivers (Myburgh, 1999).

Bedrock plays a very important role in controlling water transmission and storage in the catchment of river systems. The extent of this role of the bedrock is determined by the hydraulic conductivity and porosity of the rock matrix and by structural features such as fissures, cracks and joints (Bosch *et al.*, 1986). Variations in these properties will influence seasonal flow patterns of rivers, stormflow characteristics, subsurface flow patterns, water quality, erosion and sedimentation (Bosch *et al.*, 1986).

In general terms, the geological foundation of the Olifants River as it occurs in each ecoregion can be summarised as follows:

Highveld Ecoregion:

This region covers the area of approximately 142km in length from the source of the Olifants River near Breyten to just downstream of the Witbank Dam and is characterised by geology of the Madzaringwe Formation (Karoo Supergroup), the Loskop Formation (Transvaal Supergroup), and the Dwyka Group (Karoo Supergroup). Rock formations of this area consist of mudstone, shale and siltstone at the base overlain by coarse to fine sandstone and coal seams (Water Research Commission, 2001; Johnson *et al.*, 2006).

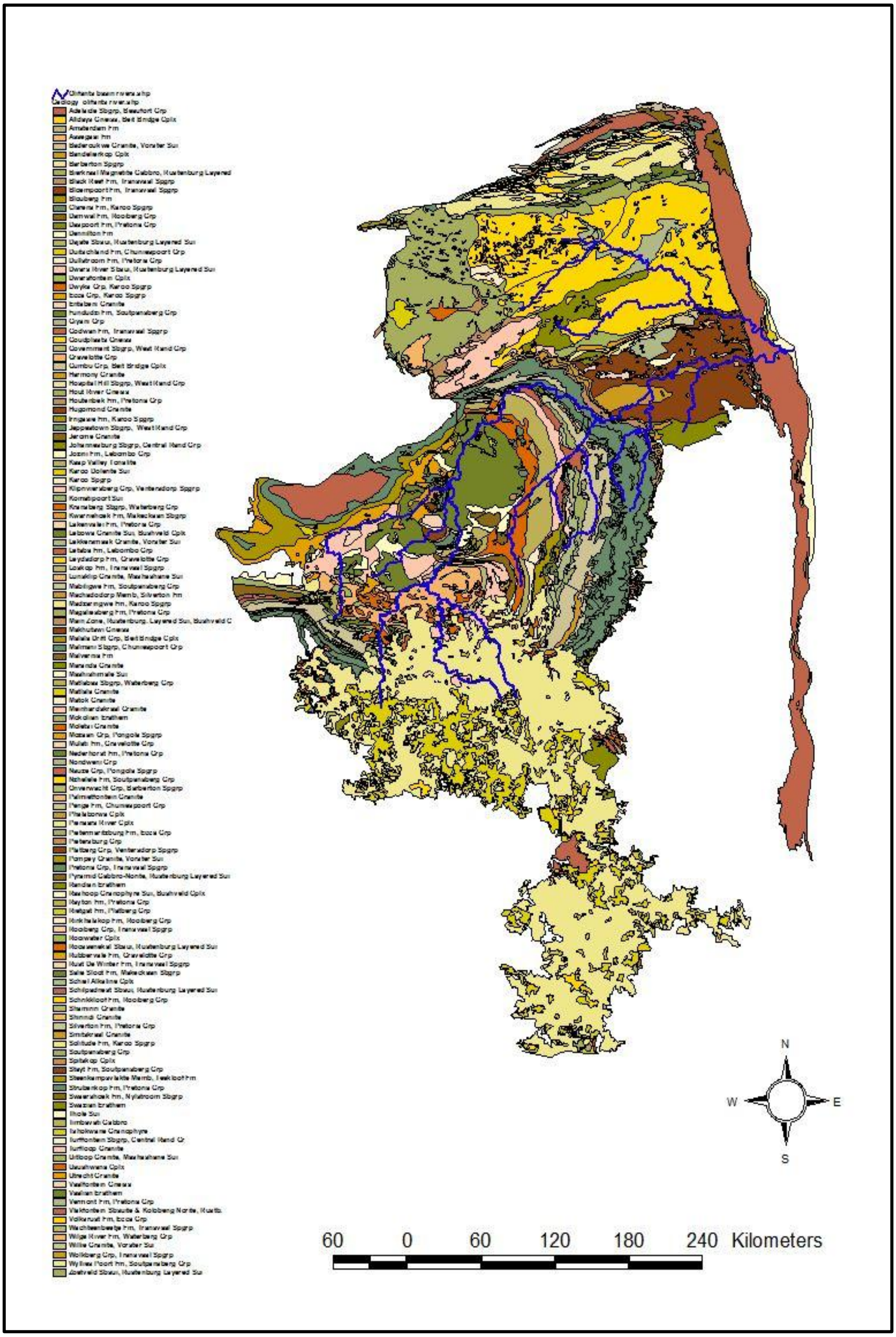

Figure 5: Broad geology of the study area showing the Olifants River superimposed in blue over the figure.

The coal seams are considered economically important and originated as peat swamps, which developed on broad alluvial plains and backswamps (Johnson *et al.,* 2006).

Central Highlands:

This region is situated in an area that can loosely be described as stretching approximately 148km in length from downstream of the Witbank Dam to just downstream of the Loskop Dam. It is characterised by geology of the Wilge River Formation (Waterberg Group) while some elements of the Pretoria Group (Lakenvalei Formation, Magaliesberg Formation, and Silverton Formation) is also present. Therefore, coarse-grained, red-bed sandstones, mudrock and conglomerates dominate the rock formations of the area (Water Research Commission, 2001). Quartzite, feldspar and conglomerates of the Rooiberg Group, Rustenburg Layered Suite (Dsjate Subsuite) and the Rashoop Granophyre Suite also occur (van der Neut *et al.,* 1991).

A further extension of the Central Highlands ecoregion is found wedged between the Bushveld Basin and the Great Escarpment Mountains ecoregions for a distance of approximately 85km of the river. This small area consists of geology of the Rustenburg Layered Suite and the Pretoria Group and Chuniespoort Group of the Transvaal Supergroup (Cawthorn *et al.,* 2006; Eriksson *et al.,* 2006). Rock types of this area are characterised by quartzitic sandstone, sandstone, quartzite, mudstone, ironstone, dolomites and asbestos deposits.

Bushveld Basin:

This region represents an area approximately 152km in length roughly from downstream of Loskop Dam to the Tuduma River downstream of the Flag Boshielo Dam. It is dominated overwhelmingly by the Rashoop Granophyre Suite and Lebowa Granite Suite subdivisions of the Bushveld Complex (Cawthorn *et al.*, 2006) with elements of the Pretoria Group also occurring in this region (Martini *et al.*, 2001). The most prominent rock types occurring in the region are: mudrock, quarzitic sandstone, ironstone, quartzite and feldspar. The Bushveld Complex is very important economically. According to Cawthorn *et al.* (2006) the Bushveld Complex contains some of the largest deposits of major mineral deposits namely the platinum group elements, chromium, vanadium, fluorite andelusite with base and precious metals including tin, copper, silver and gold as well as dimension stone (gabbro, norite and granite) (Cawthorn *et al.*, 2006).

Great Escarpment Mountains:

The Great Escarpment Mountains ecoregion is situated in an area of approximately 68km in length between the Motse River near the town of Penge to area roughly halfway between the Steelpoort and Blyde Rivers. The geology of this region consists of Black Reef Formation (Transvaal Supergroup), the Wolkberg Group, Makhutswi Gneiss and Harmony Granite (Martini *et al.*, 2001). The most prominent rock types of characterising this ecoregion are: quartzite, basalt, sandstone, mudrock quartzitic sandstone and light-grey gneiss (Eriksson *et al.*, 2006; Robb *et al.*, 2006).

Lowveld:

This area of the river stretches for a distance of approximately 186km from roughly halfway between the Steelpoort and Blyde Rivers to the Letaba River in the Kruger National Park. According to Martini *et al.* (2001), the dominant geological formations of this area are Makhutwsi Gneiss, Mulati Formation (Gravelotte Group), Harmony Granite, Clarens Formation (Karoo Supergroup) and the Letaba Formation (Lebombo Group). Rock types typically encountered in this ecoregion includes: granitic gneisses with infolded greenstone belts or greenstone belt remnants, massive quartzitic sandstones, granites and olivine rich basalts (Robb *et al.*, 2006; Johnson *et al.*, 2006, Duncan and Marsh, 2006; Brandl *et al.*, 2006).

The greenstone belts are described as early Archaean rocks and constitute the oldest preserved material on the earth's surface. These rocks are vital in deciphering the evolutionary history of the earth's crust. Although not uncommon in many parts of the world there are only two cratons known (Pilbara in Western Australia and the Kaapvaal Craton in South Africa) which have retained large tracts of relatively pristine rocks. South Africa's Kaapvaal Craton is particularly well endowed with large areas of granitoid gneisses containing a number of infolded greenstone belts or their remnants.

Lebombo Uplands:

The final 8km of the Olifants River before it crosses the international border with Moçambique is situated in the Lebombo Uplands ecoregion. This region is characterised by the Jozini Formation of the Lebombo Group (Martini *et al.*, 2001). The dominant rock type found in this region is rhyolites (Duncan and Marsh, 2006).

LANDFORMS OF THE OLIFANTS RIVER BASIN

Landforms are a map unit denoting land that can be mapped at the 1:250 000 scale over which there is a marked uniformity of climate, terrain form and soil pattern (Soil Science Society of South Africa, 2006). According to the Soil Science Society of South Africa (2006), there are five terrain morphological units or land forms commonly identified. These are: crest, scarp, midslope, footslope and valley bottom. According to this classification, the riverbanks and river system of the Olifants River is situated in the footslope and valley bottom terrain morphological units.

BIOMES AND BIOREGIONS OF THE OLIFANTS RIVER BASIN

The concept of biomes has broad-scale applicability to those who develop conservation and management strategies over large areas. A biome can be viewed as a high-level hierarchical (therefore, simplified) unit having a similar vegetation structure exposed to similar macroclimatic patterns, often linked to characteristic levels of disturbance such as grazing and fire (Mucina and Rutherford, 2006). Biomes are described by Cox and Moore (2000) as a "large-scale ecosystem". Strictly speaking the term biome includes both plant and animal communities but because of the dominant nature of vegetation cover in all terrestrial ecosystems, biomes have been based on vegetation characteristics only (Mucina and Rutherford, 2006).

A bioregion is a composite spatial terrestrial unit defined on the basis of similar biotic and physical features and processes at the regional scale (Mucina and Rutherford, 2006). Bioregions occupy the intermediate level between that of vegetation type and biome (Mucina and Rutherford, 2006).

The Olifants River catchment flows through only two biomes namely the Grassland Biome and the Savanna Biome which includes four bioregions (i.e. Mesic Highveld Grassland Bioregion, Central Bushveld Bioregion, Lowveld Bioregion and the Mopane Bioregion) and fifteen vegetation types (see table 3).

Table 3: Biomes, Bioregions and Vegetation Types of the Olifants River (after Mucina and Rutherford, 2006) in relation to ecoregions and conservation status.

Ecoregion (WRC, 2001)	Biome	Bioregion	Vegetation Type	Percentage Protected	Percentage Remaining	Conservation Status	Protected Status
Highveld	Grassland	Mesic Highveld Grassland	Soweto Highveld Grassland	0.2	52.7	Endangered	Hardly Protected
Highveld	Grassland	Mesic Highveld Grassland	Eastern Highveld Grassland	0.3	56.0	Endangered	Hardly Protected
Highveld/Central Highlands	Grassland	Mesic Highveld Grassland	Rand Highveld Grassland	0.9	58.5	Endangered	Hardly Protected
Central Highlands	Savanna	Central Bushveld	Loskop Mountain Bushveld	14.5	97.6	Least Threatened	Moderately Protected
Central Highland	Savanna	Central Bushveld	Loskop Thornveld	11.3	75.8	Vulnerable	Poorly Protected
Bushveld Basin	Savanna	Central Bushveld	Central Sandy Bushveld	2.4	75.9	Vulnerable	Poorly Protected
Bushveld Basin/Central Highlands	Savanna	Central Bushveld	Sekhukhune Plains Bushveld	0.8	74.5	Vulnerable	Hardly Protected
Great Escarpment Mountains	Savanna	Central Bushveld	Ohrigstad Mountain Bushveld	7.6	90.7	Least Threatened	Poorly Protected
Great Escarpment Mountains	Savanna	Central Bushveld	Poung Dolomite Mountain Bushveld	9.9	94.1	Least Threatened	Poorly Protected
Lowveld	Savanna	Lowveld	Granite Lowveld	17.5	79.2	Vulnerable	Moderately Protected
Lowveld	Savanna	Mopane	Lowveld Rugged Mopaneveld	34.4	80.2	Least Threatened	Well Protected
Lowveld	Savanna	Lowveld	Makuleke Sandy Bushveld	31.5	7303	Vulnerable	Well Protected
Lowveld	Savanna	Mopane	Mopane Basalt Shrubland	100.0	99.6	Least Threatened	Well Protected
Lowveld	Savanna	Lowveld	Tshokwane-Hlane Basalt Lowveld	64.4	83.5	Least Threatened	Well Protected
Lebombo Uplands	Savanna	Lowveld	Northern Lebombo Bushveld	98.8	99.8	Least Threatened	Well Protected

Grassland Biome (Figure 6):

The Grassland Biome is characterised by grasslands which are structurally simple and strongly dominated by grasses (Poaceae). The canopy cover is moisture-dependant and decreases with lower mean annual rainfall but is influenced by the amount and type of grazing and by the presence of fire (Mucina and Rutherford, 2006). Minimum temperature plays an important role in structurally distinguishing temperate grasslands from those where frost is rare (Walker, 1993). Woody species are limited to specialised niches/habitats in the Grassland Biome while forbs are also considered by Mucina and Rutherford (2006) to contribute heavily to the species richness of grasslands.

Savanna Biome (Figure 6):

Savanna usually has an herbaceous layer dominated by grass with a discontinuous or open tree layer. According to Mucina and Rutherford (2006) the term "bushveld" used in southern-Africa, seems appropriate because the woody component of savanna areas often does not form a distinct layer as in miombo vegetation to the north. The vegetation exhibits an irregular series of interlocking, low canopies with openings and little distinction between tall shrubs and small trees. Savanna is influenced by rainfall in terms of leaf retention into winter, soil moisture through the concentrated application of water to the soil by stemflow, absence of rainfall during drought when smaller trees show marked mortality and to some extent frost (Mucina and Rutherford, 2006). The strong seasonality of rainfall in the southern African savanna allow for plant material produced in the wet season to dry and burn during the dry season. Fire has long been regarded as a tool for directly influencing the woody components of savanna to control bush encroachment and to maintain trees and shrubs at an available height and acceptable state for browsing animals (Trollope, 1980).

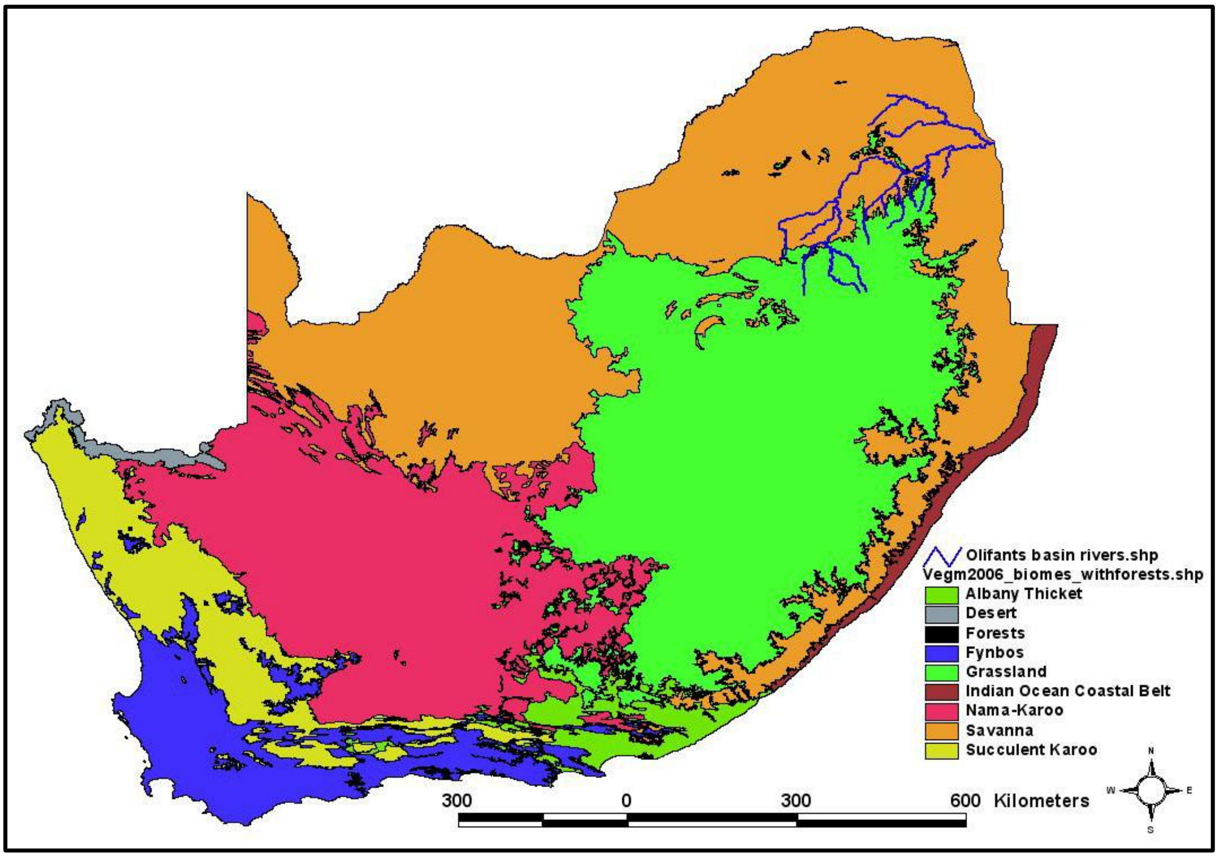

Figure 6: Biomes of South Africa showing the Olifants River superimposed in blue over the north-east of the country.

Mesic Highveld Grassland Bioregion:

There are four bioregions in the Grassland biome and the Mesic Highveld Grassland Bioregion is the largest and has the highest number of vegetation types. It is found mainly in the high precipitation parts of the Highveld and extends northwards along the eastern escarpment and includes bushveld summit grasslands (Mucina and Rutherford, 2006). The

Olifants River flows through three vegetation types of this bioregion namely; Soweto Highveld Grassland, Eastern Highveld Grassland and Rand Highveld Grassland (Table 3; Figure 7).

Central Bushveld Bioregion:

The Savanna Biome contains six bioregions of which three is crossed by the Olifants River. The Central Bushveld Bioregion has the highest number of vegetation types and covers most of the high-lying plateau west of the main escarpment from the Magaliesberg in the south to the Soutpansberg in the north (Mucina and Rutherford, 2006). In this bioregion, the Olifants River flows through six vegetation types namely; Loskop Mountain Bushveld, Loskop Thornveld, Central Sandy Bushveld, Ohrigstad Mountain Bushveld and the Poung Dolomite Mountain Bushveld (Table 3; Figure 7).

Lowveld Bioregion:

The Lowveld Bioregion extends from the eastern foot of the Soutpansberg southwards along the base and lower slopes of the escarpment through the lower parts of Swaziland to the low-lying areas of Zululand in KwaZulu-Natal (Mucina and Rutherford, 2006). In this bioregion, the Olifants River flows through four vegetation types namely; Granite Lowveld, Makuleke Sandy Bushveld, Tshokwane-Hlane Basalt Lowveld and Northern Lebombo Bushveld (Table 3; Figure 7).

Mopane Bioregion:

The Mopane bioregion has the smallest area of the bioregions in the Savanna Biome and lies at a relatively low altitude north of the Soutpansberg and north-eastern flats of the Limpopo province (Mucina and Rutherford, 2006). The Olifants River flows through two vegetation types of the Mopane Bioregion, namely the Lowveld Rugged Mopaneveld and the Mopane Basalt Shrubland (Table 3; Figure 7).

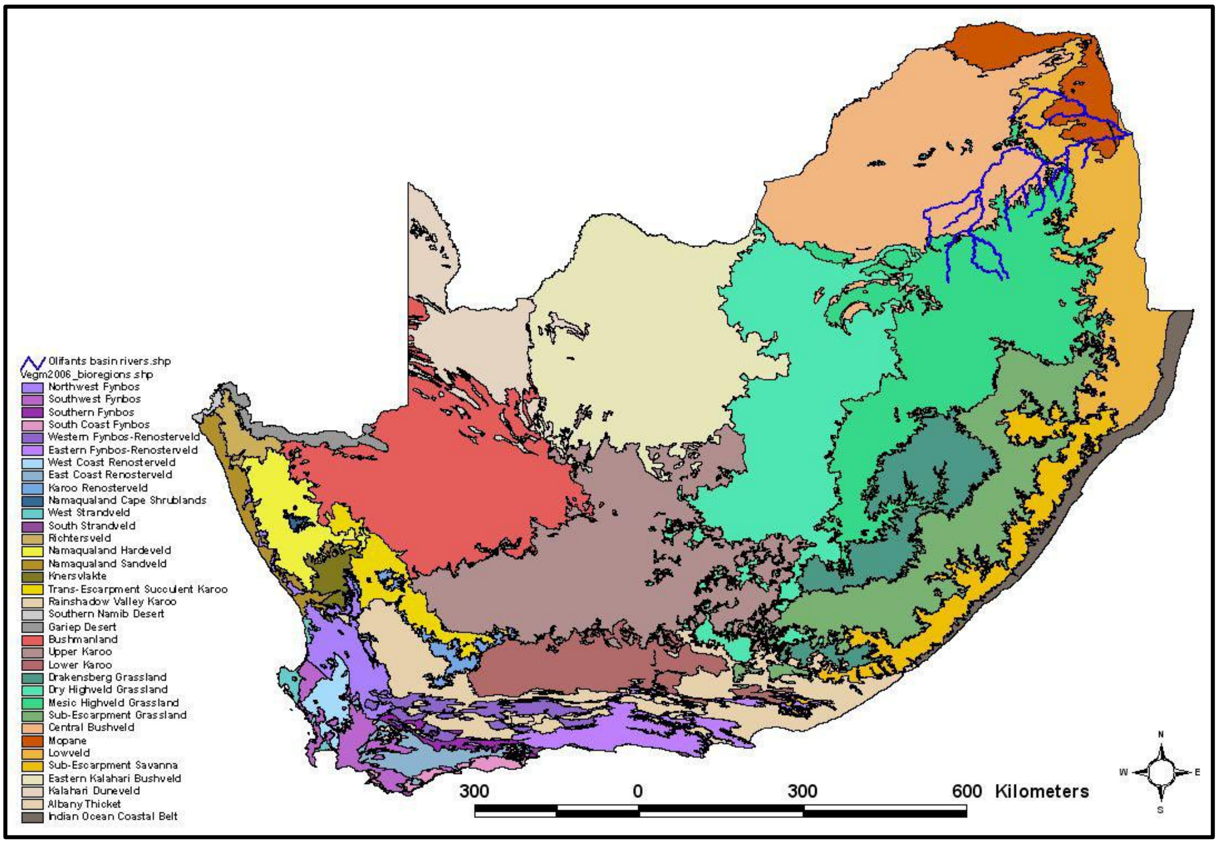

Figure 7: Bioregions of South Africa showing the Olifants River superimposed in blue over the north-east of the country.

VEGETATION TYPES OF THE OLIFANTS RIVER BASIN (FIGURE 8)

The concept of veld types was defined by Acocks in 1953 when he wrote a veld type could be defined as a unit of vegetation whose range of variation is small enough to permit the whole of it to have the same agricultural potentialities. However, Mucina and Rutherford (2006) defined the basic map unit, referred to as vegetation units, used for mapping the vegetation of South Africa, Lesotho and Swaziland as *"a complex of plant communities ecologically and historically (both in spatial and temporal terms) occupying habitat complexes at the landscape scale".*

The Olifants River flows through fifteen vegetation types as described by Mucina and Rutherford (2006). These are discussed below in order of occurrence from the river's origin to where it crosses the international border with Moçambique.

<u>Soweto Highveld Grassland:</u>

This vegetation type occurs at altitudes of 1420 - 1760 m above mean sea level on the gently to moderately undulating landscape of the Highveld plateau which characterised by short to medium-high tufted grassland (Mucina and Rutherford, 2006). This vegetation type is dominated almost entirely by *Andropogon appendiculatus, Brachiaria serrata, Cymbopogon pospischilii, Cynodon dactylon, Elionurus muticus, Eragrostis capensis, E. chloromelas, E. curvula, E. plana, E. planiculmis, E. racemosa, Heteropogon contortus,* *Hyparrhenia hirta, Setaria nigrirostris, S. sphacelata, Themeda triandra, Tristachya leucothrix* and *Hermania depressa* (Mucina and Rutherford, 2006). The continuous grassland cover is only interrupted by small scattered wetlands, narrow alluvial streams, pans and occasional ridges or rocky outcrops.

Mucina and Rutherford (2006) describe this vegetation type as endangered and hardly protected in South Africa. They estimate that only 52.7% of the vegetation type remains intact with only 0.2% being protected in provincial nature reserves and private conservation areas. Soweto Highveld Grassland is threatened by cultivation, urban sprawl, mining, road building and flooding by dams (Mucina and Rutherford, 2006).

Eastern Highveld Grassland:

This vegetation type occurs at altitudes of 1520 - 1780 m above mean sea level but also as low as 1300 above mean sea level on slightly to moderately undulating plains including low hills and pan depressions (Mucina and Rutherford, 2006). The vegetation is characterised by short dense grassland dominated by *Aristida aeguiglumis, A. congesta, A. junciformis subsp. galpinii, Brachiaria serrata, Cynodon dactylon, Digitaria monodactyla, D. tricholaenoides, Elionurus muticus, Eragrostis chloromelas, E. curvula, E. plana, E. racemosa, E. sclerantha, Heteropogon contortus, Loudetia simplex, Microchloa caffra, Monocymbium ceresiiforme, Setaria sphacelata, Sporobolus africanus, S. pectinatus, Themeda triandra,* *Trachypogon spicatus*, *Tristachya leucothrix*, *T. rehmannii*, *Berkheya setifera*, *Haplocarpha scaposa*, *Justicia anagalloides* and *Pelargonium luridum* (Mucina and Rutherford, 2006).

Mucina and Rutherford (2006) describe this vegetation type as endangered and hardly protected in South Africa. They estimate that only 56.0% of the vegetation type remains intact with only 0.3% being protected in provincial nature reserves and private conservation areas. Eastern Highveld Grassland is threatened by cultivation, plantations, urbanisation and flooding by dams to the extent that roughly 44% of the vegetation type is already transformed (Mucina and Rutherford, 2006).

Rand Highveld Grassland:

This vegetation type occurs at altitudes of 1300 - 1635 m above mean sea level but reaches 1760 above mean sea level in places where this vegetation type is situated in a highly variable landscape with extensive sloping plains and a series of low ridges (Mucina and Rutherford, 2006). The vegetation is described as wiry sour grassland alternating with low sour shrub land on rocky outcrops and steeper slopes and the dominant grasses, herbs and shrubs on the plains are *Ctenium concinnum*, *Cynodon dactylon*, *Digitaria monodactyla*, *Diheteropogon amplectens*, *Eragrostis chloromelas*, *Heteropogon contortus*, *Loudetia simplex*, *Monocymbium ceresiiforme*, *Panicum natalense*, *Schizachyrium sanguineum*, *Setaria sphacelata*, *Themeda triandra*, *Trachypogon spicatus*, *Tristachya biseriata*, *T. rehmannii*, *Acanthospermum australe*, *Justicia anagalloides*, *Pollichia campestris* and *Lopholaena* *corrifolia* (Mucina and Rutherford, 2006). The following species are considered to be endemic to this vegetation type: *Melanospermum rudolfii, Polygala spicata, Anacampseros subnuda* subsp. *lubbersii, Frithia humilis, Crassula arborescens* subsp. *undulatifolia, Delosperma purpureum, Encephalartos lanatus* and *E. middelburgensis* (Mucina and Rutherford, 2006).

This vegetation type is described by Mucina and Rutherford (2006) as endangered and hardly protected in South Africa. They estimate that only 58.5% of Rand Highveld Grassland remains intact with only 0.9% being protected in provincial nature reserves and private conservation areas and list cultivation, plantations, urbanisation and flooding by dams as the major threats to this vegetation types.

Loskop Mountain Bushveld:

This vegetation type occurs at altitudes of 1050 - 1500 m above mean sea level along low mountains and ridges with open tree savanna (Mucina and Rutherford, 2006).. Dominant species in this vegetation type are: *Acacia burkei, A. caffra, Burkea africana, Combretum apiculatum, C. zeyheri, Croton gratissimus, Faurea saligna, Heteropyxis natalensis, Ochna pulchra, Protea caffra, Pseudolachnostylis maprouneifolia, Terminalia sericea, Diplorhynchus condylocarpon, Elephantorrhiza burkei, Rhus zeyheri, Aristida transvaalensis, Loudetia simplex,* and *Trachypogon spicatus* (Mucina and Rutherford, 2006). The following species are considered to be endemic to this vegetation type: *Gladiolus pole-evansii* and *Haworthia koelmaniorum* (Mucina and Rutherford, 2006).

Mucina and Rutherford (2006) describe this vegetation type as least threatened but moderately protected probably because about 15% is protected in provincial nature reserves. They estimate that 97.6% of Loskop Mountain Bushveld remains intact with less than 3% of the vegetation type being transformed by cultivation and urbanisation (Mucina and Rutherford, 2006).

Loskop Thornveld:

This vegetation type occurs at altitudes of 950 - 1300 m above mean sea level in the valleys and plains of the upper Olifants River catchment and is described by Mucina and Rutherford (2006) as open, deciduous to semi deciduous, tall thorny woodland usually dominated by *Acacia* species. Dominant vegetation in these areas are *Acacia burkei, Sclerocarya birrea subsp. caffra, Acacia gerrardii, A. sieberiana var. woodii, Euclea crispa subsp. crispa, Rhus pyroides var. pyroides, Clematis brachiata, Rhynchosia minima, Bothriochloa insculpta, Digitaria argyrograpta* and *Themeda triandra* (Mucina and Rutherford, 2006)

Mucina and Rutherford (2006) describe this vegetation type as vulnerable and poorly protected in South Africa. They estimate that roughly 75.8% of the vegetation type remains intact with 11.3% being protected in provincial nature reserves and private conservation areas. Loskop Thornveld is mainly threatened by the cultivation of agricultural crops requiring irrigation. Crops planted in this vegetation type include maize, cotton, citrus, grapes and wheat with a dramatic increase in the establishment of vineyards (Mucina and Rutherford, 2006). Old lands are often invaded by *Acacia tortilis, Hyparrhenia hirta, Cereus jamacaru, Opuntia ficus-indica, Melia azedarach, Lantana camara* and *Solanum seaforthianum*.

__Central Sandy Bushveld:__

This vegetation type occurs at altitudes of 850 - 1450 m above mean sea level in low undulating areas, between mountains on sandy plains and catenas where the vegetation is dominated by T*erminalia sericea* and *Burkea africana* woodland on deep sandy soils, and low broadleaved *Combretum* woodland on shallow rocky or gravely soils (Mucina and Rutherford, 2006). Dominant species in this vegetation type are: *Acacia burkei, Burkea africana, Combretum apiculatum, C. zeyheri, Terminalia sericea, Agathisanthemum bojeri, Indigofera filipes, Dichapetalum cymosum, Brachiaria nigropedata, Eragrostis pallens, E. rigidior, Hyerthelia dissolute, Panicum maximum, Perotis patens* and *Dicerocaryum senecioides* (Mucina and Rutherford, 2006).

This vegetation type is vulnerable and poorly protected in South Africa (Mucina and Rutherford, 2006). It is estimated that roughly 75.9% of this vegetation type remains intact with only 2.4% protected in provincial nature reserves and private conservation areas.

Approximately 24% of Central Sandy Bushveld is transformed. Much of this vegetation type in the broad arc south of the Springbok flats is heavily populated by rural communities. Several alien plant species have invaded the area. Among these are: *Cereus jamacaru, Eucalyptus sp., Lantana camara, Melia azedarach, Opuntia ficus-indica,* and *Sesbania punicea*.

Sekhukhune Plains Bushveld:

This vegetation type occurs at altitudes of 700 - 1100 m above mean sea level on semi-arid plains and is characterised by open valleys between chains of hills and small mountains running parallel to the escarpment with predominantly short open to closed thornveld vegetation, with an abundance of *Aloe* spp. (Mucina and Rutherford, 2006). Dominant species in this vegetation type are: *Acacia erioloba, Philenoptera violacea, Acacia mellifera subsp. detinens, A. nilotica, A. tortilis* subsp. *heteracantha, Boscia foetida* subsp. *rehmanniana, Euphorbia tirucalli, Rhus engleri, Felicia clavipilosa* subsp. *transvaalensis, Seddera suffruticosa, Aloe cryptopoda, Euphorbia enormis, Kleinia longiflora, Cenchrus ciliaris, Enneapogon cenchroides, Panicum maximum, Urochloa mosambicensis, Becium filamentosum* and *Phyllanthus maderaspatensis* (Mucina and Rutherford, 2006).

Mucina and Rutherford (2006) describe this vegetation type as vulnerable and hardly protected in South Africa. It is estimated that 74.5% of this vegetation type remains intact with only 0.8% protected in provincial nature reserves and private conservation areas.

According to Mucina and Rutherford (2006), 25% of Sekhukhune Plains Bushveld is transformed and is mainly threatened by dry-land subsistence cultivation and chrome and platinum mining with its associated urbanisation. Much of the remaining vegetation is threatened by unsustainable harvesting and utilisation resulting in widespread high levels of erosion and donga formation. Several alien plant species have invaded the area. Among these are: *Caesalpinia decapetala*, *Lantana camara*, *Melia azedarach*, *Nicotiana glauca*, *Opuntia* sp., *Verbesina encelioides* and *Xanthium strumarium*.

Ohrigstad Mountain Bushveld:

This vegetation type occurs at altitudes of 500 - 1400 m above mean sea level and is characterised by open to dense woody layer with herbaceous shrubs and open grass layer on moderate to steep slopes of mountainsides and deeply incised valleys (Mucina and Rutherford, 2006). Dominant vegetation includes: *Sclerocarya birrea* subsp. *caffra*, *Acacia exuvialis, A. karroo, A. tortilis* subsp. *heteracantha, Combretum apiculatum, C. molle, Kirkia wilmsii, Euphorbia tirucalli, Dichrostachys cinerea, Grewia vernicosa, Psiadia punctulata, Aloe castanea, A. fosteri, Pterolobium stellatum,* and *Loudetia simplex* (Mucina and Rutherford, 2006). The following species are considered to be endemic to this vegetation type: *Encephalartos cupidus, Asparagus lynnetteae, Rhoicissus laetans* and *Ceropegia distincta* subsp. *verruculosa* (Mucina and Rutherford, 2006).

According to Mucina and Rutherford (2006) this vegetation type is regarded as least threatened but poorly protected in South Africa. They estimate that roughly 90.7% of the vegetation type remains intact while only 7.6% is being protected in provincial nature reserves and private conservation areas. According to Mucina and Rutherford (2006), Ohrigstad Mountain Bushveld is probably about 9% transformed and is mainly threatened by cultivation. Several alien plant species have invaded these areas with the most common being *Melia azedarach*, *Caesalpinia decapetala* and *Nicotiana glauca.*

<u>Poung Dolomite Mountain Bushveld:</u>

This vegetation type occurs at altitudes of 600 - 1500 m above mean sea level extending to about 1600 above mean sea level and is characterised by open to closed woodland with well developed shrub layers occurring on low to high mountain slopes (Mucina and Rutherford, 2006). Dominant vegetation includes *Hippobromus paucifloris*, *Kirkia wilmsii*, *Seemannaralia gerrardii*, *Asparagus intricatus*, *Plectranthus xerophilus*, *Brewsia biflora*, *Brachiaria serrata*, *Eragrostis lehmanniana*, *Loudetia simplex*, *Melinis repens*, *Panicum maximum*, *Themeda triandra* and *Cheilanthes dolomitica* (Mucina and Rutherford, 2006). The following species are considered to be endemic to this vegetation type: *Encephalartos dolomiticus*, *E. inopinus*, *Melhania integra*, *Delosperma vandermerwei*, *Euphorbia grandialata*, *Barleria dolomiticola*, *Lotononis pariflora*, *Brachystelma minor*, *B. parvulum*, *Gladiolus dolomiticus*, *G. pavonia*, *Ledebouria dolomiticola*, *Aloe branddraaiensis*, *A.*

monotropa, *Gasteria batesiana* var. *dolomitica*, *Huernia blyderiverensis* and *Plectranthus dolomiticus* (Mucina and Rutherford, 2006).

Mucina and Rutherford (2006) describe this vegetation type as least threatened but poorly protected in South Africa. They estimate that roughly 94.1% of the vegetation type remains intact while 9.9% is being protected in provincial nature reserves and private conservation areas. According to Mucina and Rutherford (2006), Poung Dolomite Mountain Bushveld is probably about 6% transformed and is mainly threatened by cultivation.

Granite Lowveld:

This vegetation type occurs at altitudes of 250 - 700 m above mean sea level and is characterised by tall shrubland with few trees to moderately dense low woodland on deep sandy uplands (Mucina and Rutherford, 2006). Dominant species in this vegetation type are: *Acacia nigrescens*, *Sclerocarya birrea subsp. caffra*, *Acacia nilotica*, *Albizia harveyi*, *Combretum apiculatum*, *C. imberbe*, *C. zeyheri*, *Ficus stuhlmannii*, *Peltophorum africanum*, *Pterocarpus rotundifolius*, *Terminalia sericea*, *Combretum hereroense*, *Dichrostachys cinerea*, *Euclea divinorum*, *Strychnos madagascariensis*, *Brachiaria nigropedata*, *Digitaria eriantha* subsp. *eriantha*, *Eragrostis rigidior*, *Melinis repens*, *Panicum maximum* and *Pogonarthria squarrosa* (Mucina and Rutherford, 2006).

Mucina and Rutherford (2006) describe this vegetation type as vulnerable but moderately protected in South Africa. They estimate that roughly 79.2% of the vegetation type remains intact with about 17.5% being protected in provincial nature reserves and private conservation areas. According to Mucina and Rutherford (2006), Granite Lowveld is probably more than 20% transformed and is mainly threatened by cultivation and settlement development.

Lowveld Rugged Mopaneveld:

This vegetation type occurs at altitudes of 250 - 550 m above mean sea level and is characterised by irregular plains with sometimes steep slopes and a number of prominent hills (Mucina and Rutherford, 2006). Dominant species in this vegetation type are: *Acacia nigrescens, Sclerocarya birrea subsp. caffra, Colophospermum mopane, Combretum apiculatum, Terminalia prunioides, Aristida congesta, Enneapogon cenchroides, Melinis repens* and *Sporobolus panicoides* (Mucina and Rutherford 2006).

According to Mucina and Rutherford (2006) this vegetation type is regarded as least threatened but well protected in South. They estimate that roughly 80.2% of the vegetation type remains intact while 34.4% is being protected mostly in the Kruger National Park but also in some provincial nature reserves and private conservation areas. Lowveld Rugged Mopaneveld is probably about 20% transformed mainly through high density rural settlements and the associated urban sprawl and agricultural activities (Mucina and Rutherford, 2006).

Makuleke Sandy Bushveld:

This vegetation type occurs at altitudes of 300 - 700 m above mean sea level and is characterised by variable landscapes from low mountains to extremely irregular plains to hills while tree savanna occurs on the deep sands and stony soils (Mucina and Rutherford, 2006).

Dominant species in this vegetation type are: *Burkea africana, Kirkia acuminata, Pseudolachnostylis maprouneifolia, Terminalia sericea, Pteleopsis myrtifolia, Andropogon gayanus, Digitaria eriantha* subsp. *pentzii* and *Panicum maximum* (Mucina and Rutherford, 2006). The following species are considered to be endemic to this vegetation type: *Euphorbia rowlandii* and *Ceratotheca saxicola* (Mucina and Rutherford, 2006).

This vegetation type is described as vulnerable but well protected in South Africa with roughly 73.3% of the vegetation type remaining intact and 31.5% protected mostly in the Kruger National Park but also in some provincial nature reserves and private conservation areas (Mucina and Rutherford, 2006). It is estimated that 27% of Makuleke Sandy Bushveld is transformed mainly through cultivation.

Mopane Basalt Shrubland:

This vegetation type occurs at altitudes of 200 - 450 m above mean sea level and is characterised by plains and slightly undulating plains with medium to low shrubs dominated overwhelmingly by multi-stemmed *Colophospermum mopane* (Mucina and Rutherford, 2006). Dominant species in this vegetation type are: *Acacia nigrescens, Philenoptera violacea, Sclerocarya birrea* subsp. *caffra* and *Colophospermum mopane* (Mucina and Rutherford, 2006).

Mucina and Rutherford (2006) describe this vegetation type as least threatened and well protected in South Africa. They estimate that roughly 99.6% of Mopane Basalt Shrubland remains intact with probably 100% being protected mostly in the Kruger National Park.

Tshokwane-Hlane Basalt Lowveld:

This vegetation type occurs at altitudes of 180 - 400 m above mean sea level and is characterised by fairly flat plains with open tree savanna often dominated by tall *Sclerocarya birrea* subsp. *caffra* and *Acacia nigrescens* (Mucina and Rutherford, 2006). Dominant species in this vegetation type are: *Acacia nigrescens, Sclerocarya birrea* subsp. *caffra, Bothriochloa radicans, Digitaria eriantha* subsp. *eriantha, Panicum coloratum, P. maximum, Themeda triandra* and *Urochloa mosambicensis* (Mucina and Rutherford, 2006). The following species are considered to be endemic to this vegetation type: *Boscia foetida* subsp. *minima* (Mucina and Rutherford, 2006).

Mucina and Rutherford (2006) rank this vegetation type as least threatened and well protected in South. They estimate that roughly 83.5% of Tshokwane-Hlane Basalt Lowveld remains intact while 64.4% is being protected mostly in the Kruger National Park and Hlane Game Sanctuary in Swaziland and that about 17% of this vegetation type is currently transformed by cultivation practises.

Northern Lebombo Bushveld:

This vegetation type occurs at altitudes of 200 - 450 m above mean sea level and is characterised by open bushveld dominated by Combretaceae on rocky slopes, ridges and hills reaching 100m and higher above the surrounding basalt plains (Mucina and Rutherford, 2006). Dominant species in this vegetation type are: *Sclerocarya birrea subsp. caffra*, *Combretum apiculatum*, *Euphorbia confinalis*, *Dichrostachys cinerea*, *Aristida congesta*, *Digitaria eriantha* subsp. *eriantha*, *Enneapogon cenchroides*, *Heteropogon contortus* and *Panicum maximum* (Mucina and Rutherford, 2006).

Mucina and Rutherford (2006) describe this vegetation type as least threatened and well protected. They estimate that roughly 99.8% of Northern Lebombo Bushveld remains intact while 98.8% is being protected mostly in the Kruger National Park. Mucina and Rutherford (2006) estimate that this vegetation has seen virtually no transformation.

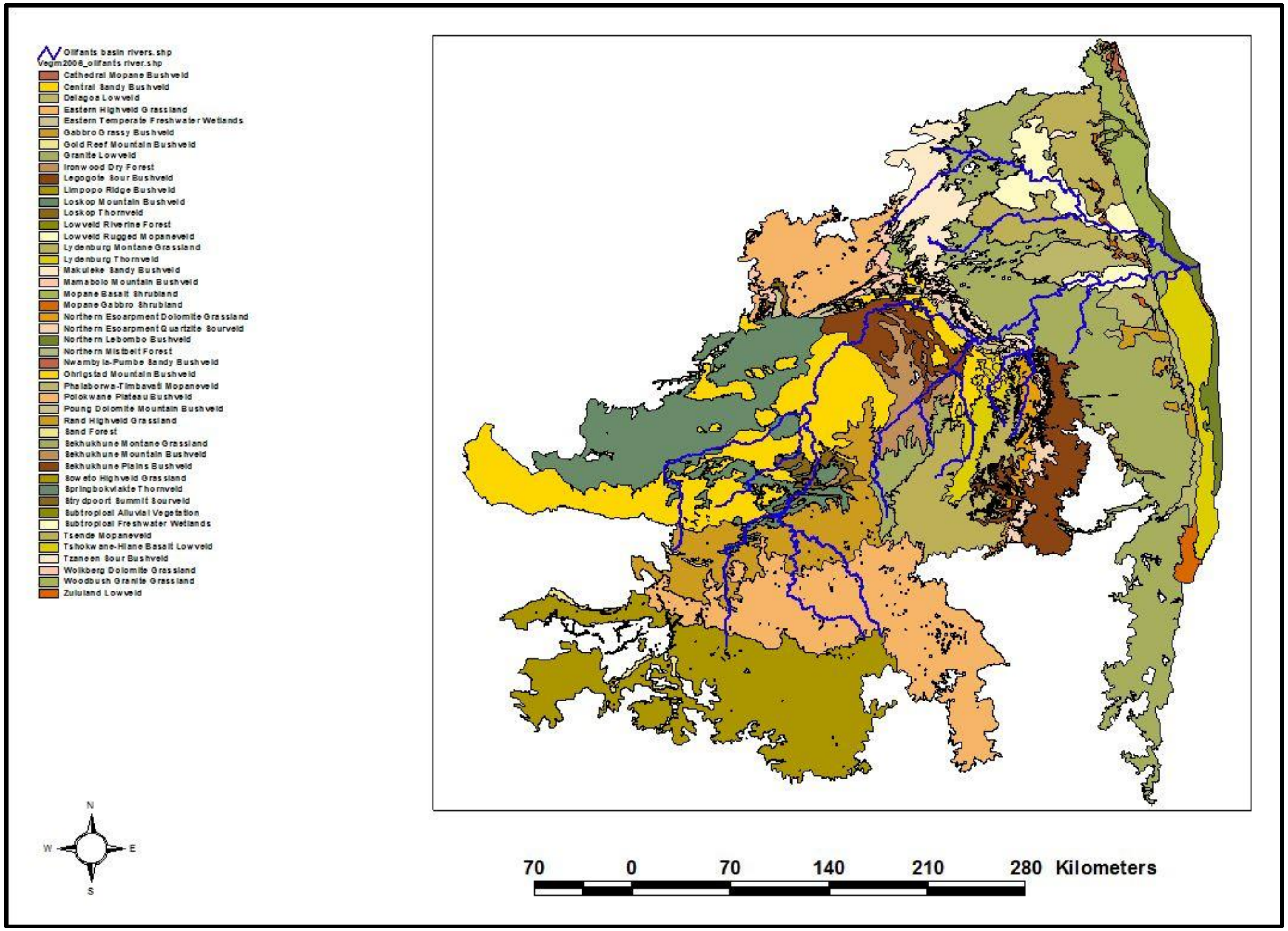

Figure 8: Vegetation types of the study area showing the Olifants River superimposed in blue over the area.

PRESENT ECOLOGICAL STATE OF THE OLIFANTS RIVER

The application of biological and habitat indices during river surveys provide a framework for determining the degree of ecological modification at specific sites in the river. The degree of modification observed in each ecoregion at particular sites was translated into the present ecological state of the catchment. The ecological state of the catchment is classified using the categories shown in table 4 below.

Table 4: Categories used to define the present ecological state of the Olifants River ecosystem (Water Research Commission, 2001).

Ecological state of river	Description
Natural	No measurable modification
Good	Largely unmodified
Fair	Moderately modified
Poor	Largely modified
Unacceptable	Seriously or critically modified

In their State of the Rivers Report, the Water Research Commission (2001) describes the present ecological state of the Olifants River summarised into one overall state as follows:

The **Highveld Ecoregion** show a fair to unacceptable state in terms of in-stream and riparian habitats with general conditions being poor to fair. Biological communities are considered to be in fair to unacceptable health. In the **Central Highlands Ecoregion,** the Olifants River is generally in good health with the in-stream conditions being variable and ranging from good to fair. The present ecological state of the **Bushveld Basin Ecoregion** is described as poor to unacceptable with in-stream biota of the Olifants River being fair to poor and the riparian vegetation being in a poor state. In the second area of the **Central Highlands Ecoregion** situated downstream of the Flag Boshielo Dam between the Tudumo and Motse Rivers, biological indicators reflect a predominantly poor ecological state with river habitats in an unacceptable state. The state of in-stream and riparian habitats in the **Great Escarpment Mountains Ecoregion** vary from unacceptable to fair with fish populations in a poor state. Some of the tributaries in this ecoregion, such as the Blyde River, Treur River and Belvedere Creek, are in a good to natural ecological state whereas the Spekboom River is slightly lower at a good to fair ecological state. The Olifants River in the **Lowveld Ecoregion** is in a fair to poor ecological state in terms of in-stream and riparian habitat while biological indicators in general suggest a fair ecological state. The water quality of the Olifants River in the **Lebombo Uplands Ecoregion** is lower than desirable. According to the Water Research Commission (2001), the reasons for this are:

(i) High concentrations of dissolved salts having accumulated as a result of activities in the upper reaches of the catchment,

(ii) The Massingire Dam across the border in Moçambique causes the river flow to decrease and result in sediment being deposited in the Olifants River Gorge.

In conclusion then, river systems in the Olifants River catchment are generally in fair to poor condition. Exceptions are the Tongwane, Mohlapitse and Blyde Rivers where a natural ecological state prevails (Water Research Commission, 2001) and the lower reaches of the Olifants River which is protected by conservation activities. In the upper parts of the catchment, mining related disturbances are the main causes of impairment of river health (Water Research Commission, 2001) and there are also extensive invasions by alien vegetation and to a lesser extent alien fauna. The Water Research Commission (2001) states that ecologically insensitive water releases and sediment from storage dams are major causes of environmental degradation downstream in the Olifants River and particularly so in the middle and lower parts of the catchment in the Olifants River Catchment.

LAND-USE IN THE OLIFANTS RIVER BASIN

Land-use activities contribute greatly to the ecological state of the Olifants River and are accepted as drivers of ecological change in the ecosystem of the Olifants River Catchment. The State of the Rivers Report (Water Research Commission, 2001) describes the following land-use activities as drivers of ecological change in each ecoregion of the Olifants River Basin:

Highveld Ecoregion:

Coal mining activities (figure 9) and other industries are the major contributors to poor in-stream and riparian habitat conditions in this ecoregion (Water Research Commission, 2001). Non-functioning sewage works in major towns such as Witbank is also considered to have a huge negative influence on water quality, in-stream and riparian habitat conditions. Acid leachate from abandoned mines is a primary contributor to the poor water quality in this ecoregion where low pH and high concentrations of dissolved salts characterise many of the streams (Water Research Commission, 2001). Activities such as access roads and stream diversions may also have a severely disrupting influence on riparian habitats by causing erosion of the riverbed which in some areas have been eroded down to bedrock leaving little suitable habitat for aquatic life.

Figure 9: Aerial view of an opencast coal mine (Kromdraai Coal Mine) situated on the watershed of the Olifants River and Wilge River (Photo: A.C Driecher).

Central Highlands Ecoregion:

Agricultural activities such as grazing but especially intensive irrigation of crop are the main influences on the aquatic habitat in this ecoregion. The heavy abstraction of water for irrigation of crops (including orchards) reduces the available water for downstream ecological functioning (Water Research Commission, 2001). Commercial farming activities reach up to the riverbank and the clearing of ground cover associated with these activities increases the potential for erosion and sedimentation in the river channel. Pump houses, weirs and other water abstraction infrastructure contribute towards changes in the flow regime of the river while unseasonal and ecologically insensitive releases from or retention of water in dams have a definite negative impact on in-stream biological communities and may cause erosion of the riverbed (Bruwer and Ashton, 1989; Water Research Commission, 2001). Alien vegetation is abundant along the river in this ecoregion.

Bushveld Basin Ecoregion:

The riparian vegetation in this ecoregion is overgrazed and over-utilised by small scale subsistence agricultural activities such as grazing by cattle and goats (Water Research Commission, 2001). As a result the riverbank is collapsing in areas due to erosion with resulting sedimentation occurring in the riverbed. Run-off from commercial agricultural activities contains agro-chemicals which may cause eutrophication and contamination of the water (Water Research Commission, 2001). Alien vegetation (including *Melia azedarach*) is abundant in this ecoregion.

Central Highlands Ecoregion:

In the second, small area characterised as part of the Central Highlands Ecoregion, land and vegetation are generally highly degraded due to bad land management practises and over utilisation (Water Research Commission, 2001). Activities in this area are mainly small-scale subsistence crop cultivation and commercial banana plantations. Sections of the riverbanks are seriously degraded due to clearing for crops and collection of fire wood (Water Research Commission, 2001). Donga erosion is common in the riparian zone.

Great Escarpment Mountains Ecoregion:

Intensive cultivation and grazing in this ecoregion have caused general degradation of land cover (Water Research Commission, 2001). Serious erosion occurs due to the highly erodible soils occurring in this ecoregion while sediment originating in the Sekhukuneland area settles here in the river resulting in siltation and loss of habitat (Water Research Commission, 2001).

Lowveld Ecoregion:

Sediment from upstream activities (including overgrazing, mining and industries) accumulates in the Phalaborwa Barrage to be released in large quantities when the barrage is flushed from time to time (Water Research Commission, 2001). This may cause severe damage to in-stream habitats and biota downstream in the Olifants River with fish dying from oxygen depletion and smothering from silt clogging their gills. Heavy metals and chlorides may reach unacceptable levels during low flow periods and abstraction of water often cause flow in the Olifants River to cease altogether (See Figure 10).

Lebombo Uplands Ecoregion:

The water quality of the Olifants River is this ecoregion is lower than desirable considering that this area is situated inside the Kruger National Park. The river is characterised by high concentrations of dissolved salts which accumulate due to activities in the upper reaches of the catchment (Water Research Commission, 2001). The Massingire Dam across the international border in Moçambique causes the flow to decrease and allow sediments to deposit in the Olifants River Gorge - once prime habitat for Nile crocodiles in the Kruger National Park (Water Research Commission, 2001).

Figure 10: Olifants River Gorge during a period of no-flow in October 2005 (Photo: Dr F. Venter).

CLIMATE OF THE OLIFANTS RIVER BASIN

The climate of the Olifants River catchment is semi-arid and is largely controlled by movement of air-masses associated with the Inter-Tropical Convergence Zone (McCartney and Arranz, 2007). During summer, high land temperatures produce low pressures and moisture is brought to the catchment through inflow of maritime air masses from the Indian Ocean. During winter, the sun moves north and the land cools, causing the development of a continental high pressure system. The regional dry season is produced by descending, out flowing air. Therefore, rainfall in the Olifants River catchment is seasonal and largely occurs during the summer months, October to April (McCartney, 2003). Mean annual precipitation for the whole catchment is 630 mm but the rainfall pattern is irregular with coefficients of variation greater than 0.25 across the catchment (McCartney and Arranz, 2007). The catchment is divided into two distinct areas by an escarpment orientated roughly north-south with the highest rainfall in the area of the escarpment. Orographic rainfall in the vicinity of the escarpment results in mean annual precipitation that exceeds 1000 mm in places (McCartney, 2003).

The mean annual potential evapotranspiration for the catchment is 1450 mm (McCartney and Arranz, 2007). Runoff from the catchment reflects the temporal and spatial distribution of rainfall with the highest volumes along the escarpment. The average annual runoff from the catchment is 37.5 mm (McCartney and Arranz, 2007).

The temperature range over the catchment shows a wide annual variation from about -4°C in winter to approximately 45°C in summer (de Lange *et al.*, 2005). This wide variation is due to the Olifants River basin being situated only 24° South of the equator but with much of the basin located at relatively high elevations above sea level (de Lange *et al.*, 2005).

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CHAPTER 3

THE CONSERVATION STATUS AND DISTRIBUTION OF NILE CROCODILES IN THE OLIFANTS RIVER

INTRODUCTION

Although the status of the Nile crocodile is relatively secure and abundant in southern and eastern Africa, where it is regarded as a species with a “moderate” need for the recovery of the wild population, it is largely depleted in western Africa (Ross, 1998). The Status Survey and Conservation Action Plan of the IUCN Crocodile Specialist Group (Ross, 1998) states that among the 20 African countries where some indication of the status of *C. niloticus* is known, their numbers are considered to be severely depleted in six (30%), somewhat depleted in 12 (60%) and not depleted in two countries (10%).

Crocodilians are threatened by many human activities. Pooley (1969) argued that the most significant of these is the destruction or alteration of the wild habitat and these concerns continue to this day. Commercial over-exploitation and indiscriminate killing have resulted in many crocodilian species suffering a decline in numbers and reductions in distribution. As with many other large commercially valuable species, hide hunting during the 1940’s to 1960’s resulted in dramatic declines in population size throughout most of the Nile crocodile's range. Overexploitation combined with loss of habitat has brought several crocodilian species to the brink of extinction. Rural communities are often intolerant of large potentially dangerous crocodiles and the deliberate destruction of nests and killing of adults are widely reported. In general, crocodilian populations become threatened in direct proportion to the proximity and density of human populations (Ross, 1998).

Because crocodiles are large animals that increase through several orders of magnitude of size during their lifetime as they grow from hatchlings to adults, they require relatively large areas of undisturbed wetland to maintain large populations. The creation of dams and impoundments has an undeniable effect on crocodile populations. The original, well vegetated marshy habitat is replaced by a lake with bare shores which can cause crocodilian populations to decline. New impoundments are often highly productive water bodies able to support crocodile populations but fluctuations in water level due to agricultural and industrial demands affect the reproductive capacity of crocodile populations negatively (Ross, 1998).

During his surveys done between 1979 and 1981, Jacobsen (1984) counted a total of 602 crocodiles of all sizes in the area then known as the Transvaal province of South Africa now the Mpumalanga, Limpopo and North West provinces. His survey included the Olifants River and some of its tributaries and he reported a total of 237 Nile crocodiles in the Olifants River system. The rivers identified as important for this study were also surveyed by

Jacobsen during his study and therefore, the current provincial boundaries in South Africa did not have a negative effect on this survey.

Since Jacobsen's survey in the 1980's, the situation regarding the conservation status of rivers in South Africa has deteriorated dramatically. Currently, an estimated 82% of all rivers in South Africa are considered to be threatened while 44% of all rivers in South Africa are considered to be critically endangered (Driver *et al.,* 2005).

The upper reaches of the Olifants River is mainly characterised by mining and agricultural activities (Water Research Commission, 2001). Over-grazing and highly erodible soils result in severe erosion and associated increased siltation especially in the middle section of the Olifants River. According to the state of rivers report (Water Research Commission, 2001) there are already more than 30 large dams in Olifants River Catchment. In addition, the many smaller dams in the catchment have a considerable combined impact on the river. Braatne *et al.* (2008) stated that the construction of dams in rivers provides a dominant human impact on river environments worldwide. Therefore, while the local impact of reservoir flooding are immediate, the ecological impacts downstream can be extensive such as: rivers downstream of dams shrink and have altered habitat resulting in changes such as less fish and reeds; dams trap sediments resulting in the release of cleaner high-energy water downstream which then erodes sediments from the river; water released from dams generate downstream flows that are unnatural, leading to changes in the life cycle and sometimes the death of aquatic fauna; water spilling over a dam usually contains large numbers of algae which are not typical of fast flowing and turbid rivers and thus introduce a new food source to the system which results in changes to the structure of the vertebrate community in the river; water released from the bottom of the dam is much colder than the river water and contain dissolved manganese, iron, sulphur and ammonia, all of which are potentially toxic to aquatic life; reduced flow downstream of a dam can lead to vegetation encroachment resulting in the narrowing of the river channel which can have devastating effects during large flood events when the river can no longer transport flood waters, and dams are barriers to fish migration (WRC, 2002; Braatne *et al.*, 2008). All these factors have an undeniable impact on the Nile crocodiles living in the Olifants River.

LOCATION OF THE SURVEY AREA

The catchment area of the Olifants River covers an area equal to 4.3% of the total area of South Africa (Kleynhans, 1992) and is situated in the north-eastern regions of South Africa (Figure 11). The Olifants River originates in the Highveld grasslands of the Mpumalanga province (Figure 12). It flows in a north-westerly direction where it is joined by the Wilge River upstream of the Loskop Dam. From the Loskop Dam the river flows through a relatively flat landscape past the towns of Groblersdal and Marble Hall to the Flag Boshielo Dam at the confluence of the Elands and Olifants Rivers. Downstream of the Flag Boshielo Dam, the Olifants River flows through the Springbok Flats which forms part of the Bushveld

Basin. After passing south of the Strydpoort Mountains, the Olifants River is joined by the Mohlapitse River. The Steelpoort River flows in a north-easterly direction and converges with the Olifants River in the Drakensberg near Kromellenboog. The Ohrigstad River joins the Blyde River at the Blyderivierspoort Dam in the Blyderivierspoort Nature Reserve after which the Blyde River meanders through the Drakensberg to enter the Lowveld where it joins the Olifants River. In the Lowveld, the Olifants River flows eastwards through the Kruger National Park. It is joined by the Letaba River just east of the Olifants Rest Camp before it flows through a narrow gap in the Lebombo Mountains and into Moçambique.

The survey area included the Olifants River from the Klein-Olifants River confluence above the Loskop Dam to the Flag Boshielo Dam, following the river to Penge and onward past the confluence of the Blyde River into the Kruger National Park up to the Moçambique border.

The following tributaries were also surveyed: the Steelpoort River from its confluence with the Olifants to the general area near the town of Roossenekal, the Ohrigstad River from the town of Ohrigstad to its confluence with the Blyde River and the Blyde to its confluence with the Olifants River. Also surveyed were the Elands River from the Flag Boshielo Dam to the Rust der Winter Dam and the Wilge River for a short distance from its confluence with the Olifants River (just before the Loskop Dam) up to a point where the habitat clearly became unsuitable for Nile crocodiles to occur and where the elevation and mean annual temperature (Alcala and Dy-Liacco, 1990) probably prohibits the occurrence of Nile crocodiles.

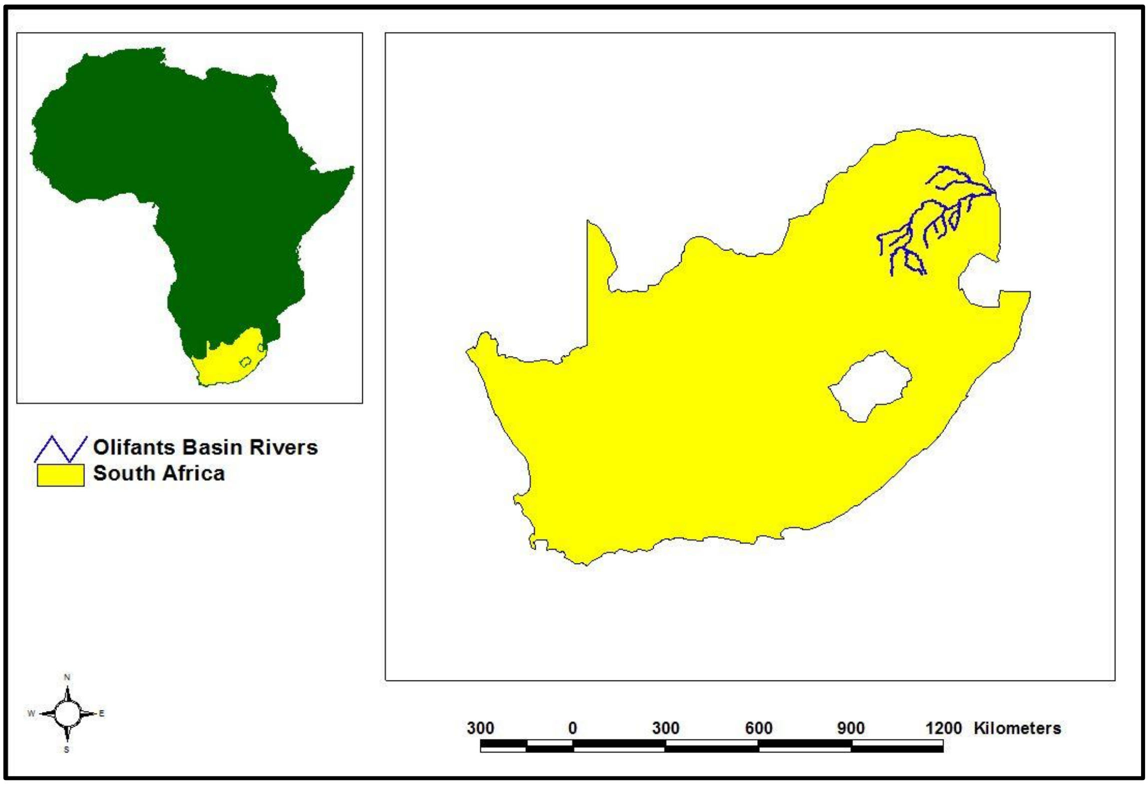

Figure 11: Locality of the Olifants River basin in South Africa.

The following dams were included in the survey: Loskop Dam, Flag Boshielo Dam, Blyderivierspoort Dam, Rhenosterkop Dam, Rust der Winter Dam. It is important to note that the entire length of some of the rivers (e.g. Wilge River) was not surveyed due to the habitat clearly being unsuitable for Nile crocodiles and as a measure to ensure that the allocated budget for the survey was not exceeded.

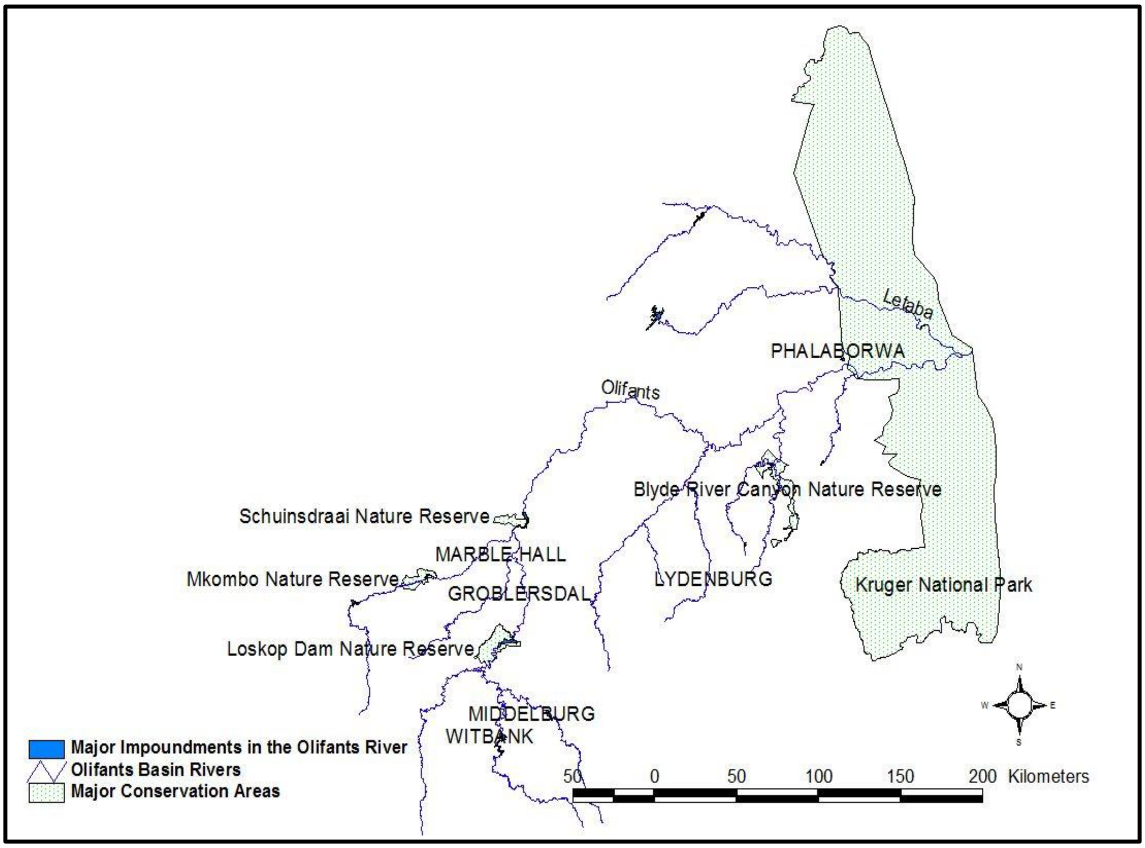

Figure 12: The Olifants River and its major tributaries in relation to major towns and conservation areas in the region.

METHODS

Population surveys of single-species populations such as crocodilians have two basic objectives (Bayliss, 1987). These are:

(i) ***To determine distribution and abundance -*** to answer the questions of where the animals are and how many there are. This is a descriptive approach and is a necessary first step in any population study and monitoring programme.

(ii) ***To monitor changes in abundance and distribution -*** to answer the question whether the population is increasing, decreasing or stable. It is also important to monitor the average trend of the population over a number of years. Trend investigations evaluate the status of the population over time and measure the impact of management practises on populations (Woodward and Moore, 1993).

Spotlight counts are regarded by many authors as a suitable and reliable method for estimating crocodilian population size (Webb and Messel, 1979; Bayliss *et al.*, 1986; Hutton and Woolhouse, 1989; Games, 1990; Woodward and Moore, 1993). Spotlight-counts using boats have definite advantages when accurate assessments of the age structure of the population are the primary objective (Hutton and Woolhouse, 1989) but factors such as poor visibility due to vegetation cover, narrow and twisting channels, difficult access to the water and the position of the crocodile in the water (Bayliss *et al.,* 1986; Hutton and Woolhouse, 1989; Bourquin, 2007) can lead to inconsistent and unreliable results.

Aerial surveys are considered to be more economical and less time consuming than boat-based spotlight-counts especially where large inaccessible areas are being surveyed (Pooley, 1982; Bayliss *et al.*, 1986). A major disadvantage of aerial surveys is that a large percentage of between 12% and up to 61% of animal populations are not observed during aerial surveys and this is especially so in the case of crocodiles less than 2.0m in total length (Parker and Watson, 1970; Caughley, 1977; Ramos *et al.,* 1994). However, aerial surveys have a number of advantages over spotlight-counts with the biggest of these being that aerial surveys are considered to be the most cost effective way to monitor population indices over time (Bayliss *et. al.* 1986). The ability to improve the precision of a population index by replication at reasonable cost is another advantage of helicopter surveys over boat-based surveys (Bayliss *et. al.* 1986). Recruitment to the populations can be assessed by long-term trends in larger size classes and associated helicopter surveys of the nesting effort (Bayliss *et. al.* 1986).

Given the inaccessibility of the terrain, the unnavigable nature of the Olifants River, the physical length of the river and problems associated with providing logistical support over such long distances and rough terrain, spotlight counts were never regarded as a viable option to survey the crocodile population in the Olifants River but aerial surveys were decided upon as the better option to survey the Olifants River Nile crocodile population.

An aerial survey of the study area was therefore carried out on 13, 14 and 15th December 2005 with a second, follow-up survey completed on 17, 18 and 19th November 2009. Although the November/December timeframe is during high summer and not the ideal time to survey crocodiles, this timeframe was chosen to include documenting nesting activity in the survey. It was originally planned to repeat the initial survey during the summer of 2006 but funding from the Department of Water and Environmental Affairs only became available during 2009 due to legal administrative requirements within the department.

Although the follow-up survey was only completed three years after the initial survey, the results produced are very valuable since earlier surveys of the Transvaal Nile crocodile population was based on single survey efforts (Jacobsen, 1984; Kleynhans and Engelbrecht, 1993).

Flights were undertaken in a Bell 206 B Jet Ranger helicopter carrying the pilot plus three observers. The survey team consisted of one navigator seated in the front of the helicopter and two observers sitting in the back of the helicopter one observing to the left and the other to the right-hand side of the helicopter. The observers in the survey team consisted of the author and ecologists of the Mpumalanga Tourism and Parks Agency. Thus all observers were skilled in the technique of aerial survey of wildlife either through previous Nile crocodile aerial surveys or through aerial surveys of mammal populations on provincial nature reserves managed by the Mpumalanga Tourism and Parks Agency.

The rivers and tributaries to be surveyed were divided into numbered 5 km segments on topographical maps using Map Source software with the Garmin Topographical Map of South Africa. Starting in the Olifants River upstream of the Loskop Dam and ending at the Moçambique border with South Africa including the Blyde River, 143 such segments were numbered giving a total distance of 715 km. A similar survey was undertaken by Kleynhans and Engelbrecht (1993) but they limited their survey to the area of the Olifants River starting at the Loskop dam wall and ending at the western boundary of the Kruger National Park.

The aircraft was flown at a constant survey height of 150 - 200 feet above ground and at a constant groundspeed of approximately 85 kph. The average flying time for both these surveys amounted to a total of 23.7 hours (including ferry time and refuelling). The channel of the Olifants River was followed and every crocodile seen was counted, its size was estimated by the observers and the information relayed via the intercom system to the navigator who recorded the sighting and marked its position with a handheld Garmin GPSMap 60 Global Positioning System (GPS). The total length (TL) of individual crocodiles was estimated by the observers to the nearest metre and animals assigned to the following size classes:

Class 1: Small sized crocodiles (all crocodiles with TL < 1.5 m)

Class 2: Medium sized crocodiles (all crocodiles with TL of 1.5 - 2.0 m)

Class 3: Large sized crocodiles (all crocodiles with a TL of 2.0 - 4.0 m)

Class 4: Very large sized crocodiles (all crocodiles with TL of > 4.0 m)

The size of completely submerged crocodiles was estimated using certain environmental and behavioural characteristics. These included factors such as habitat type, water depth, water swirl, mud trails and wakes (Woodward and Moore, 1993; Jacobsen, 1984). According to

Jacobsen (1984) the tendency to underestimate the size of crocodiles spotted from the air is regarded as a constant factor and can therefore be ignored. While it is difficult to spot hatchlings and smaller sized crocodiles from the air, Woodward and Moore (1993) suggest that despite its weakness, the approach to include "unknown length" animals is still superior to ignoring them in the analysis of different size classes.

The position of all nesting sites identified from the air were also marked using a Garmin GPSMap 60 GPS. No nests were inspected for eggs. Data collected were downloaded from the GPS to a notebook computer at the end of every survey-day. The data was then plotted on maps using the ArcView Geographic Information System (GIS) and Garmin MapSource (ver. 6.5) software.

Stirrat *et al.* (2001) have argued that helicopter survey data will take much longer to detect population trends and that they would not be able to detect trends in declining populations in time for effective management options to be implemented. However, Bourquin (2007) states that in a personal communication with Grahame Webb, the latter indicated to him that helicopter counts in western Australia continue to provide accurate and precise tracking of population trends in their crocodile populations.

The density of the Nile crocodile population in the Olifants River was calculated by dividing the number of crocodiles counted in each area by the length of that area. The result was then expressed as the number of crocodiles per kilometre of river in each particular area (See Table 7).

RESULTS

Estimated number of crocodiles

An average of 23 hours was flown over three days during each survey of the Olifants River basin. The total number of individual Nile crocodiles counted was 734 during the 2005 survey and 747 during the 2009 survey. According to Swanepoel (2001) and Bayliss (1987), the undercount associated with aerial surveys may vary as much as 30% to 37% whereas Botha (2005) reported an undercount of 35% during his study in the Flag Boshielo Dam. Other authors describe undercounts that vary between 12 and 61% (Caughley, 1977; Bourquin, 2007). To account for the number of crocodiles missed by observers during the aerial survey, correction factors must be calculated and applied to the data (Magnusson *et al.*, 1978; Bayliss, *et al.,* 1986; Hutton and Woolhouse, 1989; Stirrat *et al.,* 2001). Botha (2005) reported an undercount of 35% in the Flag Boshielo Dam which converted to a correction factor of 1.54 based on population data calculated with the double-survey method described by Magnusson *et al.* (1978). Therefore, since aerial survey results indicate that the Flag Boshielo Dam population is one of the very important populations in the Olifants River and reliable data exists for this population the estimation of numbers for the rest of the Olifants River was based on the Flag Boshielo Dam correction factor. By applying the correction factor, it became possible to adjust and estimate the total number of crocodiles in the Olifants River during December 2005 at about 1130 individual crocodiles and during November 2009 at about 1150 individual crocodiles.

Table 5 (below) summarises the aerial survey and adjusted number of crocodiles per size class as surveyed in the Olifants River and tributaries. Size classes provide an indication of the population structure in the survey area.

Table 5: The number of Nile crocodiles counted in each size class during aerial surveys of the Olifants River, Mpumalanga in 2005 and 2009 and the adjusted population size to correct for the undercount (figures in brackets indicate percentage of the total).

Size class	Aerial survey 2005		Aerial survey 2009		Adjusted population 2005		Adjusted population 2009	
Small (<150 cm TL)	49	*(6.68)*	44	*(5.89)*	75	*(6.68)*	68	*(5.89)*
Medium (150-200 cm TL)	237	*(32.29)*	223	*(29.85)*	365	*(32.29)*	343	*(29.85)*
Large (200-400 cm TL)	393	*(53.54)*	334	*(44.71)*	605	*(53.54)*	514	*(44.71)*
Very Large (>400 cm TL)	55	*(7.49)*	60	*(8.03)*	85	*(7.49)*	92	*(8.03)*
Unknown size	0	*(0.00)*	86	*(11.51)*	0	*(0.00)*	132	*(11.51)*
Total	**734**	***(100)***	**747**	***(100)***	**1130**	***(100)***	**1150**	***(100)***

Number of crocodiles per area

During both surveys it became evident that crocodiles prefer and utilise certain areas better than others. To identify these areas, the entire study area was divided into nine distinct geographical units and the number of crocodiles in each unit was then determined. Results in table 6 show that during the 2005 survey, not surprisingly, the largest concentration of crocodiles was found in the Kruger National Park (*n* = 482; Olifants River Gorge *n* = 213; Rest of Olifants River in the Kruger National Park *n* = 269) whereas the second largest concentration was found in the Flag Boshielo Dam (*n* = 135). The only other populations of note were found in the Olifants River between the confluence of the Blyde River and the border of the Kruger National Park (*n* = 63) and also the Olifants River between Loskop Dam and Flag Boshielo Dam (*n* = 24). However during the 2009 survey it become clear that while the largest concentration of crocodiles still occurred in the Kruger National Park (*n* = 558; Olifants River Gorge *n* = 211; Rest of the Olifants River in the Kruger National Park *n* = 347) a noticeable decrease of 27.41% in the concentration of Nile crocodiles occurred in the Flag Boshielo Dam since 2005 (Table 6). Despite this serious decrease in numbers, the Flag Boshielo Dam population is still the second largest concentration of Nile crocodiles in the Olifants River if one considers that the crocodiles occurring in the Olifants and Letaba Rivers are all members of one very large population. A total of 21 Nile crocodiles (Small: 0; Medium: 9; Large: 10; Very Large: 2; Total: 21) were counted in the Elands River from its confluence with the Olifants River at the Flag Boshielo Dam to the Rhenosterkop Dam. In contrast with 2005 (before inundation of the Flag Boshielo dam) when no crocodiles were counted in the Elands River, the 2009 survey indicates that the Elands River is now an extremely important refuge area for Nile crocodiles in the Groblersdal area of the Olifants River. As with the 2005 survey, populations of note still occurred in the Olifants River between the confluence of the Blyde River and the border of the Kruger National Park (*n* = 49; representing a decrease of 22.22% from 2005) and also the Olifants River between Loskop Dam and Flag Boshielo Dam (*n* = 16; representing a decrease of 33.33% from 2005). The big difference reported between surveys in the Blyde River (-86.67%) is possibly due to a survey error due to riverine vegetation overgrowing the riverbanks making the spotting of crocodiles difficult during the 2009 survey.

Population density

Population density is defined as the number of individuals in a population in relation to a unit of space/area; it is generally assayed and expressed as the number of individuals (or the population biomass) per unit area or volume (Carpenter, 1956; Hanson, 1962; Odum, 1971). The influence that a population exerts on the ecosystem depends largely on the number of animals, therefore the population density (Odum, 1971). The current mean density of the crocodile population in the Olifants River was found to range between 0.04 and 21.20 crocodiles/km of river. When broken down into the different geographical areas, the Olifants River Gorge in the Kruger National Park showed the highest mean density (21.20 crocodiles/km) but not the highest number of individual crocodiles.

Table 6: Number of Nile crocodiles counted in each area of the Olifants River system during both survey years.

Area of the Olifants River	Length of sector (km)	Number of crocodiles surveyed per size class during 2005				Total crocodiles 2005	Number of crocodiles surveyed per size class during 2009					Total crocodiles 2009	Percentage difference
		Small	Medium	Large	Very Large		Small	Medium	Large	Very Large	Unknown size		
Loskop Dam (incl. inlets to the Klein-Oilfants and Wilge Rivers)	90	2	1	4	0	**7**	1	3	4	0	0	**8**	14.29
Olifants River between Loskop Dam and Flag Boshielo Dam	80	4	8	11	1	**24**	2	5	8	0	1	**16**	-33.33
Flag Boshielo Dam	40	2	27	88	18	**135**	4	28	53	13	0	**98**	-27.41
Olifants River between Flag Boshielo Dam and the Blyde River	250	1	4	2	0	**7**	1	3	9	0	1	**14**	100
Olifants River between the Blyde River and Kruger National Park	75	7	12	38	6	**63**	1	8	33	7	0	**49**	-22.22
Olifants River in the Kruger National Park (excluding the gorge)	95	25	104	129	11	**269**	33	123	165	26	0	**347**	29.00
Olifants River Gorge in the Kruger National Park	10	8	75	112	18	**213**	2	50	61	14	84	**211**	-0.94
Blyde River	55	0	5	9	1	**15**	0	1	1	0	0	**2**	-86.67
Blyderivierspoort Dam	20	0	1	0	0	**1**	0	2	0	0	0	**2**	100
Total	**715**	**49**	**237**	**393**	**55**	**734**	**44**	**223**	**334**	**60**	**86**	**747**	**1.77**

Table 7: Mean number of crocodiles their density and percentage of the total population per sector of the survey area both surveys combined.

Area of Olifants River system	Length of sector (km)	Mean number of crocodiles	Adjusted mean number of crocodiles	Mean density crocs/km	Adjusted mean density crocs/km	Percentage of total population
Loskop Dam (including inlets to the Klein-Oilfants and Wilge Rivers)	90	8	12	0.08	0.13	1.01
Olifants River between Loskop Dam and Flag Boshielo Dam	80	20	31	0.25	0.39	2.70
Flag Boshielo Dam	40	117	179	2.91	4.49	15.73
Olifants River between Flag Boshielo Dam and the Blyde River	250	11	16	0.04	0.06	1.42
Olifants River between the Blyde River and Kruger National Park	75	56	86	0.75	1.15	7.56
Olifants River in the Kruger National Park (excluding the gorge)	95	308	474	3.24	4.99	41.59
Olifants River Gorge in the Kruger National Park	10	212	326	21.20	32.65	28.63
Blyde River	55	9	13	0.15	0.24	1.15
Blyderivierspoort Dam	20	2	2	0.08	0.12	0.20
Total	**715**	**741**	**1140**	**1.04**	**1.59**	**100**

The next highest mean density was recorded in the Kruger National Park outside the gorge area (3.24 crocodiles/km) with the Flag Boshielo Dam showing the third highest mean density of crocodiles in the Olifants River with 2.91crocodiles/km of shoreline. Other populations of note are the Olifants River between the confluence of the Blyde River and the western boundary of the Kruger National Park (0.75 crocodiles/km) and also the Olifants River between the Loskop Dam and the Flag Boshielo Dam (0.25 crocodiles/km).

Population structure

Based on this and the results of the aerial surveys as given in table 5, analysis of the population structure of the Olifants River crocodile population showed that during 2005 the small and medium sized individuals form approximately 38.96% (*n* = 286) of the total crocodile population in the Olifants River. In contrast with this, crocodiles in the large size class form 53.54% (*n* = 393) of the total population and crocodiles in the very large class make up the remaining 7.49% (*n* = 55) of the total crocodile population (*n* = 734) in the Olifants River. By 2009, these figures had changed to a population structure where the small and medium sized individuals account for 35.74% (*n* = 267) of the total crocodile population in the Olifants River. Also, crocodiles in the large size class now represent 44.71% (*n* = 334) and very large sized animals represent 8.03% (*n* = 60) of the total crocodile population (*n* = 747) in the Olifants River. The 2009 total population includes 86 animals of unknown size which represents 11.51% of the total crocodile population in the Olifants River. The population structure based on the number of crocodiles estimated to be present in the Olifants River during November 2009 is shown as an age pyramid in figure 13.

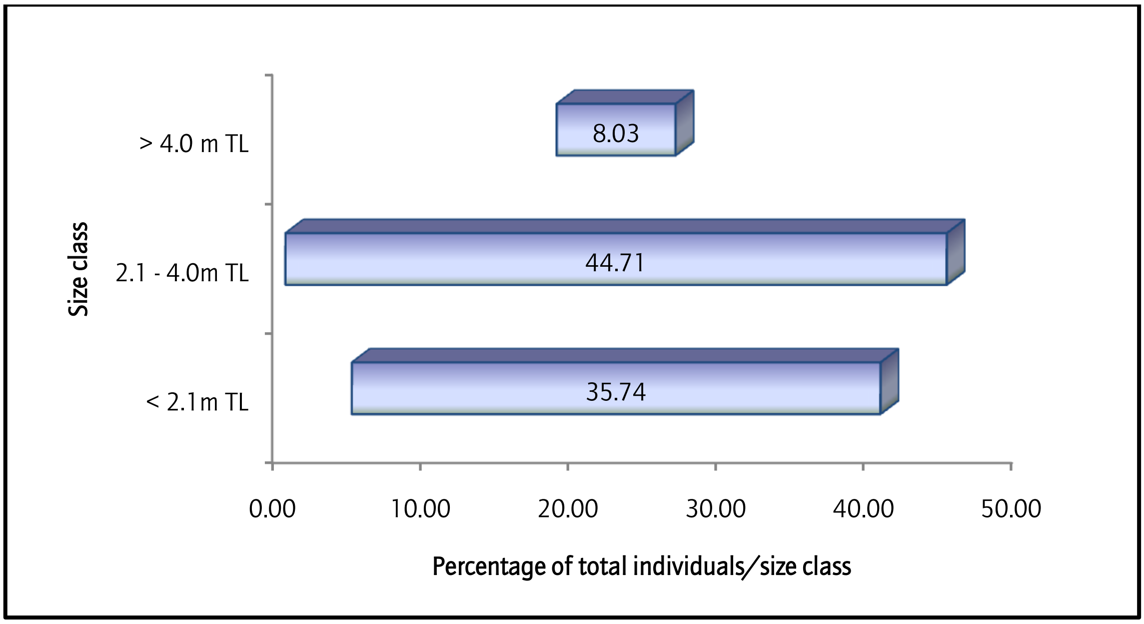

Figure 13: Age pyramid (both sexes combined) showing the percentage of crocodiles in each of the major size classes of the Nile crocodile population present in the Olifants River during the final aerial survey completed during November 2009.

<u>**Dispersal of Nile crocodiles in the Olifants River**</u>

The dispersal and movements of crocodiles throughout their environment are important factors of their basic population ecology (Hutton, 1984). Most animals do not move randomly but they also do not occupy the total space available to them while the norm is rather a prolonged occupancy of limited space with associated movement patterns (Hutton, 1984). The distribution of individuals within the habitat is often determined by their social behaviour (Lang, 1987). Hutton (1984) noted that the way in which crocodilian size classes are dispersed is of crucial importance. The reason for this is that adult crocodiles are several orders of magnitude heavier and longer than hatchlings. Cott (1961) has also suggested that cannibalism and ecological separation are basic population processes for Nile crocodile populations.

Hatchlings, young crocodiles and adult animals likely all occupy distinct habitats which are appropriate for age and/or sex-specific activities. Botha (2005) found a distinctive seasonal movement pattern in the study of the Flag Boshielo Dam Nile crocodile population. Swanepoel (1999) also reported that a distinctive seasonal movement pattern exist in the Nile crocodile population of the Olifants River in the Kruger National Park. For example adult crocodilians require deep, open water for mating and the females require very specific sites for nesting. Similarly, young crocodilians require shallow water with abundant cover in which to feed. Hutton (1984) showed that changes in the home range behaviour of Nile crocodiles occur as they grow from juveniles to reproductive animals. Effective management of crocodilian habitats requires a great deal of information regarding where and when crocodiles utilise various habitats. All of these requirements must be met if healthy viable wild Nile crocodile populations are to be maintained (Lang, 1987).

As shown in table 7, the areas of the Olifants River that appear to be the most preferred habitat during the 2005 survey in terms of percentage occurrence of crocodiles in that area were those in the Kruger National Park (36.65% of the total population), the Olifants River

Gorge in the Kruger National Park (29.02% of the total population), the Flag Boshielo Dam (18.39% of the total population), the Olifants River outside the Kruger National Park (between the Blyde River confluence and the western boundary of the Kruger National Park) (8.58% of the total population) and the area between the Loskop Dam and the Flag Boshielo Dam, including the Groblersdal area (3.27% of the total population). Although the percentages had changed by 2009 the areas occupied by Nile crocodiles remained the same i.e. the most preferred area was still the Olifants River (excluding the gorge) in the Kruger National Park (46.45%) followed by the Olifants River Gorge in the Kruger National Park (28.25%). The Flag Boshielo Dam (13.12%), the Olifants River between the Blyde River confluence and the western boundary of the Kruger National Park (6.56%) and the area between the Loskop Dam and the Flag Boshielo Dam near Groblersdal (2.14%). One significant change in the dispersal of Nile crocodiles is the occurrence of crocodiles in the Elands River. During 2005, just after first inundation of the new bigger Flag Boshielo Dam, no crocodiles were seen in the Elands River, however by 2009 a total of 21 animals including seven nests were seen in the Elands River between the confluence with the Olifants River and the Rhenosterkop Dam (a distance of about 85km). This confirms a change in dispersal patterns from the Flag Boshielo Dam into the Elands River. A total of 238 crocodiles were also observed in the Letaba River (between the Letaba Camp and the Olifants River confluence, distance of approximately 45km) indicating possible dispersal of crocodiles from the Olifants River Gorge into the Letaba River.

Further, the dispersal pattern of crocodiles clearly indicated that the area below the Flag Boshielo Dam and up to the confluence of the Blyde and Olifants Rivers is not a preferred habitat (Figure 14). This area accounts for 49 of the 5 km segments (245 km) and only seven animals (0.95% of the total population) were spotted over the entire length of the area during the 2005 survey but the 2009 survey results showed that this number had improved to 14 animals (1.87% of the total population). However, despite this increase in numbers, the figure of 14 individual crocodiles still represent less than 2% of the total Nile crocodile population in the Olifants River

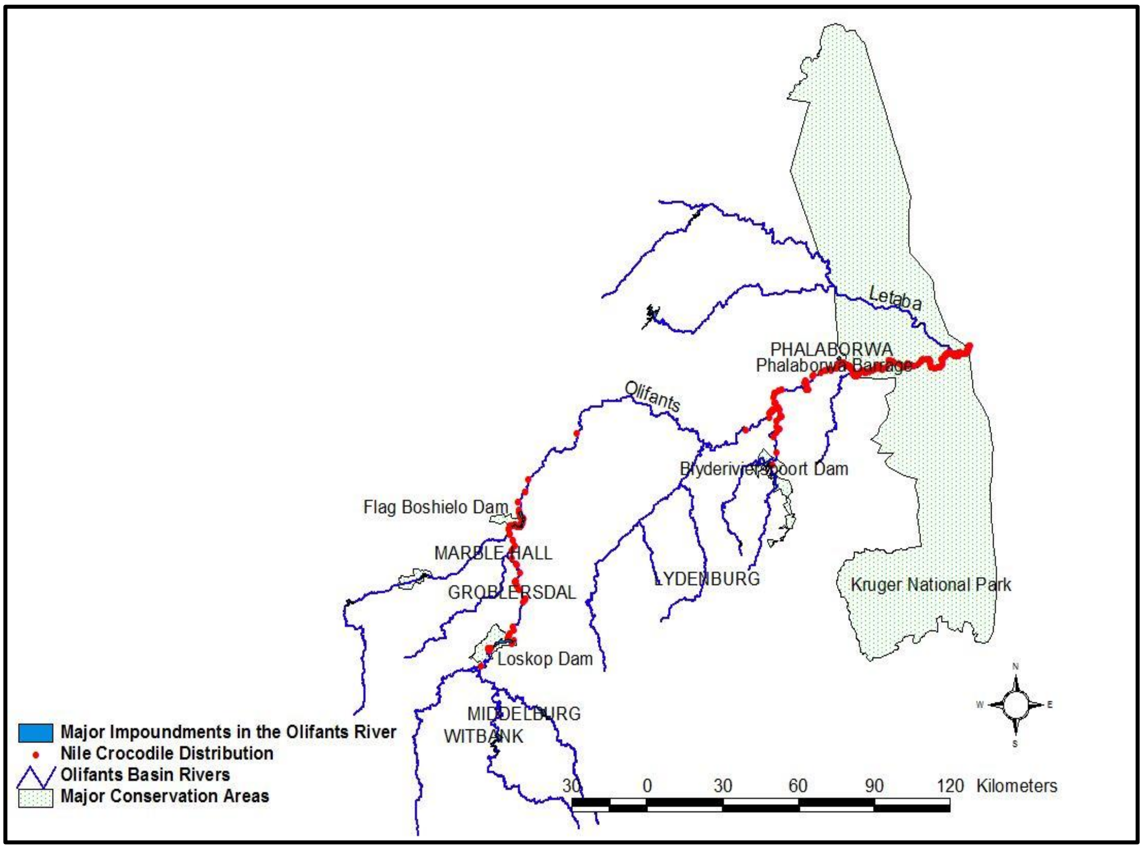

Figure 14: Dispersal of Nile crocodiles over the entire length of the survey area in the Olifants River as observed during December 2005. Red dots represent areas where Nile crocodiles occur in the river.

This statement is supported by surveys done over four years since 2005 under the auspices of the South African Reptile Conservation Assessment (SARCA). Data gathered and mapped by SARCA (Figure 15) show the same gap in the distribution of Nile crocodiles in the Olifants River between the Flag Boshielo Dam and the Blyde River confluence reported during this study (South African Reptile Conservation Assessment, 2009).

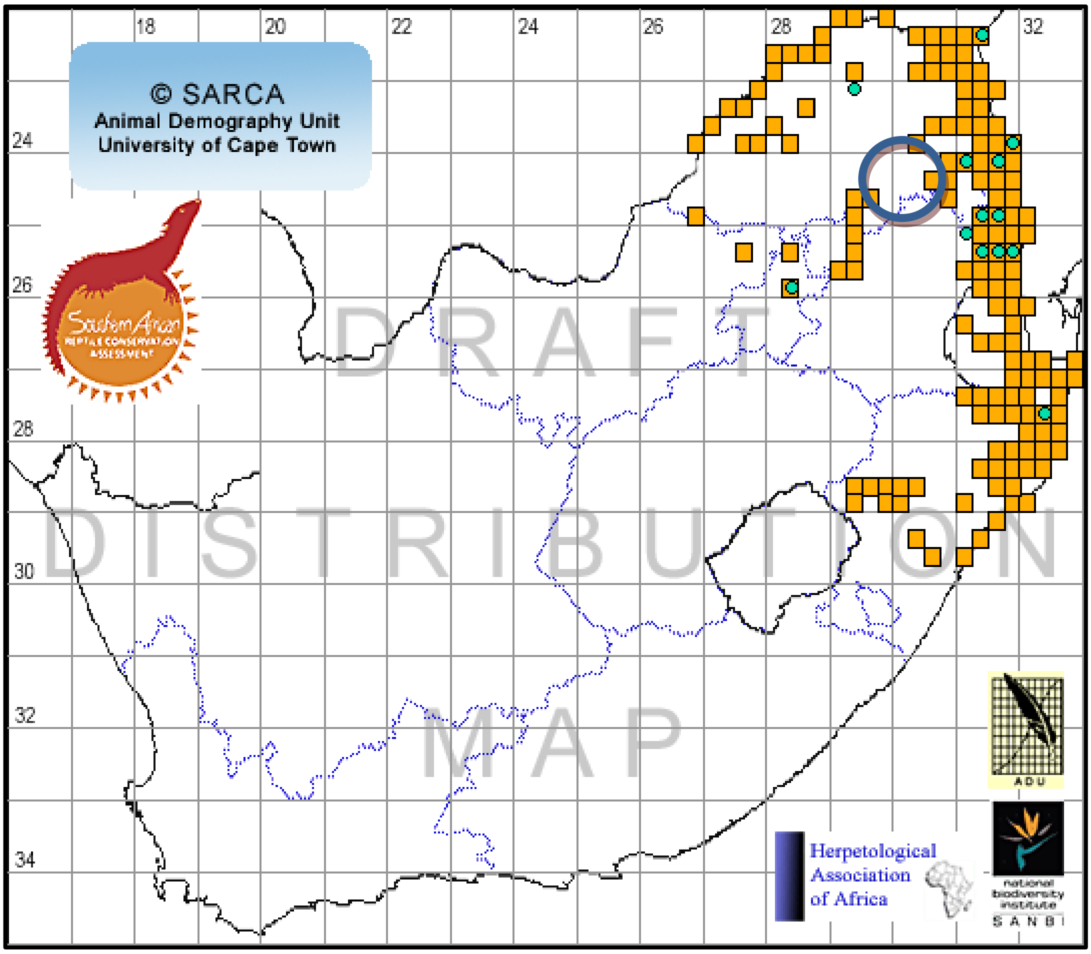

Figure 15: South African reptile conservation assessment distribution map of *Crocodylus niloticus.*

Nesting effort

Bayliss (1987) reported that the more structurally complex the habitat the less the chance of detecting crocodiles and therefore their nests. This survey located a total of 21 nests in the Olifants River (Figure 16).

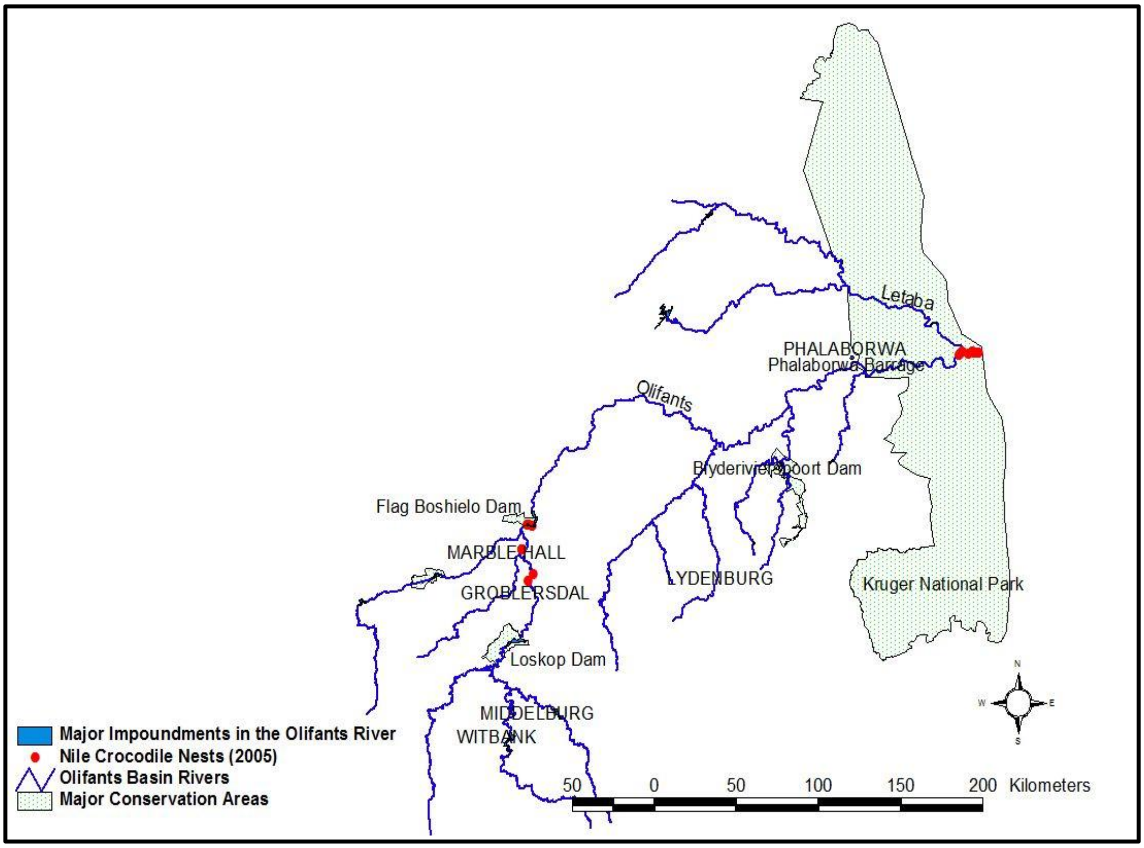

Figure 16: Distribution of Nile crocodile nests during December 2005 in the survey area including the Kruger National Park.

Thirteen of the nests found during the 2005 survey were located in the Kruger National Park while a further five nests were located in the area between the Loskop and Flag Boshielo Dams and three nests were found on the shores of the Flag Boshielo Dam. During the 2009 survey however a total of 14 nests (Table 8) were found with seven of these in the

Table 8: Number of Nile crocodile nests located during the 2005 and 2009 aerial surveys of the Olifants River.

Area of Olifants River system	Length of sector (km)	Number of nests located 2005	Number of nests located 2009	Mean number of nests located 2005 & 2009	Percentage of total nesting effort
Loskop Dam (including inlets to the Klein-Oilfants and Wilge Rivers)	90	0	2	1	5.71
Olifants River between Loskop Dam and Flag Boshielo Dam	80	5	3	4	22.86
Flag Boshielo Dam	40	3	1	2	11.43
Olifants River between Flag Boshielo Dam and the Blyde River	250	0	1	1	2.86
Olifants River between the Blyde River and Kruger National Park	75	0	0	0	0.00
Olifants River in the Kruger National Park (excluding the gorge)	95	4	-	4	11.43
Olifants River Gorge in the Kruger National Park	10	9	-	9	25.71
Blyde River	55	0	0	0	0.00
Blyderivierspoort Dam	20	0	0	0	0.00
Elands River		0	7	7	20.00
Total	**715**	**21**	**14**	**18**	**100**

Olifants River (two nests above the Loskop Dam in the inlets of the Olifants River; three nests in the Olifants River between Loskop Dam and Flag Boshielo Dam; one nest in the Flag Boshielo Dam and one nest in the Olifants River between Flag Boshielo Dam and the Blyde River confluence). The other seven nests were found in the Elands River (Table 8). No nests could be located in the Kruger National Park during the 2009 survey due to inclement weather. GIS Maps based on survey data show that the Flag Boshielo Dam nesting areas were used repeatedly over the previous five years (Figure 17). Of particular interest are the nests in the area known as the "old nests". This area was last used for nesting during the 1993 - 1996 nesting seasons. Construction to raise the Flag Boshielo Dam by 5 m began in June 2004 (announced by Minister Sonjica in her Budget Vote Address to the South African Cabinet on 18 May 2005) and all recreational access to the water including boating and shore fishing was banned for the duration of the construction phase. I believe this gave female crocodiles the opportunity to once again nest at the "old nests" site without having their nesting sites disturbed. Unfortunately, though after completion of construction all existing basking and nesting sites were flooded by the new full supply level of the raised dam wall leaving no useable areas for crocodiles to bask or nest. Areas elsewhere in the Olifants River that were shown to have been used more than once during the previous five years include an area downstream from the confluence of the Moses and Olifants Rivers and also an area upstream from the weir at Desmond Miller's farm (Figure 18). Finally, all nests located in the Kruger National Park during the 2005 survey were situated in the Olifants River Gorge.

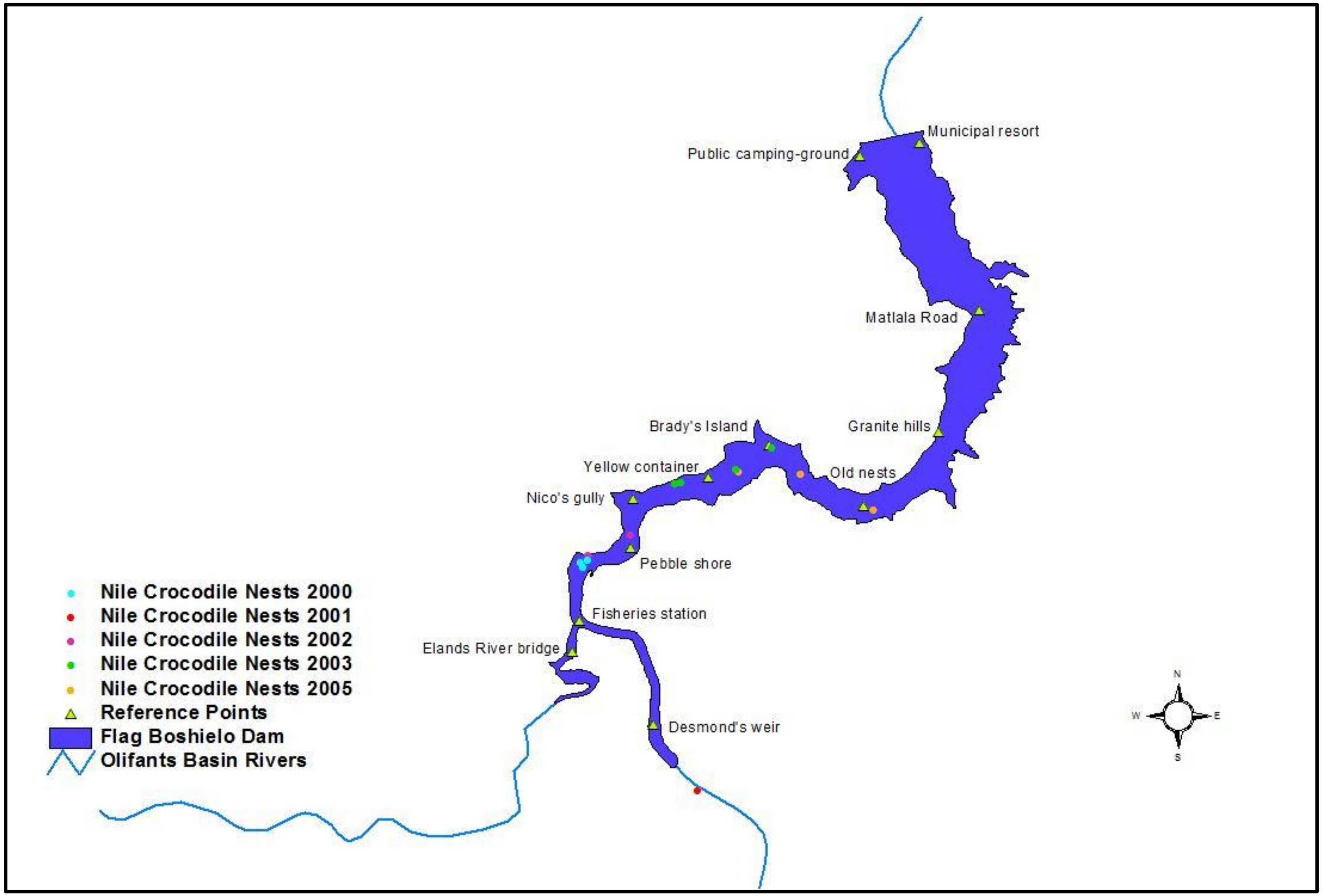

Figure 17: Nile crocodile nests at Flag Boshielo Dam during the 2000, 2001, 2002, 2003 and 2005 nesting surveys.

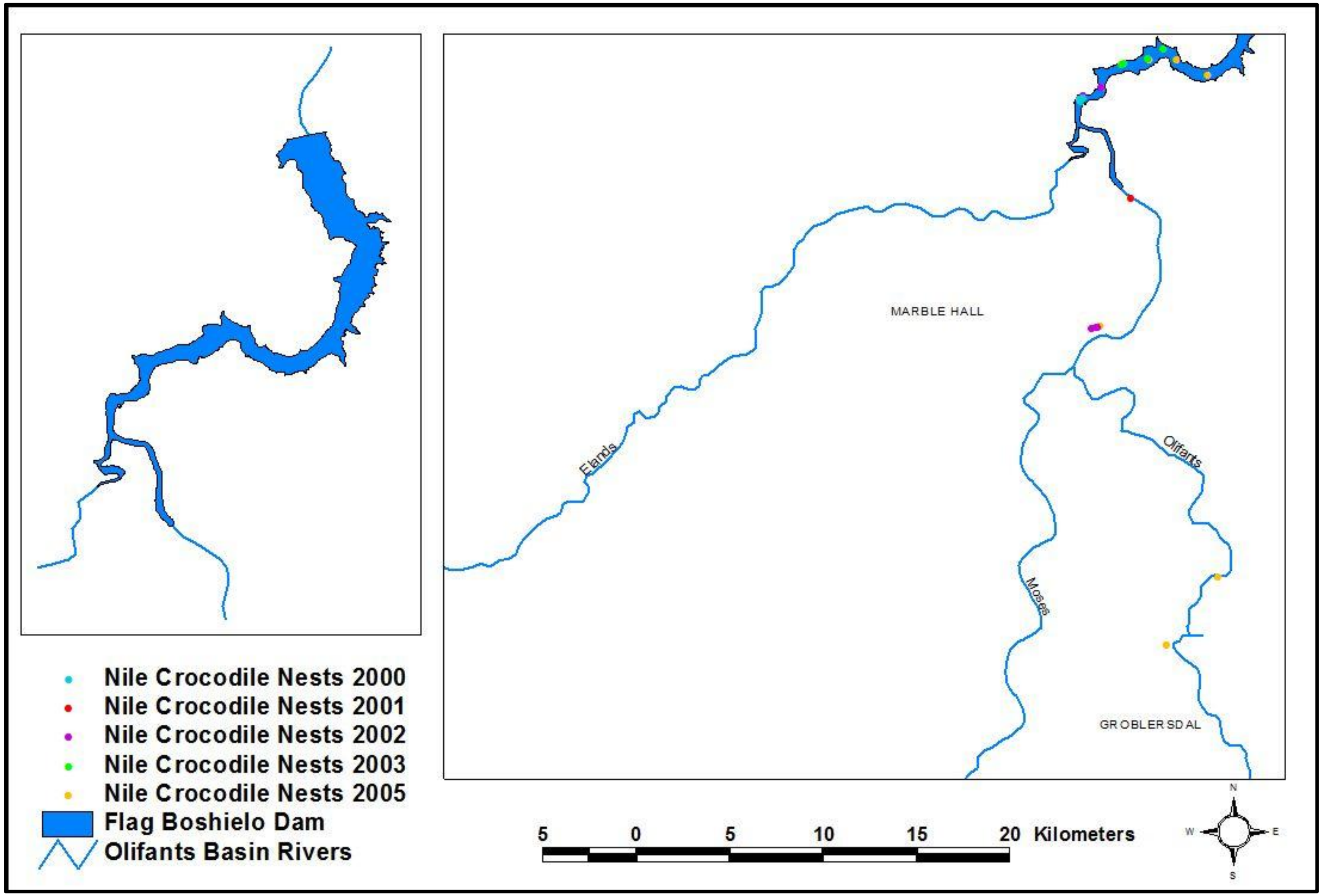

Figure 18: Nile crocodile nests located along the Olifants River and inlet of the Flag Boshielo Dam during 2000, 2001, 2002, 2003 and 2005.

DISCUSSION

Estimated number of crocodiles

Aerial surveys are recognised as quick, cost-effective and simple but they are inherently subjected to large biases, such as observer competency (observer bias), density of vegetation (visibility bias), water visibility (concealment bias) and time of year (Hutton, 1992; Games *et al.*, 1992). It therefore becomes necessary to estimate the total population size by calculating and applying a correction factor to the collected data to account for animals missed by observers (Magnusson *et al.,* 1978; Bayliss *et al.,* 1986; Hutton and Woolhouse, 1989; Stirrat *et al.,* 2001). The possibility of underestimating the number of crocodiles especially in the under 1.5m TL size class is unfortunately very high. However, this can be mitigated by timing the survey when river levels are at their lowest during the months of August and September. Both the 2005 and the 2009 aerial surveys however, could not be done at the most optimal time of year due to administrative regulations within the government department that funded the surveys and in the interest of at least gathering some useable data; the survey went ahead during November/December which is the less optimal time of year for aerial surveys of wildlife. However surveying during November/December enabled us to not only survey the number of crocodiles but also to survey the number of nests in the Olifants River using the same flight.

Jacobsen (1984) reported a total number of 237 individual Nile crocodiles in the Olifants River from surveys done over the whole of the Transvaal province during the period 1979 to 1981. Kleynhans and Engelbrecht (1993) also surveyed the Olifants River and they reported a total of 208 Nile crocodiles. Both of these surveys did not include the crocodiles inside the boundaries of the Kruger National Park. The 2005 survey found a total of 252 individual Nile crocodiles in the Olifants River, excluding the Kruger National Park population while the 2009 survey reported a total of 189 in the Olifants River, outside the Kruger National Park. There is only a slight variation in the numbers reported by the 1981, 1993 and 2005 surveys which were done by chance with a 12 year interval (Table 9).

Table 9: Comparison of different Nile crocodile surveys done in the Olifants River excluding the Kruger National Park between 1981 and 2009.

Author	Year of survey	Survey method	Population size	Percentage difference
Jacobsen	1981	Aerial survey (helicopter)	237	0
Kleynhans & Engelbrecht	1993	Aerial survey (helicopter)	208	-12.24
Botha (Current study)	2005	Aerial survey (helicopter)	252	+21.15
Botha (Current study)	2009	Aerial survey (helicopter)	189	-25.00

The difference between the 1981 survey and the 2005 survey is an increase of 15 animals and the 2009 survey resulted in the lowest number of crocodiles being reported since 1981. The small increase in numbers between 1981 and 2005 seem to be very low indeed even if one considers that crocodile populations increase very slowly and that less than 2% of crocodiles survive to five years from every 1000 eggs laid (Northern Territory Government, 2005). Surveys done 20 years apart in Lake Chamo, Ethiopia indicated a population increase of over 800 animals (Bolton, 1984; Wakjira *et al.*, 2004). This represents an increase of 228.61% in the size of the Lake Chamo Nile crocodile population. The unregulated harvesting of wild Nile crocodiles ended during the late 1950's and 1960's when crocodiles were declared game animals in terms of conservation legislation and crocodile farming was established to satisfy the growing market for crocodile skin products (Hutton *et al.,* 2004; MacGregor, 2006). In view of this long history of conservation and growing organised crocodile farming, it seems fair to accept that the most likely explanation for the low and possibly declining number of Nile crocodiles in the Olifants River could be a combination of poor water quality, over utilisation of the water resource by increasing the height and size of existing dams, building more and larger new dams in the river and pressure on the water resource and riparian habitat from expanding human rural populations has placed the crocodile population under stress over a long period of time. By adjusting the number of crocodiles counted to accommodate the expected undercount, the total population of Nile crocodiles in the Olifants River during 2009 is estimated at approximately 1150 individual animals.

Estimated number of crocodiles per area

Survey results clearly show that Nile crocodiles prefer and utilise certain areas of the Olifants River more than other areas. The Kruger National Park and specifically the area of the Olifants River Gorge was one of the areas with the highest number of crocodiles present, to the extent that 28.63% (*n* = 212) of all crocodiles observed where located in this area. The even higher percentage of 41.59% (*n* = 308) of all crocodiles observed, occurred in the rest of the Olifants River in the Kruger National Park. Therefore more than seventy percent (70.22%) of all crocodiles in the Olifants River occurs within the boundaries of the Kruger National Park (this constitutes 16.45% of the total Olifants River length). The ecological status of the Olifants River in this region is given as Class C which means that it is considered to be only moderately modified (Nel *et al.,* 2004). The ecological status of the river was determined by taking factors such as flow, inundation, water quality, stream bed condition, introduced in-stream biota and the riparian or stream bank condition into account (Nel *et al.*, 2004). This means that the river and its surroundings are probably still providing good basking and nesting sites, probably have an abundant food source and provide enough deep pools and flowing water for crocodiles to shelter and survive in this area. The other 29.78% of the population occur over 83.55% of available river. The ecological status of the Olifants River in this area is given as Class D which means that the river is considered to be largely modified and transformed from its original state (Nel *et al.,* 2004). It is therefore, conceivable that the river no longer provide good basking and nesting sites and that the food source is probably not plentiful making this area less suitable for crocodiles to survive. In contrast with this, 15.73% of the total Nile crocodile population in the Olifants River occur in the Flag Boshielo Dam. The ecological status of this area is given as Class E/F which means that the river is seriously to critically modified in that specific area (Nel *et al.,* 2004). However the dam did provide excellent basking and nesting sites and a plentiful food source before the wall was raised causing the high percentage of crocodiles present in the area. However this situation has now changed with a reported drop of 27.41% in crocodile numbers since 2005 to a mean population of only 117 animals. Furthermore 7.56% of the crocodile population occurred in the area between the Blyde River and the Kruger National Park where the ecological status has been determined as Class C indicating that the river in this particular area is considered to be only moderately modified (Nel *et al.,* 2004) and capable of providing nesting and basking sites and a stable food source. The Olifants River between Loskop Dam and the Flag Boshielo Dam hosted 2.70% of the population in the Olifants River. All other areas provide habitat for populations which number less than 2.70% of the total crocodile population resident in the Olifants River basin. The areas in the Olifants River least preferred by Nile crocodiles were the area between the Flag Boshielo Dam and the confluence of the Blyde River (Class D ecological status, largely modified) and also the Loskop Dam. Although these areas account for approximately 1% of the total population each, the river area (Flag Boshielo Dam to the Blyde River confluence) covers such a long shoreline that in terms of density, the river area is the least preferred habitat. The Nile crocodile population in Loskop Dam once numbered over 80 crocodiles and has declined to the current eight animals as the industrialisation of the upper catchment increased. The Blyde River is considered to be one of few rivers in Mpumalanga that is still largely natural (Class B) and still intact (Nel *et al.*, 2004) and capable of providing good nesting and basking sites and perhaps also a stable food source.

Population density

Results from this survey show that the Olifants River Gorge in the Kruger National Park has the densest population of crocodiles in the whole of the Olifants River at 21.20 crocodiles/km of river. This is followed by the Olifants River inside the Kruger National Park (excluding the gorge) with 3.24 crocodiles/km of river and the Flag Boshielo Dam with a density of 2.91 crocodiles/km of river. The high density of Nile crocodiles in the Kruger National Park can be attributed to the aquatic habitat in the Kruger National Park being in a much better condition than the river habitat outside this protected area. The Kruger National Park is a well protected conservation area where the ecology is still functioning which means that important criteria such as the availability of food, basking and nesting sites are abundant. In this situation, the crocodiles can fulfil their natural role as apex predators without competition for the food and water resource from humans. In all other areas of the Olifants River, the crocodiles had to adapt to living in environments that are considered to be largely, seriously and even critically modified and transformed. Nile crocodiles like all crocodilians are less dependent on water for their existence than fish for example but pollutants in the water can still affect them indirectly because it is acquired through ingestion of fish rather than absorption from the water (Swanepoel, 1999).

However, the low percentage of occurrence (density) in some areas compared to that of the Kruger National Park indicate that areas such as the Flag Boshielo Dam (15.73% of the total population), the area of the Olifants River between the Blyde River and the western boundary of the Kruger National Park (7.56% of the total population) as well as the area between the Loskop Dam and Flag Boshielo Dam (2.70% of the total population) should be considered as habitats of critical importance to the continued survival of crocodiles in the Olifants River. Equally so should the Elands River from its confluence with the Olifants River and the Letaba River in the Kruger National Park be considered to be habitats of critical importance to the continued survival of crocodiles in the Olifants River due to the apparent redistribution of crocodiles from the Olifants River. Most of the habitats in the Olifants River (except for those in the Kruger National Park) are totally unprotected by official conservation agencies and it is therefore the responsibility of landowners, farm managers, communities and government institutions to ensure that these habitats do not become unsuitable to crocodiles through unplanned and unmanaged use of the water resource. Given the fact that South Africa's water resources have already been fully allocated and, in some cases, over-used to the point of collapse, this country does not have any buffering capacity against climate change (Hartdegen, 2009a). Table 10 gives an indication of the utilization and projected requirements of the major water user categories in the Olifants River at the year 2025.

Table 10: Major water users in the Olifants River in 1987 and 2000 and projected use for 2010 and 2025 (Theron *et al.*, 1991; Basson and Rossouw, 2003).

Water-user group	Percentage water use year 2000	Year 1987 water required (million m^3 L/a)	Year 2000 water required (million m^3 L/a)	Year 2010 water required (million m^3 L/a)	Year 2025 water required (million m^3 L/a)
Power generation	15.17	208	181	208	219
Irrigation	46.69	538	557	640	557
Forestry	4.53	56	54	63	54
Urban and rural	10.98	90	131	180	244
Mining and industrial	7.80	80	93	100	118
Ecological reserve	14.84	200	177	177	177
Total	**100**	**1172**	**1193**	**1368**	**1369**

Population structure

The structure of an animal population needs to be defined in terms of sex, age and/or size (Hutton, 1984; Nichols, 1987). The ratio of different age groups in a population determines the reproductive status of that particular population and indicates what may be expected in the future (Odum, 1971). In general terms a rapidly expanding population will contain a large proportion of young individuals, a stationary population a more even distribution of age classes and a declining population a large proportion of old individuals (Odum, 1971).

Nichols (1987) recommends that size structure rather than age class should be used to develop models for crocodile populations due to the following reasons:

(i) Most data sets for crocodiles are generally collected by size class and then converted to age class through the application of growth curves. However, growth curves are generally considered to be difficult to estimate in crocodilians and other ectothermic vertebrates (Nichols, 1987).

(ii) Demographic variables of crocodiles seem more likely to be functionally dependent on size than age. Predation mortality, for example, seems very likely to be a function of size, with larger size classes being vulnerable to fewer potential predators. Reproduction may also be more closely tied to the size than age in crocodilians. For example, there is evidence that sexual maturity in *Alligator mississippiensis* is dependent on size, rather than age (Whitworth, 1971; Joanen and McNease, 1975). The form of the data and the underlying biology both seem to favour the use of size-specific population models for crocodilians (Nichols, 1987).

Because it is known that reproduction may be more closely related to size than age in crocodilians (Cott, 1961; Graham, 1968; Hutton, 1984; Games, 1990; Whitworth, 1971; Joanen and McNease, 1975; Magnusson *et al.*, 1990) crocodiles in the small and medium size classes (all crocodiles less than 2.1m TL) were grouped together as they are likely to be pre-reproductive animals. Similarly all crocodiles in the large size class (all crocodiles between 2.1 and 4.0m TL) were grouped together as they are likely to be the reproductive animals while all crocodiles over 4.0m TL were separated out as they are likely to be the large dominating males in the population.

Analysis of the data from the 2009 survey (Table 5; Figure 13) showed that the small and medium size classes (all crocodiles with a total length of less than 2.0 m) constitutes 35.74% (*n* = 267) of the total crocodile population in the Olifants River. In contrast the large size class (animals in the 2.0 - 4.0 m TL range) form 44.71% (*n* = 334) with the very large crocodiles, all likely males (over 4.0 m TL) 8.03% (*n* = 60) of the total crocodile population (*n* = 747) in the Olifants River. It is important to note that the pre-reproductive group is significantly smaller than the reproductive group. This reflects in the classical shape of a shrinking population (Ryke, 1978; Odum, 1971). Although it is acknowledged that these conclusions are based on information from surveys with a high probability of underestimating the number of animals in the under 1.4m TL size class, it should still serve as an early warning to at least implement a strategy for regular monitoring of the Nile crocodile population in the Olifants River.

Crocodiles are long-lived animals that suffer high juvenile mortality (Pooley, 1969; Parker and Watson, 1970; Magnusson *et al.*, 1990; Swanepoel, 2001). Females must therefore, produce many young over their lifetime to ensure sufficient recruitment and population persistence. Events that include substantial adult mortality can result in long periods of little or no recruitment (United States Fish and Wildlife Service, 1999). Failure to successfully recruit age classes in consecutive years can, if repeated periodically depress small populations (United States Fish and Wildlife Service, 1999). Various studies have confirmed a recruitment percentage of between 2% and 5% of the population per annum for Nile crocodiles (Pooley, 1969; Parker and Watson, 1970; Magnusson *et al.*, 1990; Swanepoel, 2001). Based on the data in table 5 the percentage of small sized crocodiles (TL < 150cm) seems to indicate that recruitment into the population is within the accepted norm. The 5.89% of small crocodiles in the population seems to reflect a healthy segment of the population at the moment but this must be confirmed with data from further surveys. Medium sized animals (150-200 cm TL) form the core of the population and they contribute to the population by producing the next generations. These animals represent 29.85% of the total while large sized crocodiles (200-400 cm TL) contributed to 44.71% of the total. These high percentages are almost certainly the result of seasonal movements which fluctuate between the wet (hot) and dry (cold) seasons (Pooley, 1969; Swanepoel, 1999; Botha, 2005). The very large sized crocodiles (>400 cm TL) comprised 8.03% of the total population size. These very large crocodiles have the potential to dominate the population and a percentage of between 6% and 10% and even up to 15% of the total population size should be considered to be normal in any crocodile population.

Dispersal of Nile crocodiles in the Olifants River

Habitat loss generally limits opportunities for the dispersal of crocodiles especially in areas where crocodiles do not occur in large numbers to begin with and human encroachment on crocodile habitat can disturb crocodiles to such an extent that normal behaviour patterns are altered (United States Fish and Wildlife Service, 1999). Even apparently innocuous human activities such as camping, fishing, and boating have been shown to affect crocodiles negatively (United States Fish and Wildlife Service, 1999). Kushlan and Mazzotti, (1989) have shown that human presence can cause crocodiles to abandon or try to relocate nests.

The dispersal of crocodiles is driven by environmental factors the biggest being their habitat requirements. Nile crocodiles require areas with deep pools of water, specific substrate and shade (Pooley, 1969; Hartley, 1990, Swanepoel, 1999; Botha, 2005). Deep pools are essential for Nile crocodiles to submerge when they feel threatened or as part of their hunting strategy and mating behaviour. They also need deep water to assist with their thermoregulation and to provide safe areas for hatchlings to survive the critical first weeks of their lives. Very specific substrate is needed to construct nests and to maintain basking sites (Botha, 2005). The substrate is possibly selected for a number of factors such as available nesting space, the ease with which a hole can be dug, and possibly the heat retention properties of the soil. A variety of soil substrates have been found in different areas where studies have been undertaken ranging from very fine silt and sand to course river sand (Pooley, 1969; Swanepoel, 1999; Botha, 2005; Bourquin, 2007). Shade on or near nesting sites provides shelter to the female when she is guarding the nest during incubation. However, the effect of shade due to vegetation around the nesting site does not seem to be a major factor in the survivability of nests. Leslie and Spotila (2001) reported that infestations of the alien plant, *Chromolaena odorata* in nesting areas around Lake St Lucia clearly posed a very serious threat to the continued survival of the Nile crocodile in the Lake St Lucia ecosystem. However, both Swanepoel (1999) and Botha (2005) found that vegetation along the Olifants River was sparse enough not to be an influencing factor in the placement or prevention of nesting.

Clearly the right habitat requirements are limited in the Olifants River. Figure 19 show the percentage of the total population per area in the Olifants River (See results in Table 7 on p 88). This map shows where the habitat meets the requirement of crocodiles and also where the habitat is not suitable for crocodiles (i.e. water is to shallow, no fine sandy beaches and little shade).

A graph based on data in Table 7(in the results section) from the 2005 and 2009 surveys together with the data from the survey by Kleynhans and Engelbrecht (1993) show a number of interesting similarities between the surveys. The 2005 graph show a number of spikes in the area between Loskop Dam and the Flag Boshielo Dam that was not present in the 1993 survey and are now again not present in the 2009 survey (Segments 5-35 in figure 20). Clearly this is alternative habitat which is possibly an important area in their seasonal migration. Therefore, this part of the river must be given a very high conservation priority because it then represents habitat of critical importance to the continued functioning of the crocodile population in the Olifants River. The spikes in the area of the Flag Boshielo Dam (Segments 35-42 in figure 20) match almost exactly but at segment 40-42 a sharp decrease in the number of crocodiles observed during the 2009 survey clearly indicates that the number of crocodiles in that area of the river has changed drastically over the last four years. The crocodile population in the area between the confluence of the Olifants and Blyde Rivers and the western boundary of the Kruger National Park seem to be more evenly distributed in both the 2005 and 2009 surveys than during the 1993 survey.

However the large number of crocodiles observed just outside the KNP boundary during 1993 (Segment 102, figure 20) could not be found during either the 2005 or 2009 surveys. Trends established during the 2005 and 2009 surveys confirm that these crocodiles did indeed redistribute into the Kruger National Park probably due to the removal of the western boundary fence of the park during 1993 which opened up previously unavailable habitat to this population of Nile crocodiles. Spikes at segment 107-110 (Figure 20) in the 2005 and 2009 graphs confirm the hypothesis that crocodiles once occurring outside the protected area have now settled inside the protected area of the Kruger National Park. fluctuations along the course of the river. This is probably due to crocodiles being able to utilise preferred habitat instead of having to make do with what is available to them.

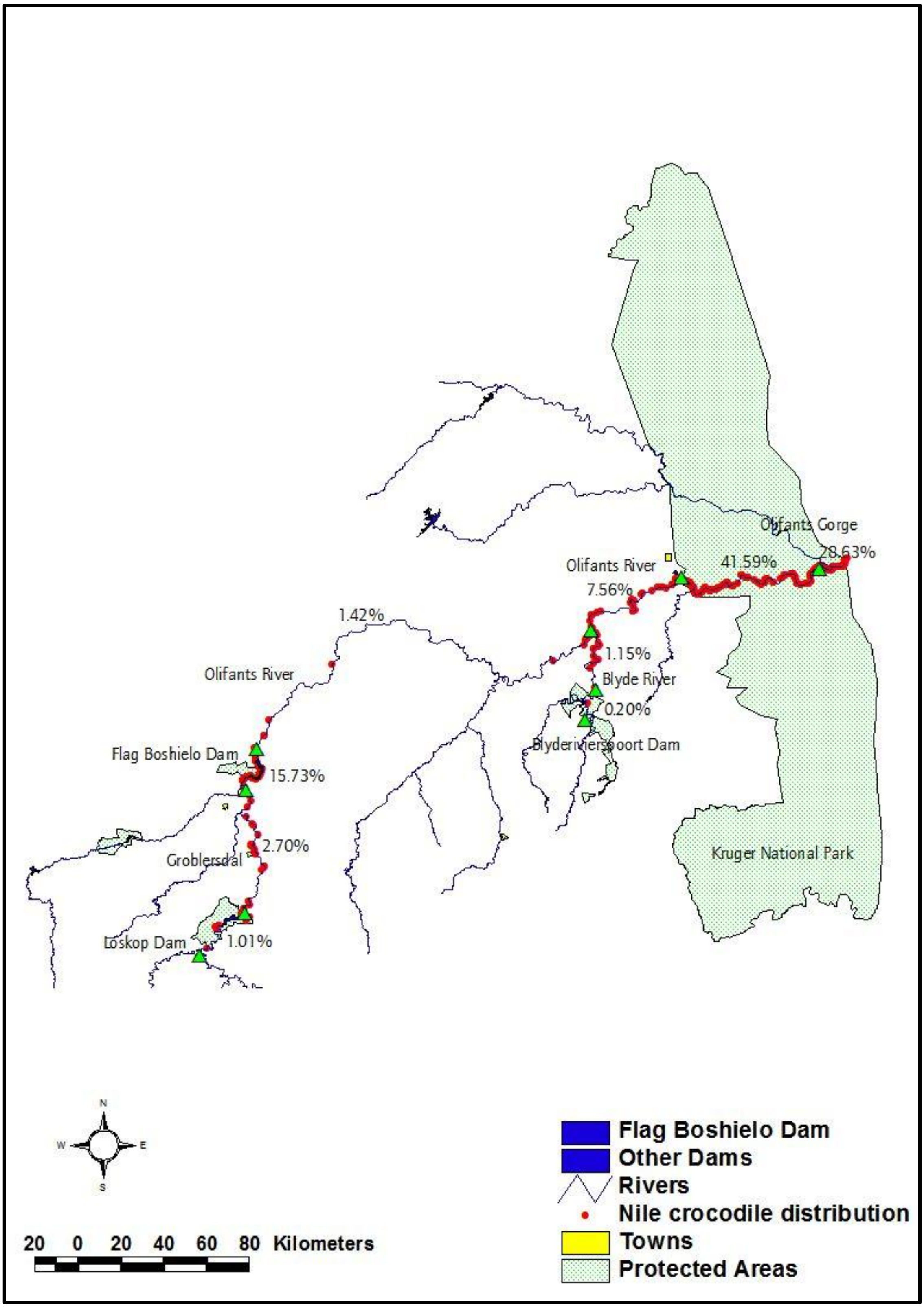

Figure 19: Preferred crocodile habitat in the Olifants River based on the combined 2005 and 2009 aerial surveys, the percentage of the total population occupying each sector is shows between the green markers.

The Nile crocodile population inside the Kruger National Park show a number of The Olifants River Gorge (Segment 127-128, figure 20) shows a very high population of Nile crocodiles and must be considered to be an area of absolute critical importance to the crocodile population of the Kruger National Park and indeed the South African population. This statement is supported by the high number of crocodiles and number of nesting sites observed in this short area of the Olifants River. Any damage or change to this area due to outside influences such as dam construction that may change the hydrology of the area will be catastrophic to the Nile crocodile population of the Kruger National Park and the whole of the Olifants River since the Kruger National Park is quite clearly the only area in the whole of the Olifants River where the total number of crocodiles is high enough to sustain

the population. This potential problem and its impact became abundantly clear during the period May to November 2008 when about 170 Nile crocodiles died in the Olifants River Gorge in the Kruger National Park (Myburgh, 2008; Pienaar & Govender, 2009). However, due to the remoteness of the area and the predisposition of crocodiles for cannibalism, it must be accepted that not all carcasses where found and therefore it is possible that twice as many crocodiles may have perished in the Olifants River Gorge during this catastrophic die-off episode. It was not only the number of crocodiles lost that became a concern but also the situation that almost all dead crocodiles were mature animals over three metres in length which will have a serious negative influence on the ability of this population to recover. The most recent survey during 2009 show a clear decrease in the number of crocodiles observed in the Olifants River Gorge (Segment 126, Figure 20).

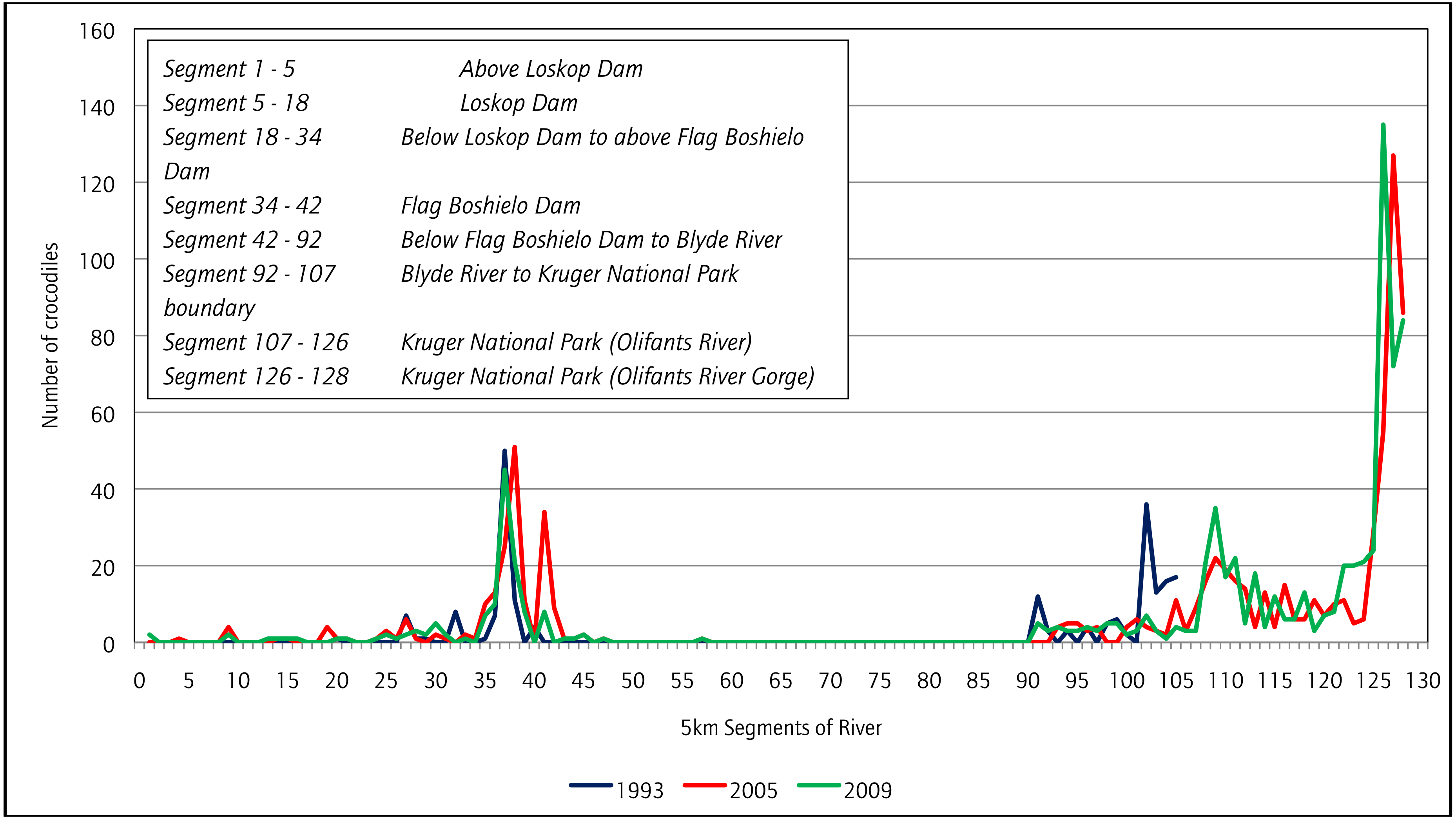

Figure 20: Number and dispersal of Nile crocodiles per 5 km segment of the Olifants River as surveyed during 1993, 2005 and 2009.

Post-mortem and histopathological investigations show that these crocodiles died of a condition known as pansteatitis. Pansteatitis is sometimes also referred to as "yellow fat disease" and is a condition primarily due to the toxic action of rancid fish oils (Huchzermeyer, 2003; Myburgh, 2008). According to Huchzermeyer (2003), this disease attacks fatty tissue causing it to die (necrosis) and undergo saponification (hardening) as well as a change in colour from white to yellow. The saponified fat is regarded as a foreign substance by the body of the affected crocodile leading to an inflammatory reaction which veterinary surgeons believe to be extremely painful. This inflammation and necrosis of fat deposits is what is referred to as "pansteatitis". The effect of the hardening of all fat deposits in the body is general "stiffening" of the animal. Saponification of the intermuscular fat deposits in the tail renders it completely immobile causing the crocodile to become unable to swim while the hardening of abdominal fat interferes with the motility of the intestines. Saponified fat is also not available as a source of energy. Typically, affected crocodiles become reluctant to move or enter the water. The disease leads to a slow death due to exposure, starvation and even drowning. There is no effective treatment to reverse the saponification of fatty tissue (Huchzermeyer, 2003).

It is not clear what triggered the outbreak of pansteatitis in the Olifants River Gorge. However it is known that the only change to the system before the die-off was that water from the Massingire Dam in Moçambique pushed into the Olifants River Gorge when the dam filled to full capacity after the wall and sluice gates where repaired. This caused the environment in the gorge to change from a shallow rocky river with deep pools into a slow flowing/standing reservoir which in turn influenced a change in fish species composition in the gorge. It is possible that the pansteatitis outbreak in the Olifants River Gorge was started by a large scale fish die-off due to pollutants entering the system through the flushing of dams upstream or perhaps inadvertently by illegal fisherman operating on industrial scale from the Massingire Dam using gill-netting in the gorge and dumping unwanted fish and intra-abdominal organs in the water. These dead fish which quickly turned rancid in the Lowveld climate represented a large food source for opportunistic predators like crocodiles. However the rancid fish then caused the occurrence of pansteatitis among the crocodile population in the Olifants River Gorge. The large volume of diseased fat present in the body of a single crocodile suffering from pansteatitis is possibly enough to trigger the reaction in healthy crocodiles feeding on the carcasses of crocodiles already dead or dying from pansteatitis.

Although it is possible that the space left vacant by crocodiles that are now gone from the gorge could be filled by crocodiles moving downstream, the fact remains that the dynamics of the crocodile population in the Olifants River Gorge have been dealt a crippling blow by the removal of such a large number of reproductive animals over a period of just six months. It is my opinion that if the 2008 pansteatitis outbreak in the Olifants River Gorge was a once off event then the damage to the population can be overcome in the long term. This could be achieved by managing the area through periodic water releases from the

Massingire Dam to retain the character of the gorge and by preventing gill netting inside the gorge. However, the decline in the crocodile population of the Loskop Dam which was also linked to pansteatitis (Myburgh, 2007) clearly show that multiple pansteatitis outbreaks will cause irreparable damage and eventual local extinction of the Nile crocodile population in the Olifants River Gorge.

Nesting effort

Selected areas along the Olifants River are used as nesting sites by the resident crocodile population in those areas. During the survey of 2005 the majority of nests were counted inside the Kruger National Park while the number of crocodile nests around the Flag Boshielo Dam was lower than the expected average number of nests per season reported by Botha (2005). This distribution pattern together with repeated nesting in certain areas over the last five years has established some areas as critically important to the nesting success of Nile crocodiles in the Olifants River.

These important areas include the Kruger National Park, the Flag Boshielo Dam and the Olifants River between the Loskop Dam and the Flag Boshielo Dam. Other areas that are also important are the Blyde River and the Blyderivierspoort Dam with the Ohrigstad River at the inlet to the dam The Elands and Letaba Rivers were also confirmed as very important refuge areas by the 2009 aerial survey. The importance of the Kruger National Park as a nesting area was highlighted by Swanepoel *et al.* (2000) as they reported a mean number of 50 nests per season in the Kruger National Park. It is important to establish the nesting trend as accurately as possible. This can be achieved through repeating the survey a number of times and ensuring that the counts are as accurate or near accurate as possible. It must be remembered that the more accurate the repetition, the more reliable the trend will be and the better it will reflect the true population dynamics. Crocodiles are known to prefer nesting on the high sandy ridges in streambeds at the end of the dry season in southern Africa (Pooley, 1969; Pooley and Gans, 1976; Kofron, 1989). The extraction of alluvial material from within or even near a streambed has a direct impact on the physical habitat characteristics of the stream (Hill and Kleynhans, 1999). It has been shown that changes to the river channel will disrupt the ecological continuum and negatively impact on the entire aquatic ecosystem (Hill and Kleynhans, 1999). According to the figures from the development assessment register of the Mpumalanga Tourism and Parks Agency, sand and aggregate mining represents 6.79% of all developments taking place in the Mpumalanga province between 2000 and 2009. These applications are open-ended in terms of the amount of sand that may be removed by the mining operator. Mining Review Africa states that aggregate and sand quarrying currently produces 120.17 million tons per year making it the sixth largest mining sector in South Africa (Mining Review Africa, 2009). The aggregate and sand mining industry generate earnings of R3.8 billion per year and is a significant generator of revenue in the South African economy with only gold, platinum group metals, diamonds and coal mining producing more revenue (Mining Review Africa, 2009). Extracting of such large amounts of sand from riverine habitats indicates that sand mining could potentially cause changes to the remaining nesting habitat of crocodiles to the extent that nesting activities and nesting success rates become seriously impeded. Such drastic use of the natural resource in the Olifants River will without doubt lead to destruction of historical nesting sites. Despite environmental legislation that requires impact assessments where an activity which may have a detrimental effect on the environment is planned, very little is known internationally about the effects of sand and aggregate mining on river and streambeds. Therefore, if important nesting areas are to be protected, then it becomes critically important for all regulatory departments involved in the review and authorisation of sand and gravel extraction projects to ensure that these operations are conducted in a manner that eliminates and minimises to the greatest extent possible any adverse effects on the in-stream and the riparian components of the aquatic ecosystem, including habitat and biota.

Nests were also observed in the area of the Flag Boshielo Dam locally known as the "old nests". Nests were last observed in that area by Nature Conservation Officers during the 1993 to 1996 nesting seasons. The value of this observation lies in the fact that these nests were made during the construction phase of the project to increase the height of the Flag Boshielo Dam and the only difference aside from the construction activities was the absence of boating due to the closure of the fishing resort and the banning of all recreational activities on the water during the construction phase. The "old nests" is a well known and popular angling and boating area, attracting large numbers of recreational visitors each year. Construction at the dam wall was carried out approximately 10 km downstream from this area behind the proper dam wall and not within sight of the nesting area and therefore would not have had any influence on the nesting females. This seem to support findings by the US Fish and Wildlife Service that even apparently innocuous human activities such as camping, fishing, and boating can affect crocodilians, in this case alligators, negatively (United States Fish and Wildlife Service, 1999).

All nesting areas of crocodiles along the Olifants River must be regarded as critical habitat and any human interference in or near these areas must be kept to an absolute minimum. Activities which take place outside these critical habitats but where the effect thereof may have a direct impact on the nesting area must be strictly controlled and where the impact is considered to be too great, alternative sites for development should be identified and used. It is strongly recommended that applicable environmental legislation should strictly applied at all times by regulatory authorities when any developments are considered in that proper environmental impact assessments are done by competent scientists. A number of important lessons were learned during this survey, these are incorporated into the recommendations section at the end of this chapter. Future surveys must take these lessons and recommendations into account to ensure the integrity of the surveys remain above suspicion. Any good monitoring programme must be able to change and adapt for the better in order to produce scientifically acceptable results.

Conservation status

Although this is at best a regional classification, the IUCN recognises that a need exists to apply the IUCN Red List Categories and Criteria to regional, national and local levels (IUCN, 2001). According to the IUCN, all the rules and definitions in the IUCN Red List Categories and Criteria Version 3.1 (IUCN, 2001) also apply at regional levels (IUCN, 2003). Provided that the regional population to be assessed is isolated from con-specific populations outside the region, the IUCN Red List Criteria (IUCN, 2001) can be used without modification within any geographically defined area (IUCN, 2003).

The best available evidence regarding the Nile crocodile population in the Olifants River indicates that the population is facing a very high risk of extinction in the geographically defined area of the Olifants River. Currently the population satisfies the following criteria of the endangered category of the IUCN Red List Categories and Criteria Version 3.1 (IUCN, 2001):

A. Reduction in population size based on the following:

   2. An observed, estimated, inferred or suspected population size reduction of ≥50% over the last 10 years or three generations, whichever is the longer, where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible, based on:

      (a) direct observation

(b) an index of abundance appropriate to the taxon

(c) a decline in area of occupancy, extent of occurrence and/or quality of habitat

(d) actual or potential levels of exploitation

(e) the effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.

C. Population size estimated to number fewer than 2500 mature individuals and:

2. A continuing decline, observed, projected, or inferred, in numbers of mature individuals and:

(a) Population structure in the form of one of the following:

(i) No subpopulation estimated to contain more than 250 mature individuals

Therefore based on the population data described in this chapter, it is suggested that the conservation status and risk of extinction of Nile crocodiles in the Olifants River be upgraded to the Endangered category since it currently satisfies the following criteria EN A2abce; C2a(i) as published in the IUCN Red List Categories and Criteria Version 3.1 (IUCN, 2001).

CONCLUSION

In terms of the recent collapse of Nile crocodile numbers in the Olifants River Gorge in the Kruger National Park, where an estimated 60% of the population where lost to an outbreak of pansteatitis (Myburgh, 2008; Pienaar & Govender, 2009), the collapse of Nile crocodile numbers in the Loskop Dam since the 1980's and the large scale loss of habitat in the Flag Boshielo Dam due to the raising of the dam wall, other areas such as the below Loskop Dam-Groblersdal-Flag Boshielo Dam area and the Blyde River-Kruger National Park Western Boundary area becomes extremely important and must be given the highest conservation priority.

The numbers of Nile crocodiles in the Elands River increased from no crocodiles observed to 21 individual animals observed between 2005 and 2009. The number of nests found increased from no nests found to seven nests found during the same period. This makes the final 15 km of this river before its confluence with the Olifants River, an extremely important refuge area for Nile crocodiles providing much needed nesting and basking sites not available in the Flag Boshielo Dam. The area along the last 15 km of the Elands River is utilised for game farming so therefore much of this area is natural to some extend with few developments. This means that food and other resources such as unhindered access to good basking and nesting sites is possible in this part of the Elands River. The game farming activities in this area virtually guarantee that only minimum disturbance of animals is allowed in the area making it ideal for basking, nesting and the establishing of nursery areas for hatchlings in contrast to the public access areas of the Flag Boshielo Dam.

However the pressure on the Olifants River from outside these areas is a very important factor in terms of the quality of the water in these sensitive areas. For example, it is known that as many as 63% of municipalities in South Africa are releasing polluted water (including untreated sewage) back into river systems without any type of treatment (Hartdegen, 2009b). It is commonly known that South African rivers, including the Olifants River, are heavily impacted by factors such as Acid Mine Drainage, Eutrophication, Microsystins, Endocrine Disrupting Chemicals, Partially metabolised medications, Radionuclide and heavy metal contamination and climate change (Hartdegen, 2009a).

The conservation status and risk of extinction of Nile crocodiles in the Olifants River must be upgraded to the Endangered category since it currently satisfies the criteria EN A2abce; C2a(i) as published in the IUCN Red List Categories and Criteria Version 3.1 (IUCN, 2001).

RECOMMENDATIONS

1. Repeat the aerial survey but include rivers such as the Elands River, Klaserie River and Letaba River while surveying rivers such as the Steelpoort River and Ohrigstad River intermittently.

2. Monitor nesting activity in late November/early December as part of the aerial survey (localities, environmental parameters etc).

3. Follow-up of future aerial surveys of nesting sites in the Flag Boshielo Dam with a spotlight count of hatchlings during middle January to confirm the number and location of nests to establish post construction nesting trends.

4. Aerial surveys of the Flag Boshielo Dam must be followed immediately by a spotlight survey to detect any population and distributional changes in the larger dam basin.

5. Critical habitats (Kruger National Park, Flag Boshielo Dam, Olifants between the Bylde River and KNP, Olifants between Loskop Dam and Flag Boshielo Dam, Elands River) must be protected from further development of any type by setting strict conditions and prescribing mitigating steps to which the developers must comply as a condition of their development authorisation.

6. The impact inside the critical habitat from development outside these areas must be determined and evaluated before such projects can be allowed by setting strict conditions and prescribing mitigating steps to which the developers must comply as a condition of their development authorisation.

7. Sandbanks along the entire river, but particularly in the critical habitat, must be protected from destruction by declining permission for development in these areas, particularly the mining of sand and the construction of tourism lodges. Illegal

operations, construction and developments must be shut down by the responsible government department and the area disturbed must be rehabilitated as a matter of urgency.

8. Limit development on or near river banks since even eco-tourism operations may have a detrimental influence on nesting crocodiles (US Fish and Wildlife Service, 1999).

9. Limit the amount of water that can be used by development, agriculture etc from the river. The Olifants River stopped flowing in the Kruger National Park for nearly three months as recently as October 2005. This situation have an undeniable negative effect on the ecology of the river and it clearly indicates that the ecological reserve is not enough to keep the river flowing.

10. Any future development projects (industrial, residential, golf estates, mining etc) that makes use of the river or is situated on the banks of the river must pay an amount of money equal to 2% of the total development cost into a trust account to fund further annual monitoring of the Olifants River crocodile population.

11. Confirmed nesting areas, both historical and recent must be protected and placed "out of bounds" for any type of development.

12. The quality and quantity of the water in the Olifants River must be maintained at all times by monitoring the use of water by industries, residential areas, golf estates and mining as well as the discharge of water from industries, residential areas, golf estates and mining in the total catchment of the Olifants River.

13. The exact dynamics of the Nile crocodile population in the Olifants River must be determined to establish whether this is declining, increasing or stable by repeating the survey frequently over time.

14. All existing and future dams must be zoned to provide wilderness areas where crocodile habitat, basking and nesting sites will be protected from recreational visitors. These sites must be identified by taking the distribution and nesting behaviour of the crocodiles into account. The zoning must be enforced by officers of the relevant provincial nature conservation authority or department.

15. During nesting seasons following completion of a dam wall in areas where Nile crocodiles occur, a rescue plan must be put in place to remove eggs from nests threatened by imminent flooding. These eggs must be taken to a reputable crocodile farm to be hatched and returned to the dam directly after hatching. An agreement must be reached between Nature Conservation and the breeder to determine a percentage of the hatchlings to be kept by the breeder to cover the expenses of

hatching the young crocodiles. This implies that accurate nesting surveys must be done before flooding occurs. Funding for the rescue plan and nesting surveys must be provided by the industrial water users on whose behalf the dam was constructed and who stands to benefit the most from the new bigger dam.

16. Implement a strategy to monitor and document the current state of Olifants River and the impact of surrounding areas on the Olifants River to determine its potential for providing suitable habitat to crocodile populations. The following should documented:

    - Document (mark) dams, weirs, impoundments
    - Document (mark) points where water is extracted
    - Determine the habitat where crocodiles are located
    - Document (mark) all deep pools
    - Document (mark) all obstructions which may hinder crocodile movements
    - Determine the extent of the fish population
    - Determine if the river has improved or degraded further since the previous survey in terms of erosion, sediment, sandbanks, vegetation, suitability for crocodile nesting etc.

17. Compare flow rates at the time of the surveys to form an idea of the level of the river at that particular time.

18. Take fixed point photographs from a high level (perhaps 1000 feet) to compare the different sectors/areas in terms of changes in vegetation, use of the resource and developments along the banks of the river.

19. Fly the Olifants River Gorge more than once (as many times as needed) to accurately determine the number of crocodiles and nests (particularly nests) because this short stretch of river (± 11 km) is so important in view of the mass mortalities during 2008 as a result of Pansteatitis. This area is unique as it used to provide habitat for so many giant crocodiles in one area that the ability of the observers to count accurately was at places impeded. The high percentage of unknown sized crocodiles must be kept to the absolute minimum.

20. Dispersal surveys should be done twice a year (winter and summer) to document any changes in the population structure over the seasons.

21. Upgrade the conservation status and risk of extinction of Nile crocodiles in the Olifants River to the Endangered category since it currently satisfies the following criteria EN A2abce; C2a(i) as published in the IUCN Red List Categories and Criteria Version 3.1 (IUCN, 2001).

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CHAPTER 4

THE CURRENT NILE CROCODILE POPULATION IN THE LOSKOP DAM

A CASE OF "CROCS IN CRISIS"

INTRODUCTION

Jacobsen stated in 1984 that the substantial decline of the population of Nile crocodiles in the Loskop Dam was already a cause for concern (Jacobsen, 1984). During a symposium in 1992 on crocodile habitat, he reported that the Loskop Dam Nile crocodile population once numbered over 80 individuals. However, during 1979 a total of 21 Nile crocodiles were known to occur in the Loskop Dam (Jacobsen, 1984) and during the 1981 aerial survey of the Olifants River, only six crocodiles could be found in the dam (Jacobsen 1984).

The declining Loskop Dam crocodile population was also mentioned in the 1982/1983, 1983/1984 and 1984/1985 annual reports of the Transvaal Nature Conservation Division. The following paragraphs from these reports indicate the gravity of the situation and some of the history behind the decline of the crocodile population in the Loskop Dam:

- "The continuing drop in the crocodile population of the dam is causing concern, and a monitor programme to determine the cause has been started." (Transvaal Nature Conservation Division, 1983).

- "Three crocodile censuses were undertaken, a maximum of 16 being counted. Three of the animals were caught below the dam on private property and released in the dam. The crocodile population in the dam causes concern and the monitoring programme to determine the cause of the falling numbers is being continued." (Transvaal Nature Conservation Division, 1985).
- "In an effort to replenish the waning numbers of crocodiles in the dam and in the upper reaches of the river, a further six crocodiles were released" (Transvaal Nature Conservation Division, 1986).

All of this prompted Jacobsen to suggest that the Nile crocodile population in the Loskop Dam may very well be on the decline and that it would only be a matter of time before this population became extinct (Jacobsen 1984).

The Loskop Dam is situated in a narrow opening or "poort" in the Olifants River approximately 32km south (upstream) of the town of Groblersdal in the Mpumalanga province of South Africa. Construction work on the Loskop Dam commenced in 1934 and was completed during 1938 by the Department of Water Affairs (Loskop Irrigation Board, 2009). A decision was later taken to increase the height of the wall and construction on the increase of the wall height was completed in 1979 raising it to its current height of 54m above the foundation (Loskop Irrigation Board, 2009).

The catchment area of the Loskop Dam is 12 300km^2 and at full supply level the surface area of the dam covers 2 350ha with the net storage capacity of the Loskop Dam currently given as 348 million m^3 of water making it one of the five largest dams in the Olifants River system (Loskop Irrigation Board, 2009). The main propose of the Loskop Dam is to provide water to the Loskop Water Scheme which supplies water for irrigation to over 16 117ha of agricultural land on 702 properties via a canal system with a total length of approximately 495km (Loskop Irrigation Board, 2009). Wheat, vegetables, tobacco, peanuts, cotton, citrus and grapes are cultivated using water from the scheme. Apart from the Loskop Water Scheme, water from the Loskop Dam is also supplied to the Hereford Irrigation Board, Olifants River Irrigation Board and the Groblersdal and Marble Hall Municipalities (Loskop Irrigation Board, 2009).

Two main reasons have been put forward to explain the decline in crocodile numbers in the Loskop Dam. The first being that pollution from higher up in the Olifants River catchment could have a detrimental effect on the reproductive potential of the crocodiles in the dam and secondly that the raising of the Loskop Dam resulted in flooding of basking and nesting areas making these unusable by crocodile (Jacobsen, 1984). The unexplained periodical deaths of large numbers of crocodiles in the Loskop Dam remain very disturbing to this day. Therefore, this study aims to determine the numbers, sizes and distribution of Nile crocodiles in the Loskop Dam due to the apparent decline in crocodile numbers in the dam.

Jacobsen warned in 1984 that should the decline in crocodile numbers in the Loskop Dam be a result of pollution, then recovery is unlikely and re-introduction of crocodiles into the system would be pointless. However, more than 20 years after Jacobsen's warnings, we are unfortunately no nearer to an answer for the question: "What is happening to the Nile crocodiles of the Loskop Dam?"

METHODS

Surveys of the crocodiles in the Loskop Dam were done using two methods, aerial counts from aircraft and spotlight counts from boats.

The 2001 aerial survey was done as an incidental survey to investigate the possibility of gathering baseline data on the numbers and size class distribution of Nile crocodiles in the Loskop Dam while the 2005 and 2009 aerial surveys formed part of the bigger survey of the entire Olifants River (see chapter 3).

Helicopters were used during the 1981, 2005 and 2009 aerial counts but a microlight aircraft was used for the 2001 aerial count (see Table 11). When using a helicopter, the survey team consisted of the pilot and a navigator seated in the front of the helicopter with two observers sitting in the back of the helicopter. Team members in the back of the aircraft are responsible for observing to the left and the right-hand side of the helicopter. During aerial counts using a microlight aircraft, the pilot acted as second observer looking out to the front, left and right of the aircraft while the passenger (sitting behind the pilot) observed to the left and right of the aircraft and operated the GPS and/or palm computer. All aerial counts were done with the aircraft flying at a constant height of about 100 to 150 feet while maintaining a constant ground speed of about 60 to 65 kph following the shoreline in one direction. The observers counted all crocodiles spotted and also estimated every animal's total length (TL) to the nearest metre. The position of each crocodile counted was marked with a handheld Global Positioning System (GPS) and the TL noted down with the waypoint number on a datasheet or palm computer. Data were later downloaded from the GPS and/or palm computer and datasheets to a notebook computer.

The size of completely submerged crocodiles was estimated using certain environmental and behavioural characteristics. These included factors such as habitat type, water depth, water swirl, mud trails and wakes (Jacobsen, 1984; Woodward and Moore, 1993). According to Jacobsen (1984) the tendency to underestimate the size of crocodiles spotted from the air is regarded as a constant factor and can therefore be ignored. While it is difficult to spot hatchlings and smaller sized crocodiles from the air, Woodward and Moore (1993) suggest that despite its weakness, the approach to include "unknown length" animals is still superior to ignoring them in the analysis of different size classes. Economic reasons eventually necessitated the decision to concentrate on spotlight counts rather than aerial counts to monitor population trends in the Loskop Dam Nile crocodile population. However, spotlight counts are regarded by many authors as a suitable and reliable method for estimating crocodilian population size (Webb and Messel, 1979; Bayliss, Webb, Whitehead, Dempsey and Smith, 1986; Hutton and Woolhouse, 1989; Games, 1990; Woodward and Moore, 1993).

Since 2006 spotlight counts were used to establish the number and size class distribution of Nile crocodiles in the Loskop Dam. An eight metre fibreglass hull boat equipped with a single 80 hp Yamaha outboard motor was used for every count. During these counts, Nile crocodiles were located using an 800 000 candlepower halogen spotlight and identifying the reflective eye-shine that characteristically glows red.

Counts were normally started after sunset as soon as conditions became dark enough to use the spotlight. The boat was always operated at an average speed of about 10 - 15 kph while using the same route. The crew consisted of two researchers (one of whom also piloted the boat) who both spotted and counted crocodiles. The coordinates of all crocodiles found in this manner would be marked by GPS while the observers would also estimate the animal's total length to the nearest metre. Crocodiles that submerged before size estimation could be made were noted as "unknown" length animals. Woodward and Moore (1993) commented on this method of size estimation saying that the ability of observers to detect crocodilians increases quickly with experience. Data were later downloaded from the GPS and/or palm computer and datasheets to a notebook computer.

In both types of survey, the total length of individual crocodiles encountered where estimated to the nearest metre and animals assigned to the following broad size classes:

Class 1: Small sized crocodiles (TL <1.5m)

Class 2: Medium sized crocodiles (TL 1.5 - 2.0m)

Class 3: Large sized crocodiles (TL 2.0 - 4.0m)

Class 4: Very large sized crocodiles (TL >4.0m)

Unless stated otherwise, all statistics were calculated using the data analysis tool of Microsoft Excel 2007 part of Microsoft Office Professional 2007 with Windows 7 Professional as operating system.

RESULTS

The surveys produced a very low total number of crocodiles and also a very poor distribution of crocodiles over the size classes compared to that expected to be present in healthy populations. A total of only 8 crocodiles were found in the whole of the Loskop Dam during the 2006 spotlight survey (Table 11). This included the Olifants River as far as the boat could navigate upstream. Previous surveys in 2001 and 2005 produced similar low results of 10 and six animals respectively. Also of interest is that no crocodiles in the large (2.0 - 4.0m) size class were found during the July 2006, January 2007, August 2007, August

Table 11: Summary of Nile crocodile surveys in the Loskop Dam showing size distribution and density of crocodiles/km of available shoreline.

Survey year	Type of survey	Size class					Total number	Adjusted number	Number re-introduced	Density (crocs/km)
		< 1.5m	1.5-2.0m	2.0-4.0m	>4.0m	Unsure				
1981[#]	Aerial survey	0	2	3	1	0	6	9	0	0.09
2001	Aerial survey	1	0	9	0	0	10	15	0	0.14
December 2005	Aerial survey	2	1	3	0	0	6	9	0	0.09
July 2006	Spotlight survey	7	1	0	0	0	8	12	0	0.11
January 2007	Spotlight survey	6	4	0	0	2	12	18	0	0.17
August 2007	Spotlight survey	7	7	0	0	2	16	25	13	0.23
August 2009	Spotlight survey	2	7	0	0	1	10	15	0	0.14
November 2009	Aerial survey	2	4	0	0	0	6	9	0	0.09
February 2010	Spotlight survey	1	3	0	0	0	4	6	0	0.06
August 2010	Spotlight survey	0	2	0	0	2	4	6	0	0.06
Total all surveys		**28**	**31**	**15**	**1**	**7**	**82**	**126**	**13**	-
Mean all surveys		**3**	**3**	**2**	**0**	**1**	**8**	**13**	-	**0.12**
Standard deviation		**2.78**	**2.42**	**2.92**	**0.32**	**0.95**	**3.82**	**5.89**	-	**0.05**

[#] = Jacobsen (1984)

2009, November 2009, February 2010 and August 2010 surveys whereas no crocodiles in the very large (>4.0m) size class were found during the 2001, 2005, 2006, 2007, 2009 and 2010 surveys (Table 11). Although these surveys failed to locate any crocodiles in the over 4.0m TL category, they did at least confirm the presence of at least three crocodiles in the 2.0 - 4.0m size class during 2005 but by 2006 these crocodiles also disappeared from the dam (Table 11). The current crocodile population density in the Loskop Dam is very low at 0.06 crocodiles/km of shoreline (Table 11). This figure has remained very low over the years since 1981. The standard deviation of the population density figures is 0.05 (Table 11) which indicates that the figures do not deviate from the mean density very much and remain fairly stable at a low level. However a scatter plot graph shows that crocodiles in the 2.0 - 4.0m TL and > 4.0m TL size classes have been clearly been declining in numbers over the last 27 years (Figure 21).

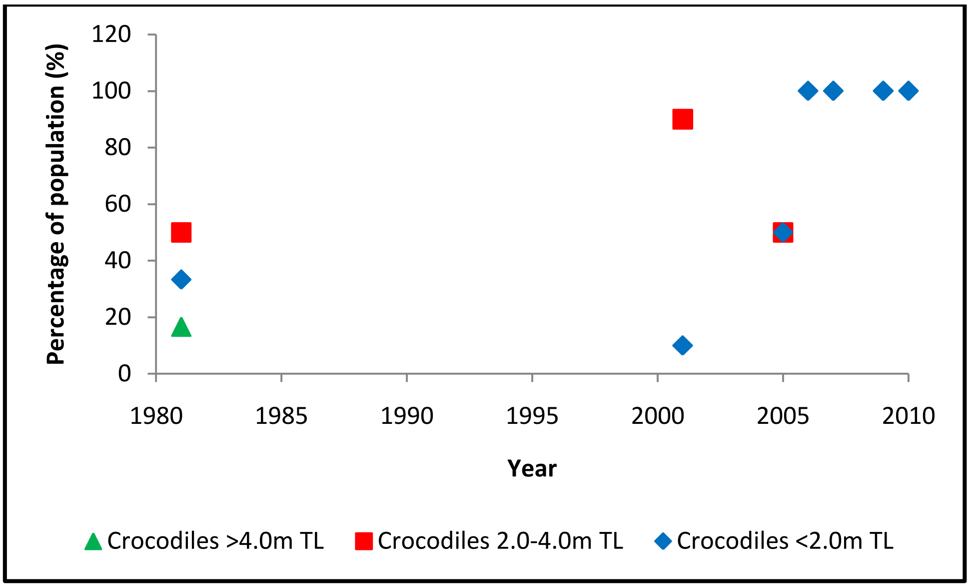

Figure 21: An illustration of the changes in the age structure of the Loskop Dam population of Nile crocodiles since 1981 (Data from Table 11).

During the 2001, 2005, 2006, 2007, 2009 and 2010 spotlight surveys crocodiles were found in the Olifants River around the western inlets of the dam and also in the area of the eastern inlets of the dam at the Kranspoortspruit and Scheepersloop areas (Figure 22). The distribution pattern of crocodiles in the Loskop Dam does not vary in any meaningful way between winter and summer periods (Figure 22) over a total of six spotlight surveys since 2001.

The line graph of the total population numbers (Figure 23) indicate that the population is declining. During 1979 a total of 21 crocodiles were counted in the Loskop Dam (Jacobsen, 1984) which translates to an estimated 32 animals which could have been present in the dam at that time. However, the February and August 2010 spotlight survey results (Table 11, Figure 23) confirm that the population is currently at an extremely low level with an only an estimated 6 animals in the total population. The brief increase registered during the July 2006 and January 2007 spotlight surveys is likely to be a function of the observers gaining experience rather than of a successful population increase.

However, an important factor is that a total of 13 animals were re-introduced during March 2007 causing an artificial increase in the number of crocodiles present in the dam during the August 2007 spotlight survey but the August 2009 spotlight survey results clearly show that these animals did not survive over the long term (Table 11, Figure 23).

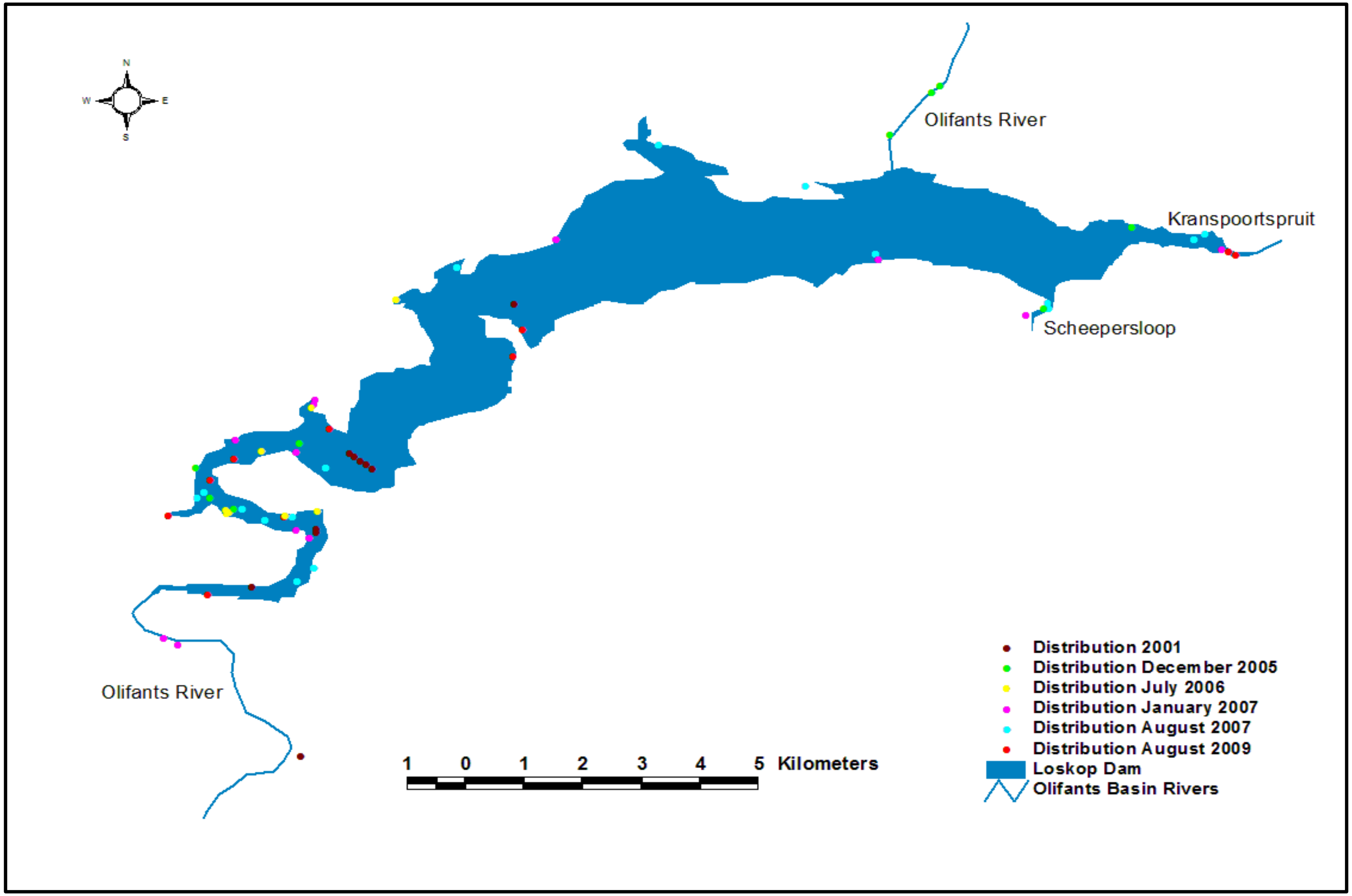

Figure 22: Distribution of Nile crocodiles in the Loskop Dam during surveys done in 2001, 05, 06, 07 and 09 (one dot represents one animal).

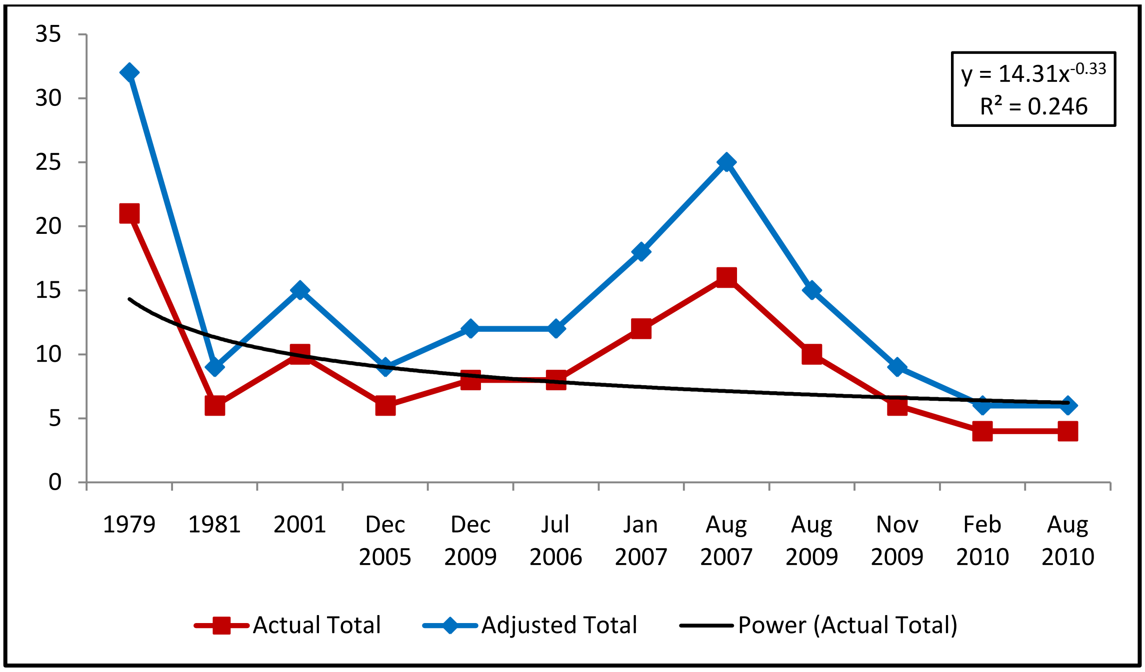

Figure 23: Actual number of Nile crocodiles counted in the Loskop Dam and the adjusted number of Nile crocodiles present in the Loskop Dam during survey years (The spike in August 2007 represent the experimental release of 13 Nile crocodiles into the system).

The 1981 population structure reported by Jacobsen (1984) indicates that the segment of the population consisting of small and medium sized crocodiles (all crocodiles less than 2.0m TL) are smaller in number than the large size class which consist of crocodiles between 2.0 and 4.0m TL (Figure 24). By 2001 and 2005 the crocodiles in the over 4.0m TL size class have disappeared from the population (Figures 25 and 26) and are still absent during 2006, 2007, 2009 and 2010 (Figures 27, 28, 29 and 30). However, by 2006, 2007, 2009 and 2010 all crocodiles in the 2.0 - 4.0m TL size class have also disappeared from the population (Figure 27, 28, 29 and 30).

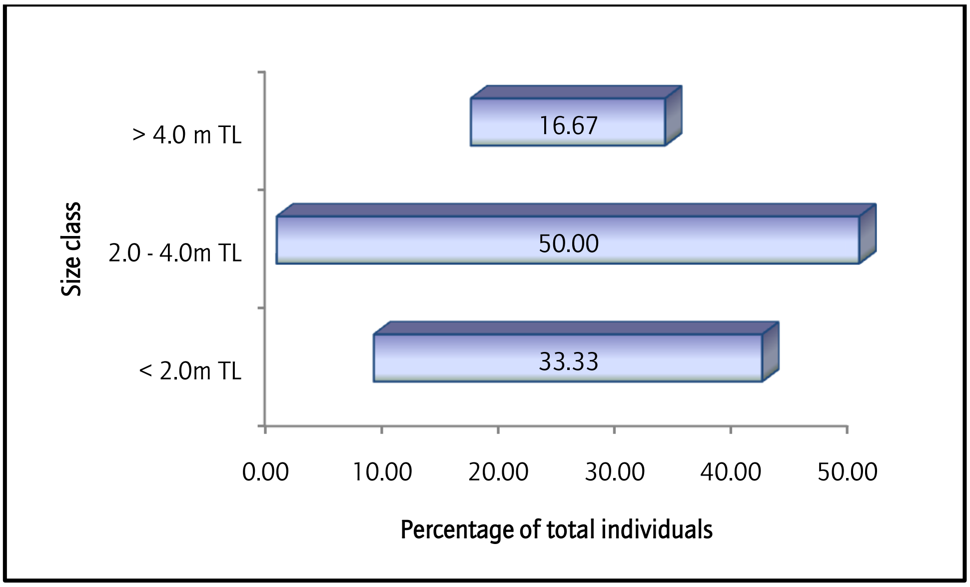

Figure 24: Population structure of Nile crocodiles (both sexes combined) in the Loskop Dam during 1981 based on aerial survey results reported by Jacobsen (1984).

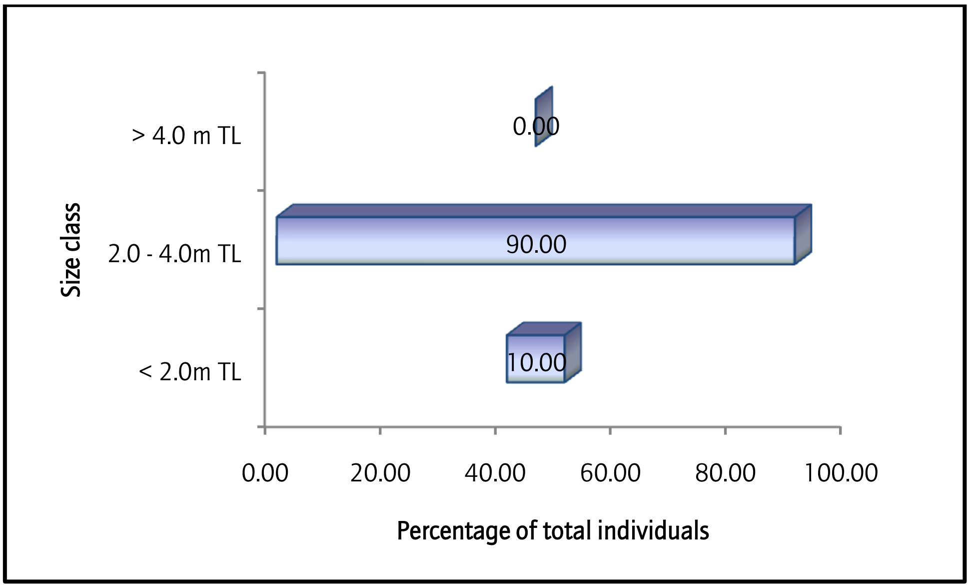

Figure 25: Population structure of Nile crocodiles (both sexes combined) in the Loskop Dam during 2001 based on aerial survey results.

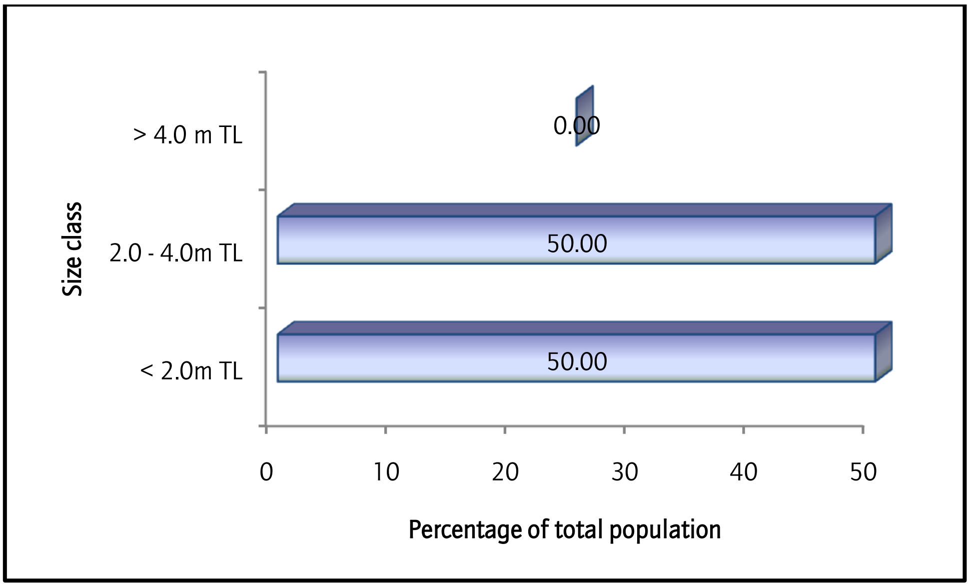

Figure 26: Population structure of Nile crocodiles (both sexes combined) in the Loskop Dam during 2005 based on aerial survey results.

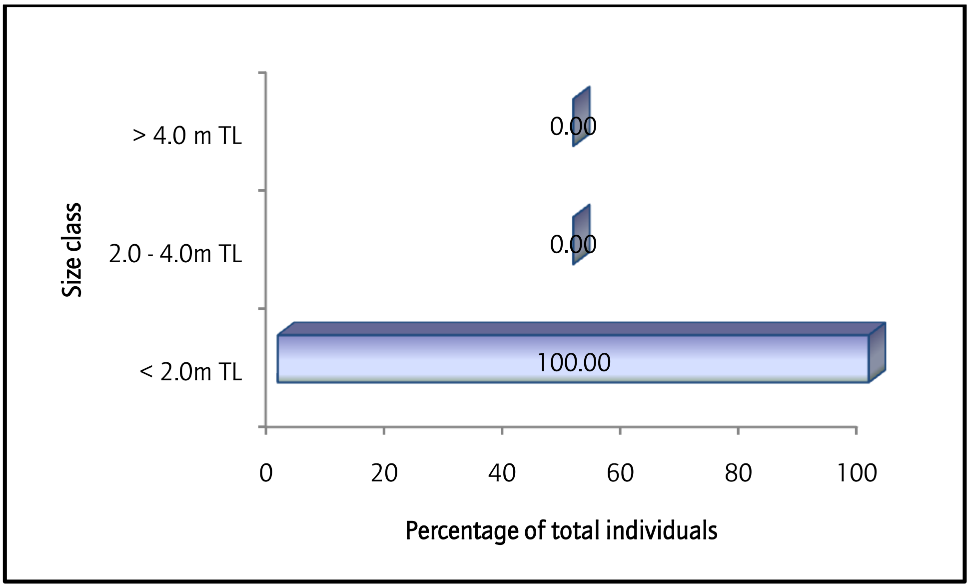

Figure 27: Population structure of Nile crocodiles (both sexes combined) in the Loskop Dam during June 2006 based on spotlight survey results.

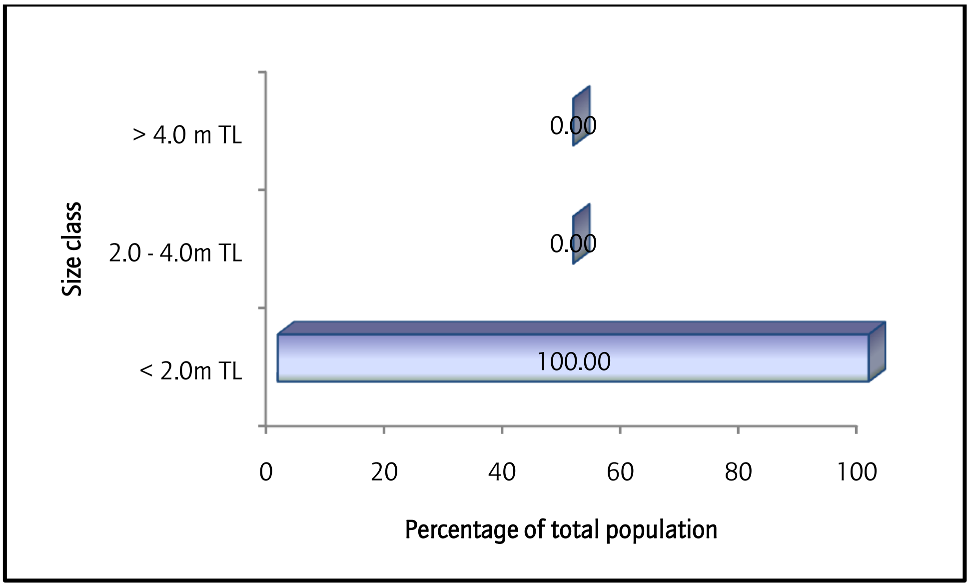

Figure 28: Population structure of Nile crocodiles (both sexes combined) in the Loskop Dam during January 2007 based on spotlight survey results.

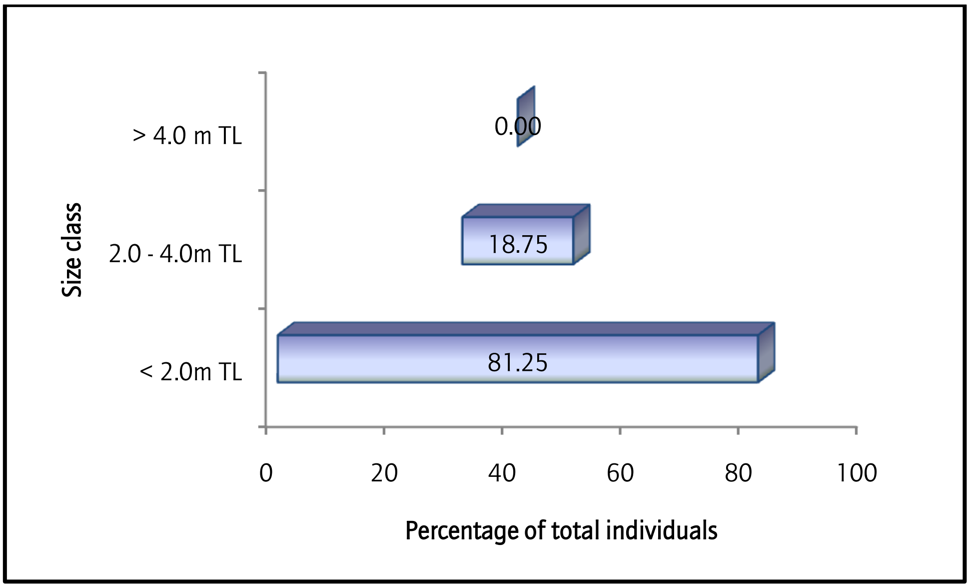

Figure 29: Population structure of Nile crocodiles (both sexes combined) in the Loskop Dam during August 2007 based on spotlight survey done after the experimental release of juvenile crocodiles in the dam.

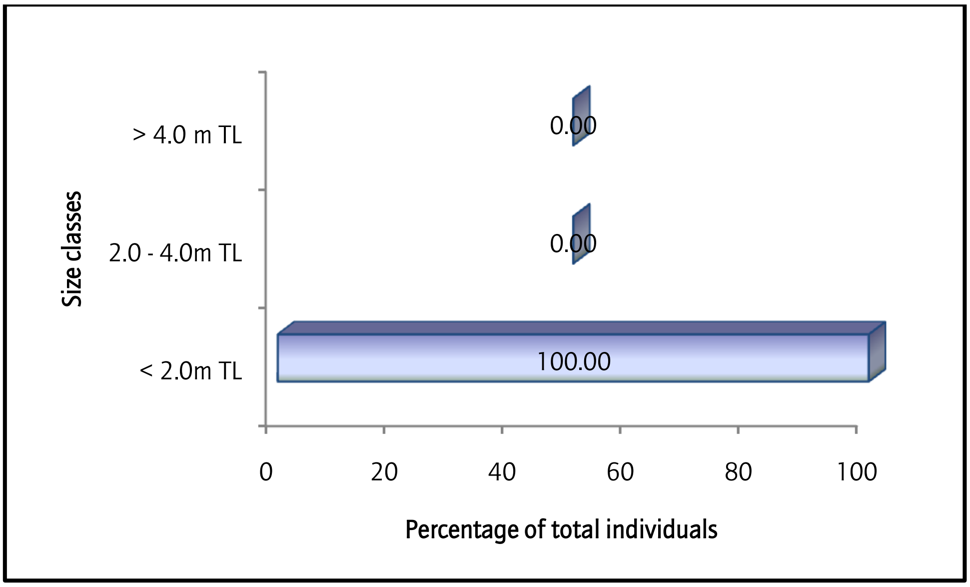

Figure 30: Population structure of Nile crocodiles (both sexes combined) in the Loskop Dam during August 2009 based on spotlight survey results.

DISCUSSION

The results of the different surveys indicate several interesting possibilities with regards to the Nile crocodile population in the Loskop Dam. The low total number of individuals encountered in the Loskop Dam during the 2006 and 2009 surveys corresponds closely with that of the 2001 and 2005 surveys. More importantly, the low number of animals in 2006 is virtually the same as the result of the 1981 survey and the very low numbers from the 2010 surveys indicate that recruitment via reproduction or immigration from the Olifants River system into the dam has been almost nonexistent for decades. This indicates that the observed decline in population size did not change over the long term is not a function of a naturally fluctuating population or poor censusing techniques.

Crocodiles do not show fluctuations in population size quickly because they are long lived animals with long generation times. Further, given the reintroductions that occurred during 1983/1984 (three crocodiles), 1984/1985 (six crocodiles) and 2007 (13 crocodiles), the population should surely have shown at least some change over 25 years but it did not.

Taking the number of animals not seen into consideration (Botha, 2005; Swanepoel, 2001; Bayliss 1987) the estimated total number of crocodiles in the Loskop Dam is possibly between four (4) and six (6) animals. This underlines the lack of population growth over a period of 28 to 30 years.

The influence that a population of animals exerts on the ecosystem depends largely on the number of animals in that population, in other words it depends on the density of the population (Odum, 1971). Population density is expressed as the number of crocodiles per kilometre of shoreline in a particular area. The population density of the current crocodile population in the Loskop Dam converts to 0.06 crocodiles/km of shoreline (Table 11). It is conceded that all of the shoreline is not good habitat but it once was good habitat. Historical records show that human settlement of the area where the dam is today started as long ago as 1886 (Loskop Irrigation Board, 2009) and that crocodiles where abundant along the Olifants River then. Therefore, it is intended to show the loss of habitat that occurred over time by taking all of the shoreline into account when determining the density of crocodiles in the area. The densities indicate a gradual increase which can be explained by the experimental re-introduction of 13 animals into the population but overall the density trend seems to indicate that the population has been at a very low level since 1981. The standard deviation for the population density from all surveys is 0.05 indicating that the figures do not deviate much from the mean. Therefore, although the total counts fluctuate, the population density remains stable at a very low level proving that the population is already severely depleted. This supports the hypotheses that the observed decline in the population numbers has continued over the long term and is not a function of a naturally fluctuating population. When compared to other crocodile populations in similar habitats (i.e. living in dams or lakes) the low population density of the Loskop Dam becomes abundantly clear (Table 12). The Flag Boshielo Dam situated downstream from the Loskop Dam in the Olifants River has a density of 3.25 crocodiles/km of shoreline. The Olifants River in the Kruger National Park has a density of 3.98 crocodiles/km of shoreline while the Olifants River Gorge in the Kruger National Park has an astounding density of 30.00 crocodiles/km of shoreline (Botha, 2005). All of this underlines the fact that the current crocodile population in the Loskop Dam is severely depleted at a density of only 0.06 crocodiles/km of shoreline.

Table 12: Comparison of Nile crocodile population densities from the Olifants River in South Africa.

Crocodile population	Reference	Length of shoreline (km)	Number of crocodiles	Density (crocodiles/km)
Flag Boshielo Dam (Olifants River, South Africa)	Botha, 2005	65	211	3.25
Kruger National Park (Olifants River, South Africa)	Current study	95	379	3.98
Olifants River Gorge (Olifants River, South Africa)	Current study	10	300	30.00
Olifants River between Loskop Dam and Flag Boshielo Dam	Current study	80	24	0.30
Loskop Dam (Olifants River, South Africa)	Current study	70	4	0.06

The stationary nature in the size of the crocodile population suggests that a situation have been reached where the mortality of the population is at least equal to but possibly even higher than recruitment into the population. Such a situation certainly indicates that the population is fast nearing the point where it won't be able to sustain itself and start to decline until none are left. In addition to the stationary nature of the population, no hatchling crocodiles (animals less than one year old) have been found during either the 2006, 2007, 2009 or 2010 spotlight surveys. The dynamics of the population is seriously challenged with only one animal in the >4.0m size class being reported during the 1981 survey and none during any of the subsequent surveys. These very large animals are considered to be the dominant animals necessary for normal competition, behaviour and successful nesting in any population. It is my contention that complete absence of this size class in a wild population will hamper that population's chances of expanding normally since large crocodile must have an ecological purpose in the population. Their disappearance from the population is unlikely to be linked to the lack of nesting areas because one would then expect the small crocodiles to disappear first due to no recruitment taking place and this did not happen. Age pyramids constructed from the various sets of aerial survey data reported by Jacobsen (1984) show that in 1981 the Loskop Dam population had an age distribution characteristic of a declining population (Figure 23) with the number of small and medium sized crocodiles (all crocodiles less than 2.0m TL) being less than the large size class which consist of crocodiles between 2.0 and 4.0m TL (Figure 24). This is a highly skewed population and could indicate a shrinking population due to poor recruitment or possibly a problem with the survey technique. However, the population changed to a top heavy structure in 2001 with few juvenile animals and a large proportion of adult animals (Figure 24) which is normally indicative of a population associated with deteriorating habitat (Odum, 1971; Ryke, 1978). By 2005 the population structure seems to have become stationary with an equal distribution of young and adult animals (Figure 25). The final age pyramids from 2006, 2007 and 2009 clearly show that all animals over 2.0m TL have disappeared out of the population (Figure 26, 27, 28 and 29). Age pyramids confirm the complete absence of any dominant animals in the population since at least 2001 while the large scale die-off of crocodiles during the period 2005 to 2007 are also reflected in the age pyramids.

A primary concern remains to be the lack of animals observed in the 2.0 - 4.0m TL size class during the latest surveys of 2006, 2007 and 2009. If one accept that animals in the >4.0m TL size class is absent from the population then one would expect the next size class (2.0 - 4.0m TL) to “stand in” so to speak for the dominant animals. However, if they too are now absent from the population then Jacobsen’s remark of the population becoming extinct is probably about to be realised in our lifetime (Jacobsen, 1984).

Die-off events in the Nile crocodile population at Loskop Dam at intervals over the last 28 years have been well documented in nature conservation files at the Loskop Dam Nature Reserve. Anecdotal evidence describe die-off events where only large (2.0 - 4.0m TL) animals were reported to have died. This could very well be the reason for their total absence from the population during the latest survey. It is important that this factor be confirmed by further surveys especially during the next couple of breeding and nesting seasons.

The distribution pattern of the crocodiles in the Loskop Dam indicates that crocodiles only really occur in numbers in the river-like area at the inlet of the Olifants River to the dam (Figure 21). This is possibly due to the raising of the dam wall which has rendered all other areas in the dam unsuitable for crocodiles. The impact of this is that the population now concentrates in areas of the river where the effects of pollution is probably worse than anywhere else in the dam due to there being less water in the river to dilute pollution agents compared to the rest of the dam. Therefore the distribution of crocodiles, because of the raising of the dam is placing them in an area where they experience pollution at higher levels than elsewhere in the dam. This could very well be a critical element in the episodes of periodic die-off witnessed in the Loskop Dam.

During the 2001, 2005, 2006, 2007, 2009 and 2010 surveys crocodiles were found to occur mostly in the Olifants River and around the inlets of the dam including the inlets of the Kranspoortspruit and Scheepersloop areas (Figure 21). The results of nine surveys since 2001 show that the distribution pattern of crocodiles in the Loskop Dam does not vary in any meaningful way between winter and summer periods (Figure 21). Distribution patterns and movements in crocodilian populations are usually associated with important population milestones such as the onset mating and nesting during summer. Definite seasonal distribution patterns are known to occur in the larger Nile crocodile population of the Flag

Boshielo Dam downstream from the Loskop Dam (Botha, 2005). The total absence of any seasonal variation in distribution support the hypothesis that no crocodiles in the large and very large size class currently occur in the Loskop Dam. It also indicates that important behaviour and population milestones do not occur in the Loskop Dam population any longer indicating that this is an unstable population. Crocodiles are regularly spotted directly below the dam wall in the Olifants River (Figure 21) indicating that the river downstream of the dam is still suitable habitat for crocodiles. In fact, 3.5 times more crocodiles were counted downstream of the Loskop Dam than in the dam itself during the 2005 aerial survey of the entire Olifants River.

CONCLUSION

The total number of Nile crocodiles in the Loskop Dam has been declining over the last 25 to 30 years. In addition there are no surviving large animals over 2.0m TL in the entire Loskop Dam leaving it in crisis for future breeding seasons. Age pyramids also confirm the complete absence of any dominant animals in the population since at least 2001. Die-off events over the period 2005 to 2007 had devastating effects on the Nile crocodile population of the Loskop Dam. It is likely that the historical distribution pattern of crocodiles in the Loskop Dam are exposing them to concentrated pollutants in the inlets of the dam as opposed to the main water body of the dam where the volume of water probably have a diluting effect on pollutants in the aquatic system. It is clear that the experimental re-introduction of crocodiles to the population failed to stabilise or contribute to its growth.

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CHAPTER 5

BLOOD BIOCHEMISTRY OF NILE CROCODILES IN THE OLIFANTS RIVER

INTRODUCTION

Blood biochemistry and haematology is used by veterinary surgeons to detect conditions affecting the health of many animals including reptiles (Campbell, 2006). Conditions detected through evaluation of the blood biochemistry and haematology of reptiles includes anaemia, inflammatory diseases, parasistemias, hematopoietic disorders and haemostatic alterations (Campbell, 2006). According to Campbell (2006), normal hematologic values for reptiles (including crocodilians), as determined by different laboratories, vary significantly due to differences in blood sampling, handling, analytic techniques, differences in the environmental conditions of the reptiles' habitat, physiologic status of the reptile, its age, gender and nutrition and the use of anaesthetics. Although blood biochemistry profiles are often used to assess the physiological status of reptilians, the clinical chemistry has not achieved the same degree of critical evaluation as seen in mammals (Campbell, 2006). Reference ranges for biochemical and also haematological values in Nile crocodiles are currently limited (Lovely, Pittman and Leslie, 2007) whereas similar reference ranges for biochemical and haematological values for saltwater crocodiles (*Crocodylus porosus*) was established for 1 to 2 year old animals only (Millan *et al.*, 1997) and some parameters have been established for female American alligators (*Alligator mississippiensis*) only (Guilette *et al*., 1997). Because of the difficulty in obtaining meaningful reference intervals for each species of reptile (Campbell, 2006), decision levels are often used when assessing reptilians. The Concise Dictionary of Modern Medicine (Segen, 2002) defines decision levels as an alternative to a reference value for reporting laboratory results; when decision levels are exceeded, a response by a clinician is required. Baseline health assessments of wild reptiles are, however, vital for detection of underlying health problems in reptilian populations. Studies that provide insight into the blood biochemistry and haematological values of reptilian populations provide important reference and comparative values for future health assessments (Gillespie *et al.,* 2000). Apart from being relevant in veterinary medicine, blood biochemistry is also an important tool in providing physiological indicators in wildlife and conservation programmes (Elamin, 2004). The usefulness of this tool in ecological studies was demonstrated by Le Resche *et al.* (1974) as well as by Seal *et al.* (1981) in Franzmann (1985). It is expected that evaluation of blood biochemistry results will indicate the basic general health of Nile crocodiles in the Loskop Dam, the Flag Boshielo Dam, the Blyderivierspoort Dam and the Olifants Gorge populations and thus allow speculation regarding the overall health of crocodile populations in the Olifants River. These populations have been chosen as research sites because they represent populations in the upper, middle and lower Olifants River with the Blyderivierspoort Dam, which is considered to be an unpolluted tributary of the Olifants River, being the control population.

METHODS

A total of 30 Nile crocodiles were captured during the period October 2007 to September 2008 at selected sites (Loskop Dam, Flag Boshielo Dam, Blyderivierspoort Dam and Olifants Gorge) in the Olifants River. No large and very large sized crocodiles occur in the Loskop Dam, therefore only small and medium sized crocodiles were caught in this area. The small number of animals in the Loskop Dam population severely limited our ability to capture a large sample of crocodiles from this lake and consequently we settled for a sample size of four animals out of an estimated population of 18 animals (Chapter 3) meaning that 22.2% of the population was sampled.

The change in habitat due to the increase in height of the Flag Boshielo Dam-wall also made it difficult to capture crocodiles in that lake. Flooding of large stands of *Acacia burkei* due to the increased height of the wall effectively prevented the capture crew from approaching crocodiles during capture operations and increased the possibility that crocodiles would be lost as a result of entanglement of the capture rope in the dense submerged *Acacias*. As a direct result of these problems, only 6 Nile crocodiles were successfully captured in the Flag Boshielo Dam for this study.

The Nile crocodile population in the Blyderivierspoort Dam was chosen as a control population since the Blyde River catchment is situated in a protected area and the river is therefore minimally affected by pollutants. The Blyde River is currently regarded as a class B river by the river component of the South African National Spatial Biodiversity Assessment (Nel *et al.* 2004). Class B rivers are categorised as largely natural while the Blyde River is also regarded as endangered in terms of its conservation status (Nel *et al.*, 2004). The Blyderivierspoort Dam population is however quite small due to the habitat not being able to sustain large numbers of Nile crocodiles. The survey sample of 3 animals from a total population of about 15 (20%) was deemed sufficient.

All Nile crocodiles studied were captured using a modified version of the methods described by Chabreck (1965), Kofron (1989) and the Florida Fish and Wildlife Conservation Commission (2003), adapted to suit local conditions and tried and tested in a previous study (Botha, 2005). Nile crocodiles were located at night by their reflective eye-shine that is a characteristic red glow using an 800 000 candlepower halogen spotlight. Animals identified for capture were approached with a boat (eight metre fibreglass hull with 80 hp Yamaha outboard motor). Capture equipment consisted of a standard self-locking 3S-72" Thompson steel snare (Thompson Snares, Lynnwood, Washington, USA) attached to a 15 mm heavy duty braided rope by a steel coupling. The snare is kept open by stretching it over a Y-shaped frame attached to a five metre aluminium catchpole. During capture, the snare is positioned just behind the head of the crocodile and pulled tight. The self-locking mechanism on the snare prevents the crocodile from opening the snare and escaping. Crocodiles less than 2.1 m in TL were pulled onto the boat while bigger animals were pulled onto shore for measuring and sampling. All crocodiles caught were physically restrained without the use of narcotics and were released within 15 minutes of being caught.

Once captured and restrained, blood samples ranging between 7 and 10 ml each were collected from the post-occipital venous sinus, dorsal midline and just caudal to the base of the head using a 20 gauge needle and a 10 ml syringe as described by Guillette *et al*. (1996; 1997) and Millan *et al*. (1997). The volume of blood collected depended on the size of the animal. All blood collected was immediately transferred to heparinized blood tubes and kept cool with ice packs. Samples were centrifuged at the end of each evening and plasma samples placed in Cryovails and frozen in liquid nitrogen until analysed in the Clinical Pathology Laboratory at the Department of Companion Animal Clinical Studies at the Veterinary Faculty of the University of Pretoria at Onderstepoort. Blood samples were only collected from living animals and all dead animals found in the study area were intentionally disregarded and did not form any part of the study.

Blood samples were analysed for Total Serum Protein (TSP), Albumin, Globulin, Alanine transaminase (ALT), Alkaline phosphatase (ALP), Aspartate aminotransferase (AST), Glucose, Sodium (Na), Potassium (K), Calcium (Ca^{2+}), Total Calcium (Ca^{Total}), Magnesium (Mg), Serum Inorganic Phosphate (SIP), Cholesterol, Creatinine, Chloride (Cl), Uric Acid, Triglycyrides, Vitamin A and Vitamin E since these are the blood biochemical tests that appear to be the most useful in reptilian diagnostics (Campbell, 2006).

Biochemical analyses were done using a Next/Vetex Alfa Wassermann Analyser (Alfa Wassermann B.V., Woerden, The Netherlands). Total protein was determined using a modified Weichselbaum biuret method (Weichselbaum, 1946). Albumin was measured using the bromocresol green method (Cheesbrough, 2005) while globulin and the albumin:globulin ratio were calculated (Johnson *et al.,* 2002). Alanine aminotransferase (ALT), alkaline phosphatase (ALP) and aspartate aminotransferase (AST) were determined by using standard IFCC methods (Bergmeyer *et al.*, 1977; Tietz *et al.,* 1983; Bergmeyer *et al.,* 1986). The glucose oxidase method (Marks, 1996) was used to determine glucose in the samples. Sodium, potassium, ionised calcium and chloride were measured using an 865 pH/Blood Gas Analyser (Chiron Diagnostics Limited, Halstead), by means of ion selective electrodes. Total calcium was measured by the Arsenazo method (Weissman *et al.,* 1980), magnesium was measured by the zylidyl blue method (American Chemical Society, 1987), cholesterol was determined by enzymatic methods (Abell *et al.,* 1952; Bergmeyer and Grassl, 1983), creatinine was determined by the picrate method (Cheesbrough, 2005) and uric acid by the uricase method (Bauer, 1982).

Analysis of variance (ANOVA) was used to test for statistically significant differences ($P < 0.05$) between location (site) and biochemical values of the blood samples collected, size class and biochemical values of the blood samples collected and also gender and biochemical values of the blood samples collected. Each parameter was tested for normality by applying the Ryan-Joiner test (similar to the Shapiro-Wilk test) using MINITAB

15 STATISTICAL SOFTWARE (Minitab Ltd, Coventry, United Kingdom). Some of the Blyderivierspoort Dam, Loskop Dam and Flag Boshielo Dam results were run twice by the Clinical Pathology Laboratory at the Department of Companion Animal Clinical Studies at the Veterinary Faculty of the University of Pretoria at Onderstepoort to ensure replication of results, in these cases the mean values of the two tests from one sample were used for statistical analyses. Data collected for this study is compared to the work done by Lovely *et al*. (2007) in Botswana because according to their published article, they used the same capture methods, sampling techniques and used the same laboratory as this study did.

RESULTS

The results of the biochemical analysis of blood samples collected from 30 Nile crocodiles in the Loskop Dam, Flag Boshielo Dam, Blyderivierspoort Dam and the Olifants River Gorge are given in table 13.

Collection of blood samples from the Olifants River Gorge took place during August 2008 and September 2008 when an outbreak of pansteatitis caused an estimated 60% of the Nile crocodile in that area to die suddenly. Where data is compared to other author's work this refers only to Nile crocodile blood biochemistry since it would be impossible to compare reptile blood values to those of mammals for instance.

Table 13: Blood biochemical parameters of Nile crocodiles at selected localities in the Olifants River (*n* = 30) compared to other recent studies of Nile crocodile blood biochemistry in southern Africa.

Parameters	Current study										Lovely *et al.* (2007)			Swanepoel *et al.* (2000)	
	Loskop Dam (n = 4)		Flag Boshielo Dam (n = 6)		Blyde River Dam (n = 3)		Olifants River Gorge (n = 17)		Olifants River Combined (n = 30)		Okavango Delta (n = 35)		Okavango Delta Range (n = 35)	Olifants River (n = 6)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Min-Max	Mean	SD
TSP (g/L)	55.64	18.44	44.94	21.82	51.02	23.77	54.90	13.79	52.62	16.67	41.2	-	28.9 - 57.1	-	-
Albumin (g/L)	21.70	2.55	16.23	7.46	17.20	3.39	15.55	2.62	16.28	3.67	14.7	1.8	11.1 - 19.4	11.72	2.69
Globulin (g/L)	51.30	0.28	34.87	22.69	35.80	26.16	39.35	12.05	39.49	13.85	26.5	6.8	16.5 - 42.6	39.20	8.75
A/G	0.43	0.05	0.59	0.28	0.61	0.35	0.42	0.10	0.46	0.16	0.58	0.12	0.34 - 0.79	0.30	0.02
ALT (IU/L)	19.50	0.71	13.00	12.29	30.00	42.43	22.94	15.94	22.00	16.90	43.9	13.1	15 - 63	-	-
ALP (IU/L	28.00	7.07	18.67	12.66	13.00	1.41	9.18	6.94	12.25	9.15	21.1	13.7	3 - 72	-	-
AST (IU/L)	40.00	0.00	24.00	7.00	38.00	45.25	47.00	24.93	42.79	24.24	66.5	56.4	14 - 211	-	-
Glucose (mmol/L)	5.68	2.76	4.01	1.17	3.87	0.65	5.45	2.54	5.04	2.27	3.8	0.5	1.8 - 4.8	5.68	4.01
Na (mmol/L)	144.25	6.03	154.25	16.53	148.67	6.90	145.97	8.75	147.67	10.43	147.9	8.3	122 - 164	141.50	17.17
K (mmol/L)	5.52	0.37	5.42	1.91	5.02	0.39	13.37	7.07	9.90	6.67	4.88	1.03	3.30 - 7.65	4.59	0.70
Ca^{2+} (mmol/L)	0.57	0.44	0.86	0.56	0.56	0.52	0.53	0.66	0.61	0.59	1.35	0.12	1.08 - 1.61	-	-

Table 13 (continued): Blood biochemical parameters of Nile crocodiles at selected localities in the Olifants River (*n* = 30) compared to other recent studies of Nile crocodile blood biochemistry in southern Africa.

Parameters	Current study										Lovely *et al.* (2007)			Swanepoel *et al.* (2000)	
	Loskop Dam (n = 4)		Flag Boshielo Dam (n = 6)		Blyde River Dam (n = 3)		Olifants River Gorge (n = 17)		Olifants River Combined (n = 30)		Okavango Delta (n = 35)		Okavango Delta Range (n = 35)	Olifants River (n = 6)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Min-Max	Mean	SD
Ca^{Total} (mmol/L)	3.10	0.18	2.77	0.60	2.85	0.08	1.38	1.32	2.04	1.27	2.73	0.19	2.34 - 3.15	3.74	2.28
Mg (mmol/L)	1.10	0.11	1.01	0.27	1.06	0.23	0.57	0.59	0.78	0.52	1.15	0.26	0.65 - 1.72	2.24	2.58
SIP (mmol/L)	2.09	0.99	1.64	0.43	2.07	0.46	1.94	0.84	1.91	0.75	-	-	-	1.17	0.50
Cholesterol (mmol/L)	3.23	2.02	4.83	2.56	7.65	0.37	3.77	2.56	4.14	2.56	5.49	2.08	0.0 - 9.86	-	-
Creatinine (µmol/L)	29.38	20.73	26.67	11.52	15.33	12.83	30.18	20.12	27.88	17.94	34.0	10.2	17 - 56	77.67	39.64
Chloride (mmol/L)	108.63	14.63	116.28	3.98	75.85	66.42	115.92	7.86	110.84	22.96	120.3	9.6	97 - 135	113.40	11.95
Uric Acid (mmol/L)	0.17	0.10	0.15	0.07	0.27	0.06	0.20	0.10	0.19	0.09	0.12	0.05	0.04 - 0.30	-	-
Triglycerides (mmol/L)	1.13	-	0.41	0.21	4.38	5.24	1.28	2.10	1.43	2.33	-	-	-	-	-
Vitamin A (µg/L)	330.61	8.41	326.37	18.40	335.81	7.41	200.79	213.62	255.66	172.87	-	-	-	-	-
Vitamin E (mg/L)	7.10	1.48	9.65	3.28	11.00	0.22	6.21	2.97	7.38	3.12	-	-	-	-	-

<u>Total Serum Protein (TSP) (Figure 31):</u>

The mean TSP concentration of all the sample sites combined (52.62 g/L) are much higher than the mean range (41.2 g/L) for Nile crocodiles reported by Lovely, *et al.* (2007) in the Okavango Delta of Botswana (Table 13).

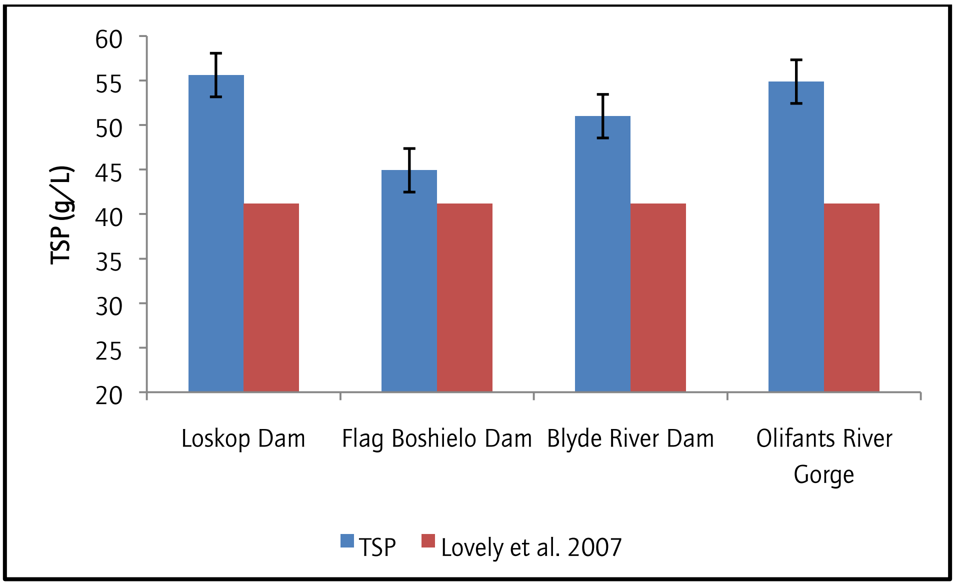

Figure 31: Mean TSP concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) for the Okavango Delta.

<u>Albumin (Figure 32):</u>

Mean albumin concentration at Loskop Dam (21.7 g/L) are higher than the maximum concentration for Nile crocodiles (Lovely, *et al.*, 2007) in the Okavango Delta but the mean concentration for the Olifants River are only slightly higher than those reported for the Okavango Delta (Table 15). However, the mean albumin concentration (16.28 g/L) are near the maximum concentration found in Botswana while Swanepoel *et al.* (2000) reported concentrations (11.72 g/L) during 2000 (Table 13) that correspond much closer to the latest minimum concentrations reported from Botswana. Since all other variables such as the size of animals, capture technique and season of capture where the same when Swanepoel *et al.* (2000) did their study, this could indicate that conditions have changed in the river over the last nine years.

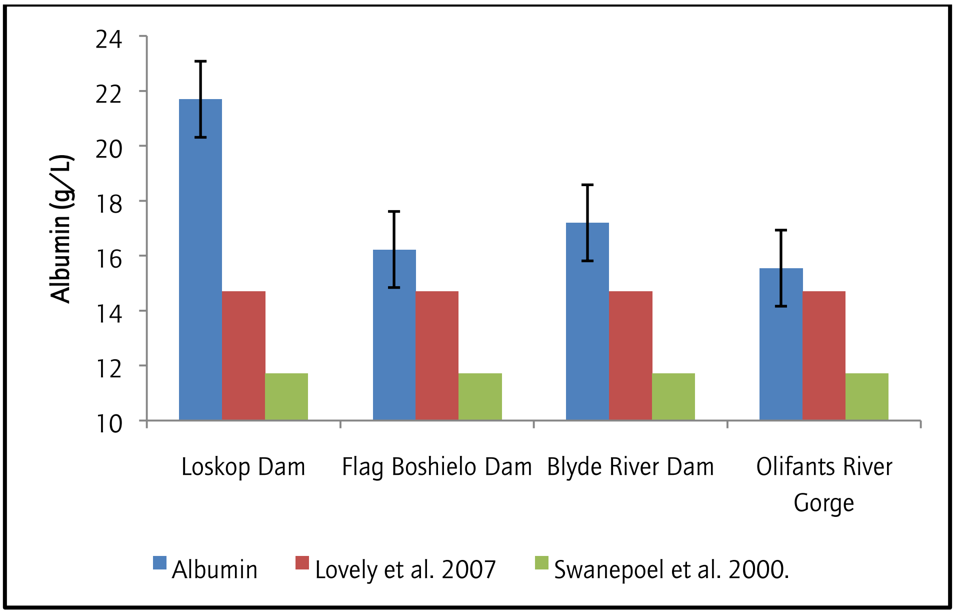

Figure 32: Mean albumin concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) and Swanepoel *et al.* (2000) for the Okavango Delta and Olifants River.

__Globulin (Figure 33):__

Globulin concentrations at Loskop Dam (51.3 g/L) are substantially higher than the maximum concentration for Nile crocodiles in the Okavango Delta as published by Lovely, *et* *al.* (2007). All concentrations except for the Flag Boshielo Dam also exceed those reported by Swanepoel *et al*. (2000) for the Olifants River in the Kruger National Park.

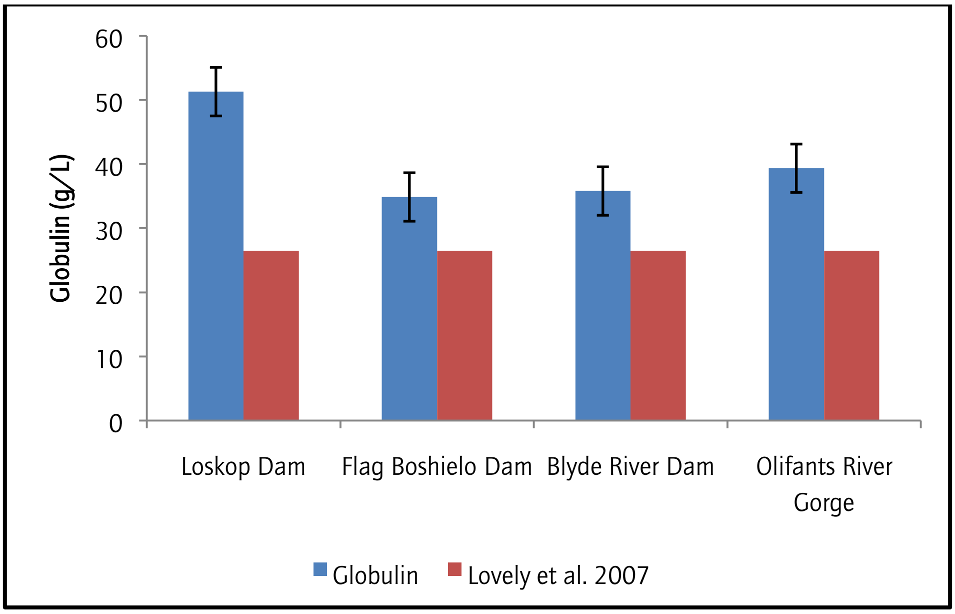

Figure 33: Mean globulin concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) for the Okavango Delta.

Albumin/Globulin ratio (A/G) (Figure 34):

The mean albumin/globulin ratio of plasma samples taken from crocodiles in the Flag Boshielo Dam (0.59) and the Blyderivierspoort Dam (0.61) corresponds closely to the mean concentration reported (0.58) for the Okavango Delta (Table 13). Swanepoel *et al.* (2000) reported a mean albumin/globulin ratio (0.30) from the Olifants River that was lower than the mean minimum concentration found in the Okavango Delta (0.34 - 0.79) by Lovely *et al*. (2007). Results from the Loskop Dam (0.43) and the Olifants River Gorge (0.42) were fairly low although still well within the range (0.34 - 0.79) reported from the Okavango Delta (Table 13).

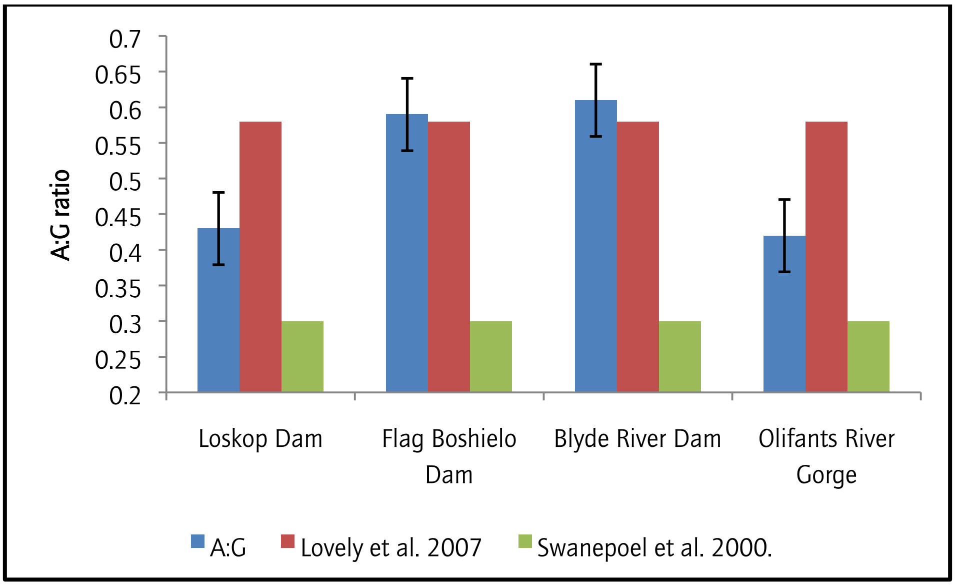

Figure 34: Mean albumin/globulin ratio measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) and Swanepoel *et al.* (2000) for the Okavango Delta and Olifants River.

Alanine transaminase (ALT) (Figure 35):

The mean concentration for alanine transaminase (ALT) at Flag Boshielo Dam (13.0 IU/L) are lower than the minimum concentration for Nile crocodiles in the Okavango reported by Lovely, *et al.* (2007). ALT concentrations at all other sampling sites in the Olifants River registered at concentrations below the mean concentrations measured in the Okavango (Table 13).

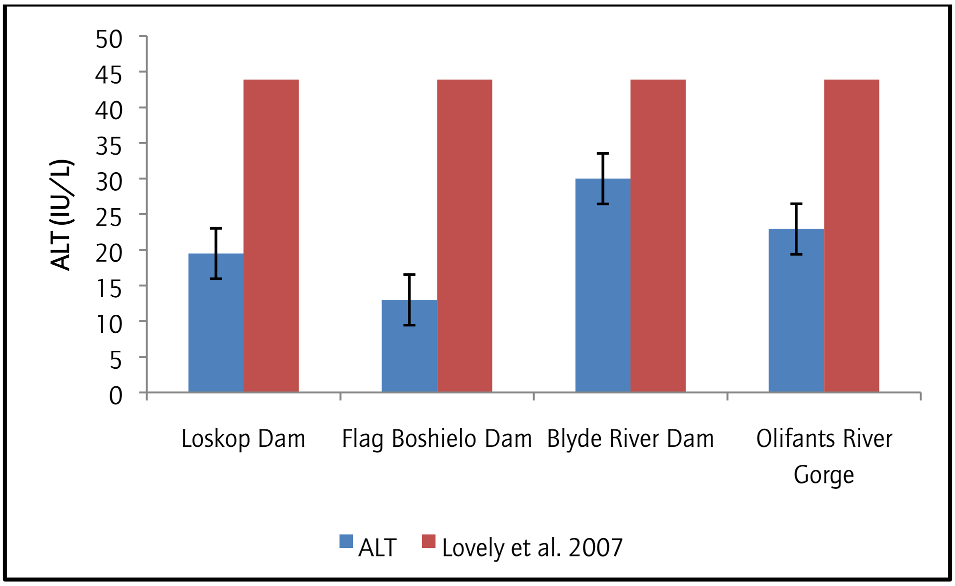

Figure 35: Mean alanine transaminase (ALT) concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) for the Okavango Delta.

Alkaline phosphatase (ALP) (Figure 36):

Alkaline phosphatase (ALP) concentrations in the plasma of Nile crocodiles exhibit a significant difference (P = 0.014) over the length of the Olifants River, in the downstream direction, with the Olifants River Gorge concentrations being much lower than those of the Loskop Dam. The ALP values at Flag Boshielo Dam (18.67 IU/L), Blyderivierspoort Dam (13.00 IU/L) and Olifants River Gorge (9.18 IU/L) are lower than the mean concentrations measured in the Okavango Delta (21.1 IU/L). Analysis of the August and September plasma samples from crocodiles in the Olifants River Gorge showed that ALP concentrations was substantially lower during August 2008 ($\bar{x}$ = 4.500) compared to September 2008 ($\bar{x}$ = 17.000).

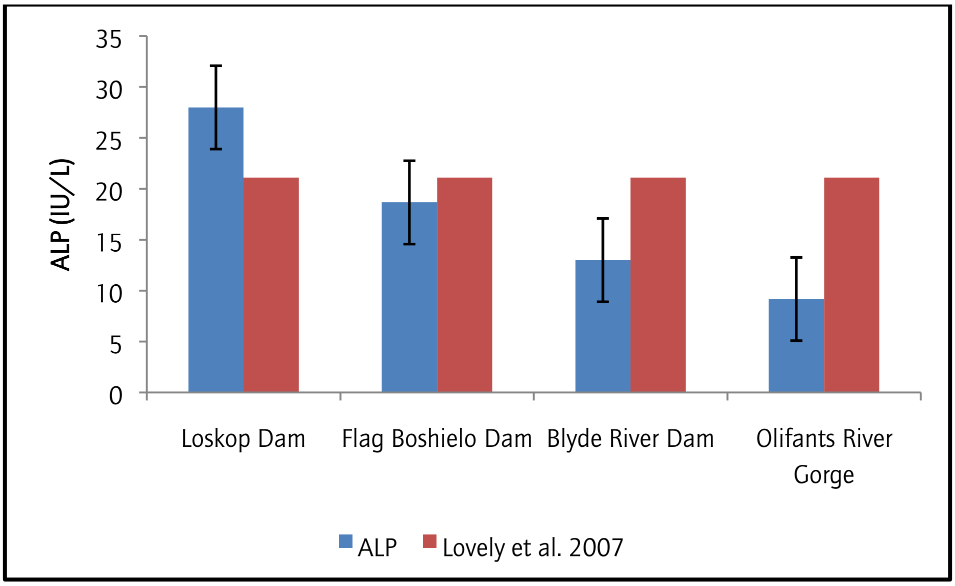

Figure 36: Mean alkaline phosphatase (ALP) concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) for the Okavango Delta.

Aspartate aminotransferase (AST) (Figure 37):

All plasma aspartate aminotransferase (AST) concentrations measured in the plasma of Nile crocodiles in the Olifants River where much lower than the mean AST concentrations found in the Okavango Delta Nile crocodile population (Table 13). In the case of the Flag Boshielo Dam population, the concentration of AST where found to be 24.00 IU/L which is substantially lower than the mean concentration for the entire Olifants River (42.79 IU/L). The Olifants Gorge registered the highest concentration at 47.00 IU/L but this was still substantially lower than the Okavango Delta mean concentration of 66.5 IU/L (Table 13).

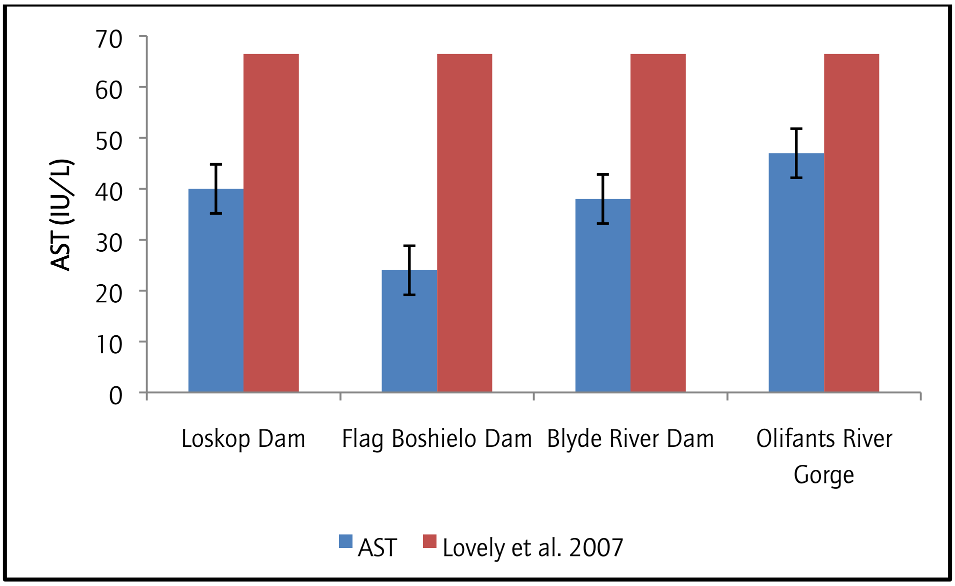

Figure 37: Mean aspartate aminotransferase (AST) concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) for the Okavango Delta.

<u>**Glucose (Figure 38):**</u>

Mean plasma glucose concentrations in the Olifants River Gorge (5.45 mmol/L) and Loskop Dam (5.68 mmol/L) are outside the maximum concentrations (1.8 - 4.8 mmol/L) for Nile crocodiles found in the Okavango Delta as reported by Lovely, *et al.* (2007). However, the mean glucose concentrations found in the plasma of the Blyderivierspoort Dam population (3.87 mmol/L) matched the mean plasma glucose concentrations reported from the Okavango Delta study (3.8 mmol/L) by Lovely, *et al.* (2007). Glucose was recorded at higher concentrations in the plasma of crocodiles in the Olifants River Gorge during August 2008 compared to September 2008 (August $\bar{x} = 6.420$ and September $\bar{x} = 3.100$).

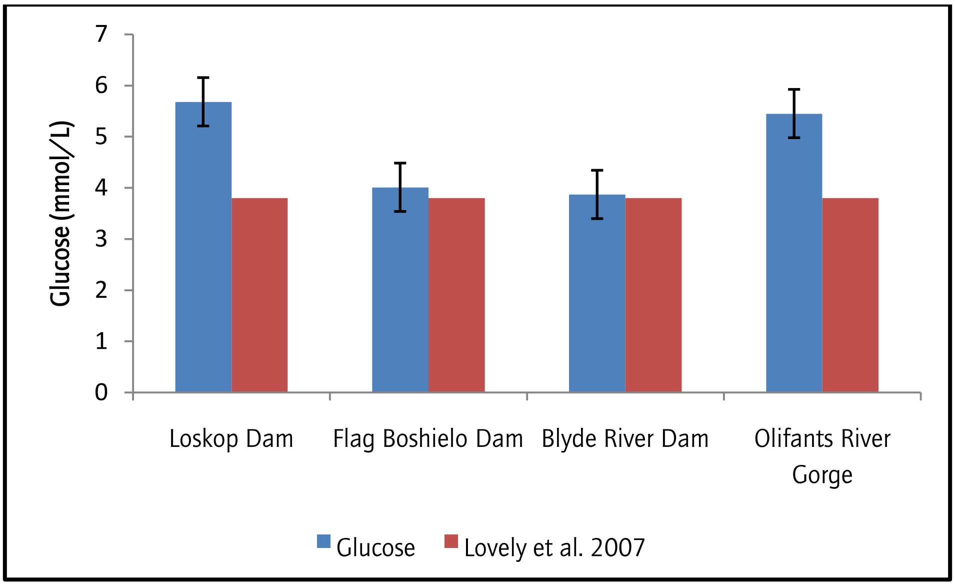

Figure 38: Mean glucose concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) for the Okavango Delta.

<u>Sodium (Na) (Figure 39):</u>

The mean sodium (Na) concentration in the Olifants River (147.67 mmol/L) correspond well with values reported by Lovely *et al.* (2007) in the Okavango Delta (147.9 mmol/L). Mean concentrations at all the sampling sites in the Olifants River also fall well within the range reported for the Okavango Delta (Table 13). Sodium plasma concentrations in crocodiles from the Olifants River Gorge were substantially lower during August 2008 ($\bar{x} = 141.25$) compared to September 2008 ($\bar{x} = 149.80$).

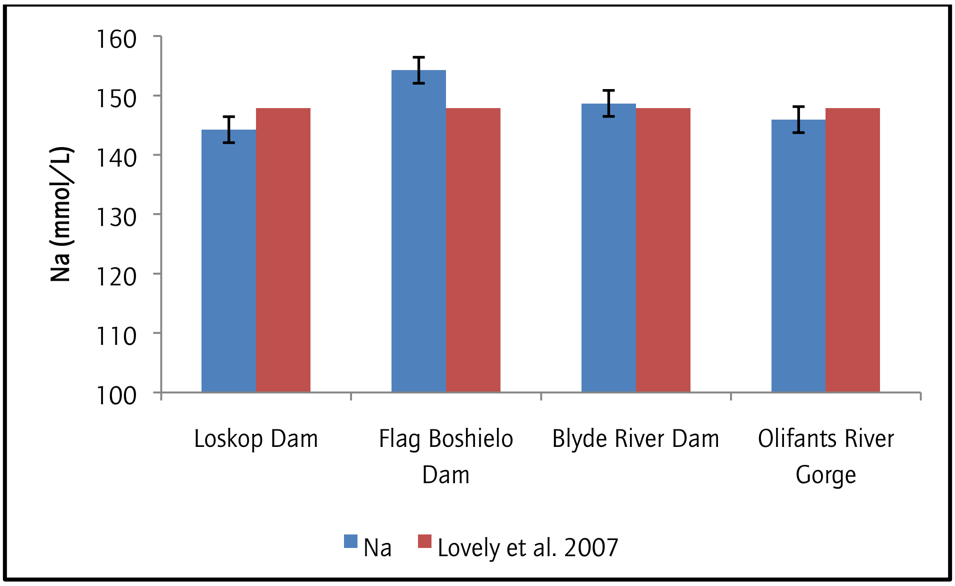

Figure 39: Mean sodium (Na) concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) for the Okavango Delta.

Potassium (K) (Figure 40):

Plasma potassium (K) concentration from Nile crocodiles in the Olifants River Gorge were between 58.71% and 62.45% higher than the concentrations measured at other sites in the Olifants River. A test of significance showed this difference to be significant ($P = 0.007$). Mean plasma potassium (K) concentrations in the Olifants River Gorge (13.37 mmol/L) are much higher than the maximum concentration for Nile crocodiles in the Okavango Delta (7.65 mmol/L): the concentrations reported here represent a marked increase of 63.50% over the mean Okavango concentrations published by Lovely *et al*. (2007) and a 65.66% increase over the mean concentration reported for the Olifants River by Swanepoel *et al.* (2000).

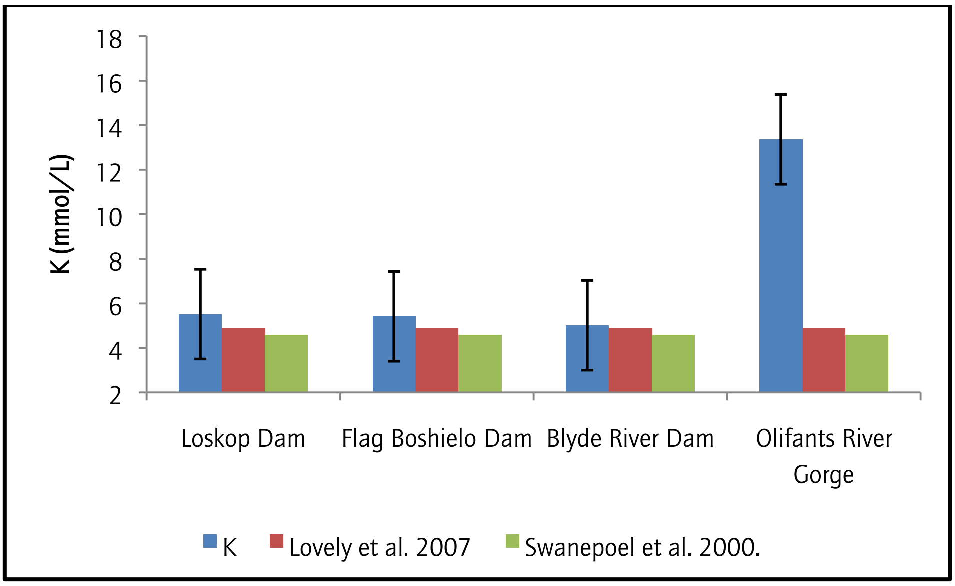

Figure 40: Mean potassium (K) concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) and Swanepoel *et al.* (2000) for the Okavango Delta and Olifants River.

Plasma potassium were recorded at higher concentrations in the plasma of crocodiles from the Olifants River Gorge during August 2008 compared to September 2008 (August $\bar{x} =$ 18.674 and September $\bar{x} = 5.388$).

Ionised calcium (Ca^{2+}) (Figure 41):

The mean concentration for ionised calcium (Ca^{2+}) are much lower at all sampling sites in the Olifants River including the control population in the Blyderivierspoort Dam (Olifants River Gorge = 0.53 mmol/L; Blyderivierspoort Dam = 0.56 mmol/L; Loskop Dam = 0.57 mmol/L; Flag Boshielo Dam = 0.86 mmol/L) when compared to the minimum concentration for Nile crocodiles in the Okavango Delta (Lovely *et al.*, 2007).

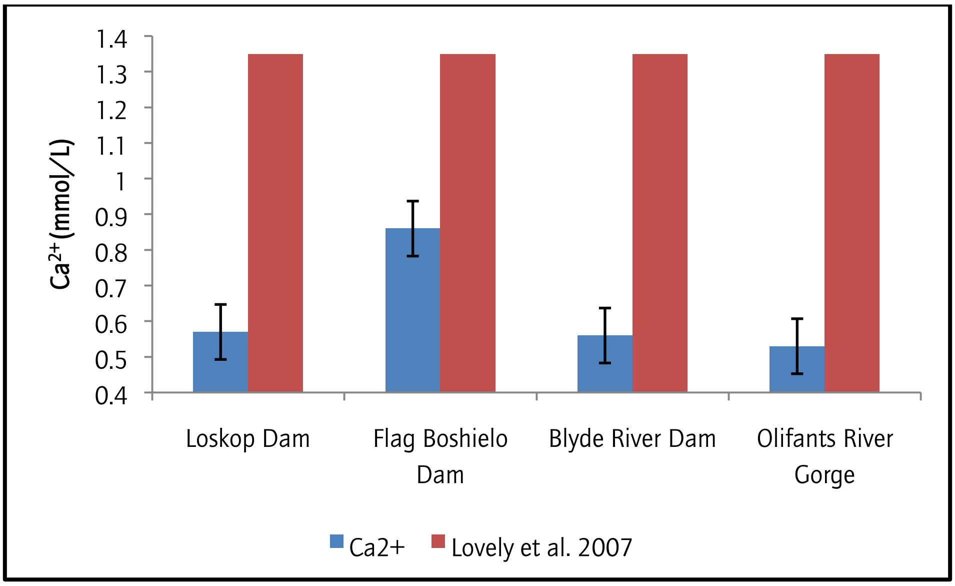

Figure 41: Mean calcium (Ca^{2+}) concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) for the Okavango Delta.

<u>Total calcium (Ca^{Total}) (Figure 42):</u>

Concentrations of total calcium (Ca^{Total}) were significantly lower ($P = 0.007$) in the plasma of Nile crocodiles in the Olifants River Gorge when compared to all other sites in the river. The mean concentration for Ca^{Total} for Loskop Dam (3.10 mmol/L) is close to the maximum concentration while the mean concentration recorded in the Olifants River Gorge (1.38 mmol/L) is substantially lower than the minimum concentration for Nile crocodiles (2.34 - 3.15 mmol/L) established in the Okavango delta (Lovely *et al.*, 2007). Total calcium concentrations in the Olifants River therefore, decreases from very high to very low in the downstream direction (Table 13). Concentrations in the Olifants River Gorge have declined by 63.10% over the intervening years since Swanepoel *et al.* (2000) completed their studies into certain chemical parameters in the blood of Nile crocodiles in the Kruger National Park. Total calcium concentrations was found to be substantially lower in the plasma of crocodiles from the Olifants River Gorge during August 2008 ($\bar{x}$ = 0.3230) compared to September 2008 ($\bar{x}$ = 2.8800).

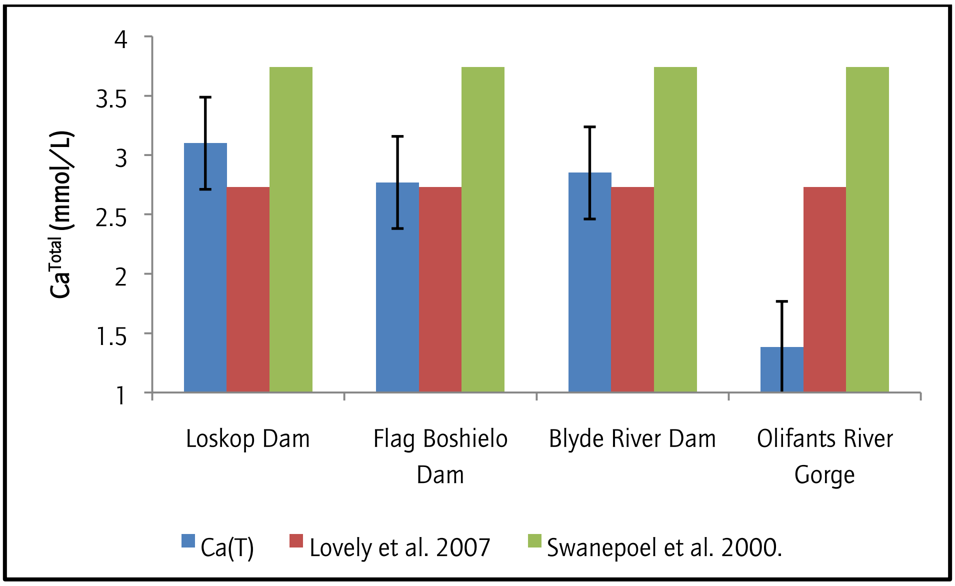

Figure 42: Mean calcium (Ca^{Total}) concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) and Swanepoel *et al.* (2000) for the Okavango Delta and Olifants River.

Magnesium (Mg) (Figure 43):

The mean concentrations for magnesium (Mg) in the Olifants River Gorge (0.57 mmol/L) are only slightly lower than the minimum concentration for Nile crocodiles in the Okavango Delta. However the Olifants River Gorge concentrations are now substantially lower than the 2.24 mmol/L recorded during the study of Swanepoel *et al*. (2000). Further, a general trend was observed of decreasing plasma Mg concentrations in the downstream direction of the river (Table 13). Magnesium concentrations in the blood of crocodiles from the Olifants River Gorge was substantially lower during August 2008 ($\bar{x} =$ 0.1020) compared to September 2008 ($\bar{x} =$ 1.2840).

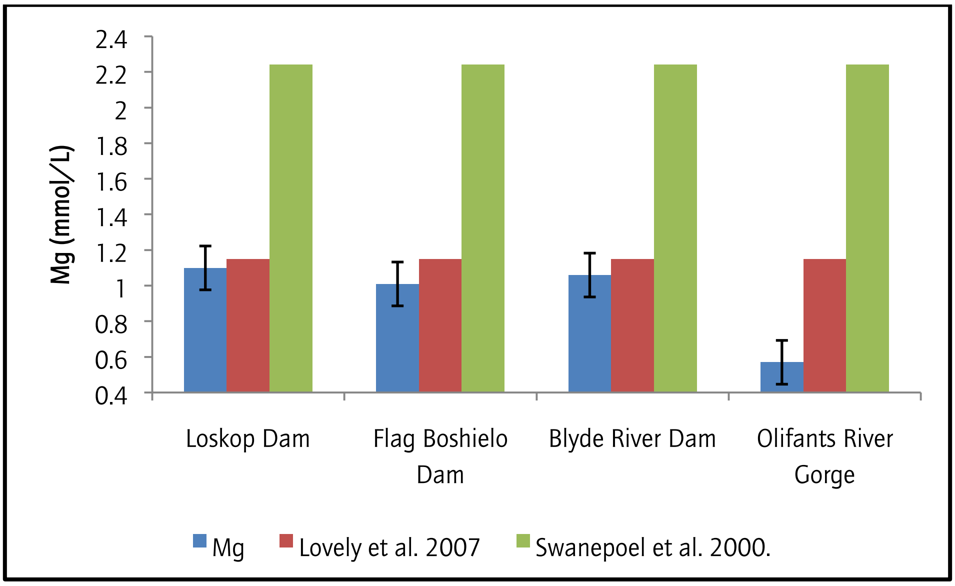

Figure 43: Mean magnesium (Mg) concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) and Swanepoel *et al.* (2000) for the Okavango Delta and Olifants River.

<u>Serum Inorganic Phosphate (SIP) (Figure 44):</u>

Serum Inorganic Phosphate (SIP) concentrations of the Loskop Dam (2.09 mmol/L), Blyderivierspoort Dam (2.07 mmol/L0 and Olifants River Gorge (1.94 mmol/L) all correspond closely to each other (Table 13). The concentrations recorded in the Flag Boshielo Dam are however lower at 1.64 mmol/L than all other sampling sites. Overall, the

SIP concentrations in the Olifants River are higher than those measured by Swanepoel *et al*. (2000) during their study.

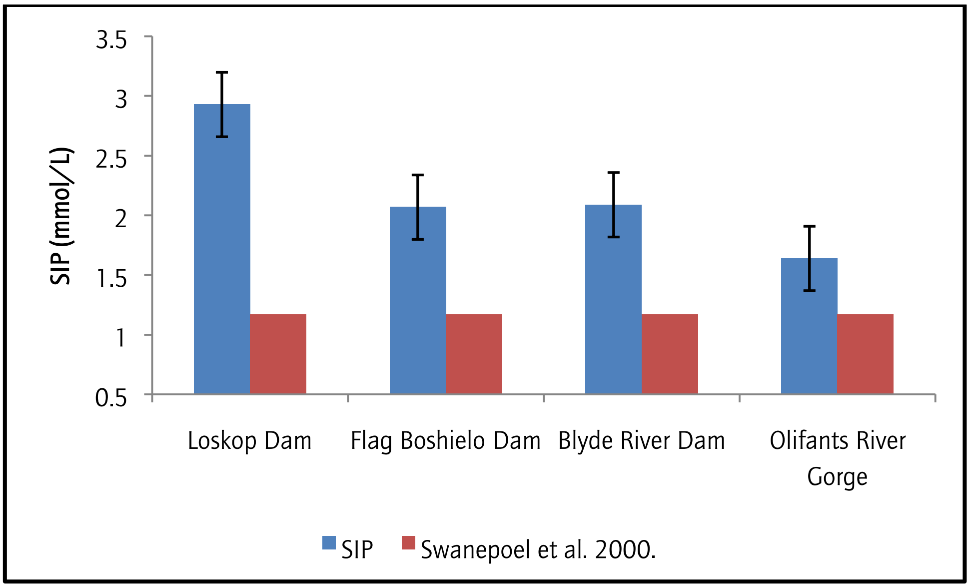

Figure 44: Mean serum inorganic phosphate (SIP) concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Swanepoel *et al.* (2000) in the Olifants River.

Cholesterol (Figure 45):

Lovely *et al*. (2007) reported that they had measured a mean cholesterol concentration of 5.49 mmol/L in the Nile crocodile population of the Okavango Delta. In the Olifants River, cholesterol in the plasma of crocodiles in the Loskop Dam (3.23 mmol/L), Flag Boshielo Dam (4.83 mmol/L) and Olifants River Gorge (3.77 mmol/L) were all measured at lower concentrations (Table 13). However, cholesterol concentrations in plasma samples collected from the unpolluted Blyderivierspoort Dam were elevated at a mean of 7.65 mmol/L (Table

13). All cholesterol concentrations in the Olifants River were however still well within the range (0.0 - 9.86 mmol/L) for Nile crocodiles in the Okavango Delta (Lovely *et al*. 2007). Cholesterol concentrations in the plasma of crocodiles from the Olifants River Gorge was substantially lower during August 2008 ($\bar{x} = 2.939$) compared to September 2008 ($\bar{x} = 5.788$).

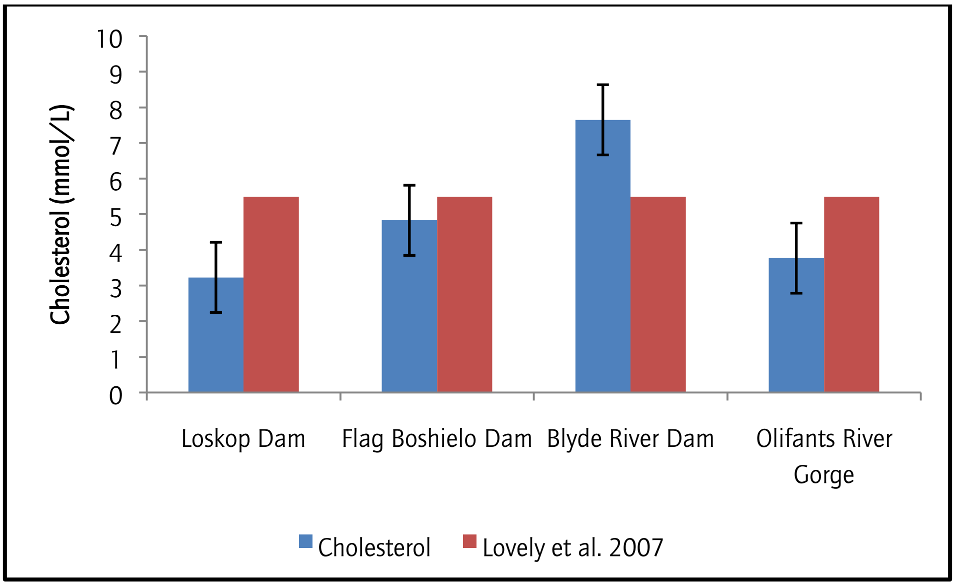

Figure 45: Mean cholesterol concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) for the Okavango Delta.

<u>**Creatinine (Figure 46):**</u>

Mean concentrations for creatinine at all sampling sites in the Olifants River are well below the mean concentrations measured in the Okavango Delta (Table 13). At 15.33 µmol/L, the mean creatinine concentration in the plasma of Nile crocodiles in the Blyderivierspoort

Dam are 54.91% lower than the mean concentration measured in Nile crocodiles in the Okavango Delta (Table 13). Creatinine concentrations in the Olifants River have also declined by 64.10% since 2000 (Table 13).

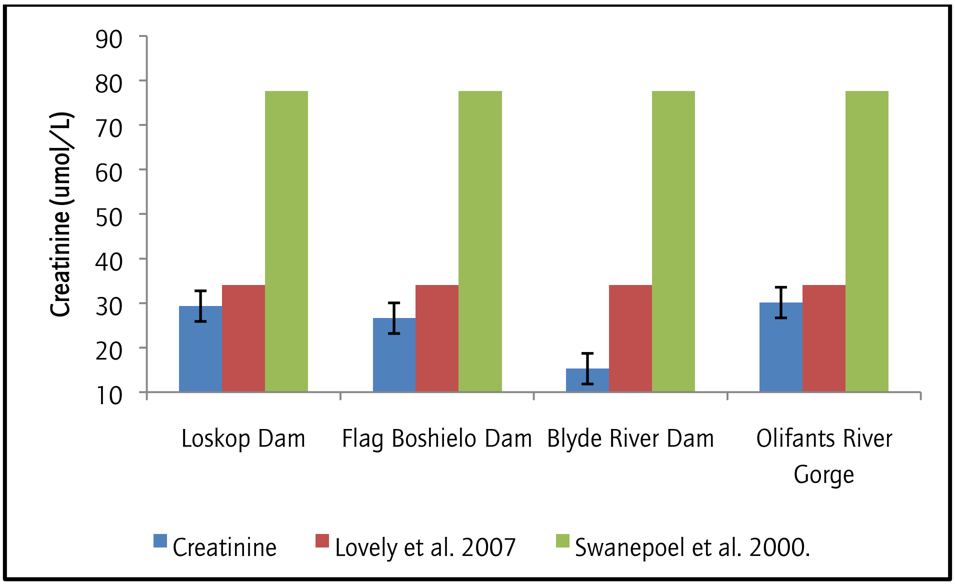

Figure 46: Mean creatinine concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) and Swanepoel *et al.* (2000) for the Okavango Delta and Olifants River.

<u>Chloride (Cl) (Figure 47):</u>

The mean chloride (Cl) concentrations in the blood of Nile crocodiles in the Blyderivierspoort Dam population (75.85 mmol/L) were substantially lower (test of significance: $P = 0.034$) than in any of the other populations sampled during this study and were also substantially below the minimum concentration for Nile crocodiles in the Okavango Delta reported by Lovely *et al.* (2007). All other sites compared well to each other (Loskop Dam = 108.63

mmol/L; Flag Boshielo Dam = 116.28 mmol/L; Olifants River Gorge = 115.92 mmol/L) (Table 13).

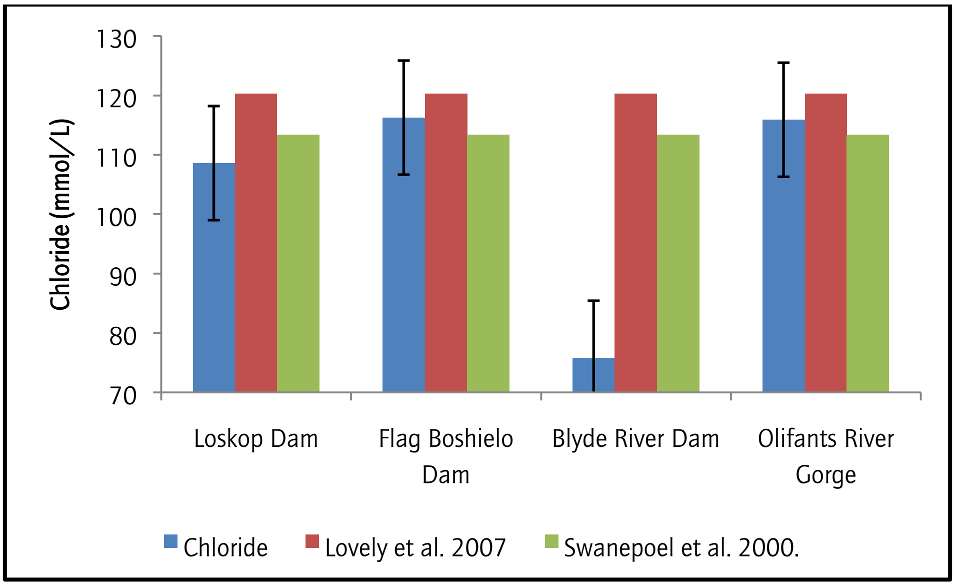

Figure 47: Mean chloride concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) and Swanepoel *et al.* (2000) for the Okavango Delta and Olifants River.

However, the mean chloride concentration in the plasma of Nile crocodiles from the Olifants River (110.84 mmol/L) compare well to that reported by Swanepoel *et al.* (2000) for the Olifants River in the Kruger National Park (113.40 mmol/L). Chloride concentrations in the plasma collected from Nile crocodiles in the Olifants River Gorge were substantially lower during August 2008 ($\bar{x} = 110.84$) compared to September 2008 ($\bar{x} = 124.08$).

Uric acid (Figure 48):

The mean concentration for uric acid recorded in the plasma of Nile crocodiles in the Blyderivierspoort Dam (0.27 mmol/L) is almost at the maximum concentration for Nile crocodiles in the Okavango Delta (0.04 - 0.30 mmol/L) as reported by Lovely *et al.* (2007).

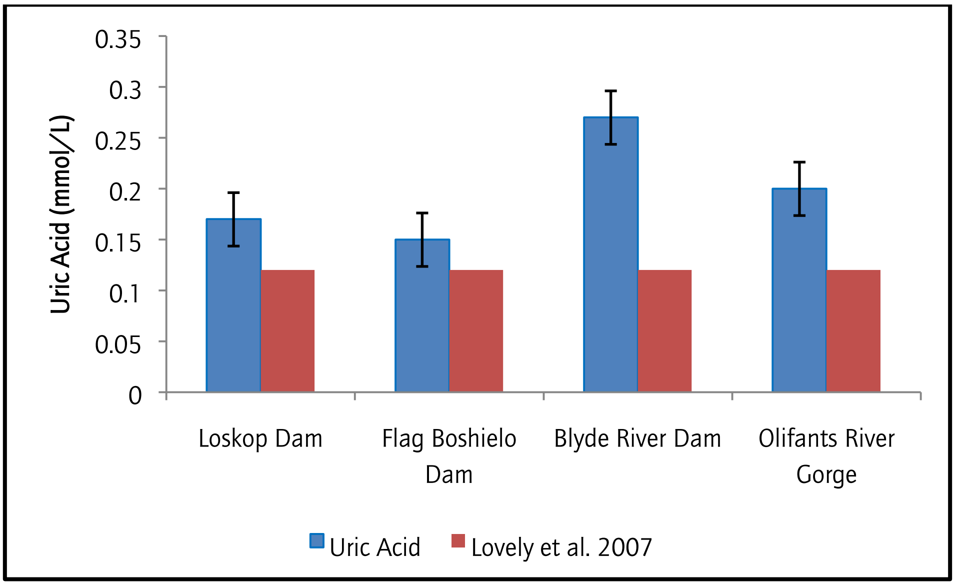

Figure 48: Mean uric acid concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River compared to concentrations reported by Lovely, *et al.* (2007) for the Okavango Delta.

Uric acid mean concentrations in the Olifants River (Loskop Dam = 0.17; Flag Boshielo = 0.15; Blyderivierspoort Dam = 0.27 mmol/L; Olifants River Gorge = 0.20 mmol/L) were higher at all sampling sites than the mean concentration recorded in the Okavango Delta (Table 13). Concentrations in the Lower Olifants River (Blyderivierspoort Dam and Olifants

River Gorge) were substantially higher than those in the Upper Olifants River (Loskop Dam and Flag Boshielo Dam) (Table 13).

Triglycerides (Figure 49):

The mean concentrations for triglycerides at the Blyderivierspoort Dam (4.38 mmol/L) are 67.35% higher than the concentrations measured at the other three sample sites (Table 13).

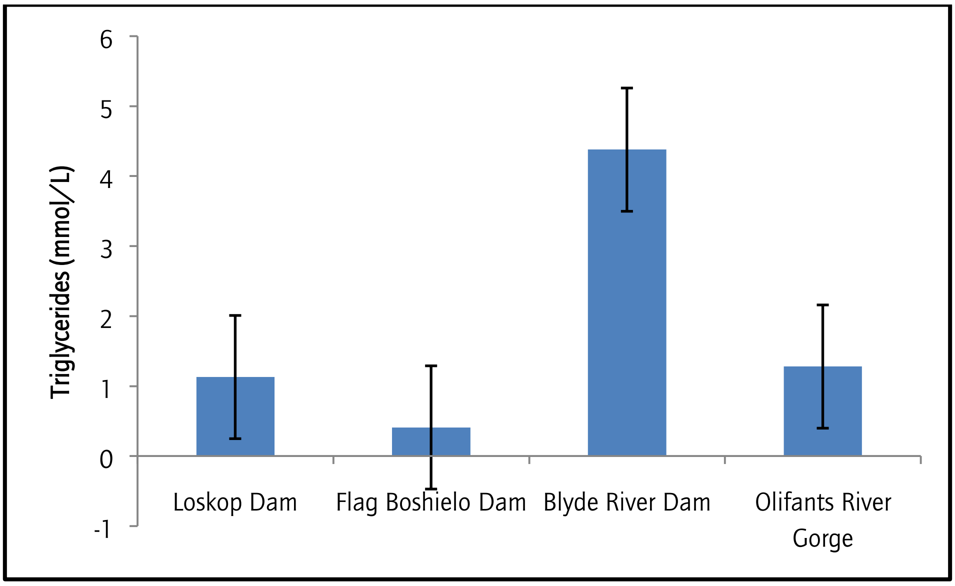

Figure 49: Mean triglyceride concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River.

Vitamin A (Figure 50):

The mean concentrations for vitamin A in the Olifants River Gorge (200.79 µg/L) are much lower than the concentrations measured at the other three sample sites (Loskop Dam =

330.61 µg/L; Flag Boshielo Dam = 326.37 µg/L; Blyderivierspoort Dam = 335.81 µg/L) (Table 13). Concentrations for the Blyderivierspoort Dam are 40.21% higher than in the Olifants River Gorge whereas the mean concentration for the entire Olifants River is 21.46% higher than values measured in the Gorge.

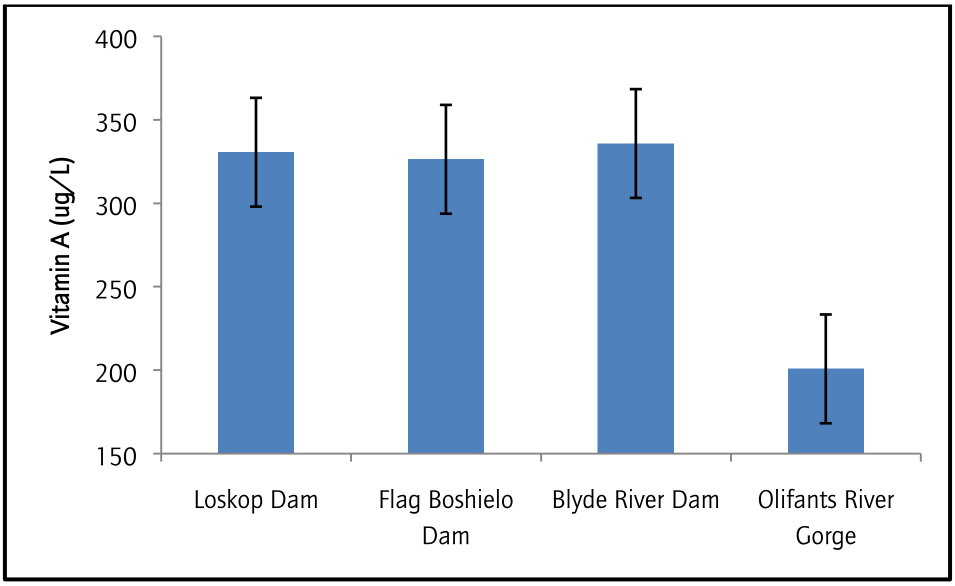

Figure 50: Mean vitamin A concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River.

__Vitamin E (Figure 51):__

A definite pattern in vitamin E values emerged with Loskop Dam ($\bar{x}$ = 7.102) and the Olifants River Gorge ($\bar{x}$ = 6.210) having the lowest concentrations whereas the Flag Boshielo Dam ($\bar{x}$ = 9.648) had slightly higher concentrations and the Blyderivierspoort Dam ($\bar{x}$ = 11.000) showed the highest concentrations of the four sample sites (Table 13). Vitamin E concentrations measured in the plasma of Nile crocodiles occurring in the Olifants

River Gorge were significantly lower ($P = 0.027$) than at any other site sampled in the river. No significant difference was found to exist in vitamin E concentrations of plasma collected from crocodiles in the Olifants River Gorge during August 2008 and September 2008.

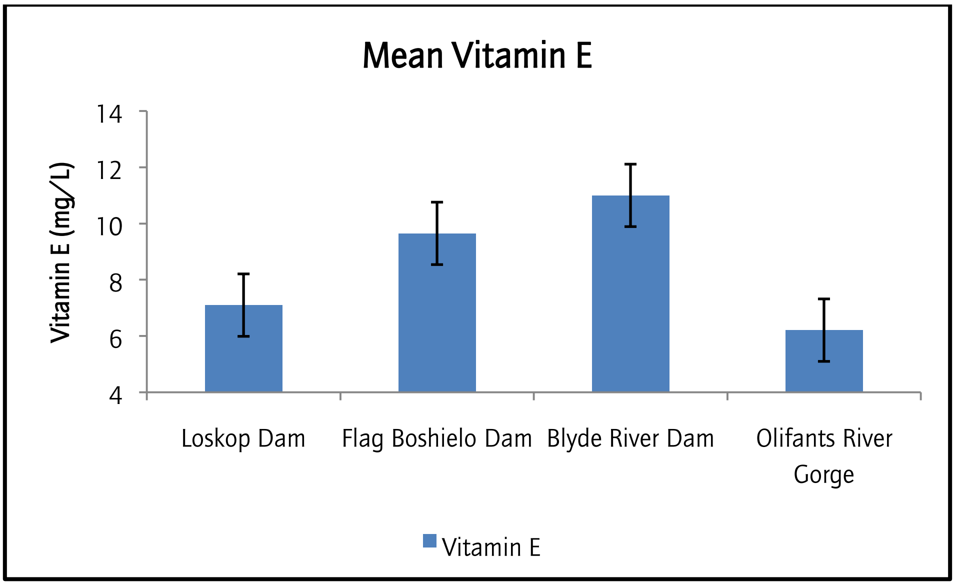

Figure 51: Mean vitamin E concentration measured in the plasma of Nile crocodiles at various sampling sites in the Olifants River.

DISCUSSION

Species, age, gender, nutritional status, season and physiological status influence the blood biochemistry of reptiles (Dessauer, 1970; Lawrence, 1987; Samour, Hawkey, Pugsley and Ball, 1986 and Thrall, Baker, Campbell, Lassen, Alan, DeNicola, Fettman and Weiser, 2004). This makes interpretation of blood biochemistry results in reptiles very challenging especially in the case of Nile crocodiles because very little previous work has been done in terms of establishing normal reference ranges for wild Nile crocodiles. Much of the work that has been published refers to captive populations or to other crocodilian species such as *Crocodylus porosus, Crocodylus palustris* and *Alligator mississippiensis* (Foggin, 1987; Millan *et al.*, 1997; Guillette *et al.* 1997; Stacy and Whitaker, 2000).

Considerable variation has been reported in biochemical and haematological values among the different crocodilian species (Millan *et al.*, 1997; Stacy and Whitaker, 2000; Lovely *et al.*, 2007) and in their review Lovely *et al.* (2007) suggest that a species-specific reference range must be developed if clinical pathology is to be used as a successfully diagnostic tool.

Mean total serum protein TSP plasma concentrations were found to be in the upper concentrations of the range as reported by Lovely *et al.* (2007). According to Campbell (2006), elevated plasma TSP concentrations could indicate possible chronic inflammation or other infection as it does in mammals and birds (Cray *et al.*, 2005).

Mean albumin concentrations (Figure 31) for the Olifants River Nile crocodile population registered in the above average, upper concentration of the range recently established in Botswana (Lovely *et al.*, 2007). The mean albumin concentrations established by Swanepoel *et al.*, (2000) correspond closely with the lower concentrations reported from Botswana (Lovely *et al.*, 2007). This indicates that conditions have changed since Swanepoel *et al.* (2000) did their study to the effect that albumin concentrations in the crocodiles of the Olifants River are now much higher with the Loskop Dam population showing concentrations above the maximum concentration recorded in Botswana. Albumin is a common plasma protein that serves as a carrier protein for other in the blood, protecting them from hepatic degradation (Tully *et al.*, 2003). Serum protein electrophoresis is used as a non-specific diagnostic tool to determine immune function and drastic changes in plasma albumin concentrations have been reported in other reptiles indicating serious cases of disease (Kaneko, 1980; Lutz *et al.,* 2001).

Mean globulin concentrations (Table 13) measured in the Olifants River Nile crocodile population were established near the upper limits of the range recently reported for Nile crocodiles in Botswana (Lovely *et al.*, 2007). These values correspond very well with the mean plasma concentration measured by Swanepoel *et al.*, (2000) which also reported concentrations just below the upper limit reported for Nile crocodiles in Botswana (Lovely *et al.*, 2007). As with the plasma albumin concentrations reported here, the globulin concentrations in the Loskop Dam Nile crocodile population were much higher than any of the other populations in the Olifants River and also well above the maximum concentrations measured in Botswana. Elevated globulin concentrations are indicative in reptiles of altered immune activity and the presence of an infectious disease in the population (Thrall *et al.*, 2004; Campbell, 2006).

Alkaline phosphatase (ALP) mean plasma concentrations in Nile crocodiles from the Olifants River show a general decline along the gradient of the river with the highest concentrations recorded at Loskop Dam and the lowest concentrations found in the Olifants River Gorge. Concentrations for Loskop Dam and Flag Boshielo Dam were just above and just below the mean concentration from Botswana whereas the mean plasma concentration from Nile crocodiles captured at the Olifants River Gorge was very close to the minimum concentration reported from Botswana. Although decreased plasma ALP concentrations is not necessarily associated with veterinary disease, it has been shown that low ALP activity in plasma can be attributed to environmental contamination in birds (Kertész and Hlubik, 2002). Therefore, the low ALP concentrations from the plasma of crocodiles in the Olifants River support the hypothesis that the river is suffering from environmental contamination and that the pollution is worse in the downstream direction of the river. This is possibly due to very few crocodiles being able to survive in the upper Olifants River thereby restricting our ability to test a large sample as was possible in the lower Olifants River.

Aspartate aminotransferase (AST) mean concentrations recorded in the plasma of Nile crocodiles from the Olifants River do not show a big difference over the gradient of the river. The concentrations are however fairly low and registered below the mean concentrations reported from Botswana but still above the minimum concentration established by Lovely *et al.* (2007). Plasma AST concentrations were higher in medium sized (TL = 1.5 – 2.0m) crocodiles compared to small sized (TL < 1.5m) crocodiles indicating that size class could play an important role in the interpretation of these values.

The mean glucose concentrations found in the plasma of Nile crocodiles from the Olifants River show elevated concentrations at Loskop Dam and in the Olifants River Gorge. These are the populations where recent catastrophic population crashes have been documented. Mean concentrations at the Flag Boshielo Dam and the Blyderivierspoort Dam correspond with mean concentrations reported from the Botswana Nile crocodile population. Concentrations described by Swanepoel *et al*. in 2000 in the Olifants River (Kruger National Park) were the same as those measured in the Loskop Dam and in the Olifants River Gorge by this study. Elevated concentrations of blood glucose in reptiles are often related to metabolic conditions, systemic diseases and stress associated hyperclycemia resulting from glucocortocoid and epinephrine release (Thrall *et al.,* 2004; Campbell, 2006) During the August 2008 pansteatitis related die-off of Nile crocodiles in the Olifants River Gorge, the animals were known to be under considerable stress due to the debilitating and painful effects of the disease. Elevated blood glucose concentrations of the Loskop Dam and Olifants River Gorge Nile crocodiles suggests that conditions in the Olifants River, especially in terms of diet which plays a central role in glucose concentrations, have changed over a long period of time leading up to the catastrophic population crash in the Olifants River Gorge during 2008.

Mean potassium (K) concentrations from the plasma of Nile crocodiles in the Olifants River were registered at concentrations close to the mean concentrations reported from the Botswana population. However, the potassium concentrations measured in the Olifants River Gorge were higher than those measured at all the other sample sites, higher than the maximum concentration from Botswana and also higher than the Olifants River mean concentrations recorded by Swanepoel *et al.* (2000). The sudden dramatic rise in potassium concentrations in the Olifants River Gorge is possibly indicative of an inadequate diet especially during August/September 2008 when most of the samples were taken and when the animals were suffering from the effects of disease. Clinical symptoms associated with elevated potassium concentrations could include tissue necrosis, hypo-adrenocorticism, acidosis and could affect the heart muscle of affected animals (Thrall *et al.*, 2004; Campbell, 2006).

The mean ionised calcium (Ca^{2+}) concentrations recorded from Nile crocodiles at all sample sites in the Olifants River, registered at concentrations even lower than the minimum concentration from the Botswana population. Concentrations of Ca^{2+} in the plasma from Nile crocodiles in the Flag Boshielo Dam were substantially below the Botswana minimum concentration. Hypocalcemia indicate dietary problems and specifically a deficiency in calcium (Thrall *et al.*, 2004; Campbell, 2006). Extremely low concentrations of calcium can result in calcium mobilisation from the skeletal bones, increased calcium absorption from the intestines and increased re-absorption of calcium from the kidneys (Thrall *et al.,* 2004;

Campbell, 2006). The results also appear to indicate that the decreased Ca^{2+} concentrations correspond with increasing size class.

Mean concentrations for total calcium (Ca^{Total}) in the plasma of Nile crocodiles occurring in the Olifants River show very low concentrations in the Olifants River Gorge. These concentrations are well below the minimum concentration described by Lovely *et al.* (2007). The very low Ca^{Total} concentrations support the low Ca^{2+} values and the conclusion that the Olifants River Gorge population suffer from hypocalcemia. All other sample sites produced concentrations that are near the mean concentration for the Okavango Delta population, except for the Loskop dam population which are at the maximum concentration measured in the Okavango Delta population. Total calcium concentrations reported by Swanepoel *et al.* (2002) were at concentrations much higher than the reported maximum concentration in the Okavango Delta population. This indicates a massive drop in Ca^{Total} concentrations in the Olifants River Gorge and Kruger National Park with extreme implications for nesting females who increase their plasma calcium concentrations for the production of eggshells (Elsey and Wink, 1986; Huchzermeyer, 2003). Other consequences of low calcium include ovarian haemorrhage, shell defects, diaphanous teeth, weak growing of bones and difficulty moving on land, spine fractures due to violent spasms and osteomalacia (Huchzermeyer, 2003).

The mean magnesium (Mg) concentrations of plasma collected from Nile crocodiles occurring in the Olifants River and especially the Olifants River Gorge, are substantially lower than those reported for the Olifants River by Swanepoel *et al.* (2000). Decreased concentrations of Mg are considered by veterinarians to contribute greatly to affected animals not eating and associated weakness (Thrall *et al.*, 2004;Campbell, 2006).

Serum inorganic phosphate (SIP) showed a drop in mean concentrations over the gradient of the Olifants River decreasing in the downstream direction. However, SIP concentrations in the river were still at higher concentrations than during 2000 when Swanepoel *et al.* studied the chemical parameters in the plasma of Nile crocodiles in the Kruger National Park. The high SIP concentrations in the Loskop Dam indicates that the current poor conditions observed in that area has probably not migrated downstream but it is my opinion that it is only a question of time before these spread beyond the wall of the Loskop Dam downstream into the Olifants River.

Mean cholesterol concentrations for Nile crocodiles in the Olifants River registered at concentrations near the mean concentrations reported by Lovely *et al.* (2007) in the Okavango Delta. However concentrations for Loskop Dam and the Olifants River Gorge were below the mean concentration of the Okavango Delta Nile crocodile population whereas at the Blyderivierspoort Dam, they were above the mean concentration of the Okavango Delta Nile crocodile population. However, since plasma cholesterol concentrations are easily influenced by the elapsed time between the crocodile's previous meal and collection of the blood sample, the implications of plasma cholesterol concentration results are often difficult to interpret.

Mean creatinine concentrations for Nile crocodiles in the Olifants River registered at concentrations near the mean reported by Lovely *et al.* (2007) in Nile crocodiles obtained in the Okavango Delta. Mean concentrations from the Blyderivierspoort Dam were the lowest of all sample sites at just below the minimum concentration for the Okavango Delta Nile crocodile population. Creatinine is a breakdown product of creatine which is an important part of muscle tissue. Low creatinine is indicative of low muscle mass (Thrall *et al.*, 2004; Campbell, 2006;). Due to the population characteristics of the specific population, most of the crocodiles captured in the Blyderivierspoort Dam were small sized animals of less than 1.0m TL with consequently less muscle mass than larger animals. This could explain the drop in creatinine concentrations registered at the Blyderivierspoort Dam.

The mean plasma chloride values for Nile crocodiles in the Olifants River registered at concentrations near to the mean reference range values reported by Lovely *et al.* (2007). The Blyderivierspoort Dam had the lowest mean values of all sample sites at concentrations much lower than the minimum reference range. Chloride values from the current study did not differ markedly from those reported by Swanepoel *et al.* (2000) from the Olifants River in the Kruger National Park. Chloride is a principle anion in blood but hypochloremia is considered to be rare in reptiles (Thrall *et al.*, 2004; Campbell, 2006) and would suggest the loss of chloride ions through overhydration with fluids low in chloride ions. It therefore remains difficult to explain the low chloride values in the Blyderivierspoort Dam samples unless low chloride is a condition that occurs in the whole Blyde River system.

The mean uric acid concentrations for Nile crocodiles in the Olifants River registered at concentrations slightly higher than the mean reported by Lovely *et al.* (2007) for the Okavango Delta Nile crocodile population. The Blyderivierspoort Dam showed a substantially higher concentration which was just below the maximum concentration recorded in the Okavango Delta. Uric acid is the primary catabolic end product of protein, non-protein nitrogen and purines and represents 80 - 90% of the total nitrogen excreted by the kidneys (Frye, 1991). Carnivorous reptiles tend to have higher blood uric acid concentrations which generally peak one day after a meal resulting in a 1.5 - 2.0 fold increase in uric acid (Frye, 1991). This likely explains the high blood uric acid concentrations measured in samples from the Blyderivierspoort Dam especially if viewed with the elevated blood cholesterol concentrations from the same sample site keeping the known effects of recent feeding on increasing blood cholesterol concentrations in mind.

Mean triglyceride concentrations measured in plasma samples collected from Nile crocodiles occurring in the Olifants River was recorded at very low concentrations at all sample sites except in the Blyderivierspoort Dam where they were substantially higher. Low triglyceride concentrations are generally indicative of malnutrition in reptiles (Thrall *et al.*, 2004; Campbell, 2006). Unfortunately, the Okavango Delta study in Botswana did not measure the triglyceride concentrations present in the plasma of that population of Nile crocodiles. It is generally accepted that it is not good practise to compare plasma values of different species because blood biochemistries can vary substantially between species and this is especially so in reptiles (Samour *et al.*, 1986; Lawrence, 1987; Dessauer, 1970 and Thrall *et al.*, 2004). However, due to the lack of relevant Nile crocodile data, comparison of triglyceride data to a similar species namely the saltwater crocodile (*Crocodylus porosus*) allows at least some interpretation of the collected information. With this in mind, the Nile crocodile data for Loskop Dam, Flag Boshielo Dam and the Olifants River Gorge seem to be near the minimum concentration. The concentrations for the Blyderivierspoort Dam are closer to the probable average of the range when compared to data from studies on *C. porosus* (Millan *et al.,* 1997) which was taken from similar sized animals. Based on these data, it is probable to hypothesize that most of the Nile crocodile population in the Olifants River is suffering from some degree of malnutrition.

The mean vitamin A concentrations measured in plasma samples collected from Nile crocodiles occurring in the Olifants River were recorded at much lower concentrations in the Olifants River Gorge than at any of the other sample sites (Loskop Dam, Flag Boshielo Dam, Blyderivierspoort Dam). Low vitamin A concentrations could indicate a vitamin A deficiency which in turn could be the result of an infectious disease.

Mean vitamin E concentrations measured in blood samples collected from Nile crocodiles occurring in the Olifants River were recorded at much lower concentrations in the Loskop Dam and Olifants River Gorge than at the other two sample sites (Flag Boshielo Dam, Blyderivierspoort Dam). Statistical analysis showed a significant difference in the low vitamin E concentrations and the different sampling sites ($P = 0.027$). Vitamin E is an important antioxidant which protects body tissue from damage by free radicals which in turn can harm all tissues and organs. Therefore, the low vitamin E concentrations encountered at sites where catastrophic events are known to have occurred within the Nile crocodile populations almost certainly indicate serious disease in the sampled animals.

CONCLUSION

Based on this study, the conclusions that can be drawn suggest, that, on average, the blood biochemistry of most of the Nile crocodiles in the Olifants River fall within the range for healthy Nile crocodiles. However, there are pertinent exceptions to this statement which when viewed in more detail certainly suggest that changes to the dynamics of the river over the longer term did have a negative impact on the Nile crocodile population. These impacts can be described as follows:

- Elevated TSP values suggest possible chronic inflammation (especially in the Loskop Dam and Olifants River Gorge populations).

- Albumin values increased substantially over an eight year period indicating changing conditions in the habitat.
- Elevated globulin values indicate the possible presence of an infectious disease (particularly in the Loskop Dam population but all other sites also showed elevated values);
- Elevated blood glucose values indicate that conditions particularly in the Loskop Dam and Olifants River Gorge populations where changing drastically over a long term and could be related to metabolic conditions, systemic diseases and stress associated hyperclycemia resulting from glucocortocoid and epinephrine release.
- The sudden drastic rise in potassium (K) values in the Olifants River Gorge indicates possible inadequate diet (especially during the pansteatitis outbreak of August/September 2008).
- Decreased concentrations of ionised calcium (Ca^{2+}) and total calcium (Ca^{Total}) support the theory of dietary problems.
- Magnesium (Mg) concentrations showed a substantial drop in concentrations in the Olifants River Gorge over a period of eight years and are considered to contribute greatly to affected animals not eating and associated weakness.
- Low triglyceride concentrations support the theory that dietary problems and malnutrition could be a factor in the health of Nile crocodiles in the Loskop Dam, Flag Boshielo Dam and Olifants River Gorge populations.

- Low vitamin A concentrations could indicate a vitamin A deficiency which in turn could be the result of an infectious disease.
- Low vitamin E concentrations could indicate serious immune problems in the Olifants River Gorge population.

Therefore the blood biochemistry of the Nile crocodile population in the Olifants River indicate that these animals have suffered and continue to suffer from chronic inflammation and infection possibly due to inadequate diet and malnutrition with associated weakness and serious immune problems over the last eight years and possibly longer.

Results from this study show that while establishing reference ranges for blood biochemistry in wild crocodiles is needed, the existing very limited information has ranges that are most often too wide and that further study in this direction is needed. It is important for future studies to note that the data must come from free ranging animals if we are to know what "normal" is. Other variables that must be investigated in future if we are to use this type of data as predictive markers of population health include the annual cycle in each of these parameters already examined, the role of temperature, dietary changes with season, reproductive activity and growth cycles. The data from this study is a start that can be added to the previous studies but much further work is needed.

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CHAPTER 6

CONSERVATION AND MANAGEMENT PLAN FOR THE WILD NILE CROCODILE POPULATION IN THE OLIFANTS RIVER, MPUMALANGA PROVINCE

This chapter represents an abbreviated version of the suggested conservation and management plan for the wild Nile crocodile population in the Olifants River in the Mpumalanga province while the detailed version is included as appendix I to this thesis. The document follows the format, layout and terminology used in most of the following existing crocodile conservation and management plans:

- Nature Conservation (estuarine crocodile) conservation plan 2007 and management plan 2007 - 2017 (Queensland Environmental Protection Agency2007).
- Management plan for *Crocodylus porosus* in the Northern Territory 2005 - 2010 (Parks and Wildlife Service of the Northern Territory, 2005a).
- Management program for *Crocodylus porosus* and *Crocodylus johnstoni* in the Northern Territory of Australia (Parks and Wildlife Service of the Northern Territory, 2005b).
- Saltwater crocodile (*Crocodylus porosus*) and freshwater crocodile (*Crocodylus johnstoni*) management plan for Western Australia 2004 - 2008 (Department of Conservation and Land Management, 2003).

- Management plan for *Crocodylus porosus* in Sabah, Malaysia (Sabah Wildlife Department, 2002).
- Policy and management plan for the Nile crocodile, (Tanzania Department of Wildlife, 1993).
- Management plan for crocodiles in Zimbabwe (Department of National Parks and Wildlife,1992)
- Conservation plan: *Crocodylus niloticus* (Jacobsen, 1992)
- Status survey and conservation action plan for crocodiles, (Ross, 1998).
- A management plan for the conservation of the Nile crocodile (*Crocodylus niloticus*) in the Okavango Delta, Botswana (Bourquin, 2007)
- The management of crocodiles in captivity (Bolton, 1989).
- Sustainable use of the Lake Chamo Nile crocodile population (Whitaker, 2007).

INTRODUCTION

The Nile crocodile is the only crocodilian species that occur in southern Africa. They are very large and robust animals and considered by many to be iconic animals of the African continent. Adult Nile crocodiles average between 2.8 and 3.5m in length but in southern Africa they can grow as large as 5.5m and weigh around 1000kg at that length (Alexander and Marais, 2007). Although even at 5.5m in length, Nile crocodiles are only second in size to the estuarine crocodile (*Crocodylus porosus*) which is widely regarded as the largest living reptiles on earth (Alexander and Marais, 2007). It is however estimated that fewer than 2% of all Nile crocodiles occurring in the wild in southern Africa exceed 3.0m in length (Alexander and Marais, 2007).

Nile crocodiles favour permanent, still or slow moving water with high, sunny, sandy banks above flood levels with enough vegetation to provide shade and shelter (Hutton and Loveridge, 1999). However, this description also fits the exact locations preferred by people. These are the places where water is pumped for irrigation schemes and domestic use, where recreational areas such as fishing and camping sites are established, subsistence fishing take place, illegal commercial fishing with gill nets are practised, exclusive upmarket eco-loges and week-end homes are constructed, weirs and dams are built to supply industry, mining and agriculture with a constant water supply equal to their demand. It is clear then that there are little room left in river systems for Nile crocodiles to go about their business as they have done for millions of years.

Therefore it has become immensely important to have written conservation and management plans which must be approved and implemented by the relevant conservation authorities, provincial and national governments.

SPECIES CONCERNED

Class	:	Reptilia.
Order	:	Crocodylia.
Family	:	Crocodylidae.
Subfamily	:	Crocodylinae.
Genus and species	:	*Crocodylus niloticus* Laurenti, 1768.
Common names	:	Nile crocodile.

AGENCY RESPONSIBLE

The Olifants River falls within the boundaries of two provinces in South Africa, therefore the responsibility for the conservation of the Nile crocodile populations in the river must be shared by the two conservation organisations namely:

1. Mpumalanga Tourism and Parks Agency

Private Bag X11338	Telephone:	+27 13 759 8300
Nelspruit, Mpumalanga	Facsimile:	+27 13 752 7012
South Africa, 1200	E-mail:	info@mtpa.co.za

2. Limpopo Department of Economic Development, Environment and Tourism

Private Bag X9484	Telephone:	+27 15 8300
Polokwane, Limpopo	Facsimile:	+27 15 8319
South Africa, 0700	E-mail:	info@ledet.gov.za

CONSERVATION STATUS AND LEGISLATIVE FRAMEWORK

Although nature conservation and the protection and management of the environment functions independently in each province of South Africa, it is also subject to national legislation and international agreements and conservation efforts ratified by the South African government.

National:

Nile crocodiles are considered to be a protected species under the *National Environmental Management: Biodiversity Act (Act 10 of 2004).* A protected species under the NEMBA legislation is defined as "any species which is of such high conservation value or national importance that it requires national protection" (Section 56(1)(d) of Act 10 of 1998). However, the current IUCN Red List categorises the Nile crocodile as LRlc (Low Risk, Least Concern) but some experts are of the opinion that Nile crocodiles may be threatened in some parts of its range (Britton, 2009).

Due to successful crocodile farming being practised in this country, the South African population of Nile crocodiles are currently listed on Appendix II of the *Convention on the International Trade in Endangered Species of Wild Fauna and Flora* (CITES).

The current South African Red Data Book for Reptiles and Amphibians (Jacobsen, 1988) lists the Nile crocodile as vulnerable. A new assessment of all reptiles and amphibians in South Africa the South African Reptile Conservation Assessment (SARCA) is currently underway but final classification of the conservation status of reptiles according to that study is not currently available.

Provincial:

Provincial conservation legislation governing the protection of Nile crocodiles in the Olifants River are: the *Mpumalanga Nature Conservation Act* (Act 10 of 1998) and the *Limpopo Environmental Management Act* (Act 7 of 2003). In the Mpumalanga province, Nile crocodiles are considered to be protected game (Schedule 2 of Act 10 of 1998) and in the Limpopo province they are considered to be specially protected animals (Schedule 2 of Act 7 of 2003). This means that in both the Mpumalanga and Limpopo provinces, Nile crocodiles may only be hunted/killed legally under the issuance of a permit from the provincial nature conservation authority.

BIOLOGY OF THE NILE CROCODILE

The most striking characteristic about crocodilians are their size. Nile crocodiles are large reptiles that can grow to more than 5.0m in total length and reportedly reaching 6.0m (TL) in rare instances (Britton, 2009; Alexander and Marais, 2007). Reports of animals over 7.0m (TL) that have been seen in the wild such as the infamous Gustave in Lake Tanganyika exist but these reports are hard to verify and in fact experts estimate that less than 2% of wild crocodiles in southern Africa exceed 3.0m TL (Alexander and Marais, 2007).

According to Britton (2009) some evidence seem to indicate that Nile crocodiles in cooler areas on the southern edge of their distribution range such as the South African population may reach slightly smaller adult sizes of around 4.0m TL.

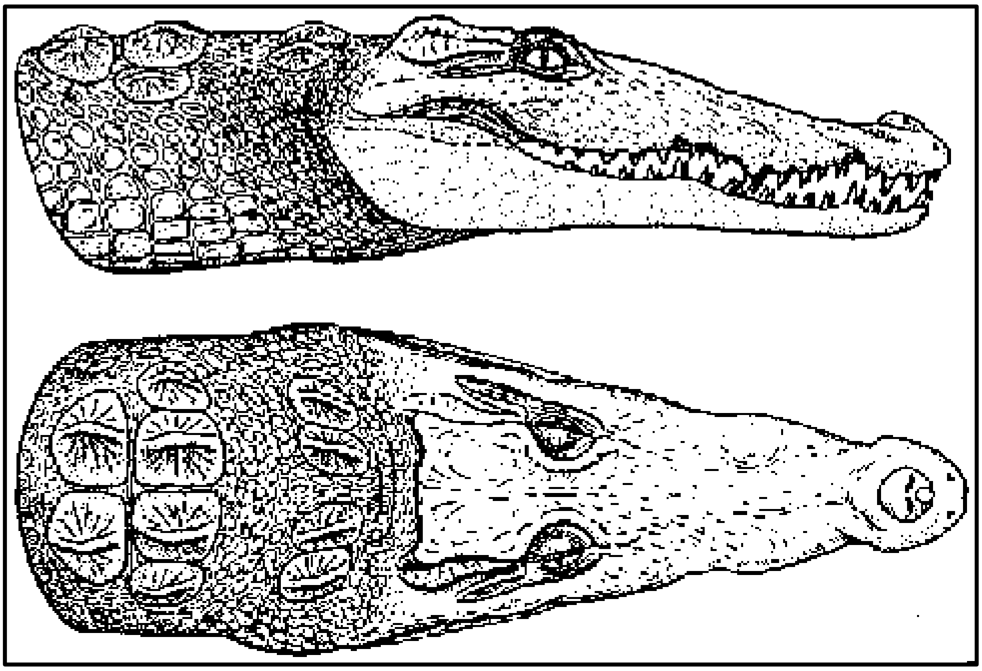

Figure 52: Head shape of the Nile crocodile (Wermuth and Fuchs, 1978).

Nile crocodiles have long snouts with large teeth that are visible even when the jaws are closed (Figure 51). Crocodilian jaws are designed for grabbing and holding prey. The teeth are conical and designed to penetrate and hold, rather than cut and chew. The upper jaw of "true" crocodiles is not as broad as that of alligators and caimans and it is sharply constricted or notched at the snout. In contrast to alligators and caimans, when "true" crocodiles close their jaws the enlarged 4th tooth on the lower jaw rests in that notch, and its tip is clearly visible. This is a major distinction between "true" crocodiles and alligators and caimans (Crocodile Specialist Group, 2009). A total of 64 - 68 teeth (5 pre-maxillary; 13 - 14 maxillary; 14 - 15 mandibular) (Britton, 2009) are set in the jaws. The eyes, nostrils and slit-like ear openings are set high on the head so they protrude from the water when the crocodile floats just beneath the surface of the water in a "minimum exposure" posture giving little indication to potential prey, of the real size of the predator's body (Crocodile Specialist Group, 2009).

Nile crocodiles show wide habitat preferences indicative of their success and distribution - e.g. lakes, rivers, freshwater swamps, and brackish water and is regarded as the top aquatic predator in freshwater ecosystems throughout large parts of Africa (Hutton and Loveridge, 1999). They are strictly carnivorous and relentless predators throughout their entire lives. Sub-adults disperse into different habitats, away from breeding areas, when they reach a length of approximately 1.2m (Hutton and Loveridge, 1999). The absence of Nile crocodiles from moist forests and extensive swamps is strongly linked to the morphological characteristics of rivers and lakes which have a direct influence on nesting behaviour (Hutton and Loveridge, 1999). Crocodiles are active during both day and night spending most of the day basking to thermoregulate and nights in the water to prevent body temperature from dropping to low. Most of their hunting activities take place during night time.

Crocodilians are efficient and fast swimmers and Nile crocodiles are no exception to this rule. While the hind feet are webbed, the legs play little part in swimming with the muscular, laterally compressed tail (which accounts for 40% of an adult crocodile's length) being used to propel their bodies through the water (Pooley and Gans, 1976). Despite their short limbs, crocodiles are capable of reaching surprising speed over short distances on land. Crocodilians are excellent divers and can remain submerged for up to four hours (Richardson, Webb and Manolis, 2002; Britton, 2009) without needing to breathe. The ability to remain submerged for prolonged periods of time is due to several unique adaptations such as: flexibility and control over blood flow enabling the crocodile to slow down its heart rate and direct oxygenated blood only to organs which cannot function without oxygen (e.g. brain and heart); ear and nostril openings which can be closed with valves; nasal passages that are separated from the mouth by a secondary palate facilitating opening of the mouth underwater; adult crocodiles keep stones in their stomachs to increase specific gravity for easier diving thereby allowing the diving crocodile to take up to 12% more air in its lungs during dives (Alexander and Marais, 2007).

Hatchling Nile crocodiles feed on smaller prey items such as insects, tadpoles, frogs and fish (Allexander and Marais, 2007; Pooley and Gans, 1976). As they grow into juvenile crocodiles their diet changes to include terrapins, water birds and small mammals but by the time they reach adulthood, Nile crocodiles prey mainly on fish, large mammals and birds. Adult crocodiles have the ability to routinely kill large prey such as wildebeest, zebra and even buffaloes but do not lose the ability to feed opportunistically on lesser prey such as frogs, crabs and small fish (Pooley and Gans, 1976). The weight gain of juvenile Nile crocodiles as they grow to adulthood is between 2400 and 4000 fold while the size of their prey increase accordingly (Pooley and Gans, 1976). Crocodiles cannot bite large chunks of meat off their prey like mammalian predators can. Therefore crocodiles have adapted to this inability by grabbing onto their prey and rolling their bodies or simply shaking the prey vigorously until it breaks apart.

Nile crocodiles are capable of cooperative feeding behaviour for example, a number of individuals will hold onto a carcass with their powerful jaws providing anchorage while allowing others to tear of large chunks of prey for easier swallowing (Pooley and Gans, 1976). Another example of cooperative feeding behaviour which has been reported is the action of several animals to cordon off an area of shallow water to concentrate fish in order to entrap them (Pooley and Gans, 1976). Pooley once observed two Nile crocodiles walking overland side by side while carrying the carcass of a Nyala well off the ground between them (Pooley and Gans, 1976).

Female Nile crocodiles reach sexual maturity when they are approximately 2.5m in length which converts to an age group of about 12 - 15 years old. Large territorial males fight for the right to mate with the females who indicates willingness to mate by lifting of the head out of the water and exposing the throat. Mating occurs several times per day over many days at the end of winter/beginning of spring between July and September (Pooley and Gans, 1976). Egg laying takes place about three months later at the start of the rainy season during October to December (Alexander and Marais, 2007; Pooley and Gans, 1976).

Female Nile crocodiles select a nesting site based on a number of environmental parameters which includes, soil type, location on the slope of the shore, incline of the shore, direct sunlight, height above the flood line, vegetation providing shade and the proximity of deep pools of water (Alexander and Marais, 2007; Pooley and Gans, 1976; Swanepoel, 1999). A hole about 300 - 450mm deep is excavated and a number of eggs (anywhere between about 30 to 75 or 80 eggs) are laid in the hole and covered up again with sand excavated from the nest hole. The nesting female protects the nest from predators such as baboons and monitor lizards (*Varanus* sp.) but despite her efforts as many as 50% to 90% of nests are destroyed by predators before hatching (Alexander and Marais 2007). Eggs are white with hard shells and hatch after an incubation period of approximately 90 to 95 days (Pooley and Gans, 1976). Incubation temperature and other factors such as humidity determine the gender of the hatchlings. Eggs incubated at 31°C to 34°C generally develop into males while eggs incubated above or below this temperature range generally develop into females. During the incubation period, the nesting female evidently does not feed at all and can loos up to 30% of their bodyweight (Pooley and Gans, 1976).

At the end of the incubation period the females open the nest and carry the hatchlings to the water. Both males and females have been reported to assist hatching by gently cracking open eggs between their tongue and upper palate. Hatchlings measure about 250 - 300mm TL when newly hatched and they remain close to the juveniles for up to two years after hatching, often forming a crèche with other females. As with many other crocodilian species, older juveniles tend to stay away from older, more territorial animals.

Nile crocodile used to occur as far south as around East London in the Eastern Cape province but today their southern African range only extend as far south as the Tugela River in the KwaZulu-Natal province and northwards into northern Zululand, Mpumalanga province, North West province, Limpopo province, Mozambique, Zimbabwe, eastern and northern Botswana and Namibia (Alexander and Marais, 2007; Jacobsen, 1988; McLachlan, 1978).

Nile crocodiles are especially dangerous animals to humans and a 3.0m (TL) animal can easily overpower an adult human while smaller crocodiles are known to have caused extensive injuries during attacks on humans. Nile crocodiles have a reputation as being man-eaters much like *Crocodylus porosus,* but according to Britton (2009) Nile crocodiles are probably responsible for more fatalities of people than all other crocodilian species combined.

THREATS TO THE NILE CROCODILE POPULATION IN THE OLIFANTS RIVER

1. The indirect destruction of habitat caused by the construction of dams and weirs in the upper reaches and catchment areas of the river reducing the amount of water available to the river lower down. This is closely associated with authorities not even allowing the minimum ecological reserve flow through the river especially during the dry season. It is clear from figures in table 1 (Chapter 2) that the water resource of the Olifants River is already heavily over utilised and the situation is only getting worse with more demands for water from the platinum mining industry. The Flag Boshielo Dam was raised intentionally to provide water for mining and the Blue Ridge Platinum Mine near Groblersdal is already demanding more water from Loskop Dam. Providing water for paying customers or providing water for the environment without showing a profit too often becomes the choice. The river system provide some of the most important habitat for crocodiles and monitoring has shown that breeding and nesting do not take place in the main water body of dams but rather in the river itself. During the dry season the lack of water due to dams and weir impeding natural flow may reach critical proportions. The Olifants River in the Kruger National Park is one such example, where the river stops flowing for some months during the dry season.

2. Abstraction of water from the river is a direct threat to the survival of Nile crocodiles in the Olifants River. Pumping water from the river including permanent dry season pools reduces the level of water available to the crocodiles that needs deep pools to thermoregulate and also reduces the food source available to crocodiles in the river and pools.

3. Incompatibility between human activities and Nile crocodiles directly threatens the well being of crocodiles in the Olifants River. On occasion crocodiles take livestock drinking at the river and more frequently take fish from illegal gill nets. Due to the social interaction within the crocodile population many sub-adult animals in the 1.4 - 2.1m (TL) size class leave the river and take up residence in irrigation ponds constructed by commercial farmers thus representing a danger to farm workers. The impact that these crocodiles have on the economic activities (irrespective of the legality of the person's activities at the time) lead directly to a high level of animosity towards all crocodiles which inevitably results in the removal of the crocodile from the system either by killing or capture (both of which are illegal). Dr Niels Jacobsen reported seven crocodiles, all of reproductive age and size, being killed by unknown persons in the Flag Boshielo Dam during the early 1990's (Jacobsen, 1992). Disturbingly, my own studies revealed a total of five male crocodiles most of which were of reproductive age and size (3.10m TL; 4.10m TL; 4.60m TL; 1.50m TL and 3.96m TL) being killed by unknown persons in the

Flag Boshielo Dam during 2002/2003 illustrating human intolerance for these magnificent beasts.

4. The destruction of nests by unknown persons. The height of the nesting season in South Africa coincides with the summer school holidays which are a time when families traditionally spend much time outdoors. Public angling is allowed on private property and in public waters like the large dams in the Olifants River. People typically spend the whole day at one spot next to the water and it often happens that they then spot a Nile crocodile lying in the same place all day, which is of course a female guarding her nest. Whether from boredom, bravery or stupidity the decision to chase the crocodile away is soon reached and the nest discovered and destroyed to "make the angling spot safe for future use"

5. Construction of fishing camps, caravan parks, camping sites, eco lodges and weekend homes. This is mostly done without considering or even studying the ecological impact of the construction and operating phase. These recreational facilities are poorly planned in most cases and based purely on bringing as many people as possible to unspoiled areas at a price. With the exponential increase in people angling at these areas, Nile crocodiles are forced to compete for the food source in terms of fish and this competition is not appreciated by the owners of such places since visitors will only return if the fishing is good. Construction sites are chosen in most cases for easy access

to the river and scenic setting on sandbanks overlooking pools in the river which is exactly where crocodiles go to nest. A returning female looking for a good nesting site and finding a huge building or compacted camping ground in its place is forced to search for and use suboptimal nesting areas with a correspondingly lower chance on hatching success.

6. Boating and recreational activities near nesting areas have a detrimental effect on nesting in those areas. It has been shown that indirect disturbance even by human activities such as camping, fishing and boating are expected to increasingly affect crocodiles (United States Fish and Wildlife Service, 1999; Beacham, Castronova and Sessine, 2000). Observations suggest that repeated close human presence may cause female crocodiles to abandon or relocate their nest sites (Beacham, Castronova and Sessine, 2000). In the Flag Boshielo Dam specific nests located on sandbanks in the dam were used for the first time in nine years when all recreational activities on the dam were banned during construction of the raised dam wall.

7. Raising of dams by the Department of Water Affairs and Forestry impacts severely on Nile crocodile populations in the Olifants River. The incidence of loss of habitat, loss of basking sites, loss of nesting areas and change in prey composition after a dam wall is increased in height is devastating to resident Nile crocodile populations. Three dams in the Olifants River were raised in height and at each site the crocodile population suffered. The Loskop Dam was raised in 1977 which changed the character of the dam

from a winding river-like appearance to flat open water with huge fluctuations in level, all basking and nesting sites in the dam were flooded and crocodiles retreated into the inlets and numbers began to decline seriously. The Flag Boshielo Dam was raised recently (2005) and again all basking and nesting sites where flooded and crocodiles retreated away from the vast expanse of water. Massingire Dam in Moçambique was repaired and increased to full supply level flooding the Olifants River Gorge changing the flowing river into standing slow moving water with increased siltation and a change in prey species composition. This contributed to a massive decline in crocodile numbers from what was once a crocodile haven.

8. Pollution in the upper catchment of the Olifants River has a direct influence on the survival of Nile crocodiles in the river. It has been shown that Nile crocodiles in Loskop Dam died in large numbers due to pansteatis, a disease contracted by predators feeding on rancid fish. It is also know that large fish die-offs occurred at the same time as crocodile die-offs possibly due to the effects of sewage and acid mine drainage into the river. The large scale die-off of crocodiles in the Olifants River Gorge during August and September 2008 was also positively linked to the pansteatitis disease. Blood biochemistry results indicate clearly that crocodiles in these populations suffer from poor health (Chapter 5).

9. Illegal hunting of Nile crocodiles for traditional medicine and to a lesser extent for their skins contributes to the loss of animals in the reproductive size class. Loss of these animals have a profound influence on the recovery of depleted populations making it almost impossible for such populations to recover as can clearly be seen in the Loskop Dam population (Chapter 4)

GOALS AND OBJECTIVES

Goals and underlying principles:

The goal of this conservation and management programme is to provide clear guidelines to ensure the long-term survival and conservation of viable Nile crocodile populations along the entire length of the Olifants River in South Africa while providing for public safety and ecologically sustainable utilisation.

This conservation and management programme is underpinned by the principle that abundant and viable populations of Nile crocodiles should be maintained in the Olifants River for their ecological and economic value whilst at the same time ensuring that crocodiles do not threaten human safety or people's enjoyment of the environment. This conservation and management plan for Nile crocodiles in the Olifants River system embraces the national environmental management principles as set out in the National Environmental Management Act (Act no 107 of 1998).

This conservation and management plan recognises the precautionary principle to ensure that scientific uncertainty will not be used as a reason to postpone management measures aimed at protecting Nile crocodile populations in the Olifants River or their environment.

Objectives:

In the Olifants River in the Mpumalanga and Limpopo provinces the specific objectives of this conservation and management plan are to:

1. Maintain viable wild populations of Nile crocodiles in the Olifants River, in the Mpumalanga and Limpopo provinces at least at current population levels.
2. Maintain, manage and protect Nile crocodile habitat (especially nesting sites) in the Olifants River, Mpumalanga.
3. Promote scientific research and long term monitoring of Nile crocodile populations in the Olifants River, Mpumalanga.
4. Increase public awareness regarding the ecological significance of Nile crocodiles in the Olifants River, Mpumalanga and the need for their conservation.
5. Manage human interaction and contact with Nile crocodiles in the Olifants River, Mpumalanga in order to ensure public safety.
6. Establish co-operative governance with other government departments, conservation organisations, academic institutions and non-government organisations who may have a direct or indirect influence on the Nile crocodile population in the Olifants River,

Mpumalanga (e.g. DWAF, Olifants River Forum, Veterinary Faculty of the University of Pretoria).

MANAGEMENT

Maintain viable wild populations of Nile crocodiles in the Olifants River, in the Mpumalanga and Limpopo provinces at least at current population levels:

1. The maintenance of the Olifants River Nile crocodile population at current levels or above must be a priority for conservation authorities in both provinces.
2. The destruction of habitat is arguably one of the most important factors in the decline of total numbers of crocodile populations in the Olifants River.
3. In terms of the above strategies to replace destroyed habitat by clearing encroached river banks from alien and invasive plants to establish basking sites must be funded and implemented.
4. The construction of artificial nesting areas in locations such as the Flag Boshielo Dam, and the Loskop Dam must be implemented. It should be relatively easy to construct a type of berm near the river bank in areas where crocodiles are frequently seen.
5. Re-introduction of crocodiles to depleted populations must also be considered. Although some experts argue that it will be pointless to re-introduce crocodiles to dams and rivers which are clearly polluted since the odds are against the introduced crocodile

to survive. However, problem crocodiles are in any case doomed and re-introducing them to depleted populations may serve a better cause.

6. The cost of maintaining viable populations and implementing strategies to achieve this should be borne by industries and mining that utilise the water produced by destroying natural habitat and who release pollutant matter into river systems. The "polluter pays" and to coin a new phrase "mega water-user pays" principle should be enforced in this instance
7. Egg harvesting and capture of wild crocodiles for crocodile ranching, although not currently allowed, must be banned until scientific research and long-term monitoring has proved that enough eggs are produced annually in the wild to sustain any sort of harvest and that population numbers are high enough to allow sustainable take off for crocodile ranching.
8. A strategy must be implemented by the two provincial conservation authorities to locate and map all/most nests annually through aerial surveys. These nests must then be tracked and their success/failure noted. If circumstance change to the effect that any nest is threatened (e.g. by development, flooding, dam construction etc) the eggs should be rescued and hatched elsewhere and the young returned to the nest site upon hatching.

Maintain, manage and protect Nile crocodile habitat (especially nesting sites) in the Olifants River, Mpumalanga:

1. The area of the middle Olifants River from Witbank Dam to the international border with Moçambique including the banks of the river for a distance of at least 300m to 500m on each side, must be declared a Protected Environment in terms section 28 (2)(c)(d)(e) of the National Environmental Management: Protected Areas Act (No 57 of 2003) to give some degree of official protection to the area and a basis from which to ensure that development is not done in an unplanned manner.
2. Sandbanks, riverbanks and the riverbed particularly in the critical habitat must be protected from destruction by declining permission for development in these areas especially for the mining of sand.
3. Nile crocodile populations occurring in provincial nature reserves must be protected by ensuring that sensitive areas such as basking, nesting and nursery areas are designated as areas not accessible for public recreation. All declared conservation areas where Nile crocodiles occur should be zoned according to the following principles:
    3.1. The area where crocodiles are most active should be zoned as an **Environmental Reserve Zone.** These areas are critically important to crocodiles because most social interactions such as mating, nesting, establishment of dominance, home range maintenance, hunting etc take place here. Detailed conditions for public access to this area are given in Appendix II.

3.2. The second area (where crocodiles are less active) should be zoned as a **Wilderness Zone** where public access will be strictly controlled. This area is important to crocodiles because most of the secondary important nesting areas and also primary important basking areas occur here. The area could also be joined with the first (Filter/Environmental Reserve Zone) area to form one continuous wilderness area. Public access to this area must be strictly controlled to ensure compliance with both conservation and public safety regulations. Detailed conditions for public access to this area are given in Appendix II.

3.3. The third area (where crocodiles are occasionally active) should be zoned as a **Conservation Zone** because important basking areas will occur here. Detailed conditions for public access to this area are given in Appendix II.

3.4. All other areas which are visited by crocodiles from time to time but which are of minor importance to crocodiles must be zoned as a **Public Access Zone**. Detailed conditions for public access to this area are given in Appendix II.

Promote scientific research and long term monitoring of Nile crocodile populations in the Olifants River, Mpumalanga:

1. A co-ordinating committee must be established between the Mpumalanga Tourism and Parks Agency, Limpopo Department of Economic Development, Environment and Tourism, South African National Parks (as lead agencies), and other departments and

tertiary education institutions who are interested in researching aspects of Nile crocodiles.

2. The functions of this committee will include the coordination and distribution of research results, ensuring that research projects are not duplicated and that therefore funding is appropriately allocated and that monitoring data are shared by all departments who deal with issues impacting on the environment.
3. Any future development projects (industrial, residential, golf estates, mining etc) that make use of the Olifants River in any way or is situated on the banks of the Olifants River must pay a percentage of the total cost of the development into a trust account to fund further research and monitoring of the Olifants River Nile crocodile population.
4. Research and monitoring programmes that must be implemented as a matter of urgency are:
   - 4.1. Confirmation of occurrence of Nile crocodiles in all waters (river and dams) of Mpumalanga and Limpopo.
   - 4.2. Crocodile numbers, populations structure and distribution in dams where they occur (spotlight and aerial surveys at least twice a year in January and August, the frequency of surveys can be adjusted after five years if the reliability of data permits changes to the survey frequency).
   - 4.3. Aerial surveys of rivers in the Mpumalanga and Limpopo provinces to determine numbers, population structure and distribution (possibly number of nests depending on the timing of the survey).

4.4. Identify and map areas of high crocodile population density in the Olifants River

4.5. Determine and map the number of nests per season in the Olifants River.

4.6. Determine and map priority areas of high conservation value for crocodiles in the Olifants River in order to develop specific strategies to conserve the animals and their habitat.

4.7. Identify, quantify and monitor the processes threatening the survival of Nile crocodiles in the Olifants River.

4.8. Determine the movement patterns and spatial requirements of crocodiles over 2.1m (TL) in the Olifants River using satellite, GPS/GSM and radio telemetry.

4.9. Maintain a GIS database for records of Nile crocodiles, their habitat in the Olifants River and all human-crocodile interactions.

4.10. River health surveys (especially in the Olifants River).

Increase public awareness regarding the ecological significance of Nile crocodiles in the Olifants River, Mpumalanga and the need for their conservation:

1. Provincial Nature Conservation Authorities (Mpumalanga and Limpopo provinces) must promote the conservation and management of crocodile populations. The importance of crocodiles and the need to protect their habitat should be widely explained to the general public.

2. Research and long-term monitoring of crocodile populations and river health must be published and promoted in layman's terms to the general public in printed and electronic media.

Manage human interaction and contact with Nile crocodiles in the Olifants River, Mpumalanga in order to ensure public safety:

A need exists and the provincial conservation authorities have an obligation in terms of the South African Constitution (No 108 of 1996) as amended and the National Environmental Management Act (No 107 of 1998) as amended to protect the public from threatening and/or dangerous crocodiles.

Due to the depleted status of most of the Nile crocodile populations in the Olifants River, there is a requirement to release wild crocodiles back into wild populations in support of critical research programmes.

Continual removal of crocodiles from the wild, with no considerations of relocation options is considered to be a negative management strategy which should be abandoned in favour of a more positive approach towards restocking dwindling crocodile populations while the cause of the reduction in numbers are addressed on another level through research and monitoring.

Problem crocodiles:

A crocodile is considered to be a "problem crocodile" if:

- It displays aggressive behaviour towards humans;
- It displays aggressive behaviour towards stock or pets (where adequate control measures are in place e.g. alternative water points, fences and barriers etc)
- It is sighted within 200m of a legally developed public facility and it is over 2.0m in total length;
- It is captured in a trap specifically set for crocodiles with the permission of the provincial nature conservation authority and it is over 2.0m in total length;
- The provincial nature conservation authority through its Chief Executive Officer or Head of Department (or his appointed delegate) considers the crocodile a threat for any other reason.

Removal of problem crocodiles:

Nature Conservation Officers should only remove problem crocodiles from any premises which have been developed or altered from its natural state in any way after the owners/developers have produced a legal document proving that the development was authorised by the competent and relevant provincial and national government departments. If such an authorisation cannot be shown by the owners/developers then the nature conservation authority must decline to remove the crocodile except where the nature conservation officer on the scene is satisfied that human lives are in eminent danger. Any nature conservation officer who removes a crocodile from any premises where the owners/developers cannot produce a legal document proving that the development was authorised by the competent and relevant provincial and national government departments, must on his return to his office immediately submit a full written motivation explaining his actions to the Chief Executive Officer or Head of Department and the relevant Herpetologist or Specialist Herpetologist in his department.

Problem crocodiles will be captured in a humane way using standard capture techniques (e.g. box trap, Pitman trap, floating trap, netting, noose and rope, fishing pole with braided line and barbless hook), removed from the wild and either relocated or sold to a crocodile farmer or other suitable facility. Crocodiles less than 2.0m (TL) are not considered to be problem crocodiles and must be returned to the wild without delay. Information regarding the species and population must be collected from each crocodile captured to help understand crocodile behaviour and their environmental needs.

The following data must be recorded from each captured crocodile and forwarded to the Herpetologist or Specialist Herpetologist of the relevant nature conservation authority:

- Description of environmental conditions at the capture site;
- Size and gender of the crocodile(s) captured;

- Number and sizes of other crocodiles spotted in the same general area;
- Photographs (preferably digital photographs) of the animal and the site;
- GPS coordinates of the capture site and release site (if released back into the wild);
- A copy of the legal document authorising the development where the crocodile presents a problem;
- If possible, blood or tissue samples taken from the captured animal to monitor pollutant levels and general health of the population.

Problem crocodiles will be disposed of by selling them to licensed crocodile farmers or relocating them to wild populations.

<u>When crocodiles are sold to crocodile farmers the following guidelines should be followed:</u>

- The crocodile farmer must have licensed facilities approved by the relevant nature conservation authority and comply with the South African National Standard (SANS 631) for keeping and transporting Nile crocodiles and with the code of practise of the Crocodile Farmers Association;
- The crocodile farmer receiving the crocodile must pay a predetermined amount the cover the conservation value of the animal lost from the wild population. This amount must be determined by applicable structures in each provincial nature conservation authority (i.e. Financial Manager or Treasury Department in conjunction with the relevant Herpetologist or Specialist Herpetologist);

- The crocodile farmer receiving the crocodile and his/her staff must have proven abilities and experience in the safe handling and managing of crocodiles in captivity, particularly large crocodiles;
- The crocodile farmer receiving the crocodile must agree to hold the crocodile received off display from visitors to the farm for a sufficient time to allow it to be habitualised to captivity and have adequate holding facilities, off display, to hold the animal in isolation while it adapts to captivity
- All relevant information regarding the captured crocodile must be forwarded as described above in the section dealing with data required by the herpetologist or specialist herpetologist of the relevant nature conservation authority.

When releasing crocodiles back into the wild, the following guidelines must be followed:

- Captured crocodiles may only be handled by nature conservation officers;
- The nature conservation officer releasing the animal must confer with the Herpetologist/Specialist Herpetologist of the relevant nature conservation authority regarding the most acceptable site for release;
- Any crocodile handled after capture must have its jaws restrained by using duct tape or electricians tape;
- The crocodile must ideally be taken directly to the release site and not be transported to holding pens or isolation ponds before release;

- At the release site the animals must be placed a maximum of a couple of paces from the water's edge and must be released facing the water;
- The release is the most dangerous time when handling a crocodile and as such crocodiles may only be released by nature conservation officers with proven experience in the capture and release of crocodiles;
- Nature conservation officers experienced in handling large crocodiles must make sure that all restraints are removed from the jaws of the animal prior to release;
- The release site must be at a location with water deep enough for the released animal to submerge immediately after release (this will assist with calming the animal down and to avoid further capture stress);
- The number of persons involved in the capture and release process must be strictly limited to ensure safety and to restrict noise during the release.
- All relevant information regarding the captured crocodile must be forwarded as described above in the section dealing with data required by the herpetologist/specialist herpetologist of the relevant nature conservation authority.

Icon crocodiles:

An "icon crocodile" is defined as a problem crocodile that is four metres or more in total length or if less than four metres in total length has unusual characteristics such as albinism for example.

Icon crocodiles can represent a significant commercial benefit to a crocodile farm, crocodile centre or zoo. However, icon crocodiles also present an exceptional opportunity to achieve educational, public awareness, scientific and conservation outcomes for crocodiles and crocodile habitat. Therefore, the decision as to how and where to dispose of such an exceptionally large crocodile must be based on scientific input. The herpetologist/specialist herpetologist of the applicable nature conservation authority will be required to motivate the disposal of such an animal and will be required to decide on returning the crocodile to the wild to supplement dwindling populations/size classes in populations or to sell the crocodile to a crocodile farm, crocodile centre or zoo. Any such motivation or decision must receive final approval from the Chief Executive Officer or Head of Department of the relevant nature conservation authority before implementation.

In the event that a decision is reached to sell the icon crocodile, the nature conservation authority will request written offers from selected licensed crocodile farms, crocodile centres and/or zoos chosen to buy the crocodile. The crocodile farms, crocodile centres and/or zoos chosen approached in this instance will be identified on the basis of the following guidelines:

- The crocodile farmer must have licensed facilities approved by the relevant nature conservation authority and comply with the South African National Standard (SANS

631) for keeping and transporting Nile crocodiles and with the code of practise of the Crocodile Farmers Association;

- The crocodile farmer receiving the crocodile must pay a predetermined amount the cover the conservation value of the animal lost to the wild population. This amount must be determined by applicable structures in each provincial nature conservation authority (i.e. Financial Manager or Treasury Department);
- The crocodile farmer receiving the crocodile and his/her staff must have proven abilities and experience in the safe handling and managing of crocodiles in captivity, particularly large crocodiles;
- The crocodile farmer receiving the crocodile must agree to hold the crocodile received off display from visitors to the farm for a sufficient time to allow it to be habitualised to captivity and have adequate holding facilities off display to hold the animal in isolation while it adapts to captivity
- All relevant information regarding the captured crocodile must be forwarded as described above in the section above dealing with data required by the herpetologist/specialist herpetologist of the relevant nature conservation authority.

Once an offer from a crocodile farm, crocodile centre or zoo to buy the icon crocodile is accepted by the nature conservation authority the buyer will be informed and required to collect the animal within 48 hours or the transaction will be cancelled and the animal forfeited.

The nature conservation authority will retain the right to release the icon crocodile back into the wild at the most appropriate location if none of the offers received are regarded as fair.

High risk crocodile nests:

Nile crocodile nests in the Olifants River that are threatened by imminent danger must be considered as high risk nests and should be rescued. The "high risk status" of nests must be measured against a number of criteria but only one of these criteria need to be present for the nest to be considered under high risk of destruction. Nests must be assessed for their risk of destruction no later than November/December each year. However, if conditions at the nest have improved at the time of the planned egg collection to such an extent that the high risk category does not apply any longer, egg collection should not proceed. Rescued eggs must be taken to a reputable crocodile farm or crocodile centre to hatch and hatchlings must be returned to the river upon hatching.

Previous policies suggested that hatchlings be reared by the crocodile farm until they reach a total length of 1.0m before they are released back into the wild. However, since we do not know how many crocodiles from nests will survive to 1.0m length, the impact of releasing a large number of 1.0m long crocodiles from rescued eggs than would normally not have survived could potentially be ecologically disrupting. It is therefore recommended that hatchling crocodiles are released back into the wild as close to the nesting site as possible as soon as they hatch.

Criteria for crocodile nests to be considered in high risk of being destroyed:

- The nest has no protection (vegetation or inlet etc) against wave action from the river or dam within 25m where it is located.
- The nest is located so low that it will be flooded by a 10cm rise in groundwater level. The average nest depth is 40cm and therefore if the water level is within 50cm of the surface the nest must be regarded as high risk. Groundwater levels can be checked by digging a hole within 0.5m of the nest.
- The nest is situated on a site where there is an 80% probability that it may be flooded by a sudden rise in water levels for example due to imminent flooding or heavy rain falls.
- The nest is situated in an area where there is constant daily threat by people or stock animals in a manner that cannot be controlled by the relevant nature conservation authority.
- The nest is situated in soil that is so impervious that the eggs will be saturated by heavy rain falls.
- The nest is situated in an area where legal authorisation has been given by the relevant competent environmental authorities for development (lodge, sand mining camping area etc) to take place and construction is about to commence.

Establish co-operative governance with other government departments, conservation organisations, academic institutions and non-government organisations who may have a direct or indirect influence on the Nile crocodile population in the Olifants River, Mpumalanga (e.g. DWAF, Olifants River Forum, Veterinary Faculty of the University of Pretoria).

1. Provincial Nature Conservation Authorities (Mpumalanga and Limpopo provinces) must be included in decision making process of the Department of Water Affairs and Forestry regarding the allocation and abstraction of water from the Olifants River (and other rivers) as well as future plans to construct dams in the Olifants and other rivers. This process is not designed to put nature conservation in a regulating position over other departments but is important to ensure the viability of the Olifants River for future generations since different departments have different views on the meaning of sustainability and viability of rivers. Because this co-operation is so important and could easily be misinterpreted, it must be agreed upon at top management level for all departments involved (i.e. Director General of Department of Water Affairs and Forestry; Chief Executive Officer of Mpumalanga Tourism and Parks Agency; Head of Department of Limpopo Department of Economic Development, Environment and Tourism).
2. Provincial Nature Conservation Authorities (Mpumalanga and Limpopo provinces) must be involved with the National and Provincial Agriculture Departments to promote soil

and water conservation especially in cases where the control of irrigation and clearing of land for agriculture is involved

3. Provincial Nature Conservation Authorities (Mpumalanga and Limpopo provinces) must be involved with the Department of Minerals and Energy particularly on the Regional Mining Development Committee (RMDEC) to promote better understanding when evaluating applications for sand mining in riverbeds, sandbanks and riverbanks.

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CHAPTER 7

THE NILE CROCODILE POPULATION IN THE OLIFANTS RIVER

IS THERE A FUTURE?

Crocodilians are one of only two, with birds living representatives of one of the most successful groups of land-dwelling vertebrates ever known, the Archosauria. These reptiles dominated animal communities on the continents during the Mesozoic era (245 - 65 million years ago). In addition to the crocodilians, the Archosauria included the dinosaurs, pterosaurs or flying reptiles, birds and an assortment of early Mesozoic forms often referred to as thecodontians, which included a variety of primitive archosaurs, some of which could have been the precursors of later groups such as crocodilians.

Hans-Dieter Sues (1990) wrote: *"Despite their antiquity it is quite inappropriate to treat crocodilians as "living fossils" whose "inferiority" forced them into a marginal ecological role as amphibious predators in a world now dominated by mammals. In fact they are highly specialized for their particular mode of life and have undergone considerable changes during their long evolutionary history which spans more than 200 million years".*

The outlook for Nile crocodiles in the Olifants River does not look optimistic. We have established that crocodiles are important to aquatic ecosystems because they maintain biodiversity in their habitats where other animals are advantaged by the activities of crocodilians such as maintaining their deep pools and trails; by feeding on abundant species and thus increasing resources for less abundant species; they could possibly contribute to limiting water borne diseases because they control predatory fish which allows other smaller fish species to thrive thereby eliminating many insect vectors of disease; crocodiles are an environmental indicator species for pollutants and contaminants in aquatic ecosystems; crocodiles have aesthetic value and attract tourism as one of Africa's legendary predators; crocodiles are economically important and huge profits are produced annually by crocodile farms in selling their skins and meat; and as a result of crocodilians feeding on adult fish cause the amounts of calcium, magnesium phosphorus, potassium and sodium in nutrient poor streams and lakes double.

Despite all of this, it was shown in this project that Nile crocodile numbers in the Olifants River have not increased as one would have expected over a time-frame of almost 30 years. The distribution patterns of crocodiles in the Olifants River have changed very little over many years with possibly just the removal of the western boundary fence of the Kruger National Park having some influence on their distribution patterns. While distribution did not change much, numbers in certain important populations have declined to the effect that one may speak of a "population crash".

The areas which are the cause of most concern are the Loskop Dam population which has dwindled from over 80 animals in the early 1970's to only about 18 individuals but even more disturbing is that two entire and very important size classes (all animals larger than 2.1m TL) have disappeared totally from the population. This effectively negated the population's ability to increase naturally and therefore there is little hope for this population to survive without intervention. All indications at the Flag Boshielo Dam are that a large percentage of that population have left the area. What is clear is that the Flag Boshielo Dam habitat has been altered dramatically by effectively removing access to all basking and nesting sites merely by raising the dam wall and dramatically increasing the full supply level (height of the water). The Olifants River Gorge population has declined sharply by as much as 60% (an estimated minimum of 160 animals) since August 2008. As in the case of Loskop Dam population, crocodiles in the Olifants River Gorge were found dead in the water in large numbers and the losses also appear to be limited to the animals in large size classes (i.e. 2.1 - 4.0m and > 4.0m TL).

Results of tests on the blood biochemistry of Nile crocodiles from populations over the entire length of the Olifants River and in the Blyde River (considered to be an unpolluted class A river) suggest that the crocodiles occurring here are generally in poor health. Based on the current results, crocodiles in the Olifants River have probably been suffering from long term chronic inflammation and infection (elevated total serum protein, elevated globulin and elevated glucose levels) with serious problems in their immune systems (low vitamin E levels) and probably suffer from an inadequate diet (elevated potassium and low triglyceride levels).

We do know that the environment of the Olifants River have changed constantly over the last 30 years. Since the increase in capacity of the Loskop Dam, the crocodile population has declined. The increase in capacity of the Flag Boshielo Dam left the crocodile population with no basking or nesting sites in fact, the only available shore was developed into a public angling area. Shortly after the Massingire Dam in Moçambique filled to full capacity an estimated 160 crocodiles died in the Olifants River Gorge, a couple of kilometres upstream from the dam.

The Olifants River is acknowledged by many experts as one of the most polluted rivers in South Africa (Engelbrecht, 1992; Batchelor, 1992; Myburgh, 1999; Water Research Commission 2001; Driver *et al*. 2004; Havenga, 2007; Hartdegen, 2009). Acid mine drainage, industrial pollution and untreated sewage in the river are all contributing to the poor water quality of the Olifants River.

Further, the Department of Water Affairs and Forestry acknowledge that water demand already exceeds their capacity to supply and the situation will worsen considerably in the near future (Havenga, 2007) which will almost certainly lead to the impoundment of more rivers in the Olifants River system thereby demanding even more from an aquatic system already stressed over its limit.

There has been a dramatic increase in construction and building projects in South Africa over the last several decades. A concern is the development of camping areas, fishing camps, eco-lodges and weekend homes on the banks of the Olifants River. These recreational areas now bring a large number of people to the river turning the entire resident crocodile population into "problem crocodiles". If these developments are authorised, then the responsible department did not take the impact on the environment into consideration when authorising development and if the developments did not follow the EIA process, then the situation is that illegal developments are forcing nature conservation officers to remove crocodiles which have become "problem crocodiles" by default unnecessarily from the ecosystem. This is a possibility which cannot be allowed to happen.

As little as seven years ago the Olifants River was the location of choice for natural history filmmakers but today this is no longer the case as one is not sure of finding a single crocodile during a whole night of surveying.

The net result of all of the above is that the coincidence in these cases is glaring, but the question must be asked: Is it possible that official government departments will make the same mistakes in the same river system? In terms of the survey and blood biochemistry results from this project and the statements from aquatic experts regarding the pollution status of the Olifants River and given the acknowledgements from the Department of Water Affairs and Forestry that they have allowed the river to be over utilised then the answer to this question must be a shameful and unambiguous: **YES!**

Few animals inspire the sort of awe and fear that crocodilians do. Those of us who study these animals and their habitats tread carefully at the water's edge and their mythology abounds with stories and legends. However, in spite of the antiquity of the animals and the awe and fear that have made them part of the mythology of the ages, it seem that some humans are prepared to destroy these keystones of aquatic ecosystems, not directly but by poisoning or destroying their habitat and by making it impossible for them to find nesting space by artificially raising water levels or by constructing buildings and fishing camps on their basking sites - all for quick financial gain. Will the human race's well documented greedy nature ultimately lead to the disappearance of a 245 million year evolutionary animal from the face of the planet within our lifetime? The answer presumably is, "Unlikely in all aquatic systems, but highly likely in many", such as the Olifants River ecosystem.

In my view, based on all of the above, Nile crocodiles will have difficulty in surviving another 20 years intact in the Olifants River as we know it, leaving no viable populations in a river that was once described as "infested" with crocodiles by the first settlers who came to the valley in the Olifants River in 1886.

In view of the arguments above and results gained from this research, it is my opinion that the conservation status and risk of extinction of Nile crocodiles in the Olifants River must be upgraded to the Endangered category since it currently satisfies the criteria EN A2abce; C2a(i) as published in the IUCN Red List Categories and Criteria Version 3.1 (IUCN, 2001).

The ultimate value of a crocodile

lies not in his belly hide,

nor his value as a tourist attraction,

nor even in his ecological significance,

but simply in the fact that he is a crocodile:

big and ancient and monstrously magnificent

James Powell, IUCN Crocodile Specialist Group, 1971.

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SUMMARY

The outlook for Nile crocodiles in the Olifants River does not look optimistic. Since the increase in capacity of the Loskop and Flag Boshielo Dams, the crocodile population was left with no basking or nesting sites and has declined over the past 30 years. Shortly after the Massingire Dam in Moçambique filled to full capacity an estimated 160 crocodiles died in the Olifants River Gorge, a couple of kilometres upstream from the dam. The Olifants River is acknowledged by many experts as one of the most polluted rivers in South Africa and acid mine drainage, industrial pollution and untreated sewage in the river are all contributing to the poor water quality of the river. Further, the Department of Water Affairs and Forestry acknowledge that water demand already exceeds their capacity to supply and that the situation will worsen considerably in the near future.

Aerial surveys of Nile crocodiles in the Olifants River was carried out during December 2005 and November 2009. An average total population of 714 Nile crocodiles were counted and corrected to an estimated 1140 individual crocodiles to eliminate the effects of undercounting. The Kruger National Park and specifically the area of the Olifants River Gorge was found to be one of the preferred habitat areas for crocodiles in the Olifants River as was the Flag Boshielo Dam, the area between the Blyde River and the western boundary of the Kruger National Park and the Olifants River between the Loskop Dam and the Flag Boshielo Dam. The absolute density of Nile crocodiles (number of crocodiles/km of river) in

the Olifants River fluctuated between 0.04 and 21.20 crocodiles/km of river depending on the habitat. Models of the population structure indicate that the reproductive size class is much bigger than the pre-reproductive and dominant size classes showing the characteristic shape of a shrinking population. Repeated nesting in areas such as the Kruger National Park, the Flag Boshielo Dam and the Olifants River between the Loskop Dam and the Flag Boshielo Dam over the last five years has shown these areas to be critically important to the success of Nile crocodiles in the Olifants River. Nile crocodiles and nests were observed in the Elands River confirming this area as an important refuge area for Nile crocodiles in the Groblersdal-Flag Boshielo Dam area of the Olifants River.

Surveys during 2001, 2005, 2006, 2007 and 2009 revealed an estimated total of only 15 crocodiles in the Loskop Dam. No crocodiles in the large (2.0 - 4.0m TL) size class were found during these surveys while no crocodiles in the very large (>4.0m TL) size class were found during any of the surveys.

Blood biochemistry results indicate that the Olifants River Nile crocodile population probably suffers from chronic inflammation (especially in the Loskop Dam and Olifants River Gorge populations), infectious disease (particularly in the Loskop Dam population but all other sites also showed elevated values), possible inadequate diet and malnutrition (especially during the pansteatitis outbreak of August/September 2008) and are suffering serious immune problems in the Olifants River Gorge.

A conservation and management plan which identifies threats to the continued existence of a viable Nile crocodile population in the Olifants River is suggested. The management plan also set a number of important goals, objectives and guidelines to better manage interaction between crocodiles and humans. The suggestion is made that the conservation status and risk of extinction of Nile crocodiles in the Olifants River be upgraded to the **Endangered** category since it currently complies to the following criteria; EN A2abce; C2a(i) published in the IUCN Red List Categories and Criteria Version 3.1 (IUCN, 2001).

OPSOMMING

Vooruitsigte vir Nylkrokodile in die Olifantsrivier lyk nie baie optimisties nie. Die verhoging in kapasiteit van die Loskopdam en ook die Flag Boshielodam het alle natuurlike sandbanke en nesplekke op die oewers vernietig en die krokodile populasies in die twee damme toon n afname oor die laaste 30 jaar. Kort nadat die Massingiredam in Mosambiek vir die eerste keer tot sy volvooraadvlak gestyg het, is ongeveer 160 krokodille dood in die Olifantspoort stroomop van die dam. Verskeie kenners beskryf die Olifantsrivier as een van die mees besoedelde riviere in Suid-Afrika met suurmynwater, indutriële besoedeling en onbehandelde riool wat bydra tot die swak kwaliteit van die water in die rivier. Voorts erken die Departement van Waterwese dat daar alreeds meer water gebruik word as wat die rivier kan voorsien. Daar word verwag dat hierdie situasie binnekort aansienlik sal vererger.

Lugsensusse van Nylkrokodille in die Olifantsrivier is gedurende Desember 2005 en November 2009 uitgevoer. Tydens hierdie lugsensusse is ʼn gemiddeld van 714 Nylkrokodille getel maar met die uitskakeling van die onderteling-faktor word die totale bevolking op ongeveer 1140 diere geskat. Die Nasionale Krugerwidltuin en spesifiek die Olifantsrivierpoort-gebied is bevestig as voorkeurhabitat vir krokodille in die Olifantsrivier. Ander voorkeur gebiede vir krokodille in die Olifantsrivier sluit die Flag Boshielodam, die area tussen die Blyderivier samevloeiing en die westelike grens van die Nasionale

Krugerwidltuin en die Olifantsrivier tussen die Loskopdam en die Flag Boshielodam in. Die absolute digtheid waarteen Nylkrokodille in die Olifantsrivier waargeneem is was tussen 0.04 en 21.20 krokodille/km van die rivier afhangend van die beskikbare habitat. Die huidige populasiestruktuur is tiperend van 'n krimpende populasie aangesien die reproduktiewe grootteklas uit heelwat meer diere bestaan as die pre-reproduktiewe en die dominante grootteklasse. Herhaalde gebruik van nesgebiede in die Nasionale Krugerwidltuin, die Flag Boshielodam en die Olifantsrivier tussen die Loskopdam en die Flag Boshielodam oor die laaste vyf jaar bevestig dat hierdie negebiede krities belangrik is vir die suksesvolle voortbestaan van Nylkrokodille in die Olifantsrivier. 'n Aantal Nylkrokodille en neste is in die Elandsrivier waargeneem wat dan bevestig dat die rivier 'n belangrike toevlugsoord vir krokodille in die Loskopdam-Groblersdal area van die Olifantsrivier geword het.

Die reslutate van opnames wat gedurende 2001, 2005, 2006, 2007 en 2009 gedoen is dui aan dat daar slegs n geskatte totaal van 15 Nylkrokodille in die Loskopdam voorkom. Hierdie opnames dui ook aan dat geen diere in die groot (2.0 - 4.0m TL) en ekstra groot (> 4.0m TL) klasse in die Loskopdam voorkom nie.

Ontleding van die bloedbiochemie van krokodille in die Olifantsrivier dui aan dat dat die diere hier waarskynlik aan chroniese inflamasie (veral in die Loskopdam en Olifantsrivierpoort), infeksie (veral in die Loskopdam) , ontoereikende dieet en wanvoeding (veral tydens die pansteatitis uitbraak van Augustus/September 2008) ly wat erenstige immuun stelsel tekorte veroorsaak het veral in die Olifantsrivierpoort van die Nasionale Krugerwidltuin.

Faktore wat krokodil bevolkings in die Olifantsrivier bedreig word geidentifiseer en 'n aantal doelwitte wat gemik is daarop om die voortdurende daling van krokodil getalle te verhoed word voorgestel in 'n bewarings en bestuursplan. Daar word aanbeveel dat die bewaringstatus en risko vir uitsterwing van Nylkrokodille in die Olifantsrivier verhoog word na die **Bedreigde kategorie** aangesien die bevolking huidiglik voldoen aan kriteria EN A2abce; C2a(i) soos gepubliseer in die IUCN Red List Categories and Criteria Version 3.1 (IUCN, 2001).

APPENDIX I

DETAILED CONSERVATION AND MANAGEMENT PLAN FOR THE WILD NILE CROCODILE POPULATION IN THE OLIFANTS RIVER, MPUMALANGA PROVINCE

The document follows the format, layout and terminology used in most of the following existing crocodile conservation and management plans:

- Nature Conservation (estuarine crocodile) conservation plan 2007 and management plan 2007 - 2017 (Queensland Environmental Protection Agency, 2007).
- Management plan for *Crocodylus porosus* in the Northern Territory 2005 - 2010 (Parks and Wildlife Service of the Northern Territory, 2005a).
- Management program for *Crocodylus porosus* and *Crocodylus johnstoni* in the Northern Territory of Australia (Parks and Wildlife Service of the Northern Territory, 2005b).
- Saltwater crocodile (*Crocodylus porosus*) and freshwater crocodile (*Crocodylus johnstoni*) management plan for Western Australia 2004 - 2008 (Department of Conservation and Land Management, 2003).
- Management plan for *Crocodylus porosus* in Sabah, Malaysia (Sabah Wildlife Department, 2002).
- Policy and management plan for the Nile crocodile, (Tanzania Department of Wildlife, 1993).

- Management plan for crocodiles in Zimbabwe (Department of National Parks and Wildlife, 1992)
- Conservation plan: *Crocodylus niloticus* (Jacobsen, 1992)
- Status survey and conservation action plan for crocodiles, (Ross, 1998).
- A management plan for the conservation of the Nile crocodile (*Crocodylus niloticus*) in the Okavango Delta, Botswana (Bourquin, 2007)
- The management of crocodiles in captivity (Bolton, 1989).
- Sustainable use of the Lake Chamo Nile crocodile population (Whitaker, 2007).

INTRODUCTION

The Nile crocodile is the only crocodilian species that occur in southern Africa. They are very large and robust animals and considered by many to be iconic animals of the African continent. Adult Nile crocodiles average between 2.8 and 3.5m in length but in southern Africa they can grow as large as 5.5m and weigh around 1000kg at that length (Alexander and Marais, 2007). Although even at 5.5m in length, Nile crocodiles are only second in size to the estuarine crocodile (*Crocodylus porosus*) which is widely regarded as the largest living reptiles on earth (Alexander and Marais, 2007). It is however estimated that fewer than 2% of all Nile crocodiles occurring in the wild in southern Africa exceed 3.0m in length (Alexander and Marais, 2007).

Nile crocodiles favour permanent, still or slow moving water with high, sunny, sandy banks above flood levels with enough vegetation to provide shade and shelter (Hutton and Loveridge, 1999). However, this description also fits the exact locations preferred by people. These are the places where water is pumped for irrigation schemes and domestic use, where recreational areas such as fishing and camping sites are established, subsistence fishing take place, illegal commercial fishing with gill nets are practised, exclusive upmarket eco-loges and week-end homes are constructed, weirs and dams are built to supply industry, mining and agriculture with a constant water supply equal to their demand. It is clear then that there are little room left in river systems for Nile crocodiles to go about their business as they have done for millions of years. Therefore it has become immensely important to have written conservation and management plans which must be approved and implemented by the relevant conservation authorities, provincial and national governments.

SPECIES CONCERNED

Class	:	Reptilia.
Order	:	Crocodylia.
Family	:	Crocodylidae.
Subfamily	:	Crocodylinae.
Genus and species	:	*Crocodylus niloticus* Laurenti, 1768.
Common names	:	Nile crocodile.

AGENCY RESPONSIBLE

The Olifants River falls within the boundaries of two provinces in South Africa, therefore the responsibility for the conservation of the Nile crocodile populations in the river must be shared by the two conservation organisations namely:

3. Mpumalanga Tourism and Parks Agency

Private Bag X11338

Nelspruit, Mpumalanga

South Africa, 1200

Telephone: +27 13 759 8300

Facsimile: +27 13 752 7012

E-mail: info@mtpa.co.za

4. Limpopo Department of Economic Development, Environment and Tourism

Private Bag X9484

Polokwane, Limpopo

South Africa, 0700

Telephone: +27 15 8300

Facsimile: +27 15 8319

E-mail: info@ledet.gov.za

CONSERVATION STATUS AND LEGISLATIVE FRAMEWORK

Although nature conservation and the protection and management of the environment functions independently in each province of South Africa, it is also subject to national legislation and international agreements and conservation efforts ratified by the South African government.

National:

Nile crocodiles are considered to be a protected species under the *National Environmental Management: Biodiversity Act (Act 10 of 1998).* A protected species under the NEMBA legislation is defined as "any species which is of such high conservation value or national importance that it requires national protection" (Section 56(1)(d) of Act 10 of 1998). However, the current IUCN Red List categorises the Nile crocodile as LRlc (Low Risk, Least Concern) but some experts are of the opinion that Nile crocodiles may be threatened in some parts of its range (Britton, 2009).

Due to successful crocodile farming being practised in this country, the South African population of Nile crocodiles are currently listed on Appendix II of the *Convention on the International Trade in Endangered Species of Wild Fauna and Flora* (CITES).

The current South African Red Data Book for Reptiles and Amphibians (Jacobsen, 1988) lists the Nile crocodile as vulnerable. A new assessment of all reptiles and amphibians in South Africa the South African Reptile Conservation Assessment (SARCA) is currently underway but final classification of the conservation status of reptiles according to that study is not currently available.

Provincial:

Provincial conservation legislation governing the protection of Nile crocodiles in the Olifants River are: the *Mpumalanga Nature Conservation Act* (Act 10 of 1998) and the *Limpopo Environmental Management Act* (Act 7 of 2003). In the Mpumalanga province, Nile crocodiles are considered to be protected game (Schedule 2 of Act 10 of 1998) and in the Limpopo province they are considered to be specially protected animals (Schedule 2 of Act 7 of 2003). This means that in both the Mpumalanga and Limpopo provinces, Nile crocodiles may only be hunted/killed legally under the issuance of a permit from the provincial nature conservation authority.

BIOLOGY OF THE NILE CROCODILE

The most striking characteristic about crocodilians are their size. Nile crocodiles are large reptiles that can grow to more than 5.0m in total length and reportedly reaching 6.0m (TL) in rare instances (Britton, 2009; Alexander and Marais, 2007). Reports of animals over

7.0m (TL) that have been seen in the wild such as the infamous Gustave in Lake Tanganyika exist but these reports are hard to verify and in fact experts estimate that less than 2% of wild crocodiles in southern Africa exceed 3.0m TL (Alexander and Marais, 2007).

According to Britton (2009) some evidence seem to indicate that Nile crocodiles in cooler areas on the southern edge of their distribution range such as the South African population may reach slightly smaller adult sizes of around 4.0m TL.

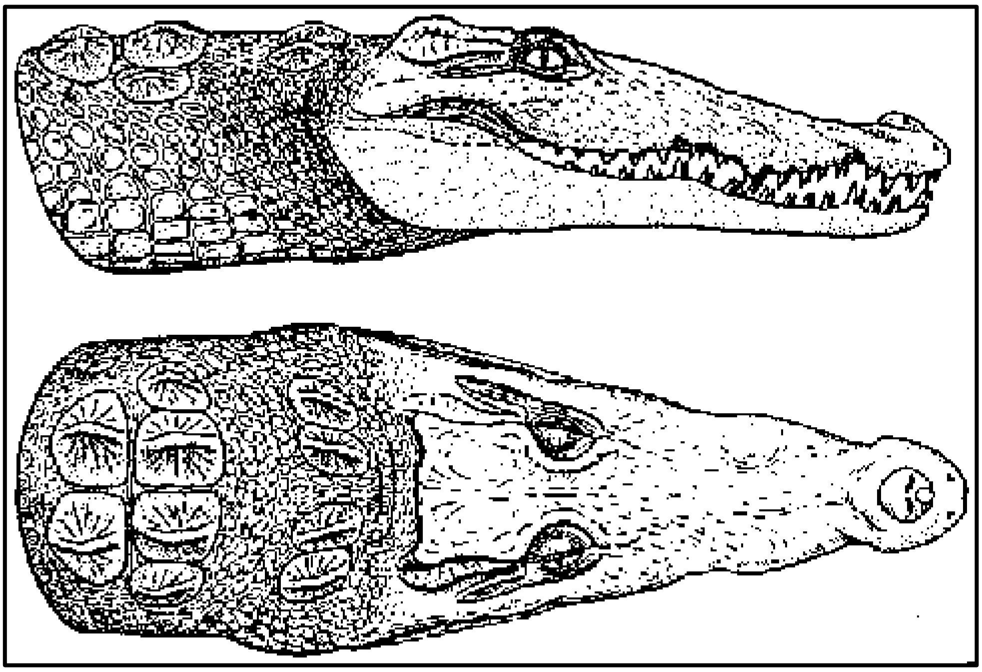

Figure 53: Head shape of the Nile crocodile (Wermuth and Fuchs, 1978).

Nile crocodiles have long snouts with large teeth that are visible even when the jaws are closed (Figure 51). Crocodilian jaws are designed for grabbing and holding prey. The teeth are conical and designed to penetrate and hold, rather than cut and chew. The upper jaw of "true" crocodiles is not as broad as that of alligators and caimans and it is sharply constricted or notched at the snout. In contrast to alligators and caimans, when "true" crocodiles close their jaws the enlarged 4th tooth on the lower jaw rests in that notch, and its tip is clearly visible. This is a major distinction between "true" crocodiles and alligators and caimans (Crocodile Specialist Group, 2009). A total of 64 - 68 teeth (5 pre-maxillary; 13 - 14 maxillary; 14 - 15 mandibular) (Britton, 2009) are set in the jaws. The eyes, nostrils and slit-like ear openings are set high on the head so they protrude from the water when the crocodile floats just beneath the surface of the water in a "minimum exposure" posture giving little indication to potential prey, of the real size of the predator's body (Crocodile Specialist Group, 2009).

Nile crocodiles show wide habitat preferences indicative of their success and distribution - e.g. lakes, rivers, freshwater swamps, and brackish water and is regarded as the top aquatic predator in freshwater ecosystems throughout large parts of Africa (Hutton and Loveridge, 1999). They are strictly carnivorous and relentless predators throughout their entire lives. Sub-adults disperse into different habitats, away from breeding areas, when they reach a length of approximately 1.2m (Hutton and Loveridge, 1999). The absence of Nile crocodiles from moist forests and extensive swamps is strongly linked to the morphological characteristics of rivers and lakes which have a direct influence on nesting behaviour (Hutton and Loveridge, 1999). Crocodiles are active during both day and night spending most of the day basking to thermoregulate and nights in the water to prevent body temperature from dropping to low. Most of their hunting activities take place during night time.

Crocodilians are efficient and fast swimmers and Nile crocodiles are no exception to this rule. While the hind feet are webbed, the legs play little part in swimming with the muscular, laterally compressed tail (which accounts for 40% of an adult crocodile's length) being used to propel their bodies through the water (Pooley and Gans, 1976). Despite their short limbs, crocodiles are capable of reaching surprising speed over short distances on land. Crocodilians are excellent divers and can remain submerged for up to four hours (Richardson, Webb and Manolis, 2002; Britton, 2009) without needing to breathe. The ability to remain submerged for prolonged periods of time is due to several unique adaptations such as: flexibility and control over blood flow enabling the crocodile to slow down its heart rate and direct oxygenated blood only to organs which cannot function without oxygen (e.g. brain and heart); ear and nostril openings which can be closed with valves; nasal passages that are separated from the mouth by a secondary palate facilitating opening of the mouth underwater; adult crocodiles keep stones in their stomachs to increase specific gravity for easier diving thereby allowing the diving crocodile to take up to 12% more air in its lungs during dives (Alexander and Marais, 2007).

Hatchling Nile crocodiles feed on smaller prey items such as insects, tadpoles, frogs and fish (Allexander and Marais, 2007; Pooley and Gans, 1976). As they grow into juvenile crocodiles their diet changes to include terrapins, water birds and small mammals but by the time they reach adulthood, Nile crocodiles prey mainly on fish, large mammals and birds. Adult crocodiles have the ability to routinely kill large prey such as wildebeest, zebra and even buffaloes but do not lose the ability to feed opportunistically on lesser prey such as frogs, crabs and small fish (Pooley and Gans, 1976). The weight gain of juvenile Nile crocodiles as they grow to adulthood is between 2400 and 4000 fold while the size of their prey increase accordingly (Pooley and Gans, 1976). Crocodiles cannot bite large chunks of meat off their prey like mammalian predators can. Therefore crocodiles have adapted to this inability by grabbing onto their prey and rolling their bodies or simply shaking the prey vigorously until it breaks apart.

Nile crocodiles are capable of cooperative feeding behaviour for example, a number of individuals will hold onto a carcass with their powerful jaws providing anchorage while allowing others to tear of large chunks of prey for easier swallowing (Pooley and Gans, 1976). Another example of cooperative feeding behaviour which has been reported is the action of several animals to cordon off an area of shallow water to concentrate fish in order to entrap them (Pooley and Gans, 1976). Pooley once observed two Nile crocodiles walking overland side by side while carrying the carcass of a Nyala well off the ground between them (Pooley and Gans, 1976).

are probably responsible for more fatalities of people than all other crocodilian species combined.

THREATS TO THE NILE CROCODILE POPULATION IN THE OLIFANTS RIVER

1. The indirect destruction of habitat caused by the construction of dams and weirs in the upper reaches and catchment areas of the river reducing the amount of water available to the river lower down. This is closely associated with authorities not even allowing the minimum ecological reserve flow through the river especially during the dry season. It is clear from figures in table 1 (Chapter 2) that the water resource of the Olifants River is already heavily over utilised and the situation is only getting worse with more demands for water from the platinum mining industry. The Flag Boshielo Dam was raised intentionally to provide water for mining and the Blue Ridge Platinum Mine near Groblersdal is already demanding more water from Loskop Dam. Providing water for paying customers or providing water for the environment without showing a profit too often becomes the choice. The river system provide some of the most important habitat for crocodiles and monitoring has shown that breeding and nesting do not take place in the main water body of dams but rather in the river itself. During the dry season the lack of water due to dams and weir impeding natural flow may reach critical proportions. The Olifants River in the Kruger National Park is one such example, where the river stops flowing for some months during the dry season.

2. Abstraction of water from the river is a direct threat to the survival of Nile crocodiles in the Olifants River. Pumping water from the river including permanent dry season pools reduces the level of water available to the crocodiles that needs deep pools to thermoregulate and also reduces the food source available to crocodiles in the river and pools.

3. Incompatibility between human activities and Nile crocodiles directly threatens the well being of crocodiles in the Olifants River. On occasion crocodiles take livestock drinking at the river and more frequently take fish from illegal gill nets. Due to the social interaction within the crocodile population many sub-adult animals in the 1.4 - 2.1m (TL) size class leave the river and take up residence in irrigation ponds constructed by commercial farmers thus representing a danger to farm workers. The impact that these crocodiles have on the economic activities (irrespective of the legality of the person's activities at the time) lead directly to a high level of animosity towards all crocodiles which inevitably results in the removal of the crocodile from the system either by killing or capture (both of which are illegal). Dr Niels Jacobsen reported seven crocodiles, all of reproductive age and size, being killed by unknown persons in the Flag Boshielo Dam during the early 1990's (Jacobsen, 1992). Disturbingly, my own studies revealed a total of five male crocodiles most of which were of reproductive age and size (3.10m TL; 4.10m TL; 4.60m TL; 1.50m TL and 3.96m TL) being killed by unknown persons in the

Flag Boshielo Dam during 2002/2003 illustrating human intolerance for these magnificent beasts.

4. The destruction of nests by unknown persons. The height of the nesting season in South Africa coincides with the summer school holidays which are a time when families traditionally spend much time outdoors. Public angling is allowed on private property and in public waters like the large dams in the Olifants River. People typically spend the whole day at one spot next to the water and it often happens that they then spot a Nile crocodile lying in the same place all day, which is of course a female guarding her nest. Whether from boredom, bravery or stupidity the decision to chase the crocodile away is soon reached and the nest discovered and destroyed to "make the angling spot safe for future use"

5. Construction of fishing camps, caravan parks, camping sites, eco lodges and weekend homes. This is mostly done without considering or even studying the ecological impact of the construction and operating phase. These recreational facilities are poorly planned in most cases and based purely on bringing as many people as possible to unspoiled areas at a price. With the exponential increase in people angling at these areas, Nile crocodiles are forced to compete for the food source in terms of fish and this competition is not appreciated by the owners of such places since visitors will only return if the fishing is good. Construction sites are chosen in most cases for easy access

to the river and scenic setting on sandbanks overlooking pools in the river which is exactly where crocodiles go to nest. A returning female looking for a good nesting site and finding a huge building or compacted camping ground in its place is forced to search for and use suboptimal nesting areas with a correspondingly lower chance on hatching success.

6. Boating and recreational activities near nesting areas have a detrimental effect on nesting in those areas. It has been shown that indirect disturbance even by human activities such as camping, fishing and boating are expected to increasingly affect crocodiles (United States Fish and Wildlife Service, 1999; Beacham, Castronova and Sessine, 2000). Observations suggest that repeated close human presence may cause female crocodiles to abandon or relocate their nest sites (Beacham, Castronova and Sessine, 2000). In the Flag Boshielo Dam specific nests located on sandbanks in the dam were used for the first time in nine years when all recreational activities on the dam were banned during construction of the raised dam wall.

7. Raising of dams by the Department of Water Affairs and Forestry impacts severely on Nile crocodile populations in the Olifants River. The incidence of loss of habitat, loss of basking sites, loss of nesting areas and change in prey composition after a dam wall is increased in height is devastating to resident Nile crocodile populations. Three dams in the Olifants River were raised in height and at each site the crocodile population suffered. The Loskop Dam was raised in 1977 which changed the character of the dam

from a winding river-like appearance to flat open water with huge fluctuations in level, all basking and nesting sites in the dam were flooded and crocodiles retreated into the inlets and numbers began to decline seriously. The Flag Boshielo Dam was raised recently (2005) and again all basking and nesting sites where flooded and crocodiles retreated away from the vast expanse of water. Massingire Dam in Moçambique was repaired and increased to full supply level flooding the Olifants River Gorge changing the flowing river into standing slow moving water with increased siltation and a change in prey species composition. This contributed to a massive decline in crocodile numbers from what was once a crocodile haven.

8. Pollution in the upper catchment of the Olifants River has a direct influence on the survival of Nile crocodiles in the river. It has been shown that Nile crocodiles in Loskop Dam died in large numbers due to pansteatis, a disease contracted by predators feeding on rancid fish. It is also know that large fish die-offs occurred at the same time as crocodile die-offs possibly due to the effects of sewage and acid mine drainage into the river. The large scale die-off of crocodiles in the Olifants River Gorge during August and September 2008 was also positively linked to the pansteatitis disease. Blood biochemistry results indicate clearly that crocodiles in these populations suffer from poor health (Chapter 5).

9. Illegal hunting of Nile crocodiles for traditional medicine and to a lesser extent for their skins contributes to the loss of animals in the reproductive size class. Loss of these animals have a profound influence on the recovery of depleted populations making it almost impossible for such populations to recover as can clearly be seen in the Loskop Dam population (Chapter 4)

GOALS AND OBJECTIVES

Goals and underlying principles:

The goal of this conservation and management programme is to provide clear guidelines to ensure the long-term survival and conservation of viable Nile crocodile populations along the entire length of the Olifants River in South Africa while providing for public safety and ecologically sustainable utilisation.

This conservation and management programme is underpinned by the principle that abundant and viable populations of Nile crocodiles should be maintained in the Olifants River for their ecological and economic value whilst at the same time ensuring that crocodiles do not threaten human safety or people's enjoyment of the environment. This conservation and management plan for Nile crocodiles in the Olifants River system embraces the national environmental management principles as set out in the National Environmental Management Act (Act no 107 of 1998).

This conservation and management plan recognises the precautionary principle to ensure that scientific uncertainty will not be used as a reason to postpone management measures aimed at protecting Nile crocodile populations in the Olifants River or their environment.

Objectives:

In the Olifants River in the Mpumalanga and Limpopo provinces the specific objectives of this conservation and management plan are to:

1. Maintain viable wild populations of Nile crocodiles in the Olifants River, in the Mpumalanga and Limpopo provinces at least at current population levels.
2. Maintain, manage and protect Nile crocodile habitat (especially nesting sites) in the Olifants River, Mpumalanga.
3. Promote scientific research and long term monitoring of Nile crocodile populations in the Olifants River, Mpumalanga.
4. Increase public awareness regarding the ecological significance of Nile crocodiles in the Olifants River, Mpumalanga and the need for their conservation.
5. Manage human interaction and contact with Nile crocodiles in the Olifants River, Mpumalanga in order to ensure public safety.
6. Establish co-operative governance with other government departments, conservation organisations, academic institutions and non-government organisations who may have a direct or indirect influence on the Nile crocodile population in the Olifants River,

Mpumalanga (e.g. DWAF, Olifants River Forum, Veterinary Faculty of the University of Pretoria).

MANAGEMENT

Maintain viable wild populations of Nile crocodiles in the Olifants River, in the Mpumalanga and Limpopo provinces at least at current population levels:

1. The maintenance of the Olifants River Nile crocodile population at current levels or above must be a priority for conservation authorities in both provinces.
2. The destruction of habitat is arguably one of the most important factors in the decline of total numbers of crocodile populations in the Olifants River.
3. In terms of the above strategies to replace destroyed habitat by clearing encroached river banks from alien and invasive plants to establish basking sites must be funded and implemented.
4. The construction of artificial nesting areas in locations such as the Flag Boshielo Dam, and the Loskop Dam must be implemented. It should be relatively easy to construct a type of berm near the river bank in areas where crocodiles are frequently seen.
5. Re-introduction of crocodiles to depleted populations must also be considered. Although some experts argue that it will be pointless to re-introduce crocodiles to dams and rivers which are clearly polluted since the odds are against the introduced crocodile

to survive. However, problem crocodiles are in any case doomed and re-introducing them to depleted populations may serve a better cause.

6. The cost of maintaining viable populations and implementing strategies to achieve this should be borne by industries and mining that utilise the water produced by destroying natural habitat and who release pollutant matter into river systems. The "polluter pays" and to coin a new phrase "mega water-user pays" principle should be enforced in this instance
7. Egg harvesting and capture of wild crocodiles for crocodile ranching, although not currently allowed, must be banned until scientific research and long-term monitoring has proved that enough eggs are produced annually in the wild to sustain any sort of harvest and that population numbers are high enough to allow sustainable take off for crocodile ranching.
8. A strategy must be implemented by the two provincial conservation authorities to locate and map all/most nests annually through aerial surveys. These nests must then be tracked and their success/failure noted. If circumstance change to the effect that any nest is threatened (e.g. by development, flooding, dam construction etc) the eggs should be rescued and hatched elsewhere and the young returned to the nest site upon hatching.

Maintain, manage and protect Nile crocodile habitat (especially nesting sites) in the Olifants River, Mpumalanga:

1. The area of the middle Olifants River from Witbank Dam to the international border with Moçambique including the banks of the river for a distance of at least 300m to 500m on each side, must be declared a Protected Environment in terms section 28 (2)(c)(d)(e) of the National Environmental Management: Protected Areas Act (No 57 of 2003) to give some degree of official protection to the area and a basis from which to ensure that development is not done in an unplanned manner.

2. Sandbanks, riverbanks and the riverbed particularly in the critical habitat must be protected from destruction by declining permission for development in these areas especially for the mining of sand.

3. Nile crocodile populations occurring in provincial nature reserves must be protected by ensuring that sensitive areas such as basking, nesting and nursery areas are designated as areas not accessible for public recreation. All proclaimed conservation areas where Nile crocodiles occur should be zoned according to the following principles:

3.1. The area where crocodiles are most active should be zoned as an **Environmental Reserve Zone.** These areas are critically important to crocodiles because most social interactions such as mating, nesting, establishment of dominance, home range maintenance, hunting etc take place here. Conditions for public access to this area must be strictly controlled and should include the following:

3.1.1. Access is limited to conservation staff, bona fide research staff and a strictly defined number of trips into the area by selected operators.

3.1.2. No vessels may be launched anywhere in this area.

3.1.3. All water craft in this area must be subjected to unannounced searches by conservation officers.

3.1.4. No person will be allowed to go ashore for any reason except for bona fide conservation and research personnel.

3.1.5. No person will be allowed to approach, on foot or by boat, any crocodile nest, basking crocodile or crocodile found in the water except for bona fide conservation and research personnel.

3.1.6. Persons found disturbing or suspected of disturbing nesting areas will be denied further entrance to the environmental, wilderness, and conservation zones.

3.1.7. Persons wishing to enter the wilderness area must pay a conservation levy over and above any other fees paid.

3.1.8. Persons found harassing; catching or killing crocodiles or plundering nests will be prosecuted.

3.1.9. No angling will be allowed in the area.

3.1.10. No water sport such as skiing, swimming or sailing is allowed.

3.1.11. No access to the area will be allowed after sunset except when special permission is granted for bona fide crocodile researchers and conservation officers.

3.1.12. No gillnetting will be allowed in this area to protect hatchlings and the food supply of the crocodiles.

3.1.13. Any development (lodge, holiday resort, housing estate, golf estate camping site etc) must follow the prescribed EIA process.

3.2. The second area (where crocodiles are less active) should be zoned as a **Wilderness Zone** where public access will be strictly controlled. <u>This area is important to crocodiles</u> because most of the secondary important nesting areas and also primary important basking areas occur here. The area could also be joined with the first (Filter/Environmental Reserve Zone) area to form one continuous wilderness area. Conditions for public access to this area must be strictly controlled and should include the following:

3.2.1. Public access will be allowed only when visitors are accompanied by a trained and certified field guide.

3.2.2. Access is limited to conservation staff, bona fide research staff and a strictly defined number of trips into the area by selected tour operators.

3.2.3. No vessels may be launched anywhere in this area.

3.2.4. All water craft in this area must be subjected to unannounced searches by conservation officers.

3.2.5. No person will be allowed to go ashore for any reason except for bona fide conservation and research personnel.

3.2.6. No person will be allowed to approach, on foot or by boat, any crocodile nest, basking crocodile or crocodile found in the water except for bona fide conservation and research personnel.

3.2.7. Persons found disturbing or suspected of disturbing nesting areas will be denied further entrance to the environmental, wilderness, and conservation zones.

3.2.8. Persons found harassing; catching or killing crocodiles or plundering nests will be prosecuted.

3.2.9. Angling in the area will only be allowed from a boat (no other vessels or motorised craft).

3.2.10. No water sport such as skiing, swimming or sailing is allowed.

3.2.11. No access to the area will be allowed after sunset except for bona fide conservation and research personnel.

3.2.12. No gillnetting will be allowed in this area to protect hatchlings and the food supply of the crocodiles.

3.2.13. Any development (lodge, holiday resort, housing estate, golf estate camping site etc) must follow the prescribed EIA process.

3.3. The third area (where crocodiles are occasionally active) should be zoned as a **Conservation Zone** because important basking areas will occur here. Conditions for public access to this area must be strictly controlled and should include the following:

3.3.1. Access with boats only (no other motorised craft) will be open to the general public.

3.3.2. No vessels may be launched anywhere in this area.

3.3.3. Boats and other vessels/motorised craft in this area must be subjected to unannounced searches by conservation officers.

3.3.4. No person will be allowed to go ashore for any reason except for bona fide conservation and research personnel.

3.3.5. No person will be allowed to approach, on foot or by boat, any crocodile nest, basking crocodile or crocodile found in the water except for bona fide conservation and research personnel.

3.3.6. Persons found disturbing or suspected of disturbing nesting areas will be denied further entrance to the environmental, wilderness, and conservation zones.

3.3.7. Persons found harassing; catching or killing crocodiles or plundering nests will be prosecuted.

3.3.8. Angling in the area will only be allowed from a boat (no other vessels or motorised craft).

3.3.9. No water sport such as skiing, swimming or sailing is allowed.

3.3.10. No access to the area will be allowed after sunset except for bona fide conservation and research personnel.

3.3.11. No gillnetting will be allowed in this area to protect hatchlings and the food supply of the crocodiles.

3.3.12. Any development (lodge, holiday resort, housing estate, golf estate camping site etc) must follow the prescribed EIA process.

3.4. All other areas which are visited by crocodiles from time to time but which are of minor importance to crocodiles must be zoned as a **Public Access Zone**. Access to this area must be strictly controlled and should include the following:

3.4.1. Access with boats and other vessels/motorised craft will be open to the general public.

3.4.2. Vessels may only be launched from officially authorised launching sites.

3.4.3. Boats and other vessels/motorised craft in this area must be subjected to unannounced searches by conservation officers.

3.4.4. No person will be allowed to go ashore for any reason except for bona fide conservation and research personnel.

3.4.5. No person will be allowed to approach, on foot or by boat, any crocodile nest, basking crocodile or crocodile found in the water except for bona fide conservation and research personnel.

3.4.6. Persons found disturbing or suspected of disturbing nesting areas will be denied further entrance to the environmental wilderness, and conservation zones.

3.4.7. Persons found harassing; catching or killing crocodiles or plundering nests will be prosecuted.

3.4.8. Angling along the shore will only be allowed for organised angling or in designated angling areas, angling in the area may also be done from a vessel.

3.4.9. No water sport such as skiing, swimming or sailing is allowed.

3.4.10. No access to the area will be allowed after sunset except for bona fide conservation and research personnel.

3.4.11. No gillnetting will be allowed in this area to protect hatchlings and the food supply of the crocodiles.

3.4.12. Any development (lodge, holiday resort, housing estate, golf estate camping site etc) must follow the prescribed EIA process.

Promote scientific research and long term monitoring of Nile crocodile populations in the Olifants River, Mpumalanga:

1. A co-ordinating committee must be established between the Mpumalanga Tourism and Parks Agency, Limpopo Department of Economic Development, Environment and Tourism, South African National Parks (as lead agencies), and other departments and tertiary education institutions who are interested in researching aspects of Nile crocodiles.
2. The functions of this committee will include the coordination and distribution of research results, ensuring that research projects are not duplicated and that therefore funding is appropriately allocated and that monitoring data are shared by all departments who deal with issues impacting on the environment.
3. Any future development projects (industrial, residential, golf estates, mining etc) that make use of the Olifants River in any way or is situated on the banks of the Olifants River must pay a percentage of the total cost of the development into a trust account to fund further research and monitoring of the Olifants River Nile crocodile population.
4. Research and monitoring programmes that must be implemented as a matter of urgency are:

4.1. Confirmation of occurrence of Nile crocodiles in all waters (river and dams) of Mpumalanga and Limpopo.

4.2. Crocodile numbers, populations structure and distribution in dams where they occur (spotlight and aerial surveys at least twice a year in January and August, the frequency of surveys can be adjusted after five years if the reliability of data permits changes to the survey frequency).

4.3. Aerial surveys of rivers in the Mpumalanga and Limpopo provinces to determine numbers, population structure and distribution (possibly number of nests depending on the timing of the survey).

4.4. Identify and map areas of high crocodile population density in the Olifants River

4.5. Determine and map the number of nests per season in the Olifants River.

4.6. Determine and map priority areas of high conservation value for crocodiles in the Olifants River in order to develop specific strategies to conserve the animals and their habitat.

4.7. Identify, quantify and monitor the processes threatening the survival of Nile crocodiles in the Olifants River.

4.8. Determine the movement patterns and spatial requirements of crocodiles over 2.1m (TL) in the Olifants River using satellite, GPS/GSM and radio telemetry.

4.9. Maintain a GIS database for records of Nile crocodiles, their habitat in the Olifants River and all human-crocodile interactions.

4.10. River health surveys (especially in the Olifants River).

Increase public awareness regarding the ecological significance of Nile crocodiles in the Olifants River, Mpumalanga and the need for their conservation:

1. Provincial Nature Conservation Authorities (Mpumalanga and Limpopo provinces) must promote the conservation and management of crocodile populations. The importance of crocodiles and the need to protect their habitat should be widely explained to the general public.
2. Research and long-term monitoring of crocodile populations and river health must be published and promoted in layman's terms to the general public in printed and electronic media.

Manage human interaction and contact with Nile crocodiles in the Olifants River, Mpumalanga in order to ensure public safety:

A need exists and the provincial conservation authorities have an obligation in terms of the South African Constitution (No 108 of 1996) as amended and the National Environmental Management Act (No 107 of 1998) as amended to protect the public from threatening and/or dangerous crocodiles.

Due to the depleted status of most of the Nile crocodile populations in the Olifants River, there is a requirement to release wild crocodiles back into wild populations in support of critical research programmes.

Continual removal of crocodiles from the wild, with no considerations of relocation options is considered to be a negative management strategy which should be abandoned in favour of a more positive approach towards restocking dwindling crocodile populations while the cause of the reduction in numbers are addressed on another level through research and monitoring.

Problem crocodiles:

A crocodile is considered to be a "problem crocodile" if:

- It displays aggressive behaviour towards humans;
- It displays aggressive behaviour towards stock or pets (where adequate control measures are in place e.g. alternative water points, fences and barriers etc)
- It is sighted within 200m of a legally developed public facility and it is over 2.0m in total length;
- It is captured in a trap specifically set for crocodiles with the permission of the provincial nature conservation authority and it is over 2.0m in total length;

- The provincial nature conservation authority through its Chief Executive Officer or Head of Department (or his appointed delegate) considers the crocodile a threat for any other reason.

Removal of problem crocodiles:

Nature Conservation Officers should only remove problem crocodiles from any premises which have been developed or altered from its natural state in any way after the owners/developers have produced a legal document proving that the development was authorised by the competent and relevant provincial and national government departments. If such an authorisation cannot be shown by the owners/developers then the nature conservation authority must decline to remove the crocodile except where the nature conservation officer on the scene is satisfied that human lives are in eminent danger. Any nature conservation officer who removes a crocodile from any premises where the owners/developers cannot produce a legal document proving that the development was authorised by the competent and relevant provincial and national government departments, must on his return to his office immediately submit a full written motivation explaining his actions to the Chief Executive Officer or Head of Department and the relevant Herpetologist or Specialist Herpetologist in his department.

Problem crocodiles will be captured in a humane way using standard capture techniques (e.g. box trap, Pitman trap, floating trap, netting, noose and rope, fishing pole with braided line and barbless hook), removed from the wild and either relocated or sold to a crocodile farmer or other suitable facility. Crocodiles less than 2.0m (TL) are not considered to be problem crocodiles and must be returned to the wild without delay. Information regarding the species and population must be collected from each crocodile captured to help understand crocodile behaviour and their environmental needs.

The following data must be recorded from each captured crocodile and forwarded to the Herpetologist or Specialist Herpetologist of the relevant nature conservation authority:

- Description of environmental conditions at the capture site;
- Size and gender of the crocodile(s) captured;
- Number and sizes of other crocodiles spotted in the same general area;
- Photographs (preferably digital photographs) of the animal and the site;
- GPS coordinates of the capture site and release site (if released back into the wild);
- A copy of the legal document authorising the development where the crocodile presents a problem;
- If possible, blood or tissue samples taken from the captured animal to monitor pollutant levels and general health of the population.

Problem crocodiles will be disposed of by selling them to licensed crocodile farmers or relocating them to wild populations.

When crocodiles are sold to crocodile farmers the following guidelines should be followed:

- The crocodile farmer must have licensed facilities approved by the relevant nature conservation authority and comply with the South African National Standard (SANS 631) for keeping and transporting Nile crocodiles and with the code of practise of the Crocodile Farmers Association;
- The crocodile farmer receiving the crocodile must pay a predetermined amount the cover the conservation value of the animal lost from the wild population. This amount must be determined by applicable structures in each provincial nature conservation authority (i.e. Financial Manager or Treasury Department in conjunction with the relevant Herpetologist or Specialist Herpetologist);
- The crocodile farmer receiving the crocodile and his/her staff must have proven abilities and experience in the safe handling and managing of crocodiles in captivity, particularly large crocodiles;
- The crocodile farmer receiving the crocodile must agree to hold the crocodile received off display from visitors to the farm for a sufficient time to allow it to be habitualised to captivity and have adequate holding facilities, off display, to hold the animal in isolation while it adapts to captivity

- All relevant information regarding the captured crocodile must be forwarded as described above in the section dealing with data required by the herpetologist or specialist herpetologist of the relevant nature conservation authority.

When releasing crocodiles back into the wild, the following guidelines must be followed:

- Captured crocodiles may only be handled by nature conservation officers;
- The nature conservation officer releasing the animal must confer with the Herpetologist/Specialist Herpetologist of the relevant nature conservation authority regarding the most acceptable site for release;
- Any crocodile handled after capture must have its jaws restrained by using duct tape or electricians tape;
- The crocodile must ideally be taken directly to the release site and not be transported to holding pens or isolation ponds before release;
- At the release site the animals must be placed a maximum of a couple of paces from the water's edge and must be released facing the water;
- The release is the most dangerous time when handling a crocodile and as such crocodiles may only be released by nature conservation officers with proven experience in the capture and release of crocodiles;
- Nature conservation officers experienced in handling large crocodiles must make sure that all restraints are removed from the jaws of the animal prior to release;

- The release site must be at a location with water deep enough for the released animal to submerge immediately after release (this will assist with calming the animal down and to avoid further capture stress);
- The number of persons involved in the capture and release process must be strictly limited to ensure safety and to restrict noise during the release.
- All relevant information regarding the captured crocodile must be forwarded as described above in the section dealing with data required by the herpetologist/specialist herpetologist of the relevant nature conservation authority.

Icon crocodiles:

An "icon crocodile" is defined as a problem crocodile that is four metres or more in total length or if less than four metres in total length has unusual characteristics such as albinism for example. Icon crocodiles can represent a significant commercial benefit to a crocodile farm, crocodile centre or zoo. However, icon crocodiles also present an exceptional opportunity to achieve educational, public awareness, scientific and conservation outcomes for crocodiles and crocodile habitat. Therefore, the decision as to how and where to dispose of such an exceptionally large crocodile must be based on scientific input. The herpetologist/specialist herpetologist of the applicable nature conservation authority will be required to motivate the disposal of such an animal and will be required to decide on returning the crocodile to the wild to supplement dwindling populations/size classes in populations or to sell the crocodile to a crocodile farm, crocodile centre or zoo. Any such motivation or decision must receive final approval from the Chief Executive Officer or Head of Department of the relevant nature conservation authority before implementation.

In the event that a decision is reached to sell the icon crocodile, the nature conservation authority will request written offers from selected licensed crocodile farms, crocodile centres and/or zoos chosen to buy the crocodile. The crocodile farms, crocodile centres and/or zoos chosen approached in this instance will be identified on the basis of the following guidelines:

- The crocodile farmer must have licensed facilities approved by the relevant nature conservation authority and comply with the South African National Standard (SANS 631) for keeping and transporting Nile crocodiles and with the code of practise of the Crocodile Farmers Association;
- The crocodile farmer receiving the crocodile must pay a predetermined amount the cover the conservation value of the animal lost to the wild population. This amount must be determined by applicable structures in each provincial nature conservation authority (i.e. Financial Manager or Treasury Department);
- The crocodile farmer receiving the crocodile and his/her staff must have proven abilities and experience in the safe handling and managing of crocodiles in captivity, particularly large crocodiles;

- The crocodile farmer receiving the crocodile must agree to hold the crocodile received off display from visitors to the farm for a sufficient time to allow it to be habitualised to captivity and have adequate holding facilities off display to hold the animal in isolation while it adapts to captivity
- All relevant information regarding the captured crocodile must be forwarded as described above in the section above dealing with data required by the herpetologist/specialist herpetologist of the relevant nature conservation authority.

Once an offer from a crocodile farm, crocodile centre or zoo to buy the icon crocodile is accepted by the nature conservation authority the buyer will be informed and required to collect the animal within 48 hours or the transaction will be cancelled and the animal forfeited.

The nature conservation authority will retain the right to release the icon crocodile back into the wild at the most appropriate location if none of the offers received are regarded as fair.

High risk crocodile nests:

Nile crocodile nests in the Olifants River that are threatened by imminent danger must be considered as high risk nests and should be rescued. The "high risk status" of nests must be measured against a number of criteria but only one of these criteria need to be present for the nest to be considered under high risk of destruction. Nests must be assessed for their risk of destruction no later than November/December each year. However, if conditions at the nest have improved at the time of the planned egg collection to such an extent that the high risk category does not apply any longer, egg collection should not proceed. Rescued eggs must be taken to a reputable crocodile farm or crocodile centre to hatch and hatchlings must be returned to the river upon hatching.

Previous policies suggested that hatchlings be reared by the crocodile farm until they reach a total length of 1.0m before they are released back into the wild. However, since we do not know how many crocodiles from nests will survive to 1.0m length, the impact of releasing a large number of 1.0m long crocodiles from rescued eggs than would normally not have survived could potentially be ecologically disrupting. It is therefore recommended that hatchling crocodiles are released back into the wild as close to the nesting site as possible as soon as they hatch.

<u>Criteria for crocodile nests to be considered in high risk of being destroyed:</u>

- The nest has no protection (vegetation or inlet etc) against wave action from the river or dam within 25m where it is located.
- The nest is located so low that it will be flooded by a 10cm rise in groundwater level. The average nest depth is 40cm and therefore if the water level is within 50cm of the

surface the nest must be regarded as high risk. Groundwater levels can be checked by digging a hole within 0.5m of the nest.

- The nest is situated on a site where there is an 80% probability that it may be flooded by a sudden rise in water levels for example due to imminent flooding or heavy rain falls.
- The nest is situated in an area where there is constant daily threat by people or stock animals in a manner that cannot be controlled by the relevant nature conservation authority.
- The nest is situated in soil that is so impervious that the eggs will be saturated by heavy rain falls.
- The nest is situated in an area where legal authorisation has been given by the relevant competent environmental authorities for development (lodge, sand mining camping area etc) to take place and construction is about to commence.

Establish co-operative governance with other government departments, conservation organisations, academic institutions and non-government organisations who may have a direct or indirect influence on the Nile crocodile population in the Olifants River, Mpumalanga (e.g. DWAF, Olifants River Forum, Veterinary Faculty of the University of Pretoria).

1. Provincial Nature Conservation Authorities (Mpumalanga and Limpopo provinces) must be included in decision making process of the Department of Water Affairs and Forestry regarding the allocation and abstraction of water from the Olifants River (and other rivers) as well as future plans to construct dams in the Olifants and other rivers. This process is not designed to put nature conservation in a regulating position over other departments but is important to ensure the viability of the Olifants River for future generations since different departments have different views on the meaning of sustainability and viability of rivers. Because this co-operation is so important and could easily be misinterpreted, it must be agreed upon at top management level for all departments involved (i.e. Director General of Department of Water Affairs and Forestry; Chief Executive Officer of Mpumalanga Tourism and Parks Agency; Head of Department of Limpopo Department of Economic Development, Environment and Tourism).
2. Provincial Nature Conservation Authorities (Mpumalanga and Limpopo provinces) must be involved with the National and Provincial Agriculture Departments to promote soil and water conservation especially in cases where the control of irrigation and clearing of land for agriculture is involved
3. Provincial Nature Conservation Authorities (Mpumalanga and Limpopo provinces) must be involved with the Department of Minerals and Energy particularly on the Regional Mining Development Committee (RMDEC) to promote better understanding when evaluating applications for sand mining in riverbeds, sandbanks and riverbanks.

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APPENDIX II

BRIEF DESCRIPTION OF THE TAXONOMY OF THE ORDER CROCODYLIA (KING AND BURKE, 1997)