

## 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 Mohlaitse 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 Roosenekal, 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.

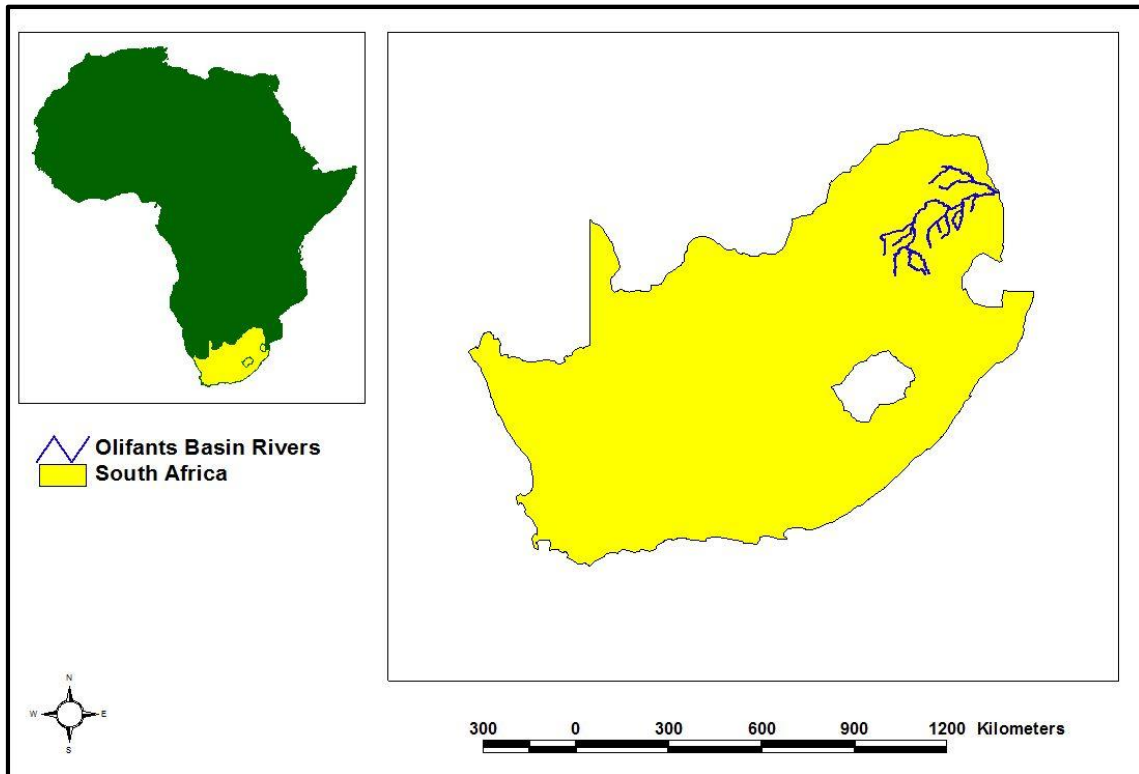


Figure 11: Locality of the Olifants River basin in South Africa.

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.

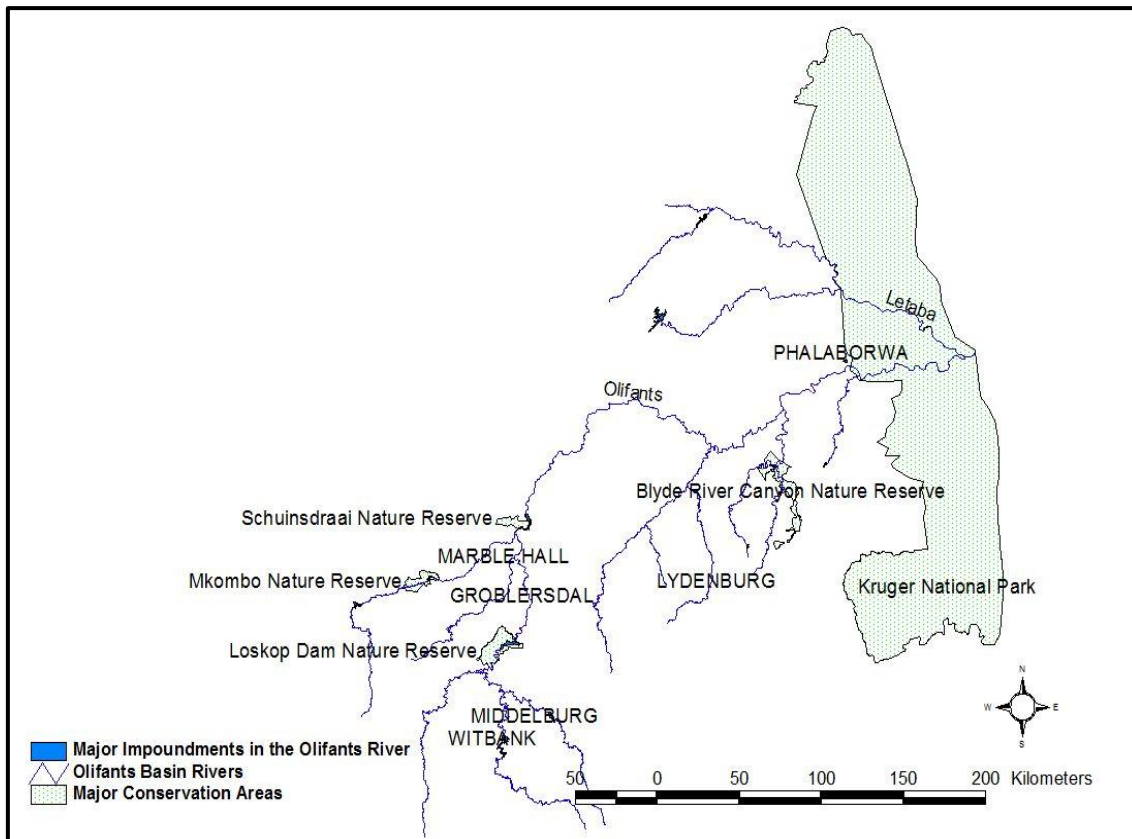


Figure 12: The Olifants River and its major tributaries in relation to major towns and conservation areas in the region.

## 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 15<sup>th</sup> December 2005 with a second, follow-up survey completed on 17, 18 and 19<sup>th</sup> 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		Aerial		Adjusted		Adjusted	
	survey 2005	survey 2009	survey 2005	survey 2009	population 2005	population 2005	population 2009	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)
<b>Total</b>	<b>734</b>	<b>(100)</b>	<b>747</b>	<b>(100)</b>	<b>1130</b>	<b>(100)</b>	<b>1150</b>	<b>(100)</b>

### 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 became 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-Olifants and Wilge Rivers)	90	2	1		4	0	7	1	3		
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
<b>Total</b>	<b>715</b>	<b>49</b>	<b>237</b>	<b>393</b>	<b>55</b>	<b>734</b>	<b>44</b>	<b>223</b>	<b>334</b>	<b>60</b>	<b>86</b>	<b>747</b>	<b>1.77</b>

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

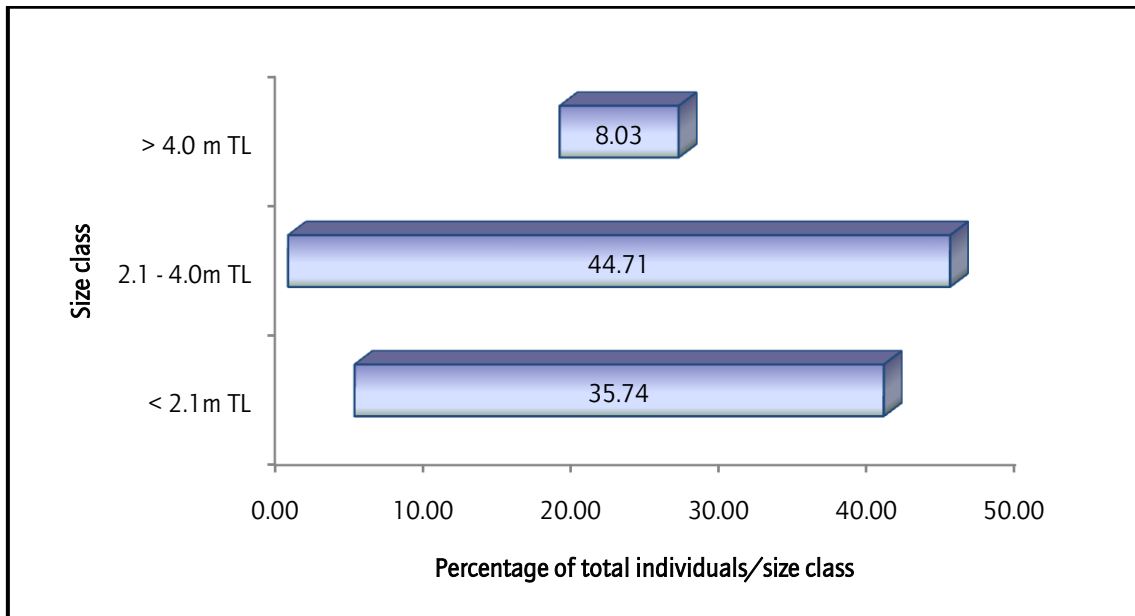
Area of Olifants River system	Length of sector (km)	Mean number of crocodiles	Adjusted mean number of crocodiles	Mean density crocs/km	Adjusted mean density crocs/km	Percentage of total population
Loskop Dam (including inlets to the Klein-Olifants and Wilge Rivers)	90	8	12	0.08	0.13	1.01
Olifants River 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
<b>Total</b>	<b>715</b>	<b>741</b>	<b>1140</b>	<b>1.04</b>	<b>1.59</b>	<b>100</b>

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 2.91 crocodiles/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.

### Dispersal of Nile crocodiles in the Olifants River

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

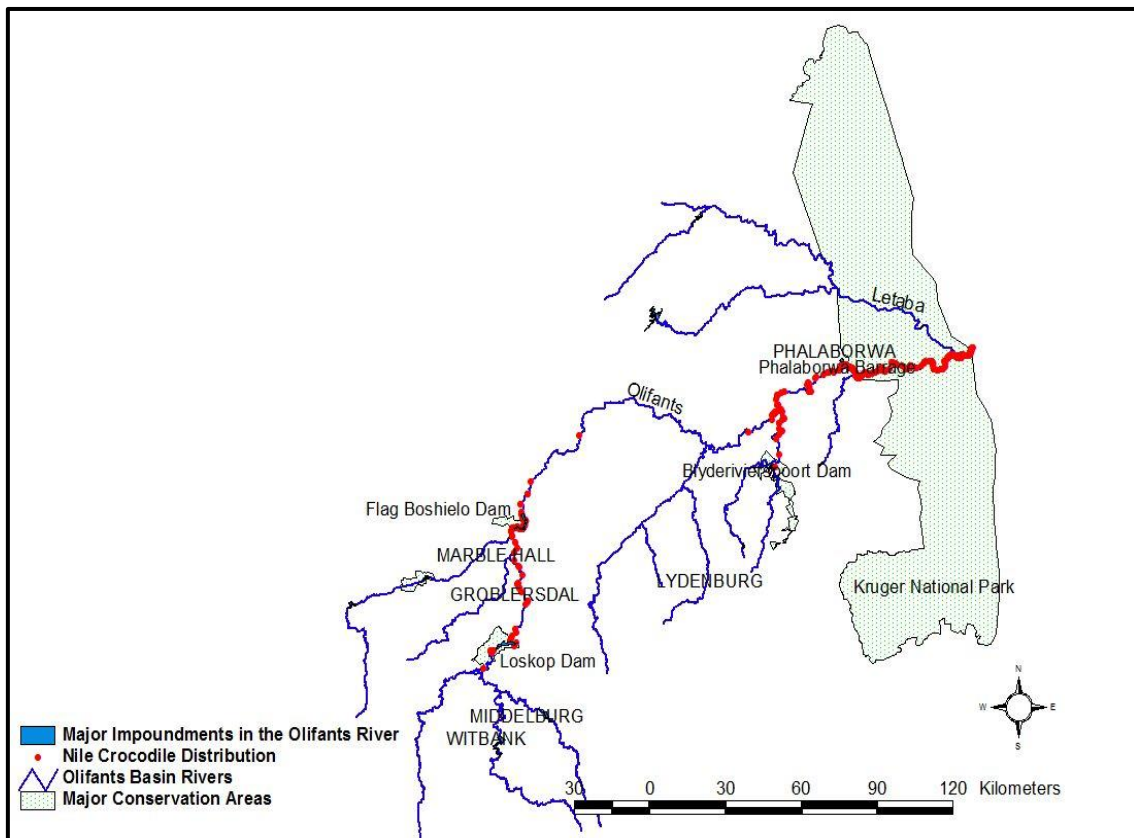
are dispersed is of crucial importance. The reason for this is that adult crocodiles are several orders of magnitude heavier and longer than hatchlings. Cott (1961) has also suggested that cannibalism and ecological separation are basic population processes for Nile crocodile populations.

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).

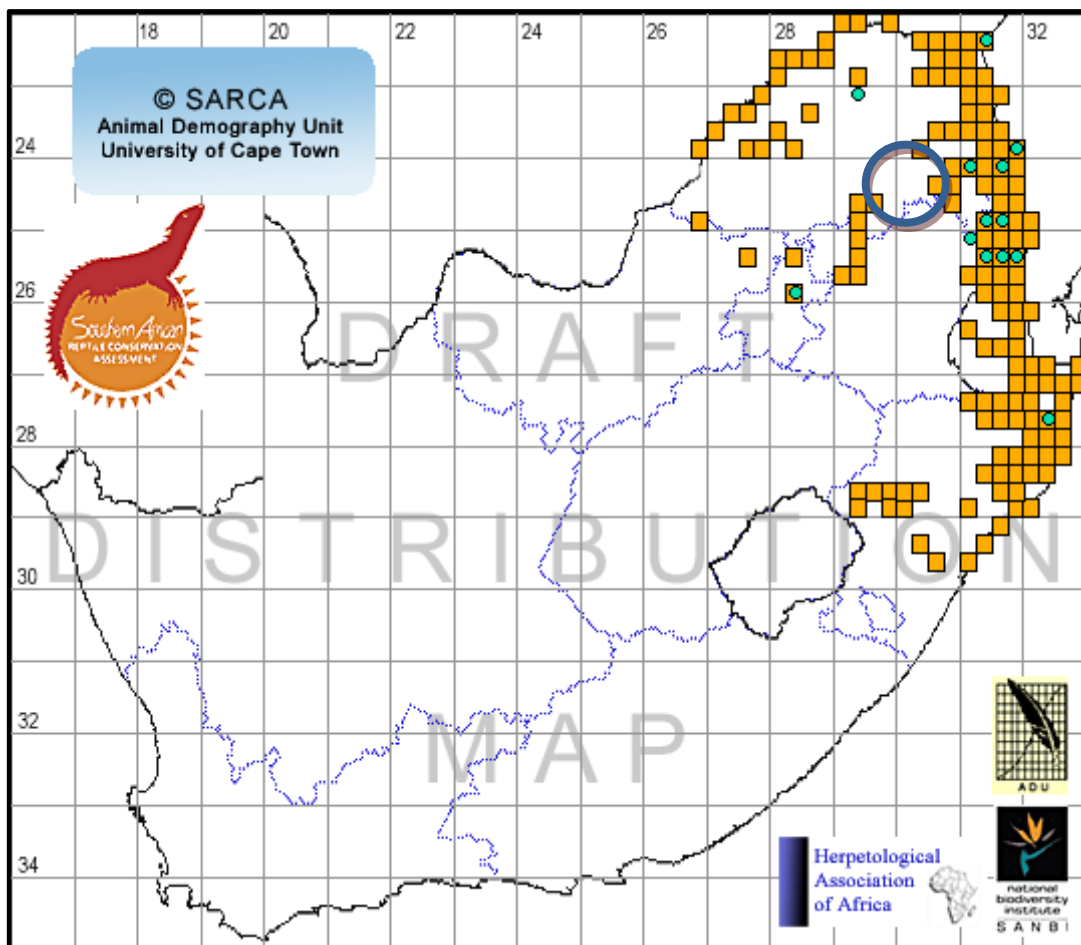
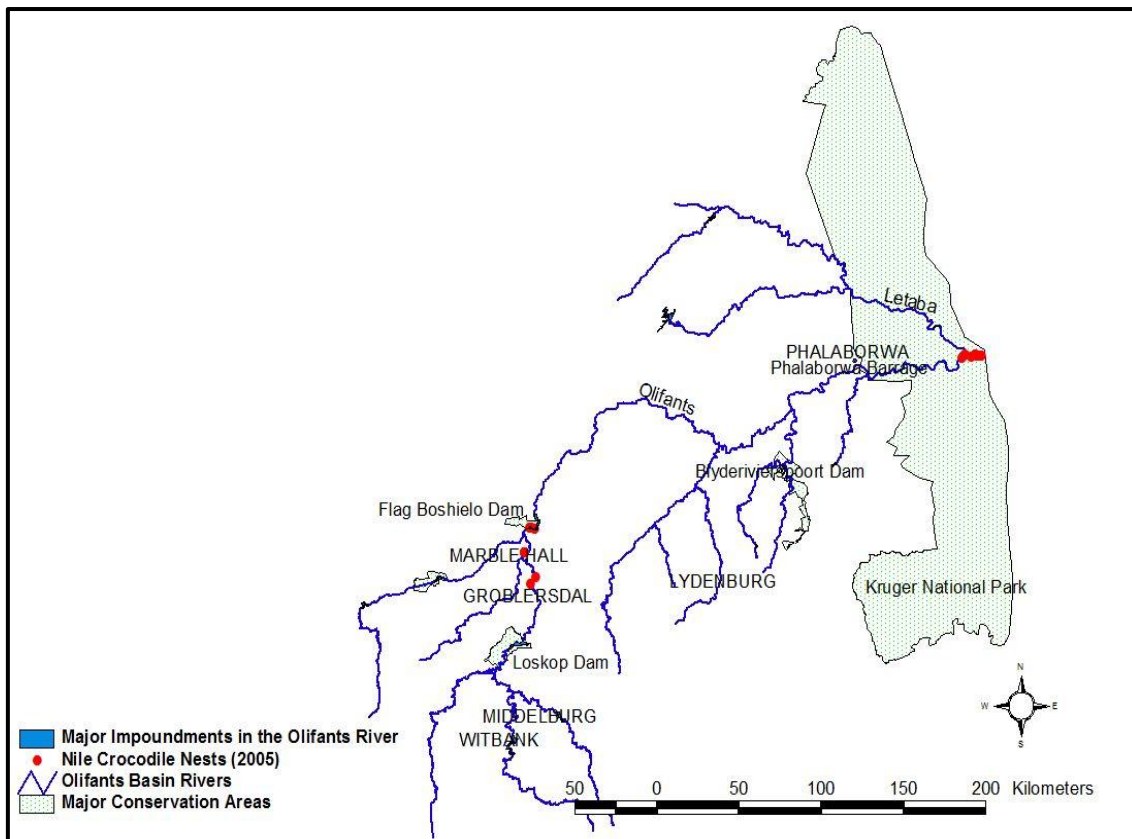


Figure 15: South African reptile conservation assessment distribution map of *Crocodylus niloticus*.



## 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-Olifants 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
<b>Total</b>	<b>715</b>	<b>21</b>	<b>14</b>	<b>18</b>	<b>100</b>

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.

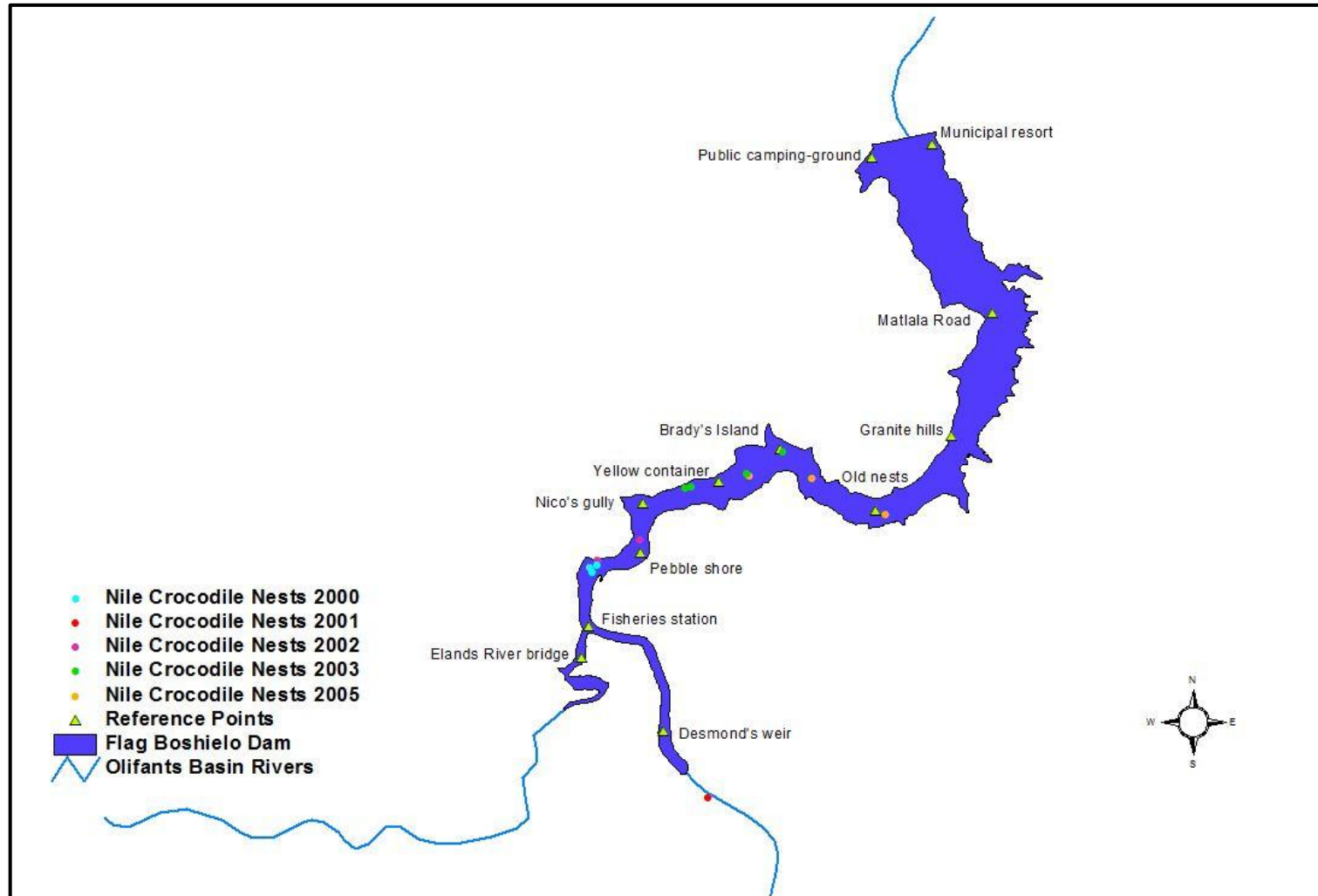


Figure 17: Nile crocodile nests at Flag Boshielo Dam during the 2000, 2001, 2002, 2003 and 2005 nesting surveys.

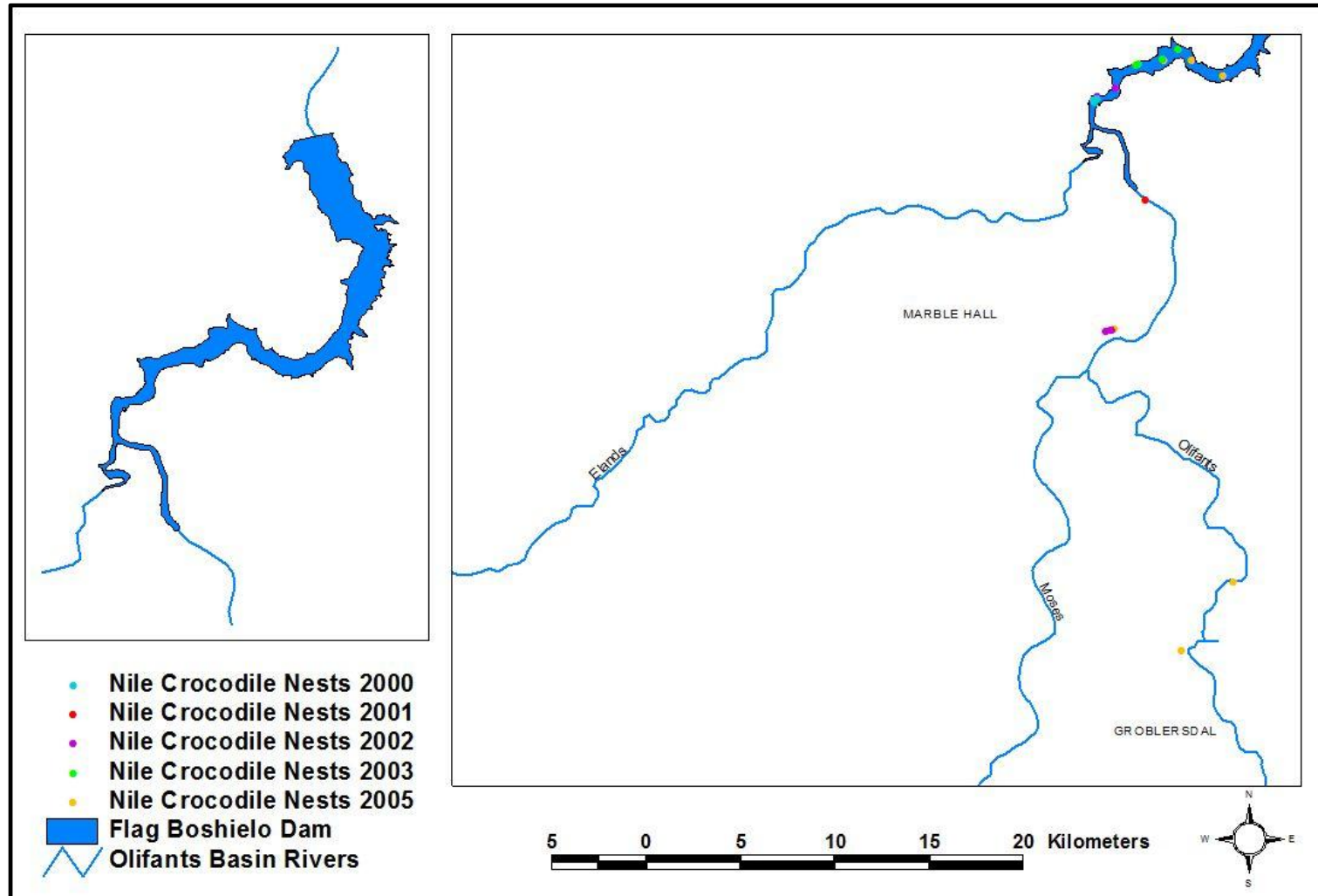


Figure 18: Nile crocodile nests located along the Olifants River and inlet of the Flag Boshielo Dam during 2000, 2001, 2002, 2003 and 2005.

## 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 were 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 crocodylians 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	Year 1987	Year 2000	Year 2010	Year 2025	
		water use	water required	water required	water required	water required
		year 2000 (million m <sup>3</sup> L/a)	(million m <sup>3</sup> L/a)	(million m <sup>3</sup> L/a)	(million m <sup>3</sup> 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	
<b>Total</b>	<b>100</b>	<b>1172</b>	<b>1193</b>	<b>1368</b>	<b>1369</b>	

### 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 coarse 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

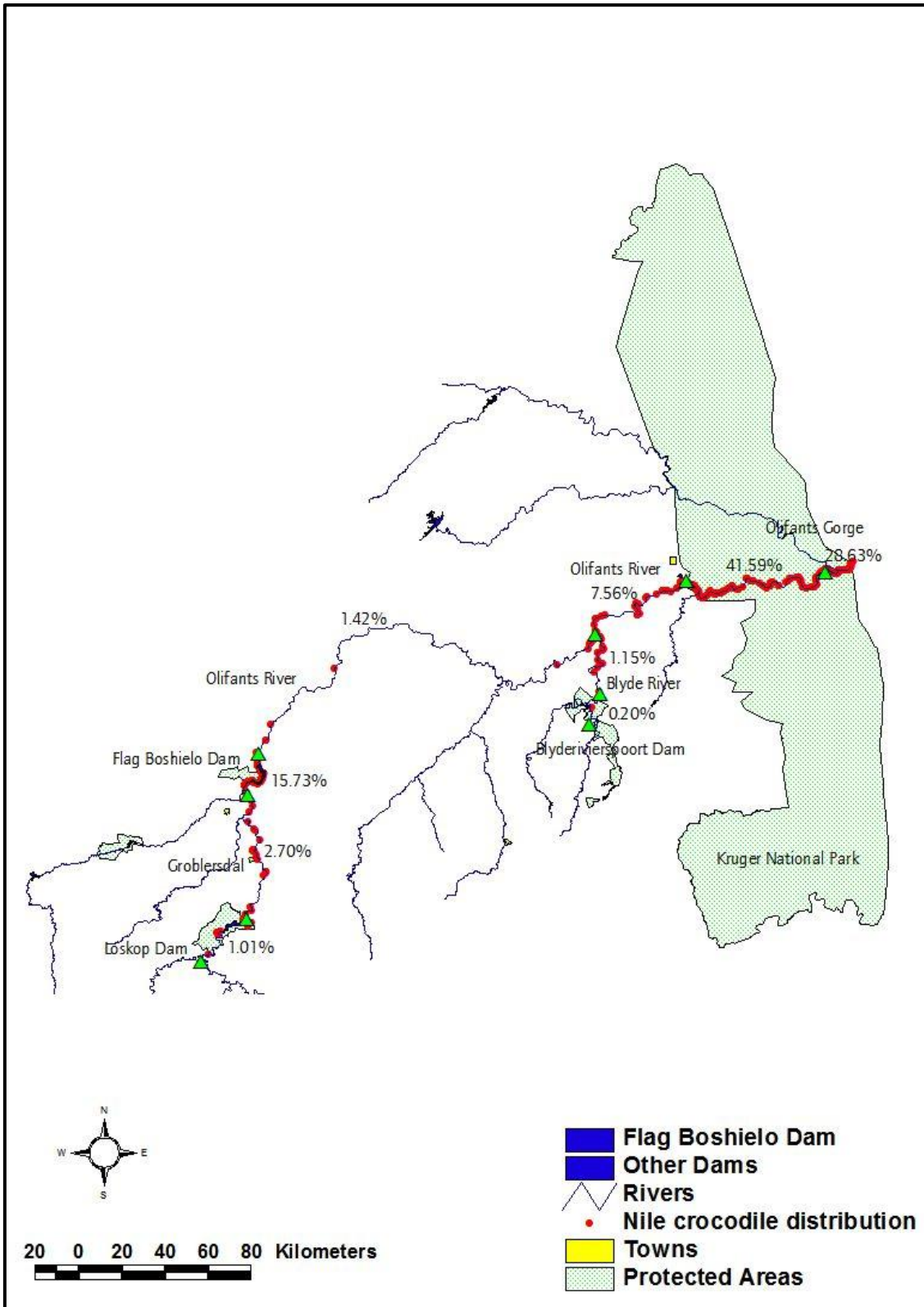
seem to be a major factor in the survivability of nests. Leslie and Spotila (2001) reported that infestations of the alien plant, *Chromolaena odorata* in nesting areas around Lake St Lucia clearly posed a very serious threat to the continued survival of the Nile crocodile in the Lake St Lucia ecosystem. 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 too 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 shown 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 were 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).

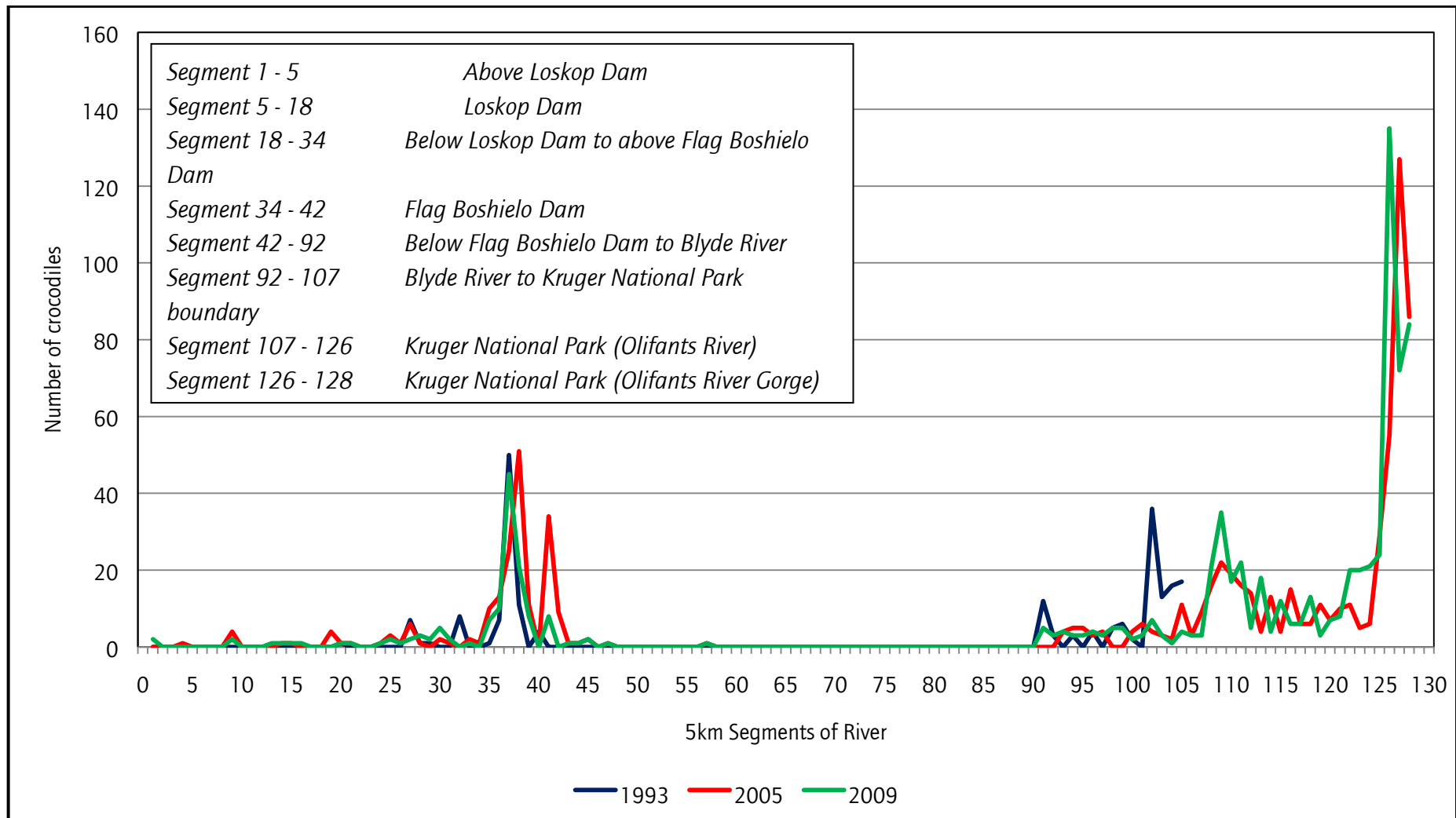


Figure 20: Number and dispersal of Nile crocodiles per 5 km segment of the Olifants River as surveyed during 1993, 2005 and 2009.

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 were 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  $\geq 50\%$  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 were lost to an outbreak

of pancreatitis (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 extent 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, Microcystins, 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 A2abc; 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 be 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 ( $\pm 11$  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).

## REFERENCES

ALCALA, A.C. and DY-LIACCO, M.T.S. 1990. Habitats. In: *Crocodiles and Alligators*. Edited by C.A. Ross. Merehurst Press, London.

BASSON, M.S. and ROSSOUW, J.D. 2003. Olifants water management area, overview of water resources availability and utilisation. Report No P WMA 04/000/00/0203. Department of Water Affairs and Forestry, Pretoria.

BAYLISS, P. 1987. Survey methods and monitoring within crocodile management programmes. In: *Wildlife management: crocodiles and alligators*. Edited by G.J.W. Webb, S.C. Manolis and P.J. Whitehead. Surrey Beatty and Sons, Chipping Norton.

BAYLISS, P., WEBB, G.J.W., WHITEHEAD, P.J., DEMPSEY, K. and SMITH, A. 1986. Estimating the abundance of saltwater crocodiles, *Crocodylus porosus* Schneider, in tidal wetlands of the Northern Territory: a mark-recapture experiment to correct spotlight counts to absolute numbers and the calibration of helicopter and spotlight counts. *Australian Wildlife Research*. 13: 309-320.

BOLTON, M. 1984. Assistance to crocodile management, Ethiopia. FAO Report No FO: TCP/ETH/2307.F Food and Agriculture Organisation of the United Nations, Rome.

BOTHA, P.J. 2005. *The ecology and population dynamics of the Nile crocodile Crocodylus niloticus in the Flag Boshielo Dam, Mpumalanga province, South Africa*. M.Sc. Thesis. University of Pretoria.

BOURQUIN, S.L. 2007. *The population ecology of the Nile crocodile (Crocodylus niloticus) in the Panhandle Region of the Okavango Delta, Botswana*. PhD Thesis. University of Stellenbosch.

BRAATNE, J.H., ROOD, S.B., GOATER, L.A. and BLAIR, C.L. 2008. Analyzing the impacts of dams on riparian ecosystems: A review of research strategies and their relevance to the Snake River through Hells Canyon. *Environmental Management*. 41:267-281.

CARPENTER, J.R. 1956. *An ecological glossary*. Hafner Publishing Company, New York.

CAUGHLEY, G. 1977. *Analysis of vertebrate populations*. John Wiley and Sons, London.

COTT, H.B. 1961. Scientific results of an inquiry into the ecology and economic status of the Nile crocodile (*Crocodylus niloticus*) in Uganda and Northern Rhodesia. *Transactions of the Zoological Society of London*. 29: 211-256.

DRIVER, A., MAZE, K., ROUGET, M., LOMBARD, A.T., NEL, J., TURPIE, J.K., COWLING, R.M., DESMET, P., GOODMAN, P., HARRIS, J., JONAS, Z., REYERS, B., SINK, K and STRAUSS, T. 2004. National spatial biodiversity assessment 2004: priorities for biodiversity conservation in South Africa. *Strelizia*. 17: 1-45.

GAMES, I. 1990. Growth curves for the Nile crocodile as estimated by skeleton-chronology. *Proceedings of the 10<sup>th</sup> working group meeting of the Crocodile Specialist Group of the Species Survival Commission of IUCN*. IUCN. Gland, Switzerland.

GAMES, I., R. ZOLHO & B. CHANDE. 1992. Estimation of crocodile numbers in the Zumbo and Messenguezi basins of Lake Cahora Bassa during 1988 and 1989. In: *The CITES Nile Crocodile Project*. Edited by J.M. Hutton & I. Games. Convention of International Trade in Endangered Species of Wild Fauna and Flora, Lausanne, Switzerland.

GRAHAM, A. 1968. The Lake Rudolf crocodile (*Crocodylus niloticus* Laurenti) population. Unpubl. Report, Kenya Game Department, Nairobi.

HANSON, H. 1962. *Dictionary of ecology*. Peter Owen Limited, London.

HARTDEGEN, P. 2009a. Water crisis - not if, not when, it's with us now. *Wattnow*. January 2009, p 16-21.



HARTDEGEN, P. 2009b. Water crisis threaten us all. *Wattnow*. January 2009, p 1.

HARTLEY, D.D.R. 1990. A survey of crocodile nests in the Umfolozi Game Reserve. *Lammergeyer* 41: 1-12.

HILL, L. and KLEYNHANS, C.J. 1999. *Preliminary guidance document for authorisation and licensing of sand mining/gravel extraction in terms of impacts on in-stream and riparian habitats*. Department of Water Affairs and Forestry, Pretoria, viewed 19 June 2009, <http://www.dwaf.gov.za/iwqs/waterlaw/discuss/sand/sandfin.htm>

HUCHZERMEYER, F.W. 2003. *Crocodiles biology, husbandry and diseases*. CABI Publishing, Wallingford, Oxon, United Kingdom.

HUTTON, J.M. 1984. *The population ecology of the Nile crocodile, Crocodylus niloticus Laurenti, 1768, at Ngezi, Zimbabwe*. Ph.D. Thesis, University of Zimbabwe, Harare.

HUTTON, J. M. 1992. The Status and Distribution of Crocodiles in Kenya in 1988. In: *The CITES Nile Crocodile Project*. Edited by J.M. Hutton and I. Games. A Publication of Secretariat of the Convention of International Trade in Endangered Species of Wild Fauna and Flora, Lausanne, Switzerland.

HUTTON, J.M., MPHANDE, J.N.B., GRAHAM, A.D. and ROTH, H.H. 1987. *Proceedings of the SADCC workshop on crocodile management and utilisation*. Kariba, Zimbabwe. 2-6 June 1987.

HUTTON, J.M. and WOOLHOUSE, M.E.J. 1989. Mark-recapture to assess factors affecting the proportion of a Nile crocodile population seen during spotlight counts at Ngezi, Zimbabwe and the use of spotlight counts to monitor crocodile abundance. *Journal of Applied Ecology*. 26: 381-395.

IUCN. 2001. *IUCN Red list categories and criteria version 3.1*. IUCN Species Survival Commission. IUCN Gland, Switzerland and Cambridge, UK.

IUCN. 2003. *Guidelines for application of IUCN red list criteria at regional levels version 3.0*. IUCN Species Survival Commission. IUCN Gland, Switzerland and Cambridge, UK.

JACOBSEN, N.H.G. 1984. The distribution and status of crocodile populations in the Transvaal outside the Kruger National Park. *Biological Conservation*, 29: 191-200.

JOANEN, T. and McNEASE, L. 1975. Notes on the reproductive biology and captive propagation of the American alligator. *Proc. Ann. Conf. Southeastern Assoc. Game and Fish Comm.* 29: 407-415.

KLEYNHANS, C.J. 1992. Daar was n rivier... *Fauna & Flora*. 48: 2-8.

KLEYNHANS, C.J. and ENGELBRECHT, J.S. 1993. A summarised assessment of the conservation status of the Olifants River (Limpopo system) from the Loskop Dam to the Kruger National Park. Unpubl. Report, Transvaal Chief Directorate of Nature and Environmental Conservation, Pretoria.

KOFRON, C.P. 1989. Nesting ecology of the Nile crocodile (*Crocodylus niloticus*). *African Journal of Ecology*. 27(4): 335-341.

KUSHLAN, J.A. and MAZZOTTI, F.J. 1989. Historic and present distribution of the American crocodile in Florida. *Journal of Herpetology*. 23(1): 1-7.

LANG, J.W. 1987. Crocodilian behaviour: Implications for management. In: *Wildlife management: crocodiles and alligators*. Edited by G.J.W. Webb, S.C. Manolis and P.J. Whitehead. Surrey Beatty and Sons, Chipping Norton.

LESLIE, A.J. and SPOTILA, J.R. 2001. Alien plant threatens Nile crocodile (*Crocodylus niloticus*) breeding in Lake St. Lucia. *Biological Conservation*. 98: 347-355.

MACGREGOR, J. 2006. *The call of the wild: Captive crocodylian production and the shaping of conservation incentives*. TRAFFIC International, Cambridge.

MAGNUSSON, W.E., CAUGHLEY, G.J. and GRIGG, G.C. 1978. A double-survey estimate of population size from incomplete counts. *Journal of Wildlife Management*. 42(1): 174-176.

MAGNUSSON, W.E., VLIET, K.A., POOLEY, A.C. and WHITAKER, R. 1990. Reproduction. In: *Crocodiles and Alligators*. Edited by C.A. Ross. Merehurst Press, London.

MINING REVIEW AFRICA, 2009. Quarrying SA's 6<sup>th</sup> largest mining sector. *Mining Review Africa*. Issue 5, June 2009: 50-52.

MYBURGH, J. 2007. Crocodiles indicate ecosystem health. *OP News*. 7(2): 4-5

MYBURGH, J. 2008. Crocodile crisis in the Kruger National Park. *OP News*. 8(2): 13

NEL, J., MAREE, G., ROUX, D., MOOLMAN, J., KLEYNHANS, N., SILBERBAUER, M. and DRIVER, A. 2004. South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 2: River Component. CSIR Report Number ENV-S-I-2004-063. Council for Scientific and Industrial Research. Stellenbosch.

NICHOLS, J.D. 1987. Population models and crocodile management. In: *Wildlife management: crocodiles and alligators*. Edited by G.J.W. Webb, S.C. Manolis and P.J. Whitehead. Surrey Beatty and Sons, Chipping Norton.

NORTHERN TERRITORY GOVERNMENT, 2005. Management plan for *Crocodylus porosus* in the Northern Territory 2005-2010. Unpubl. Report, Department of Natural Resources, Environment and the Arts, Palmerston NT.

ODUM, E.P. 1971. *Fundamentals of ecology*. Saunders College Publishing, Philadelphia.

PARKER I.S.C and WATSON, R.M. 1970. Crocodile distribution and status in the major waters of western and central Uganda in 1969. *East African Wildlife Journal*. 8: 85-103.

PIENAAR, D. and GOVENDER, D. 2009. *Crocodiles: sentinels for river health monitoring?* Animal and Human Health for the Environment and Development, New York, USA, viewed 16 June 2009, [http://wcs-ahead.org/gltfca\\_march2009/23\\_pienaar09.pdf](http://wcs-ahead.org/gltfca_march2009/23_pienaar09.pdf).

POOLEY, A.C. 1969. Preliminary studies on the breeding of the Nile crocodile *Crocodylus niloticus* in Zululand. *Lammergeyer*, 10: 22-44.

POOLEY, T. 1982. *Discoveries of a crocodile man*. William Collins Sons and Co Ltd. Johannesburg.

POOLEY, A.C and GANS, C. 1976. The Nile crocodile. *Scientific American*, 234: 114-124.

RAMOS, R., BUFFRENIL, D. and ROSS, J.P. 1994. Current status of the Cuban crocodile, *Crocodylus rhombifer*, in the wild. In: *Proceedings of the 12<sup>th</sup> working meeting of the Crocodile Specialist Group of the Species Survival Commission of the IUCN*. IUCN, Gland, Switzerland.

ROSS, J.P. (ed.) 1998. *Crocodiles. Status survey and conservation action plan*. 2<sup>nd</sup> edition. IUCN/SSC Crocodile Specialist Group. IUCN, Gland, Switzerland.

SOUTH AFRICAN REPTILE CONSERVATION ASSESSMENT. 2009. *Virtual museum: Species summary Crocodylus niloticus*. Animal demography unit, Cape Town, viewed 07 April 2009, [http://www.vmus.adu.org.za/vm\\_sp\\_summary.php](http://www.vmus.adu.org.za/vm_sp_summary.php)

STIRRAT, S.C., LAWSON, D., FREELAND, W.J. and MORTON, R. 2001. Monitoring *Crocodylus porosus* populations in the Northern Territory of Australia: a retrospective analysis. *Wildlife Research*. 28: 547-554.

SWANEPOEL, D.G.J. 1999. *Movements, nesting and the effects of pollution on the Nile crocodile Crocodylus niloticus in the Olifants River, Kruger National Park*. M.Sc. thesis. University of Natal.

SWANEPOEL, D.G.J. 2001. The raising of the Arabie Dam wall and the impacts on the Nile crocodile population. Unpubl. Report, Department of Water Affairs and Forestry, Pretoria.

SWANEPOEL, D.G.J., FERGUSON, N.S. and PERRIN, M.R. 2000. Nesting ecology of Nile crocodiles (*Crocodylus niloticus*) in the Olifants River, Kruger National Park. *Koedoe*. 43(2): 35-46.

THERON, P., GRIMSEHL and PULLEN CONSULTING ENGINEERS. 1991. Water resources planning of the Olifants River basin. Study of the development potential and management of the water resources. DWAF Report No. P.B000/00/0191.

UNITED STATES FISH AND WILDLIFE SERVICE, 1999. American crocodile. In: *Multi species recovery plan for South Florida*. U.S. Fish and Wildlife Service, Atlanta, Georgia.

WAKJIRA, K., CHEMERE, Z., ASSEGRID, G and CHOGO, B. 2004. A report on crocodile survey at Lake Chamo. Unpubl. Report, EWELCO and Buro of Africulture and Natural Resources Development, Addis Ababa.

WATER RESEARCH COMMISSION, 2001. State of the rivers report: Crocodile, Sabie-Sand and Olifants River systems. Report No. TT 147/01. Water Research Commission. Pretoria.

WATER RESEARCH COMMISSION, 2002. State of the rivers report: uMngeni River and neighbouring rivers and stream. Report No. TT 200/02. Water Research Commission. Pretoria.

WEBB, G.J.W. and MESSEL, H. 1979. Wariness in *Crocodylus porosus*. *Australian Wildlife Research*. 6: 227-234.

WHITWORTH, J. 1971. Notes on the growth and mating of American alligators *Alligator mississippiensis* at the Cannon Aquarium, Manchester Museum. *International Zoo Yearbook*. 11: 144.

WOODWARD, A.R. and MOORE, C.T. 1993. Use of crocodilian night count data for population trend estimation. Paper presented at: Second Regional Conference of the Crocodile Specialist Group, Species Survival Commission, IUCN held in Darwin, NT, Australia 12-13 March 1993.