MOVEMENTS, NESTING AND THE EFFECTS OF POLLUTION

ON THE

NILE CROCODILE *Crocodylus niloticus*

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OLIFANTS RIVER, KRUGER NATIONAL PARK

D.G.J. SWANEPOEL

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by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

A pilot study was launched in 1993 to determine the movements of crocodiles in the Olifants River in Kruger National Park (KNP). This turned into a research project in 1994 and lasted for five years until 1998. The objectives of the study were to determine movement, study nesting preferences and to investigate the possible effects of metal pollution in crocodiles.

The movements of the total population were studied by doing regular foot counts, four times per annum. The basis for movement was found on the principle that a change in numbers signified movement. Foot counts were supported by spot counts at three different locations in the study area at 14 day intervals. The foot counts were done along a pre-determined route, followed with every count, and this resulted in data indicating a definite change in numbers at certain times of the year. A comparison was made between the movements of crocodiles in large bodies of open water (lakes & estuaries), a so called "closed" system and the Olifants River or "open" system. There was a movement of the population during August of every year, followed by another one in December/Jan and yet another in May. The largest movement, in August, co-coincided with the prelude to mating and ultimately nesting.

The spot counts indicated that there was a smaller and probably localized movement during May and December of each year. This corresponds to nesting behaviour and the flood status of the river. All indications are that major movements took place during periods of high flow and thus during the rain season (Sept - Feb). A major flood was experienced during February 1996 which changed the geomorphology of the river.

In addition to the foot and spot counts, eleven large adult crocodiles were fitted with radio transmitters to monitor their movements for a period of one year (1997 - 1998). The results indicated that movements over large distances occurred. The longest distance covered was in access of 36 km. Some individuals returned to the location of origin, thus completing a round trip from their point of departure. The majority of crocodiles fitted with transmitters left the protection of KNP, spent time in neighbouring Mozambique

and some returned to Kruger after an average period of three months. Indications are that there is a lack of territorial dominance amongst large individuals at certain times of the year, allowing for less restricted movement up and down the river. A difference was found between the movements of crocodiles in the Olifants River as opposed to a large body of water eg. a lake or estuary.

The second objective was to collect data on nesting preference, nest content and egg dimensions. A total of seven parameters were measured including slope, distance to water, height above water, soil type, vegetation, exposure to direct sunlight and the size of the female. Besides these parameters, a comparison was made between egg size, mass and length and the correlation with female size. The results indicated that egg mass and length increased with an increase in female size. The average clutch size was 34 eggs. A difference was found between two nesting years (1997 and 1998) with the larger females nesting in 1998 (egg mass 122.7g). A higher rainfall was measured for 1998, leading to the conclusion that smaller females nested during dryer years. The larger females, because of physical abilities, dug deeper nests ,36 cm in 1998 as opposed to 25 cm in 1997. No difference was found between nesting habits elsewhere in Africa and that in the Olifants River.

Twelve individuals of varying sizes ranging from 1.4 m to 4.1 m, were collected from three locations and various tissue samples were analysed for metal content. Tissue from muscle, liver, kidney and fat were analysed for Al, Cu, Cr, Fe, Mn, Ni, Pb, Section ranger and Zn. As this was the first data of its kind to be collected, no meaningful conclusions could be reached, except to offer the data as base line data and for future comparisons. There was however a correlation between Fe concentration in muscle tissue and body size, total length (TL). An increase in TL resulted in an increase in Fe concentration. The opposite were found with Fe in fat tissue. Smaller crocodiles (TL) had higher concentrations of Fe in their fat tissues.

Besides the large amount of base line data that resulted from this study, it also highlighted the shortage of knowledge on this species, particularly in Kruger, to enable us to manage and protect them successfully.

CHAPTER 1:

INTRODUCTION

Crocodilians and alligators belong to archosaurs. Most became extinct by the end of the Cretaceous period, about 65 million years ago. Only the crocodiles, alligators, gavial and birds remained. There are 27 known species of Crocodilia, suborder Eusuchia, throughout the world, and they are grouped into three families, Crocodylidae (*Crocodylus and Osteolaemus*), Alligatoridae (*Alligator, Caiman, Paleosuchus and Melanosuchus*) and the Gavialidae (*Gavialis*) (Steel, 1989).

Only three species of Crocodylidae occur in Africa (Blake & Loveridge, 1992), with the Nile crocodile (*Crocodylus niloticus*) having the widest distribution and the only species occurring in southern Africa. The first written report on *Crocodylus niloticus* appeared as early as 58 BC (Guggisberg, 1972). Its historical distribution included the Nile River Delta and Mediterranean coast from Tunisia to Syria (Rue, 1994). African countries within its range include: Angola, Benin, Botswana, Burundi, Chad, Congo, Egypt, Ethiopia, Gabon, Gambia, Ghana, Ivory Coast, Kenya, Liberia, Madagascar, Malawi, Mali, Mozambique, Namibia, Nigeria, Rwanda, Somalia, Sudan, Tanzania, Uganda, Zaire, Zambia and Zimbabwe (Webb & Smith 1987). In South Africa it was once abundant as far south as the Kei river in the Eastern Cape Province. Today the distribution is limited to the northeast of the country with the Tugela river as the most southern boundary. (Figure 1.1)

Until 1969 crocodiles were classified as vermin to be shot on sight, but the introduction of the Reptiles Protection Ordinance No. 32 provided some protection for the species (Leslie, 1997). By 1975 there was a dramatic decrease in crocodile numbers because of habitat destruction. This led to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) giving official international protection to crocodiles (Hutton, 1984). In some countries, for example Zimbabwe, recovery was so remarkable that at present a no-limit collection of eggs from the wild is allowed (Loveridge, 1992). Though *Crocodylus niloticus* were downlisted from Appendix I to Appendix II of CITES in Zimbabwe in 1983, it only happened in South Africa in 1996.

This means that legal trade with set quotas was allowed. The only remaining viable wild populations are now in Kruger National Park (KNP), the Greater St. Lucia Wetlands in Kwazulu/Natal and the
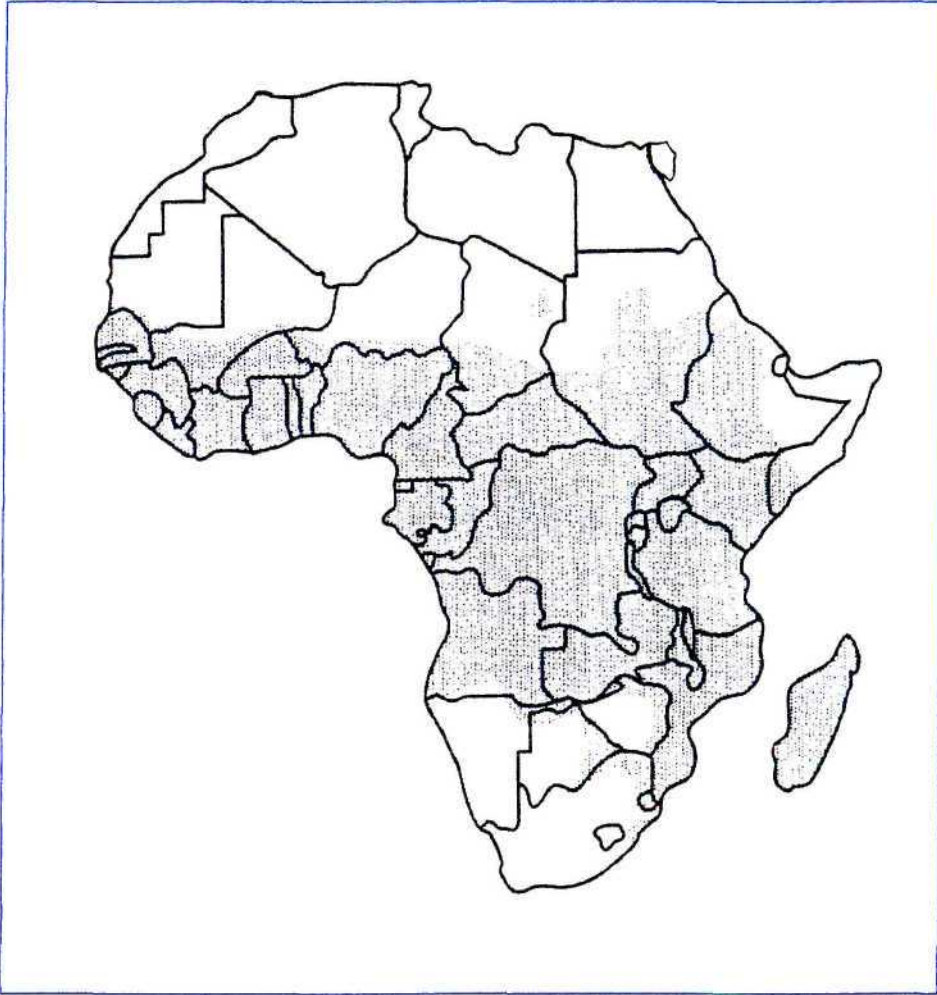
Figure 1.1   The distribution of *Crocodylus niloticus* in Africa (Leslie 1997).

Ndumo Game Reserve. In 1996 the total adult population of St. Lucia Lake was 851 (Leslie, 1997), and in KNP the total was 2716 according to the unpublished annual aerial census data.

In 1961 Cott wrote one of the first comprehensive, though unscientific reports on the general ecology of Nile crocodiles (Cott, 1961). Up until then knowledge of the species was unknown and based on mythology, legends and sometimes bizarre stories. Subsequently the works of Graham (1968), Guggisberg (1972), Pooley & Gans (1976), Modha (1978), Hutton (1984), Games (1988) and Leslie (1997) have provided further information regarding the physiology and ecology of the Nile crocodile. In Zimbabwe many studies have been undertaken on various aspects of crocodilian behaviour, and this has resulted in more scientific although fragmented data on the species. Pooley (1969) broke new ground with his studies on captive breeding of crocodiles, and this signalled in many respects,

the beginning of crocodile research in South Africa. More recently Leslie (1997) investigated various aspects of the ecology and physiology of the Nile crocodile at St. Lucia.

A considerable volume of literature concerning other crocodilians, in particular *Alligator mississipiensis, Crocodylus johnstoni and Crocodylus porosus* has emerged in the past few years (Chabreck, 1975; Webb *et.al.*, 1977; Webb *et al.*,1982; Messel & Vorlicek,1987; Davenport, *et al.* 1990; Brandt, 1991). As knowledge of each species increased, similarities between species became more striking. For example, complex maternal behaviour was first identified in *Crocodylus niloticus* (Cott 1961), and has been found to occur in a remarkably similar form in *A. mississipiensis, C. crocodilus crocodilus, C. porosus* and *Gavialis gangeticus* (Hutton, 1984). Increasingly it is found that much of the information regarding other species is relevant to, and useful for comparisons with *Crocodylus niloticus* (Bayliss *et al.*, 1986; Bellairs, 1987; Nichols, 1987 and Kofron, 1990).

Most studies of the Nile crocodile have been conducted in large "closed" bodies of water (Graham, 1968; Hutton, 1984; Leslie, 1997) rather than in a river system. As South Africa is poor in natural lakes and because the current distribution of the Nile crocodile is mainly confined to rivers with lake St. Lucia and Ndumo Game Reserve as the exceptions, it is of ecological importance to study the crocodiles in an "open" river system. The Greater St. Lucia Estuary in Kwazulu/Natal hosts some 851 adult crocodiles (Leslie, 1997), and differs considerably from the habitat in Kruger National Park. The most obvious difference in habitat is the estuary in St. Lucia as opposed to a river system in Kruger. This study was initially conceived following a pilot study of the basic ecology of *C niloticus* in the lower Olifants River in KNP. It soon became apparent that there were no data available on the Nile crocodile in the KNP besides census figures from 1989 onwards. The KNP hosts the largest population of Nile crocodiles in their natural environment (Leslie, 1997) in South Africa, and despite this, no research was ever done on any aspect of their ecology.

The primary objective of this study was to collect data on the movements of adult individuals in the Olifants River. The study aims to shed some light on the distance travelled and times of movement, but less emphasis will be placed on the reasons for the movement. From a conservation perspective

it is imperative to determine it the species leaves the area of protection and moves into areas where they are in conflict with humans.

The second but equally important objective is to collect data on the nesting behaviour of female crocodiles. It is important to be able to predict possible recruitment in any population and the factors influencing recruitment if a population is to be conserved and managed successfully. Data on the nest size, location and numbers as well as the dimensions of the eggs will be collected to address this specific objective. It is hoped that this objective will indicate

a) the ability of the population in the Olifants River to maintain itself and

b) the suitability of the river system for Nile crocodiles.

The last objective is to examine some tissue samples of a random selection of crocodiles from the Olifants-, Sabi- and Shingwedzi Rivers. The samples will be analysed for possible pollution from selected metals, and it is hoped that this data will serve as a bench mark in future studies on the influence of pollutants on the physiology of crocodiles. In addressing this objective, groundbreaking research will be done as no similar studies have ever been done in Africa and possibly the world on any species of Crocodylia.

CHAPTER 2:

STUDY AREA

2.1 INTRODUCTION

The Kruger National Park is the largest of 21 national parks under the authority of South African National Parks (SANParks), previously known as the National Parks Board. Kruger covers an area of 1 948 528 ha in the north east of the Lowveld in Mpumalanga Province, between $22^0 20'$ - $25^0 31'$ S and $30^0 50'$: $32^0 20'$ E (Pienaar, 1978). See Figure 2.1. From north to south the park extents almost 400 km and about 55 km east to west. This area includes a wide variety of landscapes and associated vegetation types. Seven major rivers, three perennial and four seasonal, cross the park from west to east. The perennial rivers are, from north to south, the Olifants, Sabi and Crocodile rivers, and the seasonal rivers are represented by the Limpopo, Levuvu, Shingwedzi and Sand rivers. Together, these rivers drain a catchment area of 54574 km^2, which is approximately 20% of the Mpumalanga, Northern and Gauteng Provinces. The Olifants River is by far the largest of the perennial rivers, and covers a total distance of 108 km in the KNP before entering Mozambique in the east. The potential mean total annual runoff at the Mozambique border is estimated to be 1950 million m^3, but the combined effects of dams, afforestation and abstraction have decreased the runoff to an estimated 1235 million m^3 per annum (Theron *et al.* 1991b).

There are more than 2500 dams in the Olifants River catchment, of which more than 90% have a volume of less than 20 000 m^3, and 30 major dams have capacities greater than 2 000 000 m^3 (Theron *et al.* 1991b). Despite the important role dams play in supplying water at a high level of assurance, two major problems arise namely sedimentation and evaporation. Sediment accumulation results in an average loss of 0.05 % per annum in storage capacity in all major dams in South Africa (Department of Water Affairs, 1986). The total combined storage capacity of the 30 major dams in the Olifants River is 1065 million m^3, and can deliver an assured yield of 645 million m^3/annum (Theron *et al.* 1991a).

This yield is sufficient to meet the total present water requirements in the Olifants River basin, but the geographic distribution of the dams is not even, and this results in water shortages and/or surpluses in certain areas. Operations at the Phalaborwa Barrage regulate the flow of the Olifants
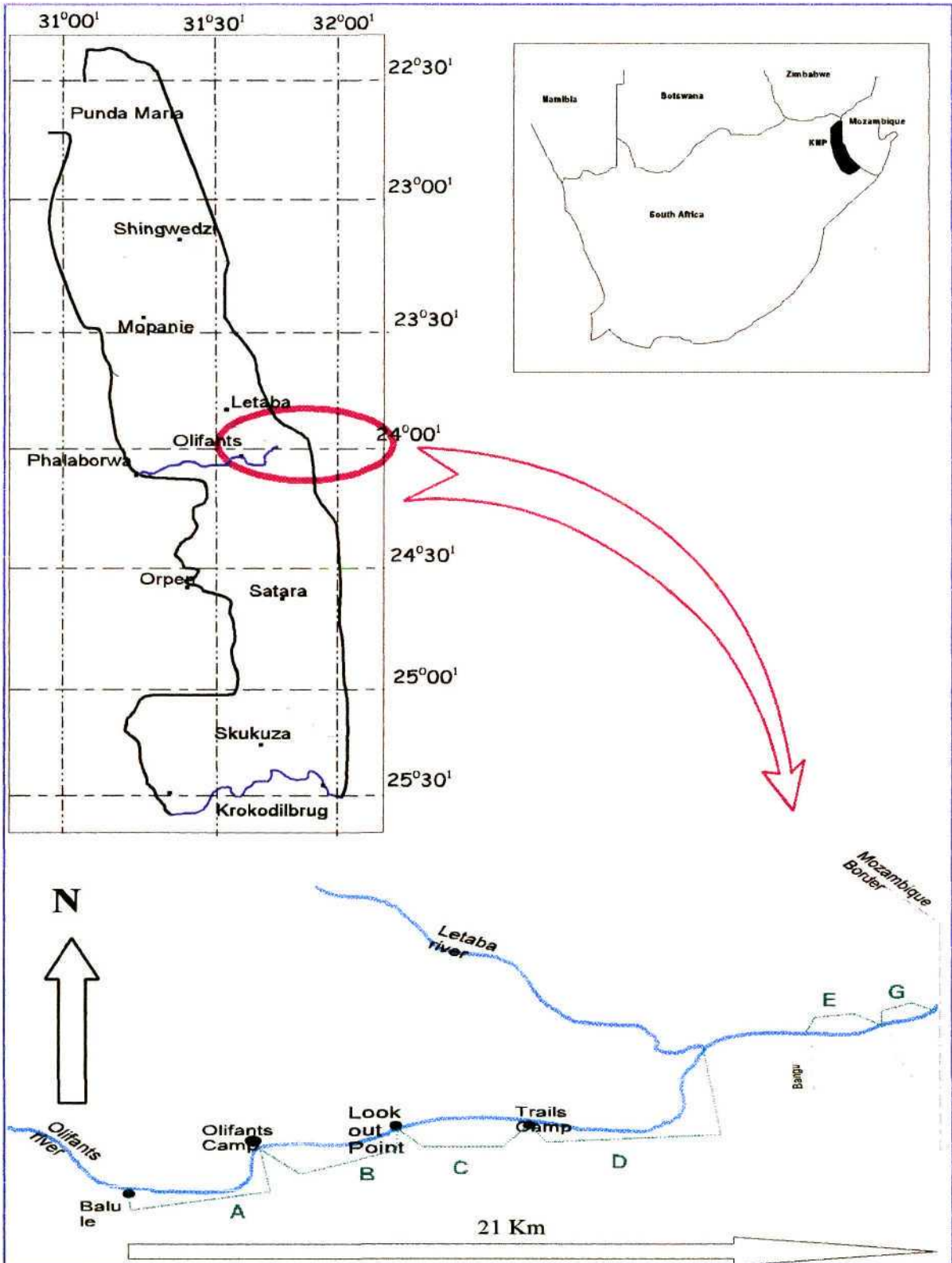
Figure 2.1 Study area in Kruger National Park, showing the different sectors of the study area along the Olifants River.

River in the Kruger National Park. When full, the base inflow into the Barrage is released as compensation for the Park, but this release is not guaranteed. A minimum stream flow of 0.025 m^3/second is required to maintain the biodiversity in the river (Theron *et al.* 1991a). When the water level in the Barrage drops below a predetermined percentile, water from the Blyderivierspoort dam is released to supplement the available water supply. The Phalaborwa Barrage mainly stores water for the copper and phosphate mining industries around the town of Phalaborwa.

With water being a limited resource, the different water user sectors are always in competition with each other. The Department of Water Affairs and Forestry (1986) recognize seven water user sectors; domestic and industrial, power generation, mining, irrigation, stock-watering, afforestation and the environment (Theron *et al.* 1991b). Table 2.1 reflects the utilization and requirements of some of the user sectors.

Table 2.1 Major water users in the Olifants River in 1987 and predictions for 2010 (Theron *et. al.* 1991b).

	Current % Use	**1987** (million m^3/a)	**2010** (million m^3/a)
Power Generation	2	208	208
Irrigation & Agriculture	53	538	640
Forestry	5	56	63
Domestic & Industrial	8	90	180
Mining	7	80	100
Environment	17	200	200
Evaporation	8	100	100
Total	100	1064	1283

The Olifants River is a vitally important source of water in the Lowveld region, and besides supplying water, it also carries pollutants (Seymore, 1994; Maartens, 1994) down stream into one of the prime conservation areas in the world namely the Kruger National Park.

During February 1996, major floods in the catchment area resulted in higher than normal water levels in the lower Olifants, exceeding the previous maximum flood of 1976 caused by cyclone Emile

(Laubsher pers comm)[1] This in turn changed the total environment along the Olifants. Big, well established *Ficus, Acacia* and *Croton* species were washed away. Most of the *Phragmites* reeds on islands and along the stream were totally destroyed, and only bare sand banks were left. Massive sand and silt deposits created new sandbanks and covered previously bare rock formations. This resulted in a relatively shallow and wide water channel, nearly covering the total river bed. The total flow of the main stream was altered and the previously single deep channel became a wide shallow one. This may have had a negative impact on the movements of crocodiles as large portions of the study area became unsuitable for crocodiles during the winter months. Crocodiles favour areas where they can submerge completely and the wide shallow stream made it impossible.

2.2   LOCATION

The Olifants River cuts through the Lebombo Mountains on the eastern side of Kruger, and the study area comprised the last 21 km of river (Figure 2.1). It stretched from Balule Camp in the west to Mozambique in the east and the river varies from a single channel deep river to a multi-channelled shallow stream. The study area was divided into six different sectors (A; B; C; D; E and G) according to topographical differences and therefore each had easily recognizable borders. Sector E will not be described as this was only used to count nests, and is similar in appearance to sector G.

2.2.1   Sector A

This sector stretches from Balule (S 24 03.162 / E 31 43.794) to opposite the Olifants Camp (S 24 00.576 / E 31 44.532), and measures 5.7 km (Figure 2.2). The river width varies from 100 to 300 m depending of the water level. This sector is shallow (< 1 m) with no rapids and a number of bare islands that are covered with *Phragmites* spp. before the flood of 1996. Large *Ficus* trees were uprooted during the flood and died. The riverbed is mainly sandy with few rocky outcrops. During floods the stream increases to cover the entire river bed, <1 deep, and in low flow periods it shrinks to a mere 40m wide and < 30 cm deep. The incline of the river bed is shallow and sandy, with mainly

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[1]   *Frans Laubsher, Chief Engineer, P/bag X402, Skukuza*
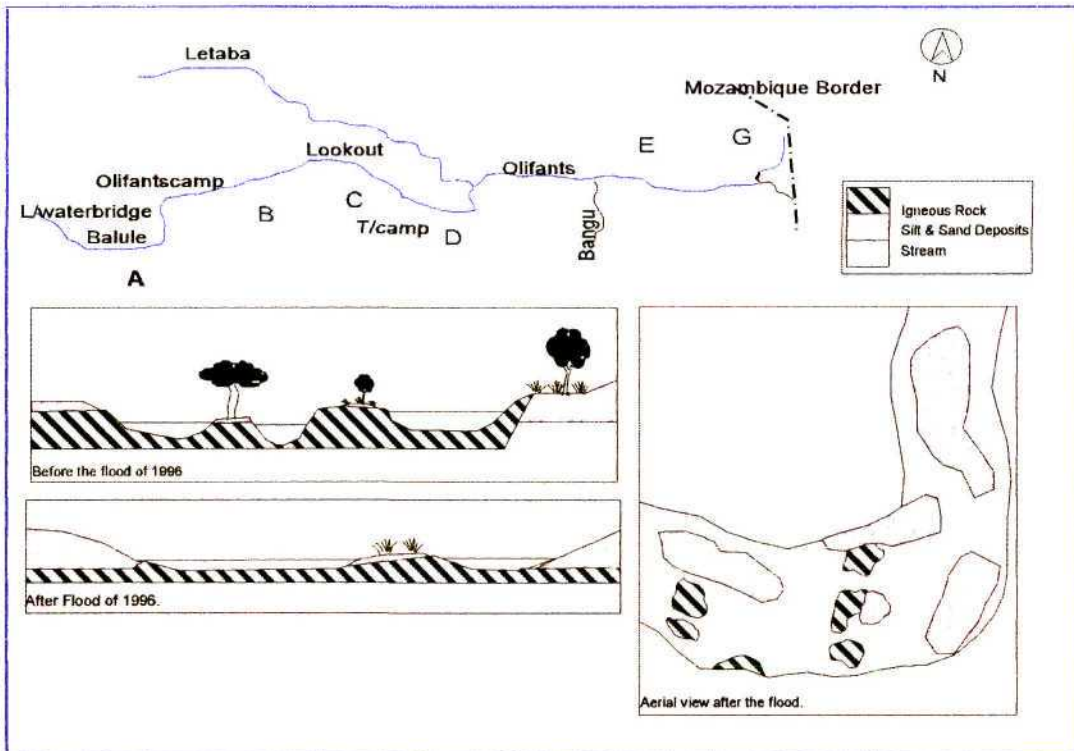
Figure 2.2   Sector A before and after the February 1996 flood.

alluvial soils. Aquatic organisms are limited to invertebrates and isolated pockets of fish. This sector is widely used by game for drinking, as the shallow stream offers some protection from crocodile attacks. The prevailing winds from the southeast affect ground and water surface temperatures.

2.2.2   Sector B

This area between Olifants Camp (S 24 00.576 / E 31 44.532) and the tourist lookout (S 23 58.974 / E 31 46.458) covers 4.5 km (Figure 2.3). The stream changes from shallow multi-channelled to a deep single stream where it cuts through a basalt dyke (Bristow *et. al.* 1986). Rapids or white water is characteristic of the first 2.3 km, and deep slow flowing water signifies the last 2.2 km. The river bed varies from rhyolite to basalt (Bristow *et. al.*, 1986) and the bottom is sandy to solid rock. The river runs in a V to U-shaped channel of varying depth. The incline is steeper than in the previous sector and therefore surface winds are unlikely to influence water surface temperature or create waves.

This sector does not host as much game as sector A as it is rocky. The rapids aerate the water and this results in periodic fish concentrations, mainly *Barbus* and *Tilapia* spp. towards the end of the winter in Aug - Sept (Pienaar, 1978). Limited crocodile concentrations can be seen during the pre-rain period, feeding off these species.
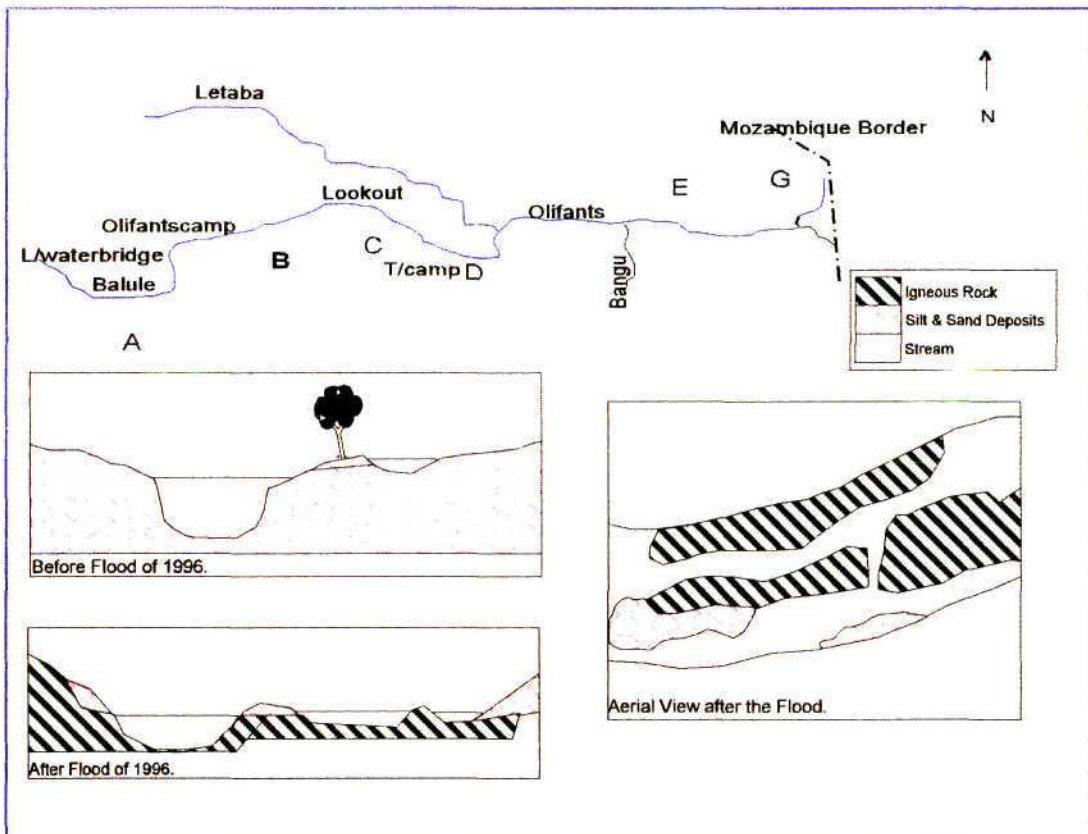
Figure 2.3   Sector B before and after the February 1996 flood.

2.2.3   Sector C

This 4.1 km section from the tourist lookout (S 23 58.974 / E 31 46.458) to the Trails Camp (S 23 59.598 / E 31 47.988), Figure 2.4, changes from a multi-channelled stream to a single deep and slow flowing stream. A number of shallow rapids mark the transition between fast and slow flowing water. The riverbed consists mainly of basalt rock with rhyolite rock on the embankments. The initial 2 km have long sandy islands and the last part have none. Depth varies from < 1 m to >3 m in the downstream part. The incline is shallow and predominantly sandy.
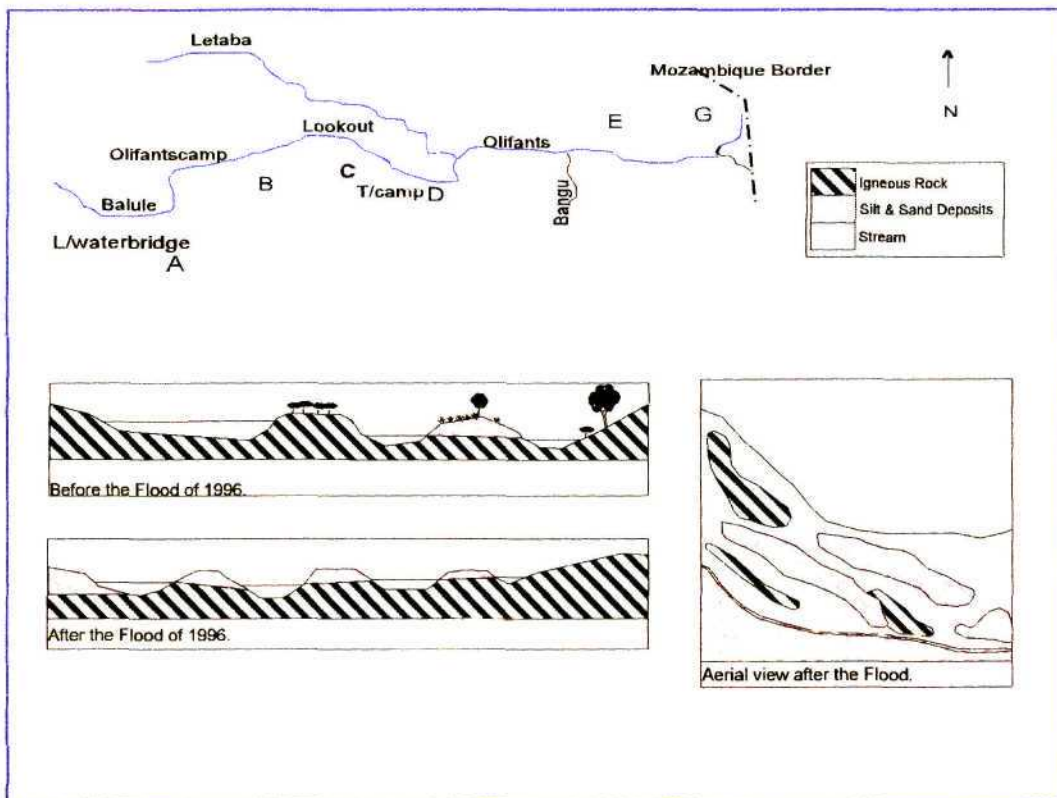
Figure 2.4   Sector C before and after the February 1996 flood.

2.2.4   Sector D

The single channelled stream (Figure 2.5) with two major but shallow rapids, extends for 4.2 km

from the Trails Camp (S 23 59.598 / E 31 47.988) to the confluence of the Letaba and Olifants

Rivers (S 23 59.340 / E 31 49.596). The riverbed is sandy to rocky and >1m deep. There are no

islands in this part and the water edge is covered with *Phragmites* reeds. A narrow flood plain on the

northern slope attracts a large number of game during summer (Sept - Feb). Rhyolite rock

dominates and the underlying basalt is only visible at certain spots.

2.2.5   Sector G

Between sectors D and E is an approximately 4 km segment of river that was omitted from the study

area due to its inaccessibility. Sector G (Figure 2.6) is the last part in the study area and ends where

the river enters Mocambique (S 23 58.926 / E 31 52.260 to S 23 57.378 / E 31 52.872). This part has
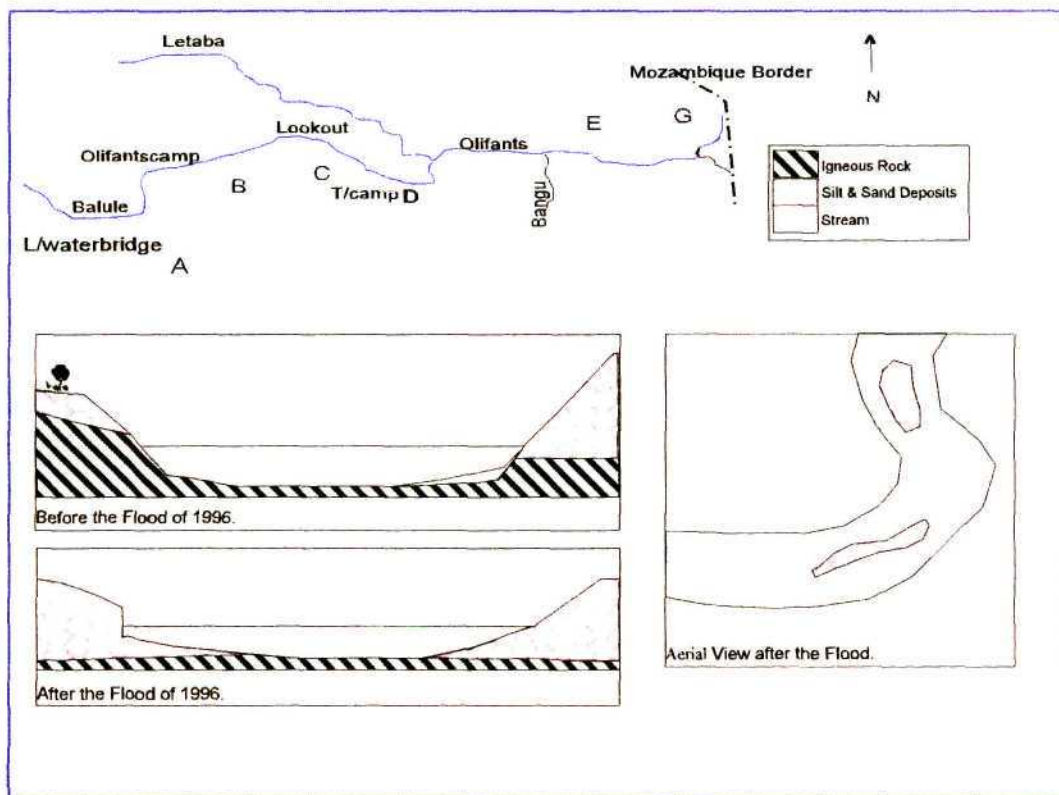
Figure 2.5   Sector D before and after the February 1996 flood.
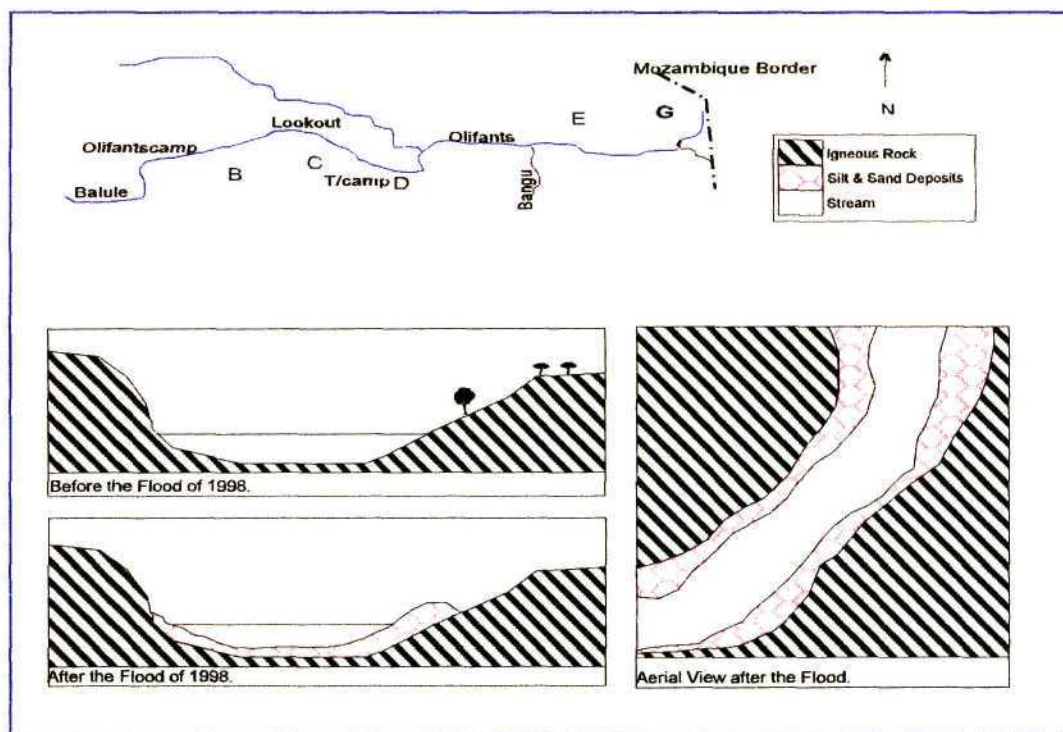
Figure 2.6   Sector G before and after the February 1996 flood.

always been known for the large concentration of crocodiles. The single stream is deep, > 2 m and narrow. The speed of the current was clearly demonstrated during the flood of 1996 and large sand and silt deposits were left behind. This resulted in the last 2,3 km being very shallow (< 0.5 m). The sides are vertical rhyolite cliffs of about 20 to 40 m high. Between the cliffs, shallow sandy patches offer suitable basking sites for crocodiles.

2.3   RAINFALL

Annual rainfall over the KNP varies from 700 mm in the south to 450 mm in the north (Bristow *et. al.* 1986). Annual precipitation for the study area is reflected in the following series of graphs (Figures 2.7 to 2.10). Runoff water from local rain showers contribute little to influence the water level, as this water normally passes through the study area within a day. Runoff from the catchment area (54574 km^2) and periodic releases from big dams, are the two major factors influencing the water level in the Olifants River.

The rainfall for Olifants does not significantly contribute to the water level in the Olifants River as the tributaries are relatively small and runoff water only impacts in the very last 3 km of the study area. Showers in the catchment area, as far as 400 km away, influenced the water level significantly as well as releases from dams in the Lowveld region. Figures 2.7 to 2.10 show the annual and long term rainfall for the Olifants Camp region.
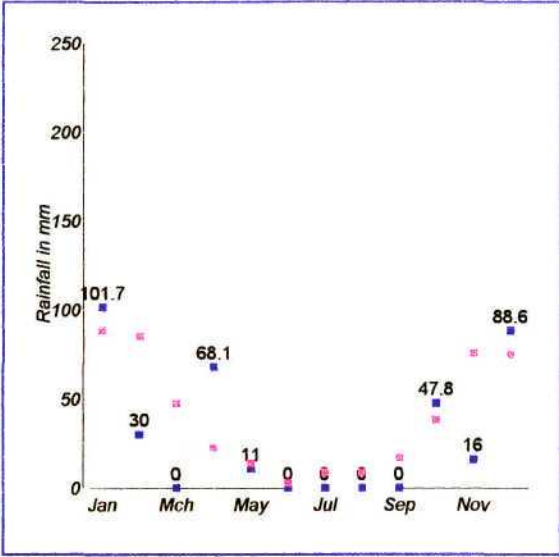
Figure 2.7 Rainfall for Olifants Camp for 1995. The red line indicates the long term average rainfall.
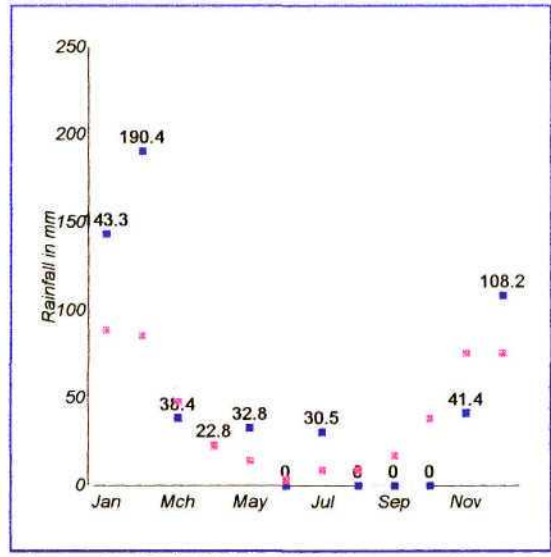
Figure 2.8 Rainfall for Olifants camp for 1996. The line in red indicates the long term average rainfall.
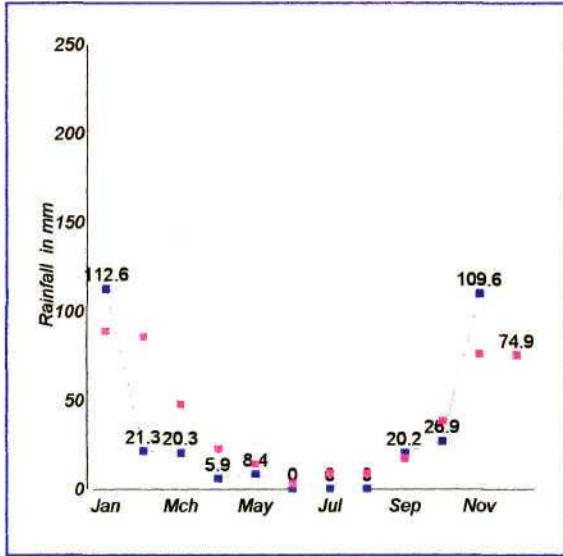
Figure 2.9 Rainfall for Olifants Camp for 1997. The red line indicates the long term average rainfall.
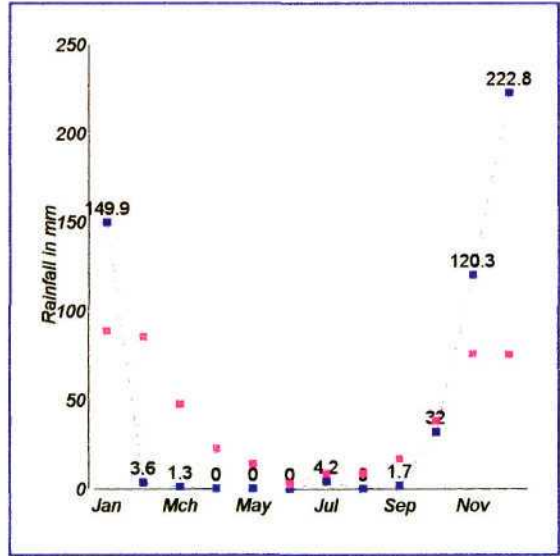
Figure 2.10 Rainfall for Olifants Camp for 1998. The red line indicates the long term average rainfall.

CHAPTER 3:

MOVEMENT

3.1   INTRODUCTION

To understand basic population processes, it is important to have knowledge of the distribution and movements of individuals within that population. Four concepts are important in studying movements of organisms namely territory, home range, dispersal and migration (Burt, 1940; Owen-Smith, 1977; Hutton, 1989),. Although there are several definitions for each of these concepts, the following will suffice for the purpose of this study. The definition of territory varies depending on the hypothesis, and can be as elementary as any defended area (Burt, 1940), or more comprehensive and complicated such as " .... *a strategy used by individuals to secure a disproportionate share of each resource of potential significance to genetic success* ." (Owen-Smith, 1977), or *".... [it] involves a geographically fixed space with associated elements of defense, exclusion and dominance."* (Burt, 1940). For the purposes of this study territory or core area will be defined as that area in which an individual, normally a dominant animal, will display antagonistic behaviour, or defend it by means of a display of aggressive behaviour or even physical contact.

Most animals do not move randomly, nor do they always occupy the total space available to them (Hutton, 1989). Home range is an area, usually around a territory or core area, over which an animal normally travels in search of food, shelter or a mate. The area of the home range may vary with sex, age, season and topography but must provide amongst others, three essential elements; food, shelter and water. Occupancy over a period of time with associated patterns of activity is the norm although variations frequently occur. An individual may be found to display aggression towards another individual at a specific location, but will tolerate the same individual in another place. Similarly, an individual will cover its home range searching for food or a mate and will tolerate other individuals, but it will only defend its territory.

Dispersal is the movement of individuals away from the area in which they have spent the initial part of their lives (Hutton, 1989), and Howard (1960) distinguished two types of dispersal: Innate dispersal is spontaneous, genetically determined and generally at random whereas environmental

dispersal is often short and directional resulting from the avoidance of an unfavourable habitat or social conditions. Migration is the temporary relocation of a population, which normally involves individuals, abandoning their home range for a prolonged period of time, and is normally associated with seasonal changes affecting the survival of the population, i.e., the availability of food, water and shelter. Migration involves a sequential return of individuals whereas dispersal does not. In the context of this study, the term "movement" refers to individuals leaving their home ranges or territories for a period of time, and should be interpreted as migration rather than dispersal. Movement can be stimulated by various environmental and population factors, usually for a shorter period of time than a migration and is normally aimed at satisfying a specific need.

The success of conserving any species will partly be determined by the effective protection of that species in an area or conservancy. If an animal has the ability to leave the area of protection, it will seldom enjoy the same status outside the conservancy, and as such will become vulnerable. Obtaining knowledge of the movement patterns of crocodiles is essential if they are to be protected in the Kruger National Park (KNP). All major river systems in the KNP are "open" systems allowing free movement into and from the reserve. The KNP is bordered by Mozambique on the east and predominantly agricultural land on the west. In both areas outside the KNP crocodiles are in conflict with human interests and as a result are vulnerable.

One of the primary objectives of this study was to determine whether individual animals leave their territory or home range and relocate (movement), either temporarily or permanently, over the period of the study. Although this objective did not include determining the reason(s) or stimulant(s) (triggers) for possible movement, some consideration was given to possible factors that could contribute to movement. To achieve the objective, the movements of individual crocodiles were studied over a medium term (3 - 5 years) rather than detailed local movements within home ranges or territories over a short period. Because of territorial behaviour and dominance of one individual over another and the physical defense of territories by dominant individuals it can be hypothesized that adult crocodiles do not move in the Olifants River system. Initial dispersal by juveniles and sub-

adults occurs seasonally, but adult crocodiles either establish a territory or occupy home ranges that allow for limited flexibility for seasonal changes.

3.2   MATERIALS and METHODS

To determine movement, it was essential to follow a standard method, but several options were not viable or practical. Spotlight counts (Hutton and Woolhouse, 1989) were not an option as the large variation in water level, the rocky nature of the study area and the presence of hippopotami in the river made the use of a boat impossible. Monetary restrictions and infrequent availability prohibited the regular use of an aircraft. A combination of three methods was therefore used to determine movement as one single method was not adequate. The methods used were foot counts, spot counts and radio telemetry. Foot counts were used to collect data on the changes and fluctuations in numbers of the population. It was felt that these counts, not being a census, will still reflect the overall fluctuations in numbers and densities of the population. The foot counts were done four times per annum, and at this resolution, one would not have been able to detect the precise time of change in numbers. Spot counts were therefore used at different locations, twice a month, to detect a more precise time scale of change in numbers.

To compensate for once off changes due to seasonal conditions like low water levels, the counts were done over a period of three years from May 1995 to December 1997. Counts were done during daylight hours, and although Montague (1983) recorded 12,9 % more individuals during night counts than day counts over the same area, it is believed that the data in this study reflected the true population in the study area because it was done over an extended period of time. The objective was not to do a census or to determine the exact number of crocodiles in the study area, but rather to determine an index of population trends by establishing times and changes in numbers within the various sectors of the river. The possible changes in crocodile numbers over an extended period of time, regardless of seasonal repetition or not, should imply a shift in density (animals/sector) and for the purpose of this study, will be interpreted as movement. This assumption will suffice to solve the hypothesis that there is no movement of adult crocodiles in the Olifants River.

The time intervals between the four foot counts per year were selected to coincide with the expected seasonal activities of *Crocodylus niloticus* (Cott 1961; Modha 1978; Hutton 1984). *The foot counts* were made at the following times.

May   This is the onset of winter with an associated drop in water temperature and a resultant inactive phase for the crocodiles. The water levels normally drop from this time onwards as this is the end of the raining season, and large sections of the river become unsuitable for crocodile habitation because of pools shrinking in both size and depth.

August   The summer period normally starts during August with a steady rise in day and water temperature. Based on personal observations, this was expected to be the beginning of the mating period for the crocodiles in the Olifants River, and should involve a movement of breeding animals to suitable sites. Deep pools with slow flowing water appear to be preferred for mating as both animals submerge during copulation (Pooley, 1969).

December   November to January is the nesting season and this could result in a shift in density as the breeding females become increasingly protective of their nests and more intolerant towards other crocodiles. This protective behaviour towards their nests might result in non-breeding individuals leaving the area.

Jan/Feb   This period signals the end of the nesting season and the count was primarily done to determine the number of nests that successfully hatched, irrespective of the number of eggs or survival rate of hatchlings.

The foot counts were done as soon as possible after sunrise, following a predetermined route. This route was followed on all counts. Two or a maximum of three observers participated in every count, each equipped with a set of standard binoculars (8X32 or 10X12). On all the counts except two, the same two observers were present. The number of observers were limited to a maximum of three so as not to cause unnecessary disturbances resulting in the crocodiles entering the water before it could be counted or the size estimated. One sector per day was monitored, as the concentration of the observers dwindled after about five hours in the heat, which was the average time it took to count a sector. The same procedure was followed by Hartley (1990) in Kwazulu/Natal. The observers utilized high ground to get the best visual coverage of the river and they would stop at regular intervals to search for crocodiles in or out of the water. Sectors A and C have multi-channeled streams during low flow periods. This implies that the total water surface in those sectors was not always visible from the predetermined route, as some areas were obscured by islands and/or *Phragmites mauritianus* reeds.

Observers walked the original route for all counts. Individual crocodiles could have been missed, but the number of repetitions (12 over four years), and the fact that this was not a census compensated for that. Sectors B, D & G are predominantly single channeled and the water level did not influence the accuracy of the count as the total water surface was visible during both high and low water level periods. With every sighting the number and size of the individuals was noted. The size of the crocodiles were estimated using methods described by Hutton (1987c). A brief description of these techniques is as follows:

If the animal was in the water with the body submerged, the head length (HL) was estimated. No estimates were made over distances > 150 m. The HL measurement was multiplied by seven to indicate the total length (TL) (Hutton 1987c). Morphometrics and field estimates done by Hutton (1987c) indicated that TL could be derived from the HL (the distance from the tip of the snout to the posterior margin of the supra-occipital) such that TL = 7.5 x (HL - 49.14) (r = 0.99). When basking, the TL was estimated and if possible, confirmed by measuring footprints, belly scales or the total length from the imprint on the ground, or if the individual slid into the water, the measurements of a

hind footprint were taken (Hutton, 1987c). When walking, the hind feet carries most of the body weight, and thus leave a deeper imprint than the forefeet. This is multiplied by 12 if TL < 2.00 m and by 13 if TL > 2.00 m (TL = 13.3 x Hind footprint + 89.3; r = 0.99). The belly scale is the largest scale on the belly and can be found anterior of the axis between the front limbs. The length of the belly scale, multiplied by 54 reflects the TL of the individual (TL = 54.9 x Belly scale +193.8; r = 0.98). All observers estimated the snout-eye or TL, and the average was noted. Any difference in the initial estimate exceeding 0.5 m was noted as "unsure."

The four size classes used were based on Hutton (1989):

Class 1:	< 1.5m (TL)	Juvenile.
Class 2:	1.5 - 2.5m (TL)	Sub-adult
Class 3:	2.5 - 3.5m (TL)	Adult (potential breeders)
Class 4:	>3.5m (TL)	Large adult males

Besides the size of the individuals, the number of groups was also noted. This was to detect mating and individuals displaying territorial behaviour. Any two individuals within their own total length (TL) from one another was noted as belonging to a group. This distance was not selected on any other criteria besides field observations, which suggested that crocodiles will normally swim to within < 1 m of another before it displays aggression. The sub-dominant individual will only submit when the dominant crocodile is about 1 m away. A group could comprise one individual or as many as thirty.

The intervals between foot counts, four months, were found to be insensitive to the time (date) of movements in the population and two locations were selected where spot counts were done at 14 day intervals. The Balule location (S 24 03.084 / E 31 43.908) was abandoned after the flood, and replaced with Nwamandzi (S 24 00.900 / E 31 39.408) whilst the Lookout site (S 23 59.070 / E 31 46.284) were used throughout the study period. See Figure 3.1 for the locations of the spot counts. The purpose of the spot counts was to detect movement by a change in numbers and ultimately provide a more sensitive estimate of the time of movements. Personal experience suggested that the crocodiles were more tolerant towards vehicles than a person on foot, thus two locations were

identified with the accessibility of a vehicle as the main criteria. On average a crocodile was found to stay submerged for about 20 minutes if undisturbed and therefore a minimum period of 40 minutes was spent at each location during which time three counts were done. The maximum of the three counts was noted. The locations were visited during late afternoons and always in the same order. This eliminated the possible influence of sun and time of the day on the counts. With the spot counts, the sizes (TL) were only estimated and no confirmation was obtained.

Standard 8x32 binoculars and a spotting scope with 45 X magnification were used. The scope was mounted on the vehicle window. The optical aids were used to identify individual animals by natural tail markings (Swanepoel, 1996). The average of the two monthly spot counts was used as the final number for the month. One initial location at Balule became unsuitable after the flood of February 1996 when the site silted up to the extent that water depth was < 80 cm on average throughout the year, except during flood periods. The number of crocodiles declined to zero in August 1996 and the location was therefore abandoned for a more suitable one further up stream at Nwamandzi.

Figure 3.1 Location of the spot count sites used in the study. The Lookout site was the only one used throughout the study. The Balule site was replaced by the Nwamandzi site in May 1996.

In addition twelve large individuals, >3 m TL, were fitted with radio transmitters to track exact movements and locations (Hutton, 1989). Tracking was done on foot and from both fixed-wing aircraft and helicopter when available. Hutton (1984), Fergusson (1992) and Leslie (1997) used radio transmitters on *C. niloticus* with mixed successes. Hutton (1984) used head-caps and/or attached the

transmitters to the dorsal osteoderms of the neck. Some head-caps, 16 in total, remained in place, on top of the cranial platform, for a period of two years whilst 10 head-caps were lost within a period of 2 - 20 months. The head-caps used by Hutton (1984) weighed 500 g whilst the transmitters were a mere 60g and measured 40 x 45x 90 mm. All transmitters attached to the nuchal scutes were lost, unfortunately no reasons for their loss were provided. Fergusson (1992) used a similar method to attach transmitters to the nuchal scutes. He released 25 captive bred individuals (1 - 1.5 m TL) into the wild and after three months only eight were alive. Leslie (1997) fitted only one transmitter on a female of 3.0 m TL and tracked it successfully for three months. She attached the transmitter to the nuchal scutes with cable-ties.

For the purpose of this study only large animals were targeted for radio transmitters as tag loss and mortalities amongst juveniles and sub-adults were expected to be substantially higher (Hutton, 1989). Males >3.5 m TL and females >3.0 m TL were fitted with transmitters. Eleven radio transmitters measuring 110 x 80 x 55 mm at the bottom, tapering to 70 x 35 mm at the top, and enclosed in black bitumen were used. The total weight of the transmitter was 420g including the two CR2032 batteries. A whip antennae protruded for 150 mm horizontally to the rear and was covered in black rubber. A series of 6 mm holes were drilled at the base of the transmitter for the cable attachment. The expected lifespan of the transmitters was three years with a reception range of about three km, depending on elevation and whether the transmitter was submerged or not. When submerged in 1.5 m water, the reception range was limited to about 500 m. A Telonics TX4 receiver on 148 MHz frequency was used with a hand-held "H"- shaped Yagi antennae. The transmitter pulse rate was set to 40 pulses per minute to extend battery life. This pulse rate proved to be adequate in locating the transmitters.

Attachment of the transmitters to the crocodile was between the nuchal scutes, anterior to the head, with 3 mm stainless steel cables after immobilizing the animal with 40 mg/ml gallamine triethiodide (Flaxedil). The drug dose of 2 mg/kg was based on the estimated total length/mass of the crocodile (Loveridge & Blake, 1972). It was found that by halving (50%) the prescribed dosage, it was still effective for the purposes of this study. Two cables were used, one anterior and the other posterior to

the transmitter. This acted as additional security if one cable broke or was torn from the scutes, the other cable should theoretically still hold the transmitter in place. Holes were drilled through the base of the scutes with a cordless electric drill and a 6 mm drill bit. The cables were fed through the hole in the scute, then through the transmitter base and again through the scute. This process was repeated for the cable at the other end of the transmitter. The ends of the cable were sealed with standard 6 mm industrial crimps. A metal washer was placed between the crimp and the scute to prevent the crimp from being torn through the scute.

Any facial scars or obvious markings on the crocodile were recorded as well as the total length and sex of the animal. Detailed sketches of the tail markings were made to confirm the identity of individuals (Swanepoel, 1996). The holes in the scutes were treated with a commercial disinfectant prior to releasing the crocodile. The average duration for attaching a transmitter was less than two hours, but this varied with temperature. Lower temperatures resulted in a longer reaction period to the immobilizing agent. Neostigmine (2.5 mg/ml) was used to neutralize the Flaxedil at a recommended dosage of 0.5 mg/kg, but not exceeding 2 ml per crocodile, regardless of size and time immobilized. When a crocodile was immobilized for longer than six hours, only half the recommended dosage of Neostigmine was used. No crocodile died during the procedure, and no subsequent infections of the holes in the scutes have been observed.

To consider the effects of water level and flow volume on the counting procedure it was necessary to obtain estimates of the level and flow volume of the river. These measurements were obtained at the Mamba weir on the western boundary, by the Department of Water Affairs and Forestry (DWAF) and are summarized in Table 3.1.

All statistical calculations, analysis and graphs were done on either Jandel Sigmastat for Windows Version 1, Statgraphics version 7 or Corel Quattro pro 8 with Windows 98 as the operating system. One way Anova analyses were performed to determine whether there were any statistical differences in numbers and groups of crocodiles between sectors, and Student t-tests determined the level of

significance. Correlations between groups and totals in each sector were done with Sigmastat for Windows.

3.3 RESULTS

A total of 16 foot counts were made over a period of four years, eight before the flood in February 1996 and another eight after the flood. Data of twelve counts were used as four counts (one per year) were used to count the number of nests that hatched successfully at the end of the season, and not to count crocodiles. The flood of 1996 changed the entire geomorphology of the river (*cf* Chapter 2) and this may have had a significant effect on the numbers of crocodiles per sector. Table 3.1 indicates the water level as either below or above the medium term (5 years) mean flow for the months of May, August and December from 1994 to end of 1997.

Table 3.1 Summary of flow rates in the Olifants River for May, August and December as measured against the five-year mean flow. *c/sec = cubic meters per second (DWAF report 1998).

Month	Five year mean flow (c/sec)*	Status of water level	Real flow volume (c/sec)
May 1994	14.8	Below	2
Aug 1994	1.6	Below	1
Dec 1994	21.7	Above	22
May 1995	14.8	Above	43
Aug 1995	1.6	Above	2
Dec 1995	21.7	Above	78
May 1996	14.8	Below	< 0
Aug 1996	1.6	Below	< 0
Dec 1996	21.7	Below	<0
May 1997	14.8	Above	69
Aug 1997	1.6	Above	10
Dec 1997	21.7	Above	143

During all December counts the river was in flood and with the exception of December 1996. Generally, May and August flow volumes were low. During high flow periods, the water covered the

majority of islands in the sectors with a resultant increase in visibility of crocodiles by the observers. Table 3.2 summarizes some of the results of the foot counts. Take note that the peak high numbers (total/sector) were reached in August for sectors A to D but only in May for sector G, indicating a possible shift in crocodiles from all sectors to sector G. Similarly the low peaks were reached in December, except for sector C, underlining the possibility that the majority of crocodiles have left the study area during the low counts.

Table 3.2 Month and year, in brackets, of the highest and lowest number and density of crocodiles per sector.

	Sector A	Sector B	Sector C	Sector D	Sector G
No. of Counts	12	12	12	12	12
Peak *(Total/sector)*					
High	42 (Aug 95)	42 (Aug 95)	45 (Aug 94)	269 (Aug 94)	670 (May 95)
Low	9 (Dec 96)	19 (Dec 97)	6 (May 95)	31 (Dec 97)	48 (Dec 95)
Density *(Crocodiles/km)*					
High	3.7 (Aug 95)	4.6 (Aug 95)	5.3 (Aug 94)	32 (Aug 94)	111.6 (May 95)
Low	0.8 (Dec 96)	2.1 (Dec 97)	0.7 (May 95)	3.7 (Dec 97)	8 (Dec 95)
Mean	2.2	3.3	2.9	13.4	40.9

In sector A which has a tourist road on the northern side of the river, only 3% of the total (n = 40) for the August 1994 count were on the northern bank of the river. In sector D and G this was not a factor as there were no islands in the river and the only basking spaces were on the land ends, and both sectors were very isolated with no vehicle traffic and very limited human activities.

The results were remarkably consistent over four years, and there was a pattern throughout the study period and in the majority of sectors with low numbers in May, highest in August and variable in December. This tendency repeated itself in the majority of the sectors. All the sectors reflected a steady decline in the total crocodile population in the Olifants river. The Gorge sector (G) reflects only the total crocodiles seen per count. This is a result of the observation distance that did not allow for an accurate estimation of sizes (average distance > 700 m). The results for the Gorge sector will therefore only be included in the calculation of total individuals in the study area and to determine movement, but not to find a possible correlation between numbers and groups.

3.3.1   Numbers and groups per sector.

Figure 3.2 shows the total number of crocodiles in Sector A. With the exception of 1996, August is

the period of greatest density. The high peaks in Figure 3.2 correspond with August of every year.

The drop in numbers from Aug 1994 to Dec 1994 represents a decrease of 72.5% (29 crocodiles)(Fig

3.2). In the following year a drop of 66.6% or 28 individuals occurred over the corresponding period.

Highest density was in Aug 1995 with 3.7 individuals per km river, and the lowest density was in

December 1996 when it decreased to 0.8 crocodiles per km river (Table 3.2). The relatively big
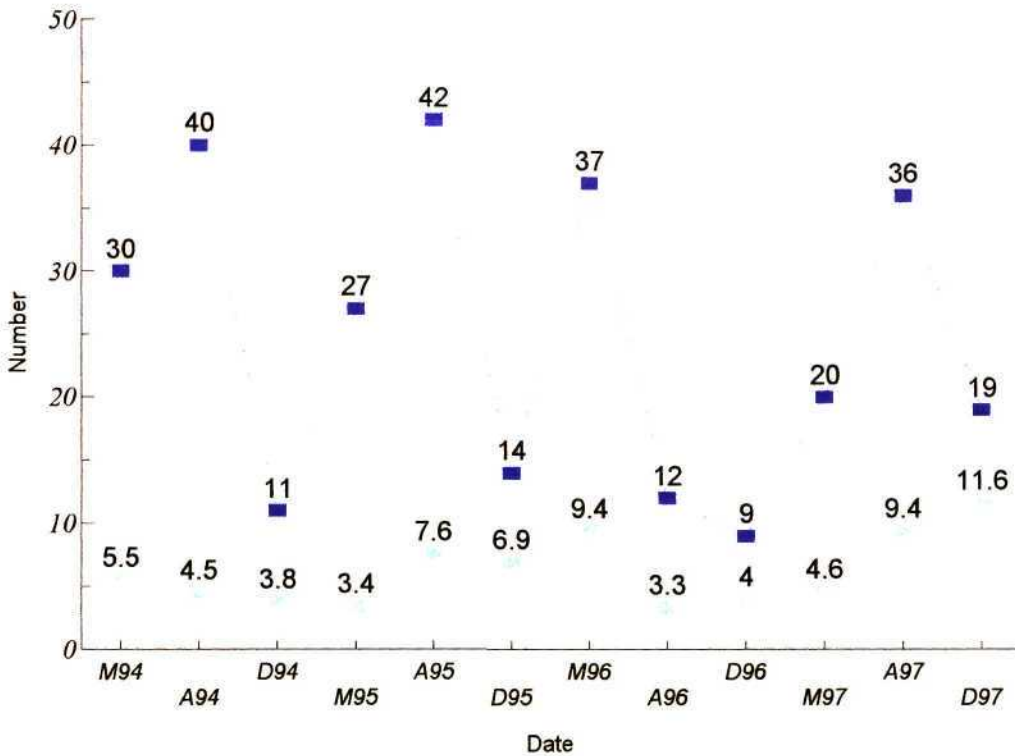
Figure 3.2 Total number of crocodiles in sector A during all the counts. The bottom line
(green) indicates what percentage of the total in the study area is represented by this sector.

difference between high and low density (2.9 animals per km river) indicates that the majority of

individuals moved out of and back into this sector.

Total numbers in sector B were considerably higher than sector A (Figure 3.3). Despite the higher density, the trend in Sector B is the same as in Sector A (Figure 3.2). A similar decrease as in sector A, from Aug 1994 to Dec 1994 of 61.2% or 30 individuals occurred, and it occurred again in
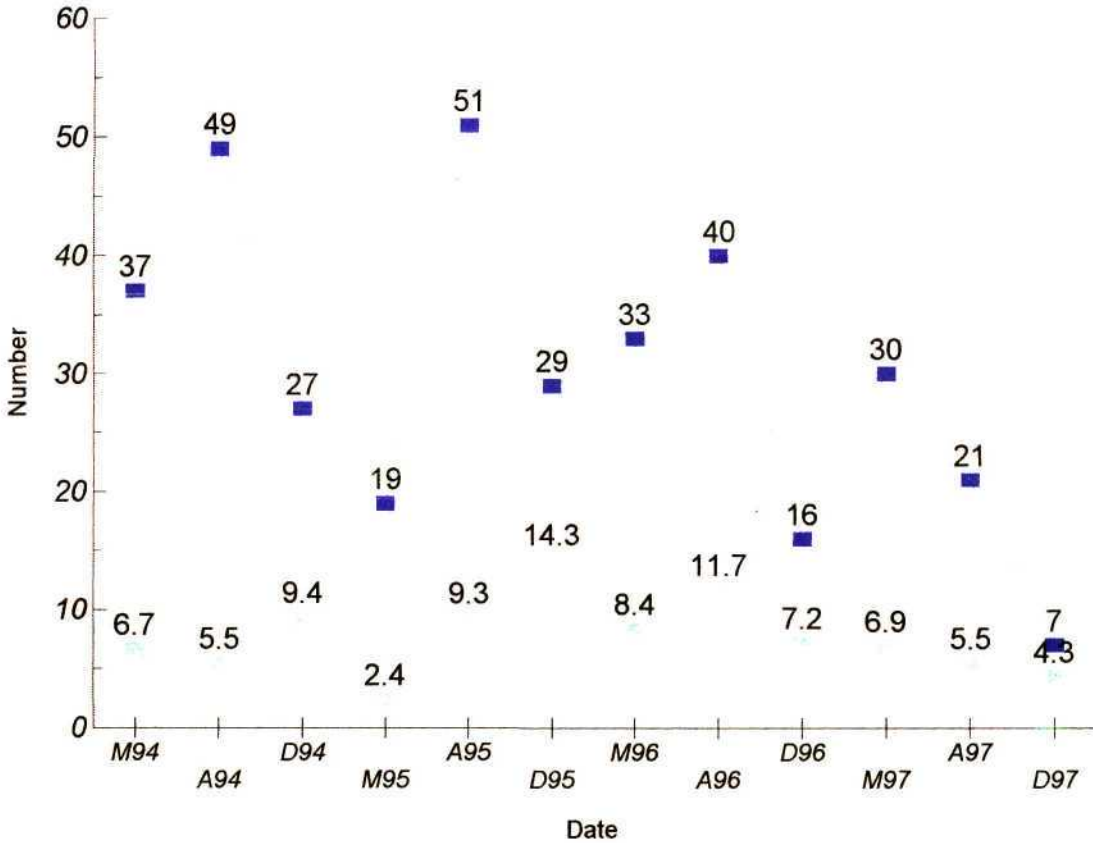
Figure 3.3 Total number of crocodiles in sector B during all the counts. The bottom line (green) indicates what percentage of the total in the study area is represented by this sector.

Aug 1996 when 24 crocodiles or 60% of the population in this sector were unaccounted for. The biggest increase of 168.4% (32 crocodiles) was experienced in May 1995 to Aug 1995 (Fig 3.3). The peaks in Figure 3.3 corresponds with those in Figure 3.2, occurring in August of every year with the exception of 1997. If the same trend occurs at a similar time in the different sectors, it is suggested that the same set of factors might be responsible for movement in both sectors. There was no significant difference between the numbers in sectors A and B (t = -1.04; df = 22; p = 0.3096). The period of highest density for sector B was in Aug 1995 with 5.6 individuals per km river and it declined to 0.7 in Dec 1997. The large difference of 4.9 crocodiles per kilometer (Table 3.2)

suggests again that the majority of individuals were not stationary/resident during the study period. The seasonal variation in numbers may be as a result of movement as no carcasses or indications of mortalities amongst adults were found. The near similar trends in Figure 3.2 and 3.3 rather suggest a temporary fluctuation and not a permanent change.
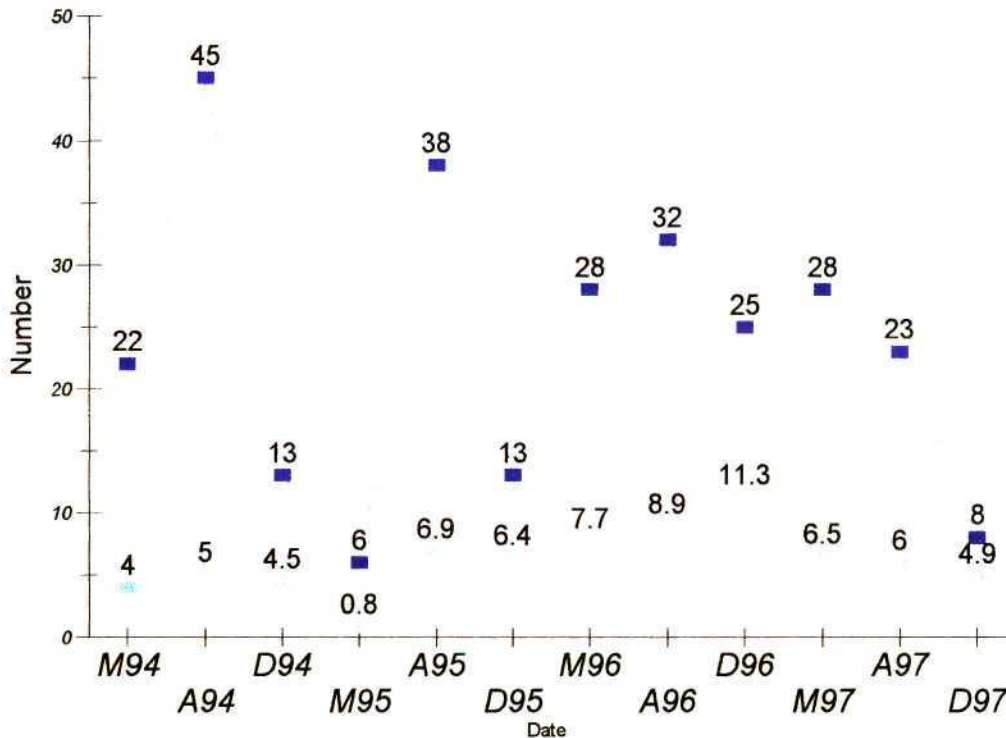
Figure 3.4 Total number of crocodiles in sector C during all the counts. The bottom line (green) indicates what percentage of the total in the study area is represented by this sector.

In sector C islands in the main stream obscured visibility and some individual crocodiles could have been missed. Islands could not be reached and are covered with *Phragmites* spp. which made locating and counting of juveniles impossible. The decline of 71.1% or from Aug 1994 to Dec 1994 is the most significant one in the three sectors A, B and C (Figure 3.4). The similarity in trends between sectors A, B and C suggest that the same set of factors may have influenced movement as there were no significant differences between these three sectors ($f = 0.935$; $p = 0.403$). The set of factors responsible for the movements are not known, but based on the evidence (high numbers in

August, variable in May and low in December) it is suggested that the same factors triggered the movements in all three sectors. During below normal flood periods, the number of islands increased and together with the increase in flight distance, it could have been possible to count the same individual more than once. During August 1994 the numbers reached a high of 45 crocodiles and in May 1995 a low of only six individuals for the whole sector. Despite the difference in high and low peak totals between sector B and C, they had a density of 4.6 and 5.3 crocodiles/km respectively.

As can be seen from Table 3.2, sector D had a higher density of crocodiles than all previous sectors (A, B and C), and predictably, it was also subject to a larger fluctuation in numbers. The result can be seen in Figure 3.5. The high density peak of 32 crocodiles per km was during August 1994 and significantly, this occurred in the mating period, August to September.
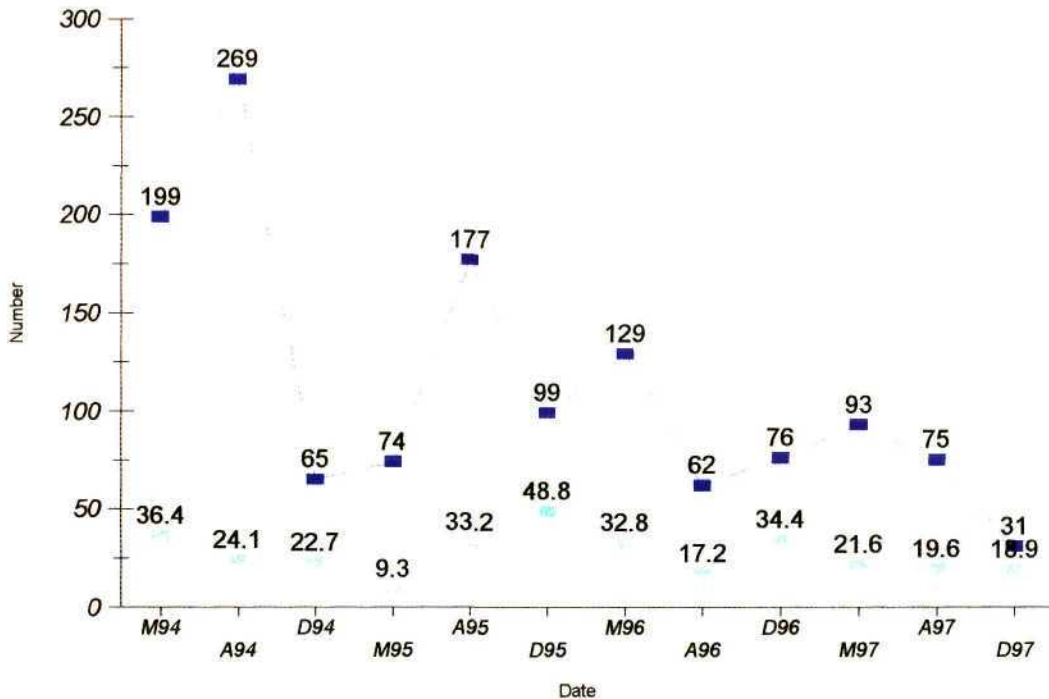
Figure 3.5 Total number of crocodiles in sector D during all the counts. The bottom line (green) indicates what percentage of the total in the study area is represented by this sector.
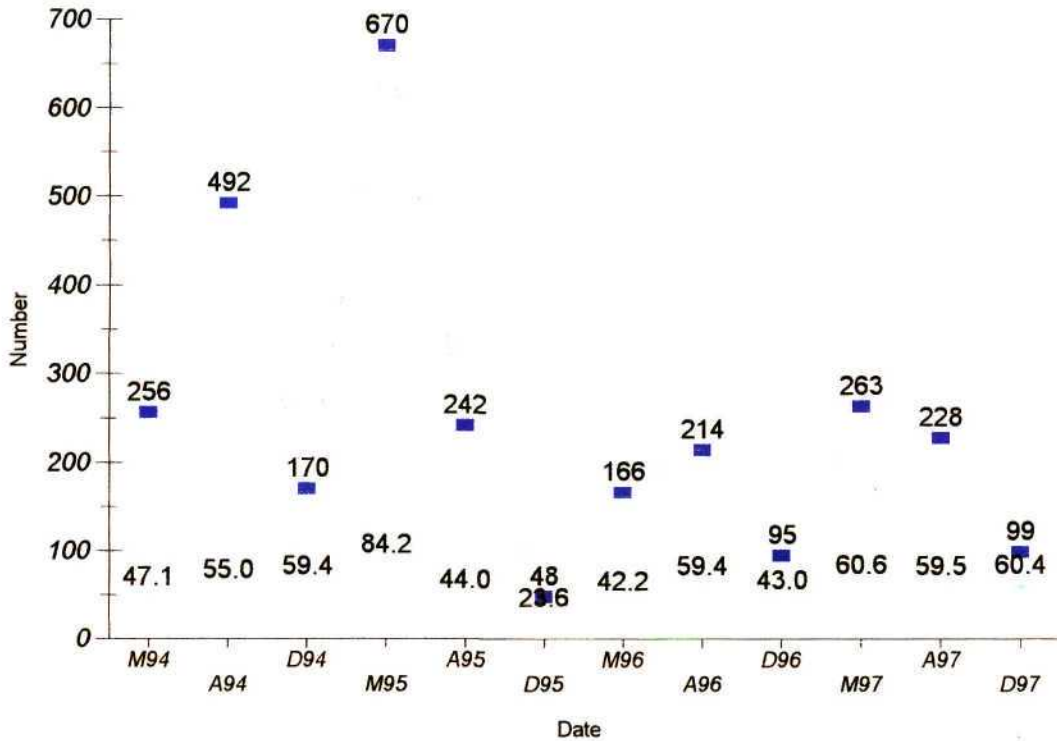
Figure 3.6 Total number of crocodiles in sector G during all counts. The green line indicates what percentage of the total in the study area is represented by this sector.

For sector G, only the total number of crocodiles was recorded (Figure 3.6). Size was not recorded because the observation distance of > 700 m, did not allow for accurate estimations of sizes (TL). High density during May 1995 was 111.6 crocodiles per km river and this declined to a low of eight individuals per km in Dec 95. The difference in densities of 103.6 crocodiles occurred in a span of only seven months. Five months later, May 1996, the density increased to 20.7 crocodiles per km and this strongly indicates a movement rather than mortalities.

A Kruskal-Wallis One Way ANOVA on ranks showed a significant difference (df = 4; p < 0.0001) between all the sectors combined, even though there were no significant differences between sectors A and B (df = 11; t = -1.41; p < 0.09), and A and C (df = 11; t = 0.38 p < 0.5). There were, however differences between B and C (df = 11; t = 2.8; p < 0.01). Figure 3.7 compares the differences in the percentages of the totals between the different sectors. An increase in numbers in sectors A, B, C and D for August 1994 was reflected as a decrease in sector G. With the exceptions of August and

December 1997, this was the tendency in all the counts. Table 3.3 and Figure 3.8 indicate the total

population for the study area from May 1994 to December 1997. The most prominent feature of the

graph is the decline of 74.4% or 593 individuals from May 1995 to December 1995. However, the

increase in numbers for sectors A, B, C and D from May 95 to Aug 95 totals 182 crocodiles whilst the

decrease in G for the same period is 428 which leaves a total of 246 crocodiles that could not be

accounted for. The only viable explanation is that those 246 individuals moved to Mocambique.
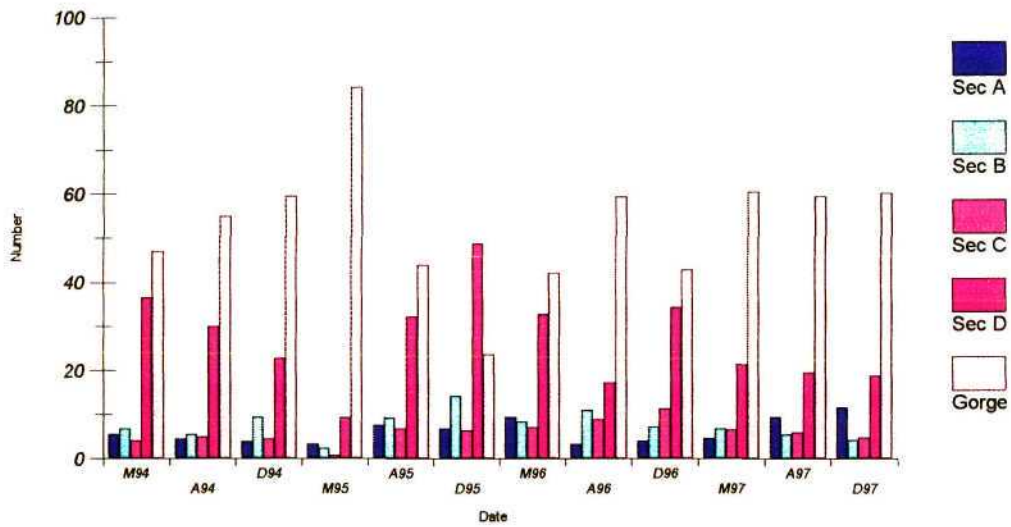
Figure 3.7 Comparitive percentages of the total number of crocodiles for the various sectors during the study period. Note that a decrease in sectors A, B, C and D normally resulted in an increase in sector G.
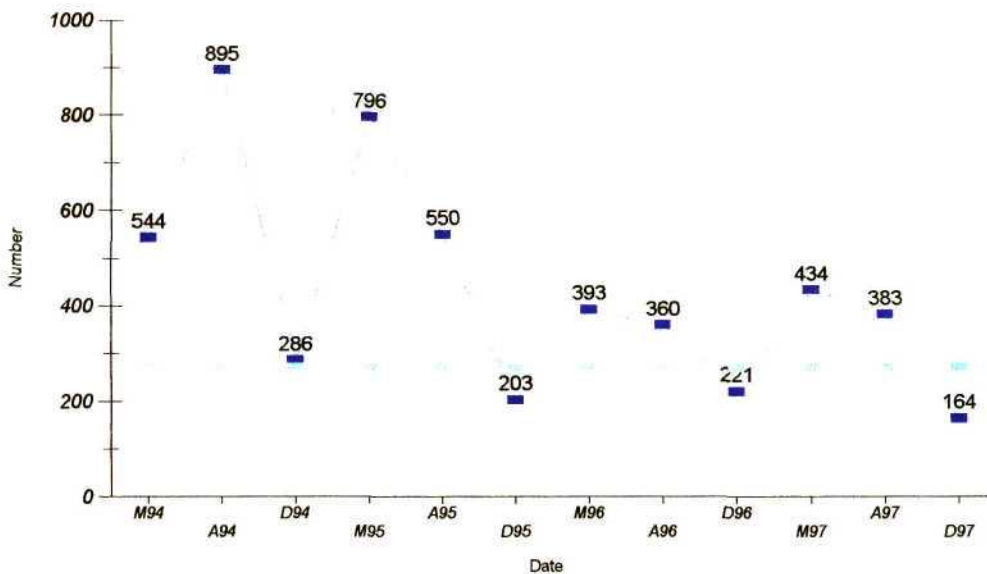
Figure 3.8 Total crocodile population in the study area for the study period. The green line indicates the mean population ($\bar{X}$ = 435 ± 52.2 SE).

Table 3.3 The total number of crocodiles per sector, number of groups and crocodiles per group for the various counts. No/group is the number of individual crocodiles within their own body length from one another and could be one individual only.

| | Sector A | | | Sector B | | | Sector C | | | Sector D | | | Sector G | | |
	Total	Groups	No/ Group	Total	Groups	No/ Group	Total	Groups	No/ Group	Total	Groups	No/ Group	Total	Groups	No/ Group
May 94	30	24	1.2	37	28	1.3	22	19	1.2	199	28	7.1	256	25	10.2
Aug 94	40	16	2.5	49	40	1.2	45	25	1.8	269	31	8.7	492	29	17
Dec 94	11	11	1	27	24	1.1	13	10	1.3	65	36	1.8	170	27	6.3
May 95	27	23	1.1	19	17	1.1	6	6.	1	74	44	1.7	670	14	47.9
Aug 95	42	39	1.2	51	40	1.3	38	23	1.7	177	33	5.4	242	33	7.3
Dec 95	14	11	1.2	29	28	1	13	13	1	99	90	1.1	48	28	1.7
May 96	37	29	1.2	33	27	1.2	28	22	1.3	129	66	2	166	25	6.6
Aug 96	12	10	1.2	40	36	1.1	32	29	1.1	62	46	1.3	214	33	6.5
Dec 96	9	9	1	16	15	1.1	25	20	1.3	76	54	1.4	95	38	2.5
May 97	20	18	1.1	30	22	1.4	28	22	1.3	93	40	2.3	263	45	5.8
Aug 97	36	23	1.7	21	18	1.2	23	20	1.2	75	58	1.3	228	37	6.2
Dec 97	19	19	1	7	7	1	8	8	1	31	28	1.1	99	20	5
Average	24	19		29	25		23	18		112	46		245	29	
Average number / group			1.3			1.2			1.2			2.9			10.2
*SE	3.49	2.57	0.08	3.79	2.93	0.13	3.43	2.07	0.13	19.96	5.31	0.74	50.58	2.41	3.60

* SE = Standard Error

Figure 3.9 summarizes the results of the aerial census for the entire Olifants River for the past eight

years from 1989 to 1997 (Whyte, 1998). The trend has been for an increase of 133% or 1107

crocodiles from 1990 to 1994 followed by a steady decline in numbers until 1997. The decline in the

population since 1994 is reflected in both the study area (Figure 3.8) and over the entire Olifants

River (Figure 3.9).
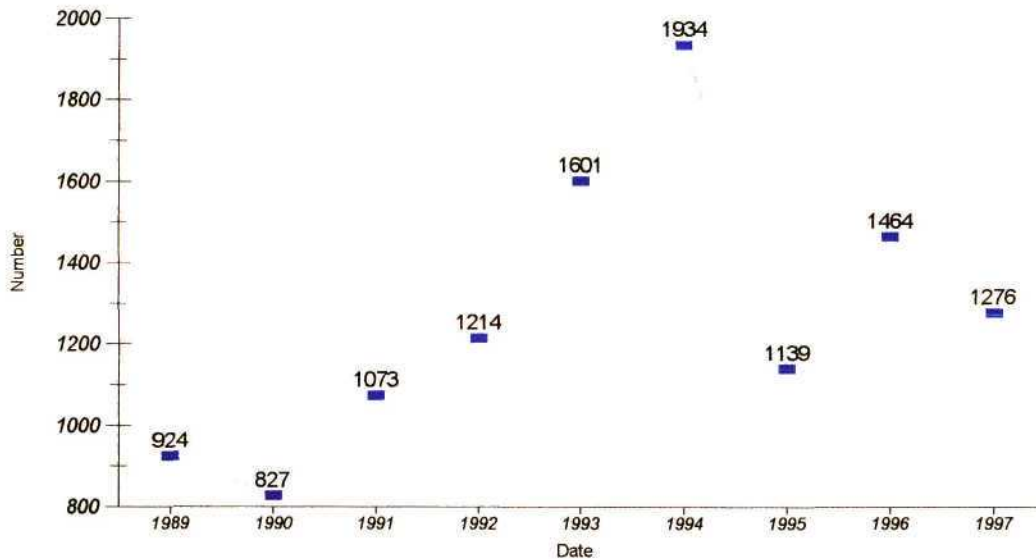
Figure 3.9 Total crocodile population in the Olifants River (blue line) based on the annual aerial census (Whyte, 1998). The green line indicates the mean population (1272) for the river since 1989 ($\bar{X}$ = 2523 ± 116.6 SE).

With every count, the groups in every sector were noted as well. When two individuals were within

their own body length from another, they were considered as a group. A positive linear relationship

was found in Figure 3.10, between totals and the number of groups in sectors A, B and C (p <

0.0001; f = 155.5; r^2 = 0.82). In these sectors the number of groups increased as the total number of

individuals increased, showing a strong dominance with individuals keeping their distances. The

opposite effect was found in sectors D and G (Figure 3.11), where the number of groups actually

decreased with an increase in total numbers.
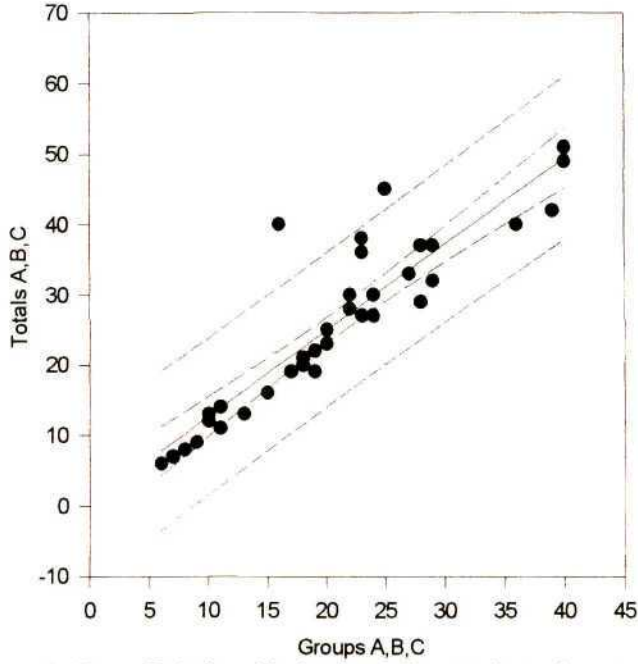
Figure 3.10 Relationship between the totals and groups in sectors A, B and C.(df = 155.5; r^2 = 0.821; p < 0.0001)
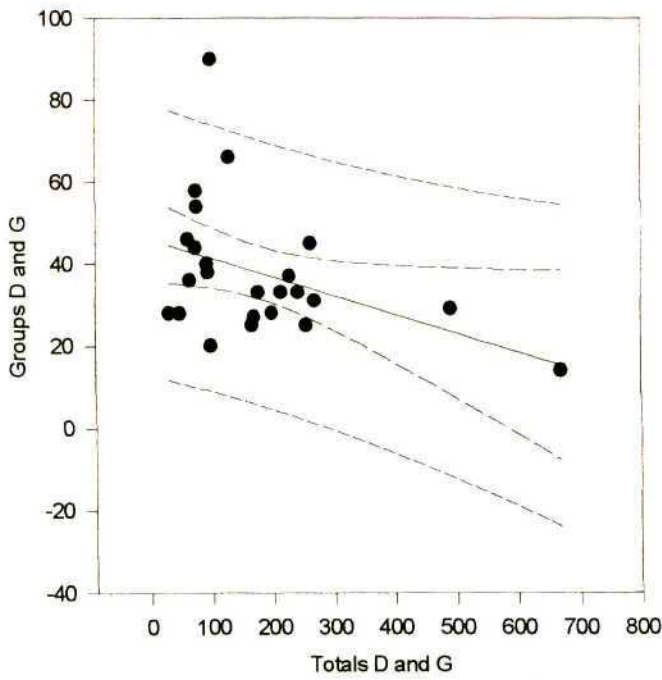
Figure 3.11 The relationship between the totals and groups in sector D and Gorge. (df = 4.44; r^2 = 0.168; p = 0.0467)

3.3.2   Classes

In analyzing the numbers in the different sectors over a four year period, there is strong evidence to

suggest that there was a movement of individual animals at different times of the year. These data

do not reflect what sex of the population has moved from which sector, and it is therefore necessary

to analyze movement in terms of the size (class) of the animals. Class 1 represents the juveniles,

class 2 the sub adults and class 3 the breeding segments of the population. Class 4 is the individuals

> 3.5 m TL and thus predominantly males but not necessarily breeding individuals (Hutton 1998). In

the class 3 animals, only sector D showed a statistically significant relationship (Pearson correlation

test) between numbers and the total in the study area ($p < 0.01$; correlation coefficient of 0.711; n =

311). Among the class 4 crocodiles there was a significant relationship between totals per sector and

the total in the study area for sectors B ($p < 0.005$; n = 108), C ($p = 0.001$, n = 108) and D ($p <$

0.0005; n = 258) but not for sector A ($p > 0.050$).

The importance of the shift from class 1 to class 2 due to growth should not be ignored and therefore

the variation in numbers cannot be interpreted on the basis of movement alone. This study did not

allow for this eventuality and as a result, no data were collected to investigate this possibility.

The data for sectors A to G for the different size classes are summarized in Tables 3.3 to 3.7.

Table 3.4 Comparison of class 1 crocodiles (<1.5m TL) in sector A, B, C and D.

	05/94	05/95	05/96	05/97	08/94	08/95	08/96	08/97	12/94	12/95	12/96	12/97	Average	SE*
Sec A	3	0	3	3	2	3	1	2	1	1	1	2	1.8	0.27
Sec B	4	0	2	1	4	2	1	1	2	2	0	0	1.6	0.37
Sec C	2	0	1	1	6	2	1	0	0	0	0	0	1.1	0.46
Sec D	5	2	1	0	0	0	0	3	0	0	0	0	0.9	0.43
Total	14	2	7	5	12	7	1	6	3	3	1	2	5.3	1.12
Average	3.5	0.5	1.75	1.25	3	1.75	0.75	1.5	0.75	0.75	0.25	0.5	1.4	0.27
SE*	0.65	0.5	0.48	0.63	1.29	0.63	0.25	0.65	0.48	0.48	0.25	0.5	0.21	

* SE = Standard Error

Table 3.5 Comparison of class 2 crocodiles (1.5 - 2.5m TL) in sector A, B, C and D.

	05/94	05/95	05/96	05/97	08/94	08/95	08/96	08/97	12/94	12/95	12/96	12/97	Average	SE*
Sec A	4	3	7	3	12	9	2	9	4	2	4	7	5.5	0.86
Sec B	8	0	6	7	13	10	7	3	9	3	1	1	5.7	1.08
Sec C	5	0	4	1	5	5	3	3	3	0	1	0	2.5	0.54
Sec D	24	9	10	10	8	0	11	8	10	7	7	2	8.8	1.54
Total	41	12	27	21	38	24	23	23	26	12	13	10	22.5	2.64
Average	10.25	3	6.75	5.25	9.5	6	5.75	5.75	6.5	3	3.25	2.5	5.6	0.66
SE*	4.66	2.12	1.25	2.02	1.85	2.27	2.06	1.6	1.76	1.47	1.44	1.55	1.29	

* SE = Standard Error

Table 3.6 Comparison of class 3 crocodiles (2.5 - 3.5m TL) in sector A, B, C and D.

	05/94	05/95	05/96	05/97	08/94	08/95	08/96	08/97	12/94	12/95	12/96	12/97	Average	SE*
Sec A	8	12	13	7	8	13	4	13	4	10	3	4	8.3	1.13
Sec B	12	8	14	10	22	21	13	14	16	11	8	3	12.7	1.55
Sec C	9	3	7	10	21	17	8	14	8	5	13	2	9.8	1.63
Sec D	15	24	54	28	6	14	19	39	23	27	45	17	25.9	4.01
Total	44	47	88	55	57	65	44	80	51	53	69	26	56.6	4.86
Average	11	11.75	22	13.75	14.25	16.25	11	20	12.75	13.25	17.25	6.5	14.1	1.22
SE*	1.58	4.48	10.78	4.8	4.21	1.8	3.24	6.34	4.23	4.77	9.47	3.52	4.03	

* SE = Standard Error

Table 3.7 Comparison of class 4 crocodiles (>3.5m TL) in sector A, B, C and D.

	05/94	05/95	05/96	05/97	08/94	08/95	08/96	08/97	12/94	12/95	12/96	12/97	Average	SE*
Sec A	11	11	14	7	2	16	5	12	2	1	1	6	7.3	1.54
Sec B	6	10	11	12	9	15	19	3	0	13	7	3	9	1.59
Sec C	5	3	16	14	10	13	19	6	1	6	10	5	9	1.61
Sec D	5	28	54	32	8	20	31	8	10	26	24	12	21.5	4.07
Total	27	52	95	65	29	64	74	29	13	46	42	26	46.8	6.93
Average	6.8	13	23.75	16.25	7.3	16	19	7.3	3.3	12	10.5	6.5	11.7	1.73
SE*	1.4	5.3	10.14	5.45	1.8	1.5	5.3	1.9	2.3	5.4	4.87	1.9	3.29	

* SE = Standard Error

3.3   Spot counts

Figure 3.1 indicates the locations of the spot counts. It is unfortunately that the Balule spot count site

had to be abandoned for the Nwamandzi site, after the flood of 1996, but the near exact duplication

of trends at Nwamandzi confirmed a possible movement as the total number of individuals at the

various sites kept on changing. See Figures 3.12; 3.13 and 3.14. Notable are the high peaks during

the colder period of the year (July), at the Balule, Lookout and Nwamandzi sites. What makes this

significant is that numbers (totals) during the foot counts seems to reach a high during August of

every year (Figure 3.2; 3.3; 3.4; 3.5 and 3.6) but the numbers (totals) at the spotcount locations (Fig

3.12; 3.13 and 3.14) indicated a high in July. The resolution of the annual foot counts failed to

indicate the exact time of movement (change in totals), it only confirmed that there was a difference

in totals in the sectors between May and August. The foot counts did not indicate at what time the

changes took place, but the spot counts, at 14 day intervals, revealed that the change actually

happened during June/July and not August. Figure 3.13 clearly indicates that the decline in numbers

took place after July of every year.

Two features are evident when looking at Figures 3.12; 3.13 and 3.14. The declines in the graphs in

Figure 3.12 and 3.14 reflect the overall decline in the crocodile population in the Olifants river. The

second feature is the near similar times of the high and low spikes at the different locations. With the

exception of June 1996 in Figure 3.12 and 3.14, the month of July signified the period of high

numbers (totals) before a noticeable decline, whilst another period of high numbers appeared to be in

November to January of every year (Figures 3.12 to 3.14). The periods of seemingly greatest

activities (changes in totals) appear to be at the peaks of the cold (July) and hot (December)

seasons, suggesting two major movements.
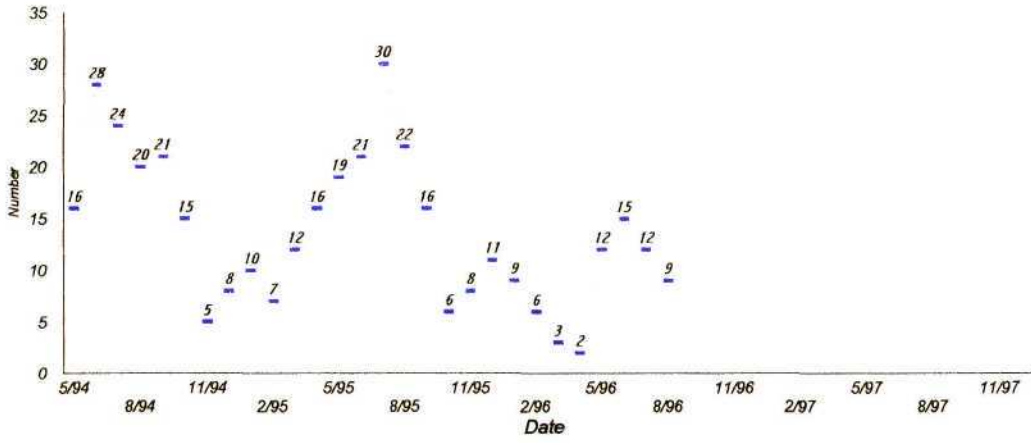
Figure 3.12 Total number of crocodiles at the Balule spotcount location (1994 to 1996).
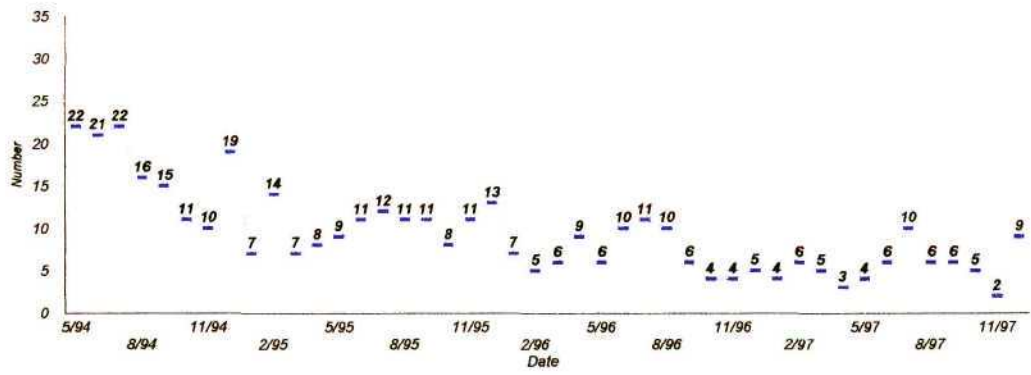
Figure 3.13 Total number of crocodiles at the Lookout spotcount location (1994 to 1997).
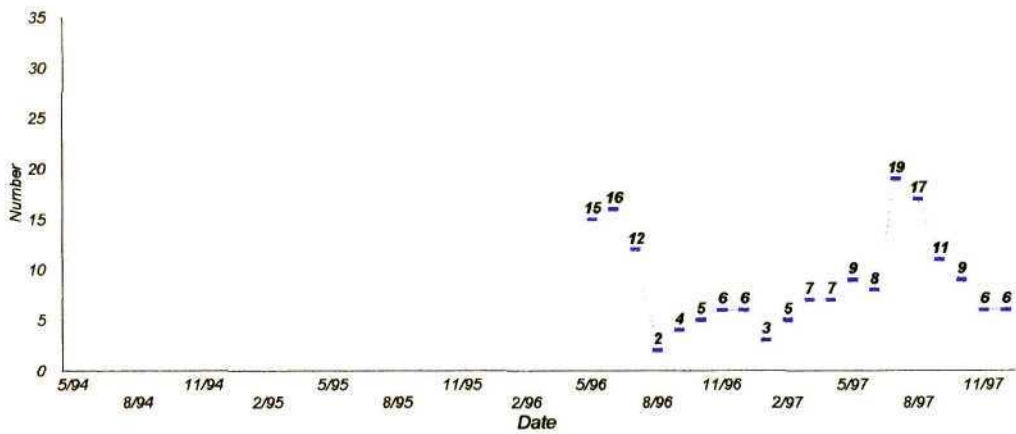
Figure 3.14 Total number of crocodiles at the Nwamandzi spotcount location (1996 to 1997).

Figure 3.15 reflects the average flow volume of the Olifants River as measured by the Department of Water Affairs and Forestry at the Mamba weir (S 24 02.490 / E 31 12.762). This weir is situated on the western border of the KNP where the Olifants River enters the park. Note the period of high flow during January which coincide with a period of activity (change in totals) on the graphs in Fig 3.12 - 3.14.
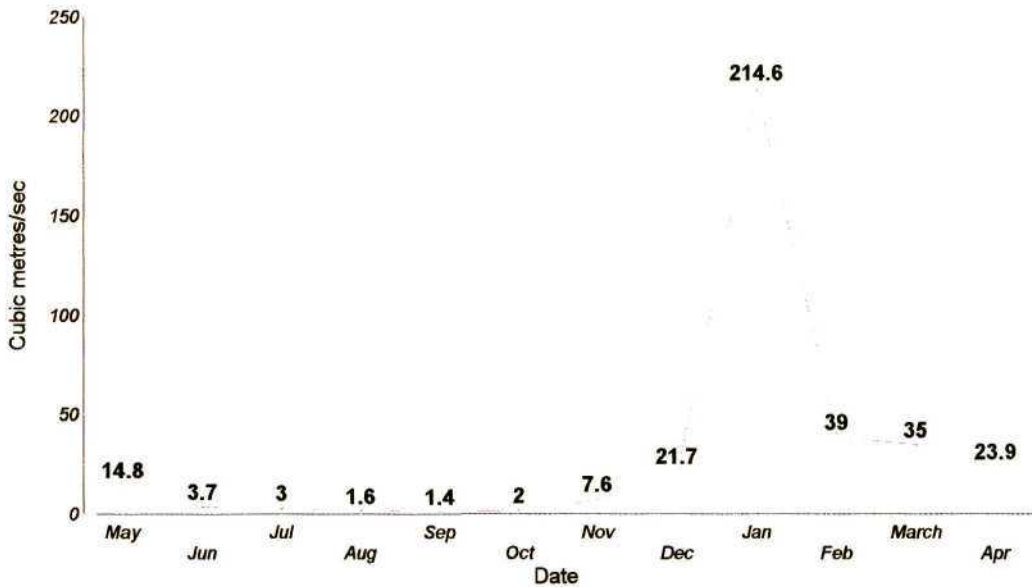
Figure 3.15 Average monthly flow volume of the Olifants River from 1989 to 1996 as measured at the Mamba weir. The weir was destroyed by the February 1996 flood. The green line indicates the mean annual flow (29±15.9). (DWA 1997)

3.3.4   RADIO TELEMETRY

The transmitters were fitted between May 1998 and June 1998. The smallest crocodile fitted with a transmitter was a female of 3.1 m TL and the largest was a male of 4.3 m TL. Table 3.8 summarize the details of the individuals that were fitted with transmitters. Tracking was carried out every 14 days and only visual sightings of individuals were noted as recaptures. By January 1999 only four crocodiles remained in the study area and five had moved into Mozambique. All four transmitters in the study area were lost within a three week period. None of the transmitters that were retrieved showed any damage or visible signs of being bitten by other crocodiles. The only possible explanation for their removal is that the cable eventually wore through the scutes because of the weight and size of the transmitter. Mating activities did not influence the transmitters as they were lost long after the mating season. The last three digits of the frequency (148.025 = 025) were used as reference for the individual crocodiles.

Table 3.8   Size and location of crocodiles fitted with transmitters. The * indicates transmitters that were lost very early in the program and no data were collected.

FREQUENCY	SEX	TOTAL LENGTH (m)	LOCATION
148.005	M	3.3	Trails camp
148.015	M	3.9	Timbavati
148.025*	F	3.2 (Lost in August 1998)	Timbavati
148.035	M	3.9	Nwamandzi
148.045	M	3.8 (Lost in August 1998)	Lookout
148.045	M	4.2 (Refitted in Sept 1998)	Lookout
148.055	M	4.3	Lookout
148.075	M	4.1	Trails camp
148.085	F	3.1	Nwamandzi
148.095	M	3.7	Lookout
148.105	F	3.1	Lookout
148.115*	M	4.1	Trails camp

Within three months two transmitters (025 and 115) were lost and although they were located, they could not be recovered as the water was too deep and densely populated with crocodiles. During August 1998 another transmitter, 045, was partly torn off and had to be removed. It was later fitted
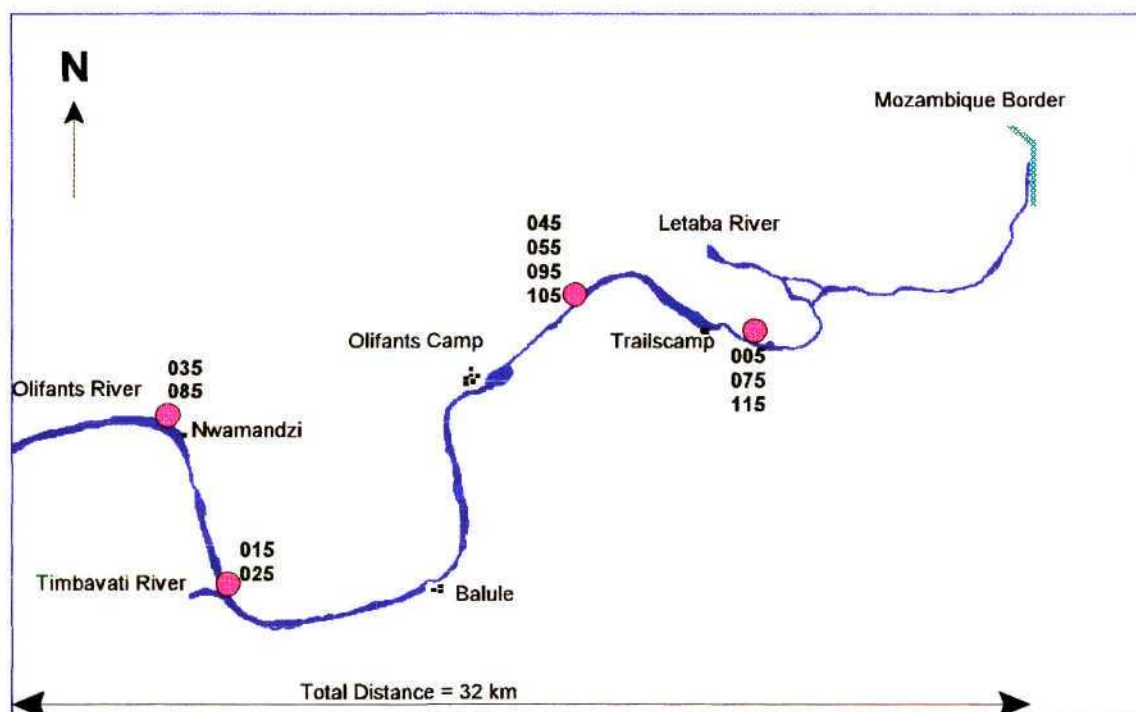
Figure 3.16   Locations of initial capture and fitting of transmitters to all the crocodiles.

to another male of 4.2 m TL at the Lookout site.

Figure 3.16 indicates the initial capture locations of all the individuals that were fitted with radio transmitters. Table 3.9 reflects the capture dates and the last known location of the transmitters. The radio telemetry study ended in May 1999.

Table 3.9 Capture dates, number of recaptures and last known location of transmitters on 22/01/99. A recapture was noted when the crocodile was physically seen and not on an audible signal alone.

Frequency	Date of capture	No. of recaptures	Date of last recapture	Last known location
148.005	03.6.98	11	12.6.99	Mozambique
148.015	13.05.98	18	22.01.99	Transmitter lost
148.035	22.06.98	17	19.01.99	Transmitter lost
148.045	21.05.98	12	19.03.99	Mozambique
148.055	19.05.98	10	04.01.99	Mozambique
148.075	30.06.98	10	12.06.99	Mozambique
148.085	15.06.98	17	22.01.99	Transmitter lost
148.095	20.05.98	10	30.06.99	Olifants Camp
148.105	22.05.98	12	30.06.99	Olifants Camp

Seven males varying from 3.3 m to 4.3 m TL were regularly recaptured. This term is used to describe the resighting of any marked crocodile (Hutton, 1989). The mean distance of movement for the males were 13.6 km. They moved over distances ranging from < 2 km for a 3.9 m male to over 32 km covered by a 3.7 m male. Incidentally, it was not the largest male that covered the longest distance, he only moved about 16 km down stream. The two females were both 3.1 m TL and one moved about 4.4 km whilst the other covered a distance of about 18 km, with 11.2 km as the mean. The latter (105) was the same female that returned to the point of departure after she had traveled about 9 km down stream. From May 1998 to January 1999 a total of 47 excursions were made to radio track individual crocodiles. On 28 excursions more than one crocodile was recaptured and on 19 occasions only one individual was sighted. Excursions took place at various times of the day and normally lasted three to four hours. Twenty one recaptures ended in a signal alone with no visual confirmation and was not noted as a recapture. Figures 3.17 to 3.25 show the movements of different individuals.
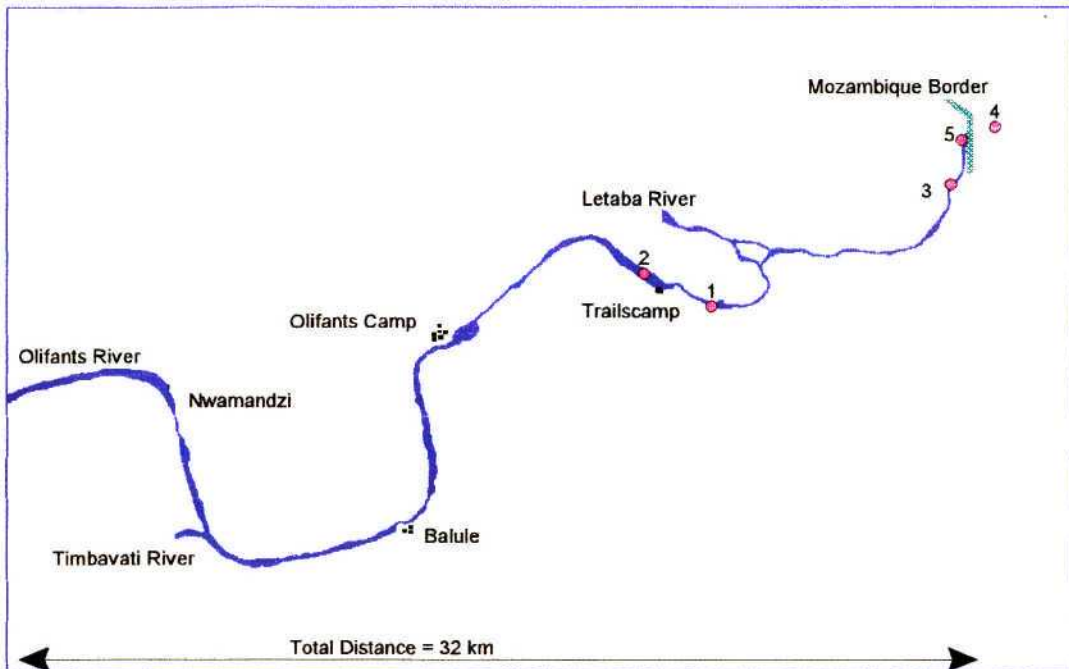
Figure 3.17   Movement of transmitter 005, a male of 3.3 m. It remained at location 1 from 3/6/98 till 2/9/98 and then moved 2.6 km upstream to location 2. On 10/11/98 it was seen at location 3,11 km downstream, and by 4/1/99 it had moved into Mozambique. On 12 June 1999 it had moved back into KNP at location 5. Total movement was at least 15.4 km.
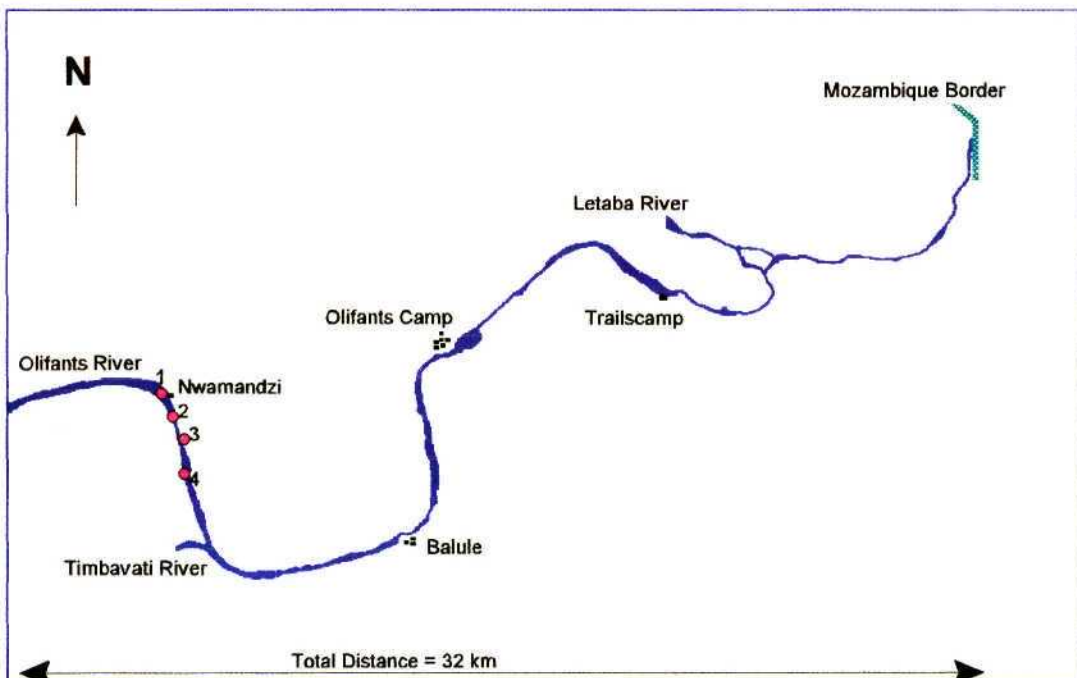
Figure 3.19   Movements for 035, a male of 3.9 m. Location 1 indicates the point of capture, 22/6/98, where the crocodile stayed until 15/10/98, and then it moved to location 2 some 0.7 km downstream. On 20/12/98 it was seen at location 3 (1.2 km downstream) and the last recapture was at location 4 on 19/1/99, 0.5 km upstream. Total movement was at least 3.1 km.
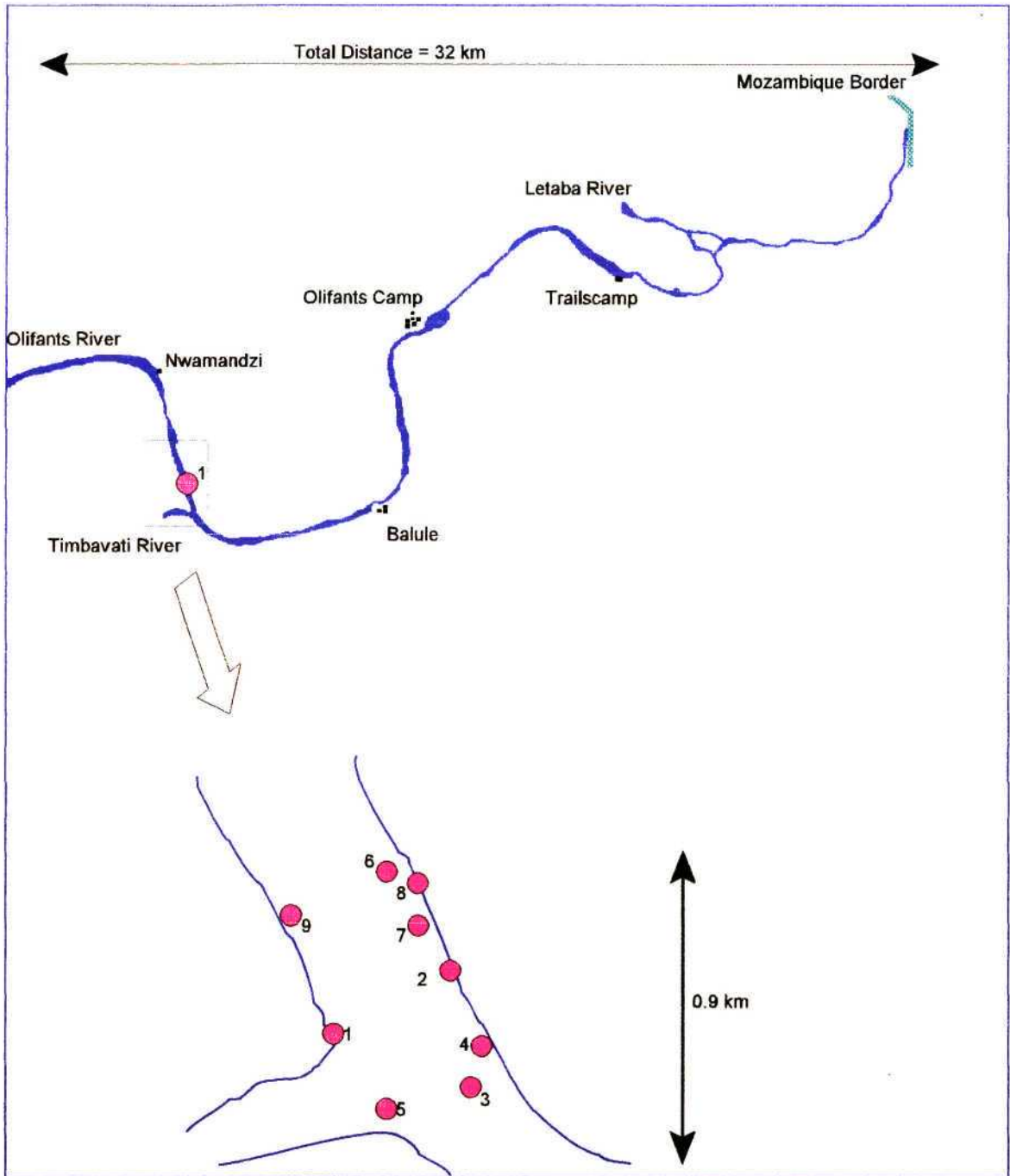
Figure 3.18   Movement for transmitter 015, a male of 3.9 m. A total of 17 recaptures were done from 13/5/98 to 22/1/99 where after the transmitter was lost. Total movement was < 2 km.
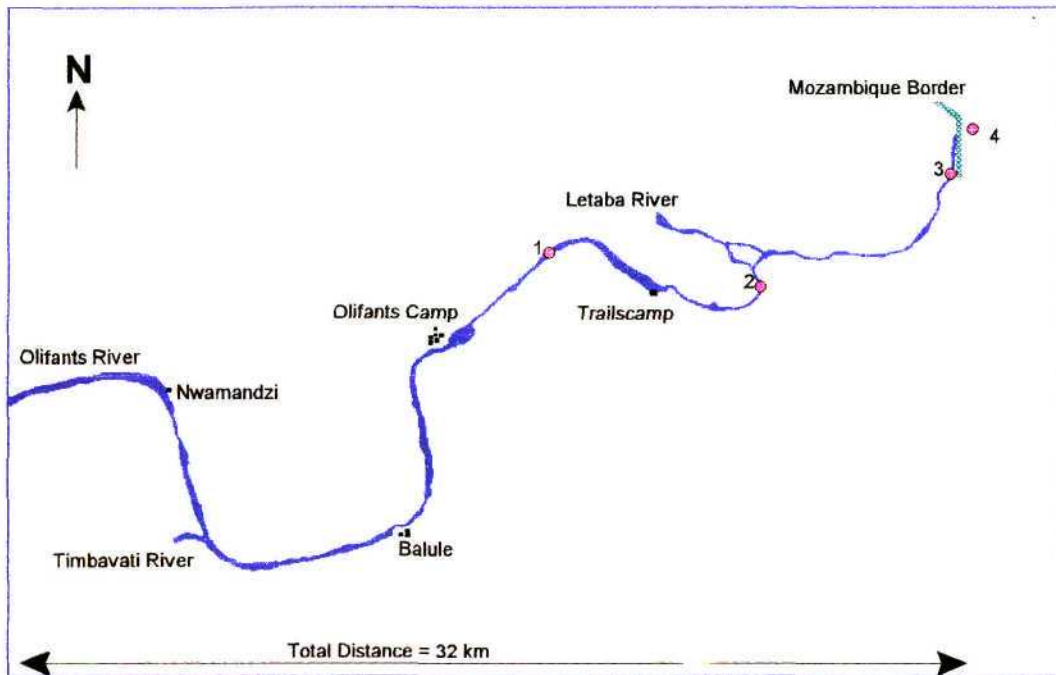
Figure 3.20 Movement for transmitter 045,a male of 3.8 m. It stayed at location 1 from 21/5/98 until 23/12/98 and moved 5.9 km downstream. On 04/01/99 it was seen at location 3. The last signal was last picked up on 19/3/99 somewhere in Mozambique. Total movement was at least 16 km.
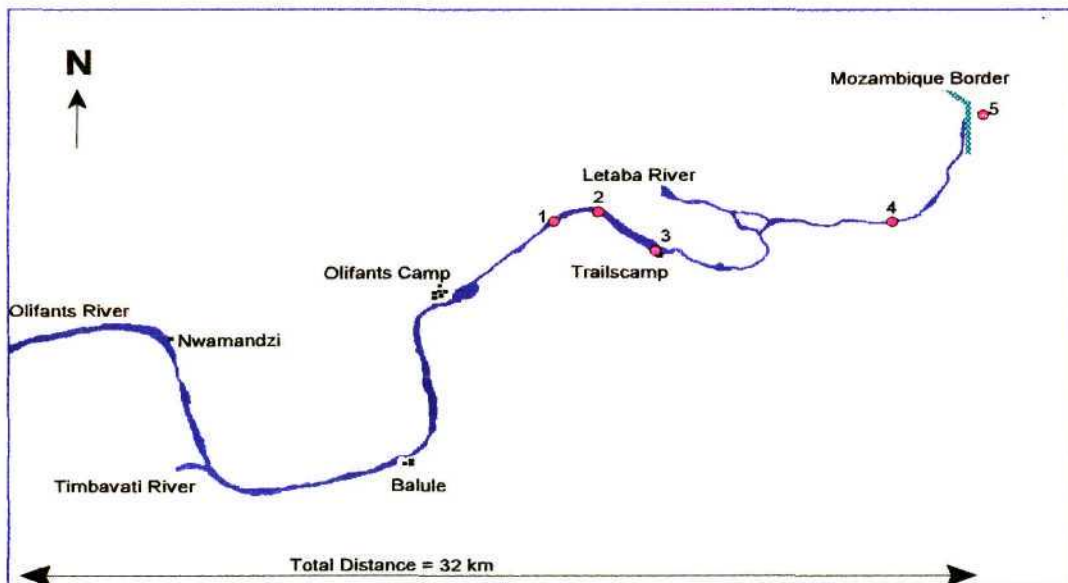
Figure 3.21 Movement of 055, the largest male (4.3 m TL), from its capture on 19/5/98 at location 1 to location 2 on 20/6/98 some 1 km downstream. It moved 2.2 km downstream on 3/9/98 (location 3), and was seen 8.1 km further downstream on 15/10/98 at location 4 where it stayed till 04/01/99 when it's signal was picked up in Mozambique. Total movement was at least 16 km.
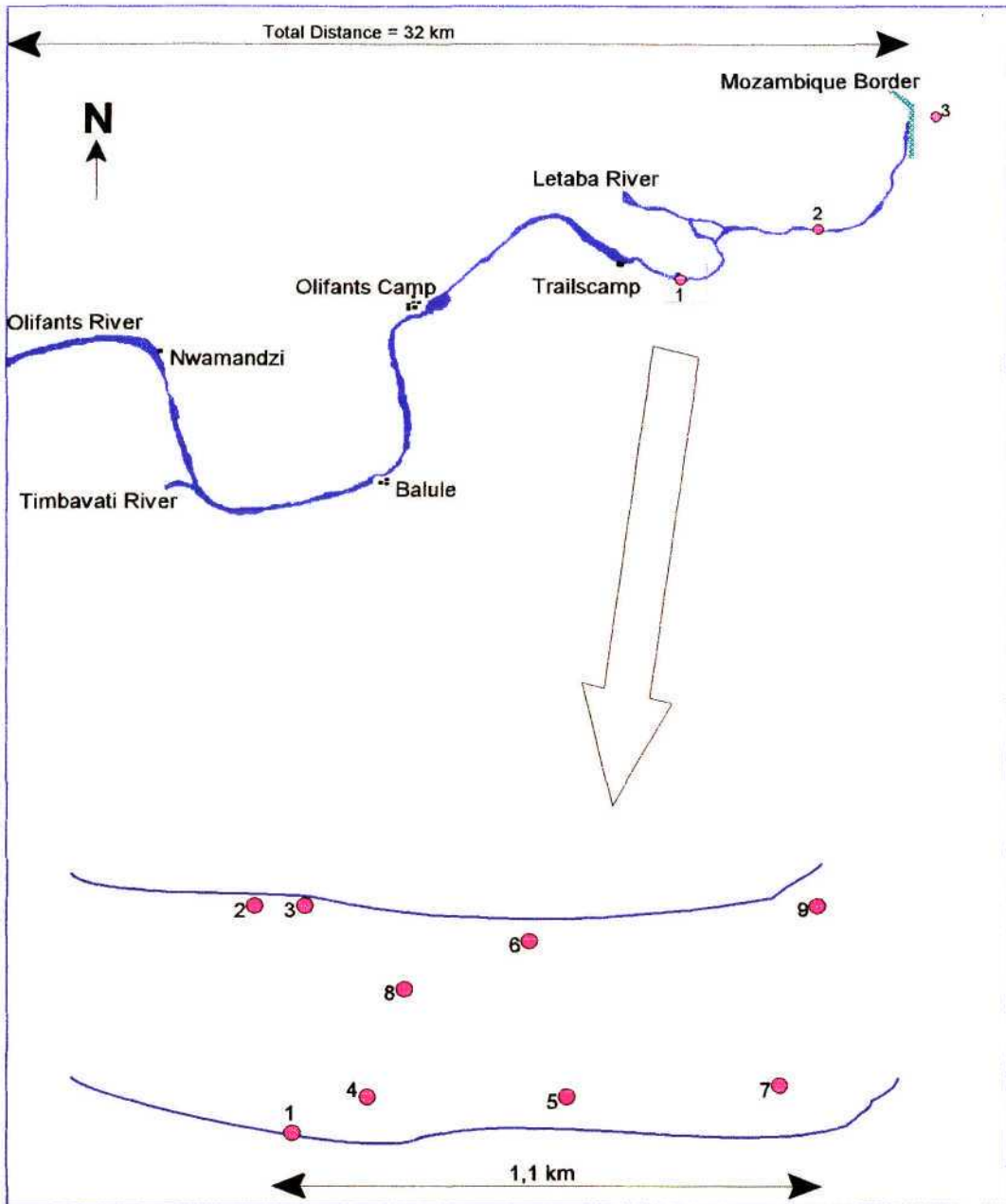
Figure 3.22 Movement of 075, a male of 4.1 m. It was captured on 30/6/98 and stayed relatively static until 20/12/98 when it moved 4.8 km downstream to location 2. On 12/6/99 the signal was received from Mozambique. Total movement was at least 9.3 km.
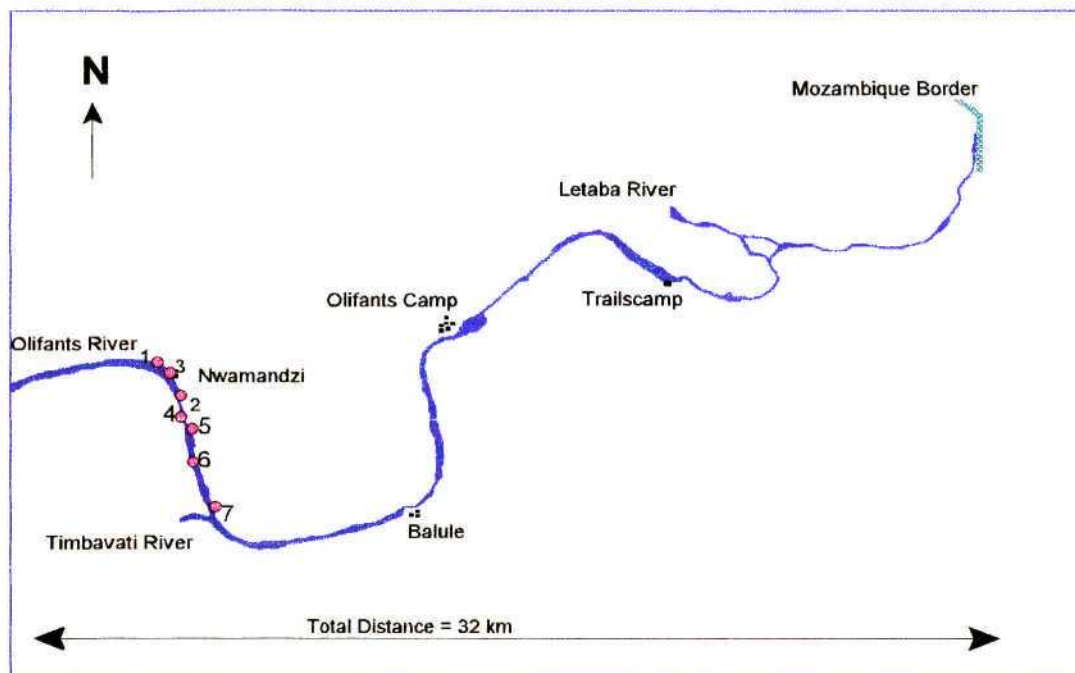
Figure 3.23 Movement of 085. This female of 3.1 m moved progressively downstream since its capture on 15/6/89 until 22/1/99 when the transmitter was lost at location 7. Total movement was at least 4.4 km.
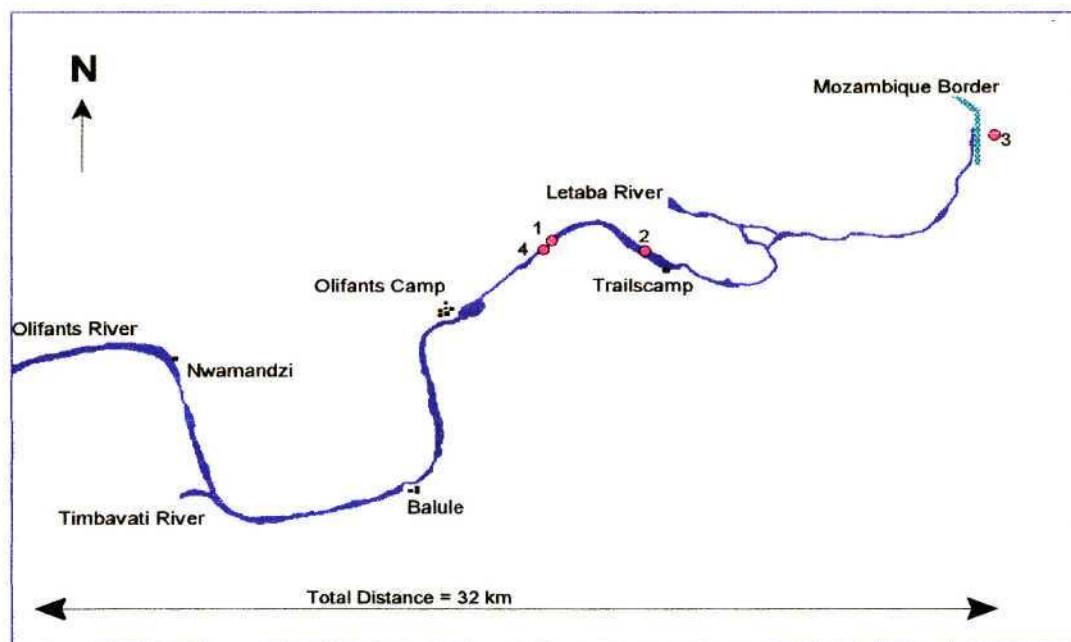
Figure 3.24 Movements of 095, a male of 3.7 m. It was captured on 21/5/98 at location 1 and moved to location 2 on 20/12/98, a distance of 2.4 km and the last signal was picked up on 4/1/99 from Mozambique. On 20/4/99 it returned from Mozambique and was seen at location 4 where it remained till 30 June 1999. This crocodile returned to the same location from where it left. Total distance moved was at least 16 km one way.
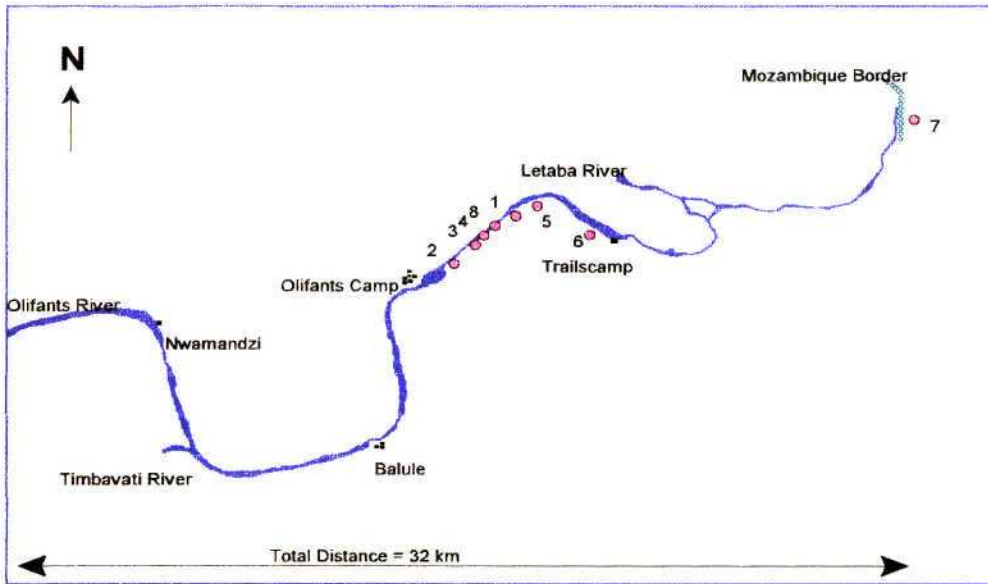
Figure 3.25 Movement of 105, the second female of 3.1 m. It was captured on 20/5/98, moved 2 km upstream on 12/6/98 and then started to move downstream again. On 20/12/98 it was seen at location 6 and the signal was picked up on 4/1/99 from Mozambique. On 23/4/99 it moved back to location 4 near Olifants camp where it remained until 30 June 1999. Total movement was at least 18 km.

A number of individual crocodiles were identified according to natural tail markings (Swanepoel, 1996), and records were kept of all individuals. These data constitute 140 different tail markings of which 38 were seen on more than one occasion. One individual of 4.2 m TL was seen on 11 occasions over the 3 year period. With monotonous regularity it appeared during November of every year at the Nwamandzi spot count site, stayed till March the following year and then "disappeared" only to be seen the following November. The sighting of this specific crocodile was always at the same location where it stayed until its disappearance. Seven crocodiles of various TL were seen on more than four occasions each and at different locations ranging from one to more than six kilometers apart. These observations were made throughout the study area, indicating a free and unlimited movement throughout the year.

One of the objectives of the study was to determine movement of *Crocodylus niloticus* in the Olifants River. The basis on which the results were interpreted was that differences in counts (totals or density per sector), when declines were followed by increases or *vice versa*, constitutes movement.

Similarly, if the number of crocodiles in the various sectors (A, B, C, D and G) were equal throughout the year (May, August and December) from 1994 to 1997, then it can be assumed that there was no movement of crocodiles in the study area. Figure 3.26 reflects the distribution of crocodile totals averaged over all years and sectors, per month for the study period and suggests that there were some differences, particularly in December. This would support the hypothesis that movement of crocodiles did occur in the study.

If totals per sector remained constant for all the years, it would have indicated that there was no movement of crocodiles in the study area. Figure 3.27 indicates that this was not the case. Averaged over all the years (1994 to 1997) and months (May, August and December), the figure shows that the totals in sector D and G differed from sectors A, B and C. This also corroborates the idea that there was a movement of crocodiles in the study area. However, when total crocodiles per year were averaged over all the sectors and months (Figure 3.28) there were no significant changes. Although there were minimal differences in total number of individuals per sector there were changes in density per sector for different times of the year and in different sectors. This suggests movement to and from sectors.
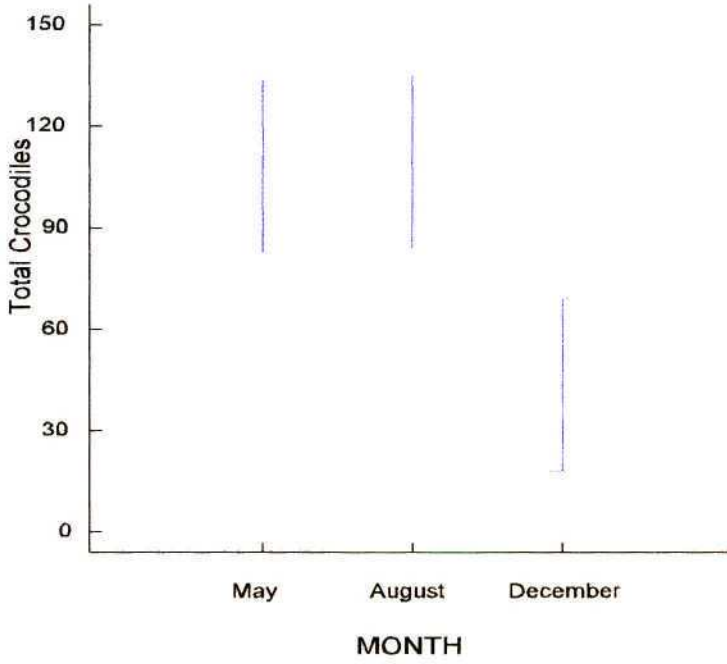
Figure 3.26 The mean and least square differences (95%) of total crocodiles per month averaged over all years and sectors.
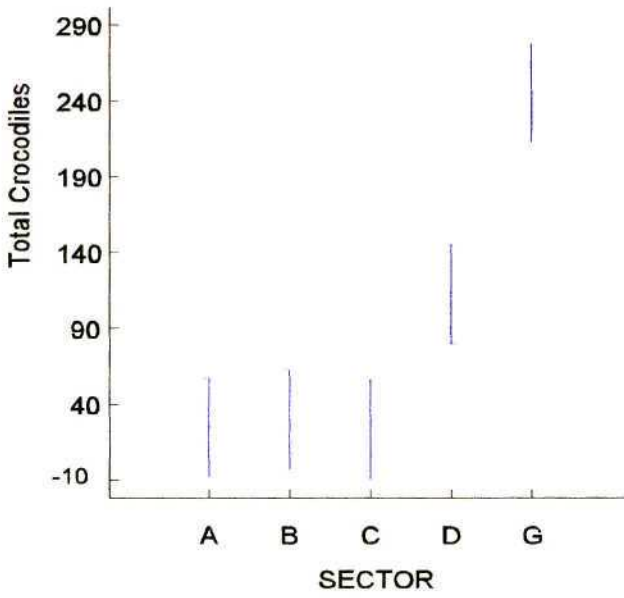
Figure 3.27 The mean and least square differences (95%) of total crocodiles per sector averaged over all years and months.
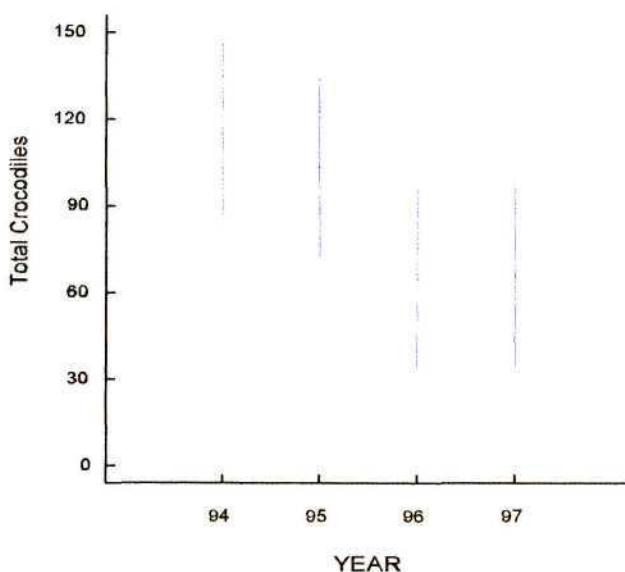
Figure 3.28 The mean and least square differences (95%)
of total crocodiles per year averaged over all sectors and
months.

3.4 Discussion

3.4.1 Numbers/totals and sizes.

Contrary to the general hypothesis, more than one period of movement was found (Table 3.3); one

large movement during December and two smaller ones in May and August. There appeared to be a

general low density during December and an increase towards May to reach a peak in August of

every year. Behavioural patterns must also be taken into consideration as crocodiles spend more

time in the water, making them less visible, during the warm season (December), and more time

basking in the sun during winter (May) which increases visibility. It can be speculated that the return

of crocodiles started in May (pre-courtship) and continued through August only to be "reversed" in

December (post mating/nesting), or possibly the opposite way around. Because two major

movements were found during different times of the year (Jun/Jul and Nov/Dec), it is possible that a

combination of factor are responsible for their movements. The reasons for the movement were beyond the scope of the study, but the following factors can be considered as possible causes:

Mating:

More individuals per group suggests a less rigid dominance structure. There were more individuals closer to one another with large groups. The definition for a group was that two individuals must be within their own body length (TL) from one another. During the study period a fluctuation in numbers per group (Table 3.3) was seen and this fluctuation suggested mating behaviour (Cott, 1961; Graham, 1968; Pooley 1969). During mating males will swim in tandem or parallel with the female and the speculation is that the male will mate with as many females as possible. Mating was observed on seven occasions in sectors A, B and D, once in sector A and D during 1995, twice in sector B in 1996 and three times in sector D in 1998. Since 1996, observations became fewer and mating was not observed since then even though foot counts continued until the end of 1997. Hutton (1989) found that the smallest breeding female at Ngezi, Zimbabwe, was 2.6 m TL and this is represented by the class 3 crocodiles. Both classes 3 and 4 reached their numerical peak in August, which corresponds with the onset of the mating season in the Olifants River, and thus could have contributed to the movement of large adult crocodiles in the Olifants River.

Water Level:

The Olifants River is subject to large fluctuations in water level (Figure 3.15). A low water level exposes rapids and this influence the movement of certain fish species which act as a food source for crocodiles. In Lake Kariba it was found that fish comprised 52 % of the diet of sub-adult crocodiles (1.2 - 2.5 m Tl) during the hot season and 41 % in the cool season (Games, 1990). In adult crocodiles (>2.5 m TL) 34% and 18% of the stomach content was fish during the hot and cool seasons respectively (Games, 1990). Crocodiles in the Olifants River rely to a large extent on barbel as a food source (Pienaar et. al., 1978). Certain fish (*Barbus spp*) move slower than normal through rapids and this makes them easy prey during July to September when the water level is normally at its lowest. Crocodiles were found in higher densities during the dry season in sectors with rapids,

where they concentrated down stream of the rapids with open jaws. This method of hunting is well documented (Guggisberg, 1972; Pienaar *et. al.*, 1978 a; Games 1988). The lower water level resulted in more rapids which in turn caused crocodiles to aggregate in certain sectors presumably because food became more easily available.

With high water levels most of the rapids were covered and this facilitated crocodile movement in the river. Obstacles could more easily be crossed during flood periods and moving down stream is a lot less energy consuming. Radiotelemetry results confirmed that the largest and longest movements occurred during flood periods i.e. November/December 1998, see Figures 3.20; 3.23; 3.24; 3.25; 3.27 and 3.28 for movements and Figure 3.15 for the average flow volumes in the study area. During December in all years, there was a decline in the total number of crocodiles in the study area, indicating that they left the study area, presumably to Mozambique or up stream out of the study area. Radio telemetry indicated that six of the remaining nine individuals (66.6%), fitted with radio transmitters, were located in Mozambique during December 1998. This movement took place after nesting commenced, and as it was well outside mating season, it would appear that these movements were related to the water level. High water levels covered obstacles and thus facilitate movement, especially down stream. Moving with a strong current is also an energy saving way of locomotion.

With the physical characteristics (predominantly basaltic rock) of sectors B, C and D, a higher water level would seemingly facilitate movement. Although higher water levels resulted in a 56% lower count in a study in Papua New Guinea (Montague, 1983), possible bias was eliminated by the number of counts (repetitions) and the four year period over which it was done. The similarity in the nature of the repetitions (Figures 3.1; 3.3; 3.5; 3.7 and 3.9) indicates a movement, rather than dispersal, as the same tendency can be seen from year to year. Migration is characterized by the return of individuals to the departure location whereas dispersal is a one-way movement.

The fluctuating water level could possibly have influenced the density and mean group sizes in certain sectors because high water levels normally limited available basking space as most islands

vanished during high flow periods. This may have forced crocodiles to aggregate in the remaining available basking areas, and in doing so could have distorted the data for mean group sizes. Low water levels as the other extreme, influence the visibility of individuals as islands obscured some areas and the total water surface was not visible from the determined route.

Again, personal experience and observations over a long period indicated that crocodiles prefer basking on islands to riverbanks. This was more obvious in areas where tourist vehicles were present along the river. The nearly constant gathering of crocodiles in the Gorge sector during May still needs further investigation. No data are available on the status of fish populations during this time of the year and there are no obvious reasons for this aggregation.

Food Supply:

The sporadic higher density of individual crocodiles in sector D (32 /km river) and G (111.6/km river), (Table 3.2), indicates a cyclic change in conditions for the crocodiles, as the increase in densities were recorded from May to September of each year, with December as the low density period (Figures 3.5 and 3.6). October is the onset of the nesting period in the Olifants River, and this aggregation is well before then. Nesting can thus be ruled out as a contributing factor for the larger numbers in the two sectors. August/September is the time of the lowest water level in the river (Figure 3.15), resulting in numerous pools being formed, especially in sectors D and G. Only a shallow stream connects the pools, and when fish negotiate this shallow streams, they become vulnerable to birds of prey. Barbel (*Clarias spp*) temporarily populate the deeper pools during this period (Pienaar, 1978) and this concentration of prey species might be the reason for the increase in densities in sectors D and G. Pienaar, *et. al.*, (1978) stated that the Nile crocodile is the main predator for barbel, and this might explain the large numbers of crocodiles in the above mentioned areas. Despite the seemingly suitable habitat for hatchlings and juveniles, except for sector B and Gorge, there was a noticeable absence of class 1 animals in all sectors. Cannibalism is a density-dependant regulating mechanism in crocodile populations (Hutton, 1989), and high adult densities impact negatively on hatchling and juvenile survival (Cott, 1961; Hutton, 1989 and Leslie, 1997). This same theory may hold true for sector B and G.

Breeding:

Hutton (1989) suggested that the breeding status of females plays a role in dispersal. Females make several nocturnal exploratory trips prior to nesting (Pooley, 1969; Hartley, 1990). During these trips she will dig a number of "test" holes, eventually selecting one to lay her eggs. The duration of this exploration phase may last from a few nights to several weeks (Pooley, 1969). However, dispersal is defined as a permanent movement from one area to another and predominantly on a seasonal basis (Hutton, 1989), and nothing in Figures 3.2 to 3.6 suggested such a dispersal, but rather a cyclic and repetitive routine. Mating and nesting behaviour should influence the class 3 (2.5 - 3.5 m TL) and 4 (>3.5 mTL) crocodiles as they are sexually mature (Hutton, 1984). There are indications that a concentration at certain locations (Table 3.6 and 3.7) is either a prelude to, or a result of mating/breeding or nesting. Mating starts towards the end of July and lasts well into September, whereas the nesting season starts mid October and hatching occurs from December to the end of January.

Some sectors are more suitable for nesting than others (Pooley, 1969), and this suggests that movement may be a consequence of searching for suitable nesting sites. Similarly, Pooley (1969) reported a concentration of crocodiles in the Mkuze River, KwaZulu-Natal, during winter months and a movement towards breeding areas during summer. Noticeably was the lower number of juveniles in sector B despite a more suitable habitat i.e. shelter, shallow water and vegetation, than the previous sectors. Only limited nesting (See Chapter 4) took place in this sector and it could suggest a seasonal movement governed by the breeding status of the females.

Hutton (1989) further speculated that the presence of tourist roads along the Ngezi River influenced the number of nests, there were fewer nests closer to the tourist roads, and similarly this might hold true for sectors C and D. This sector has no tourist roads, and hosted predominantly class 3 and 4 individuals. Flight distance also increased with size (Montague, 1983), and as most of the breeding females are in the class 3 and 4 category, it should result in sector A and B having less females than sectors C and D. This is supported by the different averages in Tables 3.6 and 3.7. Similarly, the results of a t-test showed that there were significant differences ($p < 0.05$) between class 3 crocodiles

in sector A and B when compared with sector C. The same significant results (p < 0.05) were obtained when class 4 individuals were compared.

3.4.2   Spot counts

The size of individuals may influence movement because of the change in dietary composition associated with an increase in size, especially in class 1 and 2. According to Pooley (1989) the diet of juveniles differ from sub-adults and therefore they may not necessarily share the same habitat because their respective prey species have different habitat preferences. Juveniles, < 1.5 m (class 1), prey predominantly on insects whilst fish form the main diet of sub-adults (class 2) (Pooley, 1989). Games (1990) reached a similar conclusion; insects and invertebrate made for > 50% of the diet of juveniles whereas nearly 98% of the stomach contents of sub-adults were fish. The predominate fish species most likely preyed upon in the Olifants River is Barbel (*Cliaris spp*) which in turn obtains it source of food from the bottom of the river. Therefore, the predominate prey species of the juvenile (insects) and sub-adult (barbel) in the Olifants River are likely to frequent different habitats and hence the possible movement of crocodiles due to size (class) (Hutton, 1984).

Unlike Hutton (1989), Webb *et al.* (1982) cited population density as an independent contributing factor for increased cannibalism. Cannibalism alone cannot be singled out as a factor for the change in averages in Table 3.4 - 3.7 but must be interpreted together with growth and the abundance of prey species in a specific sector for the different size classes.(Games, 1990).   It is well documented (Hutton, 1989; Pooley, 1989 ; Games, 1990) that adult crocodiles prey on juveniles and sub-adults, and a higher density of this two classes could have resulted in class 3 and 4 individuals converging at certain locations to prey on class 1 and 2 individuals. Similarly class 1 and 2 could have moved as a result of predation pressure from larger crocodiles. Cannibalism can work both ways to affect movements of all the size classes. Hutton (1984) reports that captive juvenile Nile crocodiles >0.8 m commonly kill and eat hatchlings when kept together. The same tendency was observed in the McKinlay river in Australia where only 3 -4 % of the number of eggs laid annually were presented as 2-year- olds (Webb *et al.*, 1982), indicating a high mortality before that age.

All three spot count locations contained deep pools with slow flowing water and rapids at either end of the pools, and this constituted the preferred breeding habitat for crocodiles (Cott, 1961; Pooley, 1969 and Modha, 1978). The cyclic appearance of the graphs (Figure 3.12 to 3.14) suggests a regular pattern of numbers and therefore it is possible that the locations of the spot counts could have been either breeding/mating and/or courtship areas. If this holds true, mating and breeding are preceded by a movement to suitable areas for these activities. Neither Cott (1961) nor Graham (1968) mentioned any possible movements prior to mating or nesting. Their studies were done in lakes and it is possible that unlike in a river environment, movement does not take place before mating and breeding.

The Lookout site is the furthest down stream (Figure 3.1) and the main period of change is in the warmer periods (Figure 3.13), while at Nwamandzi, about 18 km upstream from the Lookout site, the majority of the activity was in the winter time (Figure 3.14). Balule is situated between the two above mentioned locations, and there seems to be two periods of activity, June (cold) and November (warm). The impression created by these numbers suggests that activity starts upstream at Nwamandzi in winter. As the crocodiles moved downstream, mixed periods of activities were registered at Balule which is the half way mark and the furthest downstream location. The activities (changes in numbers) took place in summer. This conclusion is supported by the results in paragraph 3.3.3. and Figures 3.12 to 3.14. The physical characteristics of the river (cf Chapter 2) renders the upstream area, Nwamandzi, unsuitable for crocodiles during winter as the water level drops too low, but deeper pools can be found lower downstream. Although this movement seems to be a search for suitable habitat, there may be a number of other factors involved as well i.e. competition, territoriality and food availability.

The data on numbers and groups support the findings from the spot counts that individual Nile crocodiles move at specific times of the year, independent of location. Hutton (1989) singled out size, population density and the breeding status of females as factors contributing to movement. He also concluded that season, cold or hot, is a factor influencing the extent of movement of juveniles (<1.2 m TL). Juveniles tended to make larger movements during the hot season (Hutton, 1989).

This movement of juveniles is not unique to the Nile crocodile and similar occurrences have been reported for *Crocodylus porosus* and *Alligator mississippiensis* (Bayliss, *et al.* 1986; Hutton and Woolhouse, 1989).

The data from both foot counts and spot counts, suggest a variety of movements throughout the year with peaks of higher activity during cool and hot seasons. Pooley (1969) found a similar seasonal movement amongst *C. niloticus* in a pan in the Ndumo Reserve in Kwazulu/Natal. Although the pan retained water throughout the year, the numbers of crocodiles fluctuated between the wet (hot) and dry (cool) season.

3.4.3   Radiotelemetry

All individuals fitted with transmitters were large adult animals. There is no certainty as to the behavioural status of the male crocodiles besides the fact that all were adults and thus potentially reproductive. At least two individuals, 045 and 095, displayed territorial behaviour i.e. raised head and tail (Cott, 1961; Modha, 1967), challenging possible rivals and physical attacks on intruders of similar or smaller size.   Transmitters 015; 035 and 085 (Figures 3.21; 3.22 and 3.26) showed limited and area-bound movements associated with home ranges and possible territories (Hutton, 1982). Crocodile 015, a male of 3.9m TL, occupied an area of approximately 0.9 km river bank which included a sandbank that was extensively utilized for basking by other crocodiles of various sizes. In contrast to 015, crocodile 085 (a female of 3.1 m TL) appeared to roam over a distance of 4.4 km river bank with no special preference for a specific location, and so did 075 (a male of 4.1 m TL) over a distance of 1.1 km river bank. The physical topography of the river did not allow for uninterrupted observations to determine territory (Hutton, 1989). This limited movement could be a search for food or a temporary shift in location as a result of areas becoming unsuitable because of low water levels. The longer movements displayed by 005; 045; 055; 075, and 095 (Figures 3.20; 3.23; 3.24; 3.25 and 3.27) indicate a longer term movement or excursion that can possibly be associated with the availability of food, density of crocodiles or high water levels, that enable movement over long distances.

Forty six percent of the recorded movements exceeding 5 km, and 72% of all movements irrespective of distance moved, occurred during periods of high water level/flow. Personal observations confirmed that *C. niloticus* move out of the main stream to shallow and slow flowing water during high water flow or floods. The possibility of adult individuals being washed downstream by the stronger current is unlikely, but juveniles and hatchlings could have been swept away which then could be attributed to dispersal. The higher water level facilitates movement over rapids and obstacles and is possibly utilized by the crocodiles to cover large distances with little expenditure of energy. There is still no satisfactory explanation as to why individual crocodiles occasionally abandon areas and move, but when coupled with time, some movements can be explained.

Movement over large distances have been reported by Leslie (1997) and Hutton (1989). The latter suggested that the physical size and reproductive status of the individual influenced the extent of movements. Hutton (1982) reported that long range movements are rare among individuals of 1.2 to 2.2 m TL but the distances increased among individuals of > 2.2 m TL. These crocodiles (>2.2 m TL), had a larger range of movement and sub-adult females (2.7 m TL) traveled widely without distinct home ranges. Arguably, the reasons for the movement of similar sized crocodiles in the Olifants River might be totally different as to what Hutton (1989) reported because of habitat differences.

Some of the findings of Hutton (1982) were supported by the results of this study, but a number of distinctive differences were observed. Unlike what Hutton (1989) found, adult crocodiles in the Olifants River appeared to follow a cyclic movement along the river (Figure 3.12 to 3.14). Six transmitters ended up in Mozambique and possibly as far as the Massangire dam before returning upstream to KNP. The dam offers suitable breeding habitat for a large variety of fish species and this source of food is probably the reason for the crocodile movement to and from the dam.

Territory and home ranges could not be determined for two main reasons. Firstly, no continuous observations could be made as visual sightings of individuals were not possible at all times, and in some cases individuals were not seen for more than three consecutive trackings. This resulted in

unreliable data from which home range and territory could be determined. Secondly, the topography of the river changed continuously and this influenced the dimensions (size and location) of the home range directly. A home range must provide certain essential elements, water, food and shelter for a consistent period of time. However, with sudden fluctuations of the water level in the Olifants River this might not be possible. In a dam or lake the fluctuation normally appears gradually, but in the Olifants River the water level can change within a few minutes (rise with floods) or over a number of weeks (decline from evaporation and artificial flow control). For these reasons, it was decided that the exact extent of territory and home range were not needed as it would have been applicable only for a very specific period of time and associated conditions (temperature, season, rainfall). The results in Figures 3.20 to 3.28 indicate that movements generally took place over large distances (> 3 km), rendering home range and territory irrelevant for the purpose of this study.

3.5   CONCLUSION

Data collected during this study, indicates that movement of individual crocodiles in the Olifants River does exist. These movements might be governed by various factors (water level, food, mating, nesting) at different times (seasons) of the year. Hutton (1984)who limited his study to juveniles and females, concluded that they do move, and their movement was governed by the breeding status of the female and changes in feeding habits of juveniles (Hutton, 1982). In this study predominantly male crocodiles were monitored and the results indicated that even, seemingly territorial males, moved downstream during the rain season.

There was a positive relationship between groups and number of crocodiles in sectors A, B and C, with an increase in the number of individuals highly correlated with an increase in the number of groups. This indicated a strong dominance effect with individual animals avoiding each other. The opposite was found in sectors D and G, and this suggests that during certain times of the year, there is a lack of territorial behaviour, allowing individuals to form larger groups. The possible lack of territorial behaviour will allow seemingly dominant males to move downstream and back again. If dominant males kept their territory throughout the year, no movement of any kind would have been possible. In dams and lakes, crocodiles can avoid territories by swimming around them, but in an

open system like the Olifants River, individuals are more likely to cross territories when moving up- or downstream. This could result in a series of encounters with territorial males, and will greatly increase the possibility of injury to the moving crocodile. A decrease in territorial behaviour at certain times of the year, would allow individuals to move more freely.

The results of this study in the Olifants River, support movement, but the question as to how individuals are allowed to cross established territories without confrontation with dominant crocodiles, needs further investigation.

CHAPTER 4:

NESTING

4.1   INTRODUCTION

The nesting ecology of *Crocodylus niloticus* has been studied by various people over the past 40 years. Cott (1961) and Graham & Beard (1990) wrote reports on the nesting behaviour of Nile crocodiles but it was Pooley (1962) that scientifically noted the breeding patterns of crocodiles in South Africa in the Greater St. Lucia Estuary. More recently both Hutton (1984) and Leslie (1997) reported extensively on nesting behaviour. Numerous articles and papers have been published on the reproduction of Crocodilia (Bellairs, 1987), particularly the alligators (Chabreck, 1975; Goodwin & Marion, 1978; Nichols, 1987; Rootes & Chabreck, 1993) and salt water crocodiles (Webb *et al.*, 1977; Webb *et al.*, 1983a,b; Messel & Vorlicek, 1987; Webb *et al.*, 1987) but only recently has particular attention been given to the reproduction and nesting ecology of *C. niloticus* (Hutton, 1984; Hutton, 1987b; Kofron, 1989; Kofron, 1990; Leslie, 1997). From these studies, one aspect has become quite clear and that is the remarkable ability of the species to adapt to a changing environment. Feeding habits and diets changed from one region to another (Games, 1990), growth rates varied from one location to another (Hutton, 1987a) and females reached sexual maturity at different ages in different regions (Hutton, 1984; Leslie, 1997).

The objective of this part of the study was to determine if there is a difference in nesting patterns and female behaviour in an open system like the Olifants River as opposed to a closed system like Lake Kariba and the Greater St. Lucia estuary. The second and equally important objective was to obtain basic nesting ecology data for crocodiles in the Olifants river on which possible future studies could be based. The emphasis was on the physical placement of the nests in relation to the immediate surrounding environment and to other nests, both of the current and previous nesting season. The hypothesis being that there should not be any difference in nesting behaviour, clutch size and egg dimensions between crocodiles in an open system when compared to those in a closed system like a lake or estuary. To test the hypothesis, nests were excavated, eggs weighed and measured and nest temperatures were recorded in four nests.

4.2   MATERIALS and METHODS

It was not always possible to examine all the nests because of the mountainous and rugged topography, and therefore the number of nests that data was collected for, does not always correspond to the total nests counted for that specific season. The total nests in both the study area and the entire Olifants River in the KNP, were obtained from aerial surveys using a Cessna 182 aircraft and four observers. Thus, the totals for each breeding season cannot be 100% confirmed as current productive nests, but only indications of the number of females nesting. These indications included tracks leading to and from the nest, markings on the ground indicating where the females lay and indents showing the nest location.

Nests that were examined were located by patrolling the river on foot, as close to the water as possible, and following any trails that led from the water. The typical markings such as indentations, foot prints and tracks of nesting females were relatively easy to find. All prospective sites were probed with a 4 mm diameter rod to determine the exact location of the eggs. By gently probing the area where the head and neck markings were a change in soil texture was felt (less resistance on the rod), indicating the egg chamber. The top soil was removed until the first eggs were exposed. Only then was the site marked as a nest and plotted on a 1:50 000 topographical map. For the 1996 and 1997 seasons a GPS (Global positioning system) was used but some problems were encountered with the reception in mountainous areas. Nest data were noted per sector. To differentiate between the area immediately before the Gorge and the Gorge itself, one additional sector (sector E) was introduced (*cf* Figure 2.1 in Chapter 2).

Once a nest was located and confirmed, a set of environmental parameters was noted. These parameters included substrate, distance to water, height above water, exposure of the nest to direct sunlight, nests from the previous and current year and vegetation.

The texture of the substrate was divided into three classes namely sand, soil and clay. Sand was defined as coarse loosely-packed river sand, silt was alluvial deposits on the flood plains adjacent to the stream and clay was defined as any substance that stuck to the metal rod used for probing.

Pooley (1969) and Hutton (1984) both found that a variety of soil types were used for nesting. Kofron (1989) indicated that the soil type influenced the shape of the nest cavity.

The ground distance from the nest to the edge of the water was measured with a 30 m tape measure. The water level in the river fluctuated on a daily basis, but the level on the day when the data were collected was noted. All measurements were rounded to the nearest metre. Distance from water is crucial for the hatchlings as they are vulnerable in the period after hatching and before they reach the water. A number of species prey on hatchlings and the mortality of the hatchlings is substantially higher before they reach the water (Cott, 1961; Pooley, 1969; Guggisberg, 1972 and Hartley, 1990).

Height above water level was measured with a wooden beam, 3 m in length and marked vertically at 50 cm intervals. An observer would stand 20 m away and measure the height by keeping a spirit level at arms length and taking the reading from the beam. The fluctuation in water level made any precise readings superfluous. Flooding of nests during incubation accounts for a large number of nest mortalities (Pooley, 1969; Hutton, 1984; Hartley, 1990).

Exposure to the sun was scored from 1 to 3, with 1 being less than three hours direct sunlight on the nest per day. Value 2 was an exposure of 3 to 6 hours sunshine per day and 3 represented >6 hours of direct sunlight. Hutton (1984) singled exposure to direct sunlight out as one of the most important factors in choosing a nesting site besides access to water. Not only is sunlight required to maintain a suitable incubation temperature, it also influences sex determination of the embryos (Hutton, 1984; Blake & Loveridge, 1992; Lang & Andrews, 1994; Leslie,1997). When the nest temperature falls below 27^0 C, egg development slows down to such an extent that embryos mortality occurs (Hutton, 1984). Similar effects of sunlight on different crocodilian species were found in *A. mississippiensis* (Garnett & Murray, 1986), *C. johnstoni* (Webb, *et. al.*, 1983a) and *C. porosus* (Webb, *et. al.*, 1987). This phenomenon seems to be unique to reptiles as sea turtles and some lizard species exhibits the same sensitivity to nest temperature (Leslie, 1997).

Signs of nests from the previous and current year, in a radius equal to that of the TL of the nesting female around the existing nest, were recorded. The most visible sign of nesting was the excavation marks around the nest. It was argued that the size of the female is in direct relation to her "personal space" (Burt, 1940; Howard, 1960) instead of a hypothetical distance. There is enough evidence in the literature (Cott, 1961; Pooley, 1969; Pooley & Gans, 1976; Webb, et. al., 1977; Webb, et. al., 1983b; Webb & Smith, 1987; Kofron, 1989) to indicate that crocodilians sometimes exhibit communal breeding habits if the environment permits it. However, the appearance of communal breeding is irregular and ill defined and therefore cannot be used to describe the nesting behaviour of C. niloticus (Kofron, 1989; Hartley, 1990). A print of the hind foot of the nesting female was measured and the TL was determined by using the equation described by Hutton (1987):

TL = 13.32 x Hind Foot + 89.3   (r = 0.991)

Females tend to use a circular trail to and from the nest (Pooley, 1969; Pooley & Gans, 1976) with the slope partly determining the accessibility of the nest. The exact slope was determined by using the cotan function of distance over height (cot = d/h).

The presence of any vegetation within a 10 m radius from the nest was indicated by a value of 1 and the absence by a value of 0. Shade for the female is quite important as soil temperatures can rise to intolerably high levels (Pooley, 1969) where upon she will take refuge in the water or shade. If no shade is available in the immediate vicinity of the nest, the female has to leave the nest unguarded and this increases the risk of predation by predominantly the Nile monitor (Varanus niloticus) and mongooses (Cott, 1961; Graham,1968).

It was only during the 1996 and 1997 breeding season that South African National Parks granted permission to open a total of 10 nests per season. Once a nest was located, a piece of canvass was laid next to it. All sand removed from the nest was placed on the canvass to limited the spreading of scent from the nest. The distance to the first eggs was measured and all eggs were removed from the nest.

A pencil mark indicated the top of the egg and care was taken not to rupture the umbilical cord of the embryo. As far as possible the eggs were divided into a top, middle and bottom layer and replaced as such.

A vernier caliper was used to measure the width and length of the egg to the nearest millimetre. The egg was then weighed (in grammes) and placed on the sand removed from the nest. Great care was taken to limit the spreading of any scent from the nest so not to attract predators. When all the eggs were removed, they were replaced in the nest in reverse sequence with a layer of sand between the layers of eggs. The soil was compacted by lightly stamping the area using the foot. All rotten eggs were removed from the nest site and a layer of topsoil, about 40 cm deep, was spread over the whole working area. This was to prevent predators from smelling the eggs and destroying the nest. All nests were revisited after 10 days to determine if the females had returned after the activities. All nests were revisited after 10 days to determine if the females had returned after the activities.

Four Anset TB 108 temperature loggers were placed in different nests during the 1998 season at the proximate centre of the nest. The four nests were selected to represent different aspect, distance from water, shade and soil types. Vegetation varied from a nest with no vegetation and thus no shade (score 3) to a nest that was nearly permanently covered in shade (score 1), distances to water varied from 3 to 12 m and three nests were on level ground whilst one nest had a north facing aspect.

All statistical calculations, analysis and graphs were done on Jandel SigmaStat for windows version 1, Statgraphics version 7 or Corel Quattro pro 8 with Windows 98 as the operating system. Correlations were done using Pearson's correlation while differences between data were compared using either a "Student's" t-test or a Chi-squared test depending on whether the data are measurements or counts/frequencies, respectively . Relationships between various physical characteristics of eggs were established using simple linear regression. All regressions were done at 95% confidence intervals.

4.3   RESULTS

4.3.1   Nests

History was made in 1993 when the first ever scientific survey of *Crocodylus niloticus* nests was done

in Kruger National Park, although it was limited to the study area along the Olifants River. Nesting

data has been recorded annually since 1993, and Table 4.1 is a summary of the results.

Table 4.1 Total number of nests per sector in the study area from 1993 to 1998.

	Sector A	Sector B	Sector C	Sector D	Sector E	Gorge	Total
1993	2	1	9	8	12	22	54
1994	3	10	5	29	10	6	63
1995	4	5	5	12	15	19	60
1996	2	2	3	7	4	23	41
1997	1	1	3	17	0	20	40
1998	0	0	4	8	11	19	42
Total	12	19	29	81	52	109	300
Mean	2	3.2	4.8	13.5	8.7	18.2	50

All nests per sector could not be reached because of terrain and Table 4.2 indicates the number of

nests per sector that were examined.

Table 4.2 Total of nests per sector examined from 1994 to 1998.

	Sector A	Sector B	Sector C	Sector D	Sector E	Gorge	Total
1994	0	8	3	13	3	10	37
1995	0	4	1	9	5	19	38
1996	2	2	3	11	1	20	39
1997	0	0	0	14	0	15	29
1998	0	0	0	4	8	10	22
Total	2	14	7	51	17	73	165
Mean	0.4	2.8	1.4	10.2	3.4	14.6	33

4.3.1.1 Location

The northern embankment of the Olifants River generally has a steeper incline than the southern side (*cf* Figure 2.2 to 2.6). Vegetation on both sides is relatively sparse throughout the whole study area. In sector A, B and C there is a tourist road on the northern side of the river and this could have caused a possible disturbance to breeding females. The differences in the number of nests between north and south banks are listed in Table 4.3. The results indicated a significant preference (Chi^2 = 11.4; df = 4; p < 0.01) for the northern bank even though there is a tourist road. The reason there was a preference for the north bank is that Sectors D, E and the Gorge account for the majority of total nesting sites and these areas have are no tourist roads and therefore minimal human disturbances.

Table 4.3 Number of nests on north and south banks of the Olifants River. Brackets indicate percentage for that specific year.

	1994	1995	1996	1997	1998	Total	Average	SE*
North bank	26 (70)	29 (76)	32 (82)	24 (86)	18 (82)	129 (79)	25.8 (79)	2.37
South bank	11 (30)	9 (24)	7 (18)	5 (14)	4 (14)	36 (21)	7 (21)	1.56

*SE = Standard Error

4.3.1.2 Texture

Although the Nile crocodile utilizes a large variety of substrate types for nesting, results indicated that along the Olifants River, locations with raised banks and ready access to deep water were preferred irrespective of the substrate type. Along the Olifants River the soil type is predominantly course river sand bordered by fine silt on the flood plains away from the main stream, or covered by a thin layer (5 -15 mm) of alluvial silt closer to the water. Along the slopes, the top layer of silt that was deposited by the flood of February 1996 has since been eroded away. This left the inclines as exposed areas of coarse river sand. Clay in nests was found at only a few locations (Table 4.4).

Table 4.4 The number of nests, per breeding season, in the different soil types from 1994 to 1998. Brackets indicate percentage of year's total.

	Coarse river sand	Fine silt / Flood plains	Clay	Total
1994	33 (89)	2 (5)	2 (5)	37
1995	33 (89)	0	5 (11)	38
1996	39 (100)	0	0	39
1997	24 (83)	2 (7)	3 (10)	29
1998	20 (91)	0	2 (9)	22
Total	149	4	12	165
Mean	29.8	0.8	2.4	33
SE*	3.42	0.48	0.81	3.33

*SE = Standard error

The majority of nests, 90% or 29.8 ±2.53 nests per year, over five years, were laid in course river sand, not necessarily by choice or preference, but as a necessity, as this was seemingly the dominant soil type along the river.

4.3.1.3 Height above and Distance to water

In the KNP it was found that distance to and height above water, were not important factors in nest location. The distance from water was determined by the topography and was interpreted in conjunction with the soil type, accessibility to deep water, height above water and vegetation. The topography of the river changed with the 1996 flood. Huge sandbanks were formed in the stream and silt was deposited on the flood plains along the river. Rains in the following seasons started to erode the sand banks and silt deposits, resulting in steep banks with huge erosion trenches.

The maximum height above water in before the 1996 flood was 14 m, and after the flood it increased to 25 m for 1996, see Table 4.5. The fluctuations in water levels throughout the five nesting seasons from 1994 to 1998 resulted in some nests being laid on dry ground well away from water only to be flooded during the incubation period. In 1994 and 1997 three and five nests respectively, were drowned by floods when the mean height of the nest above water was 4.1 m. This increased to a height of 10.0 m and a distance of 32.5 m from the water in 1998 (Table 4.5).

Table 4.5 The minimum and maximum nest distances and height from water. The increase in distance for 1998 can be attributed to soil erosion.

	Min to water (m)	Max to water (m)	Min above water (m)	Max above water (m)	Distance (m)		Height above water (m)	
					mean	SE*	mean	SE*
1994	2	70	1	12	18.0	2.96	4.1	0.42
1995	3	46	1	14	18.3	2.08	6.1	0.63
1996	3	39	1	25	14.4	1.91	5.9	0.81
1997	2	20	1	8	11.3	0.97	4.1	0.37
1998	2	89	2	18	32.5	5.3	10.0	1.01
Mean	2.4	52.8	1.2	15.4	18.9	2.64	6.0	0.64
SE*	0.24	12.08	0.2	2.89	3.63		1.07	1.07

* SE = Standard Error

There was a significant correlation between height above and distance from the water ($r^2 = 0.446$; p < 0.001)(Figure 4.1). From this it can be deduced that the majority of nests were on slopes with a near similar incline (20.5°). The majority of nests were between 0 and 6 m above and < 20 m from
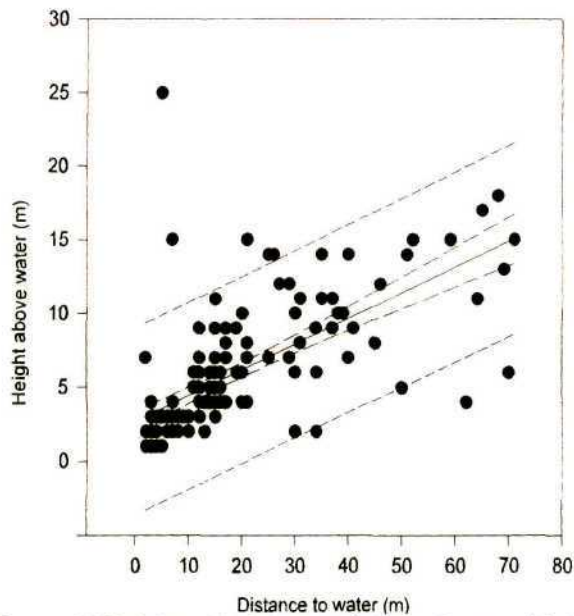
Figure 4.1 Relationship between distance from and height above water's edge for nests from 1994 to 1998. (- - -) 90 and 95 % confidence intervals. ($r^2 = 0.446$; p < 0.001)

the water. This occurred over a period of five years, showing a possible preference for a slope ratio which might be a balance between effort (energy spent) and achievement (safe nesting site).

4.3.1.4 Exposure to sunlight

Although there is riverine vegetation along the Olifants River, it is nowhere dense enough to be an influencing factor in either the placement or prevention of nesting. As far as exposure to direct sunlight is concerned, the whole study area is seemingly well suited as a nesting terrain because of the sparse vegetative cover. The alluvial soils close to the main and secondary streams cannot sustain large woody vegetation, and therefore the general vegetation is limited to shrubs, creepers, grass and reeds. Table 4.6 indicates the percentage sunshine on nests for the study period.

Table 4.6 Number and percentage (%) of nests in the various score categories[1] for direct sunlight on the nest.

	Score 1	%	Score 2	%	Score 3	%	Total
1994	0	0	19	51	18	49	37
1995	2	5.4	7	19	28	76	37
1996	0	0	17	44	22	56	39
1997	2	7	7	24	20	69	29
1998	5	23	10	45	7	32	22
Total	9	5.5	60	36.6	95	57.9	164
Mean	1.8	5.4	12	36	19	57.6	33
SE*	0.91		2.52		3.43		3.27

[1]Score 1 is < 3 hours sunlight; Score 2 is 3 to 6 hours; Score 3 is > 6 hours
*SE = Standard Error

The majority of nests fell in the score 3 category (Table 4.6) although those nests receiving < 3 hours of direct sunlight survived and hatched successfully. In all years, the majority of nests were found in either sector D or the Gorge, and both sectors have relatively steep slopes. This could prevent surface winds blowing over the nests and possibly cause nest temperature to increase. It is therefore quite possible that nest temperatures in sector D and G were higher than those in sector A, B and C. All the nests, except one in 1997 and those destroyed by predators, hatched successfully. This suggests that the amount of direct sunlight a nest received was not crucial for the survival and hatchability of the eggs. However, direct sunlight may affect the internal nest temperature which does determine the survivability of the eggs. It can therefore be assumed that eggs were laid at a depth whereby the internal nest temperature were not adversely affected by direct sunlight. Similarly if the

nests are not exposed to direct sunlight the internal nest temperature can be maintained at temperatures that are required for successful hatching. Leslie (1997) observed successful hatching from nests where alien plant invaders had shaded the nesting sites from direct sunlight.

Four temperature loggers were placed in different nests during the 1998 season at the proximate centre of the nest. The four nests were selected to represent different aspect, distance from water, shade and soil type (Table 4.7 and Figures 4.2 to 4.5). The variation in nest temperature is an indication that a combination of direct sunlight, soil type, distance from water, aspect and vegetation appears to govern the internal nest temperature. It is notable that the nest temperature plunged after every rain shower and took an average of 2.6 days to recover again (Figure 4.2 to 4.5). This could have been the result of the wet substrate and moisture in the soil that absorbed heat more readily than the soil particles. It appears that 2.6 days was sufficient enough time to dry out the moisture at the average nest depth.

Table 4.7 Details of nests used for temperature loggers.

No	Vegetation[¶]	Slope	Distance to water (m)	Height above water (m)	Distance to first egg (m)	Female size TL (m)	Clutch size	Soil type	Initial temp[§] (^{0}C)
1	None (Score 3)	None	5	3	0.25	2.6	43	River sand	30.8
2	Sparse (Score 2)	North facing	4	3	0.43	3	61	River sand	30.4
3	None (Score 3)	None	3	2	0.3	3.1	37	River sand	30.6
4	Dense (Score 1)	None	12	4	0.39	2.7	48	River sand	28.5
Mean			6	3	0.34	2.85	47.25		30.08
SE*			2.04	0.41	0.04	0.12	5.11		0.53

*SE = Standard Error
[¶] Dense vegetation which covered nests in shade achieved a score of 1 whilst no vegetation within 10 m from the nest was rated as score 3.
[§] This was the initial temperature of the nest when the loggers were inserted.

A series of shift experiments done by Webb et.al. (1987) on C. johnstoni and C. porosus indicated that the sex of embryos are determined between 21 - 35 days after laying (mean = 28 days). From Figures 4.2, 4.4 and 4.5 this would suggest the period up to 5 December 1998. However, in nest 2 (Figure 4.3) hatching occurred on 6 January 1999 and therefore it falls outside this period. Data for only the last few days of sex determination were captured by the loggers, as they were inserted

during the last tri-semester of incubation. The loggers were inserted between 06:00 and 08:00 and set to start recording at 14:00. The initial temperatures for nests 1, 2, 3 and 4 were 30.8; 30.4; 30.6 and 28.5° C respectively. The very same day the loggers were inserted, 35 mm of rain was recorded from 17:00 in the afternoon. This event adversely influenced the nest temperatures as the average temperature up to and including 5 December 1998 was 27.3; 28 and 26.3° C for nests 1, 3 and 4 respectively. It can be assumed that the first recording was representative of the nest temperature before the effect of the rain and based on this, all three nests should have produced predominantly females. Nests 1, 3 and 4 all hatched within two days from one another, indicating that egg laying must have been synchronised.
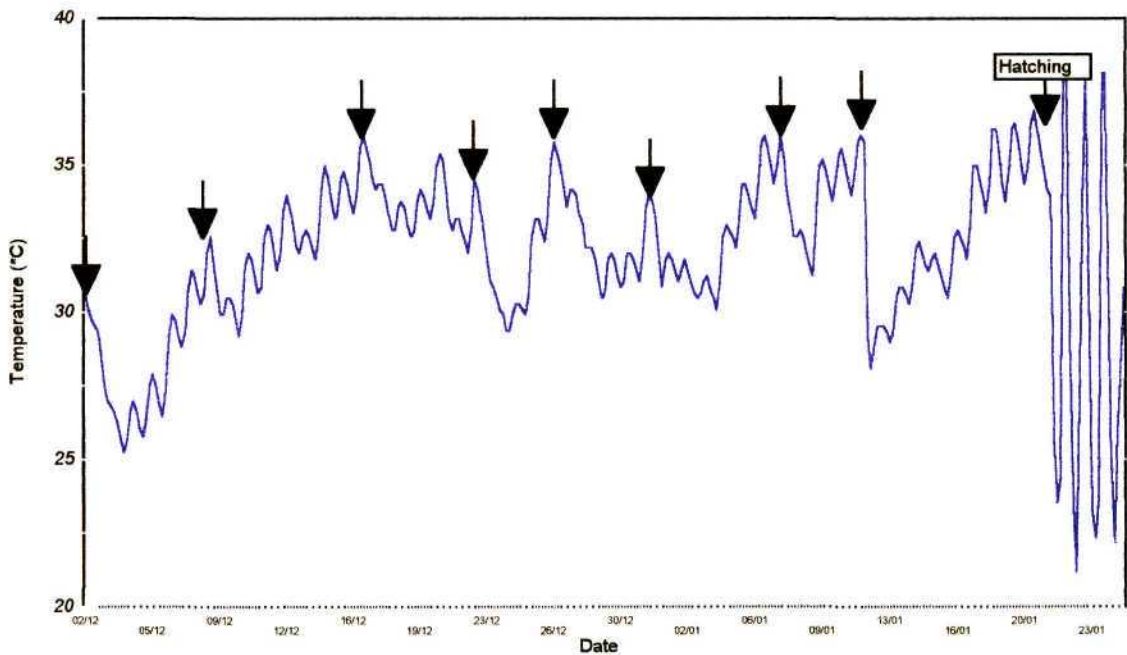
Figure 4.2 Nest temperatures for nest 1 with an average temperature of 32.1 °C. The arrows indicate rainstorms. The nest was 17 m from and 9 m above water level, in course river sand with a north facing slope and no vegetation in a 5 m radius from the nest. The nest had 36 eggs.
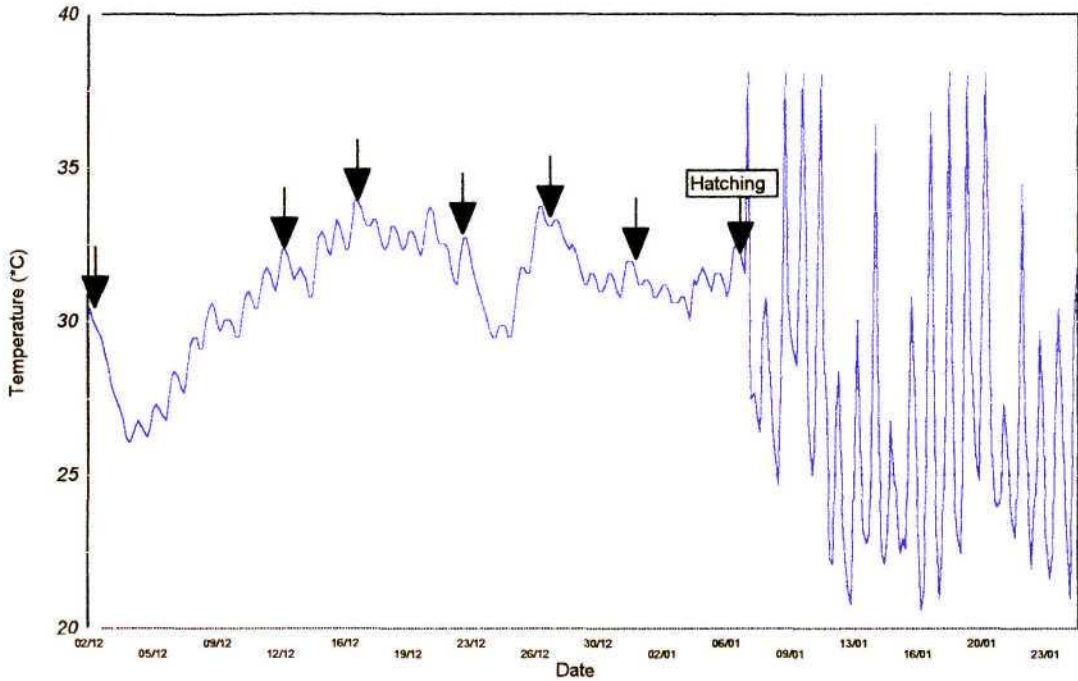
Figure 4.3 Nest temperatures for nest 2 with an average temperature of 30.6 °C. The arrows indicate rainstorms. The nest was 12 m from and 4 m above water level, in course river sand with a north facing slope and dense vegetation in a 5 m radius from the nest. The nest had 48 eggs.
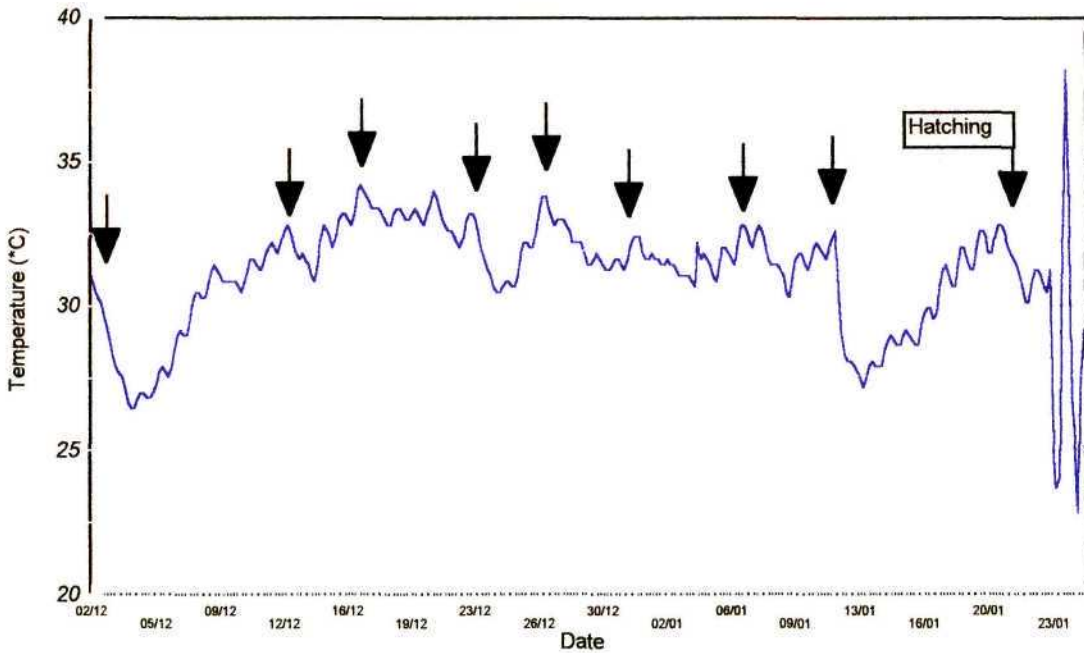
Figure 4.4 Nest temperatures for nest 3 with an average temperature of 31.1 °C. The arrows indicate rainstorms. The nest was 4 m from and 3 m above water level, in silt with a north facing slope and some vegetation in a 5 m radius from the nest. The nest had 61 eggs of which 3 were spoiled.
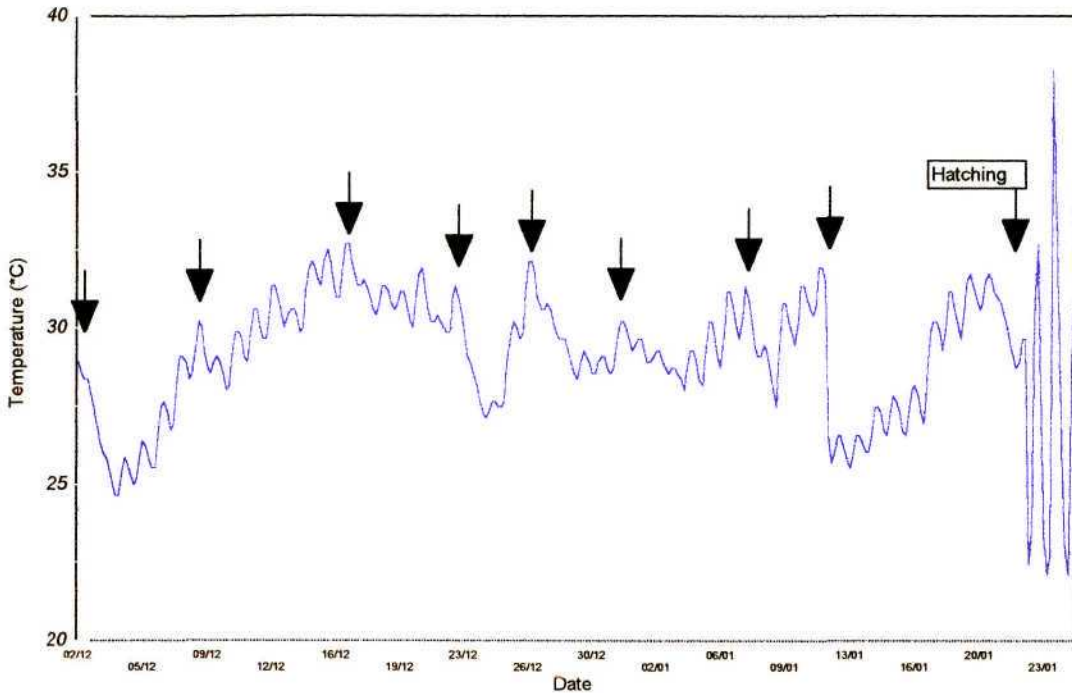
Figure 4.5 Nest temperatures for nest 4 with an average temperature of 29.2 °C. The arrows indicate rainstorms. The nest was 3 m from and 2 m above water level, in course river sand and some vegetation in a 5 m radius from the nest. The nest had 37 eggs of which 5 were rotten.

4.3.1.5 Slope

The angle of the slope, and to a lesser degree the distance from the water's edge, will determine the amount of energy spent to reach the nest. Breeding females do not actively feed during nesting (Pooley, 1969; Graham,1968) and as such, the conservation of energy should be an important factor and could be influenced by the slope and distance from water. The inclination was computed from the cotan of distance over height and converted to degrees (Table 4.8). This was to give an indication of effort expanded in reaching the nest site. There were no significant difference between the inclines/slopes for the various nesting seasons indicating that slope might influence the choice of nesting site. If there was a large variation in the slope, one could deduce that slope was random, but with it being more or less constant ($20.5^0 \pm 1.09$) it rather suggests a preference for this incline.

Table 4.8 Average slope in degrees, of nests measured from the edge of the water.

	Total number of nests (n)	Mean slope (^{0})	SE*
1994	37	20.31	1.89
1995	38	21.00	1.21
1996	39	25.05	2.1
1997	29	21.78	1.58
1998	22	24.22	3.55
Mean	33	18.04	2.06

* Standard Error

4.3.1.6 Communal nesting

Various authors (Hartley, 1990; Hutton, 1984; Pooley 1969) mentioned the occurrence of communal nesting, but unfortunately none defined it clearly. Hartley (1990) defined two nests as communal breeding even though the nests were spread over a 400 m distance. Crocodiles do not qualify as communal breeders in the true sense of the word as pertaining to birds (Howard, 1960). For the purpose of this study, when a nesting female was within her own body length (TL) from another nest, it was regarded as a group (community) regardless of the number of individuals involved. The number of nests from 1994 to 1998 are shown in Table 4.9.

Table 4.9 Frequency of occurrence of nests in previous and current nesting seasons within body length of one another.

	Previous season	Current season	Total
1994	6	3	9
1995	3	5	8
1996	5	0	5
1997	0	5	5
1998	5	3	8
Total	19	16	35
Mean	3.8	3.2	7
SE*	1.07	0.92	0.84

*SE = Standard Error

There was no significant difference between the two seasons (df = 8; p> 0.05) thus supporting the non-communal breeding theory. The number of nests within body length from one another is too low

to indicate a trend, but can and should rather be viewed as individuals nesting in close proximity of one another and not communal nesting. Even though there was a change in environment (flood) no differences were found between the nesting numbers in different years (t = 0.42; df = 8; p > 0.5), indicating that females chose to nest at a suitable habitat rather than at a communal breeding site.
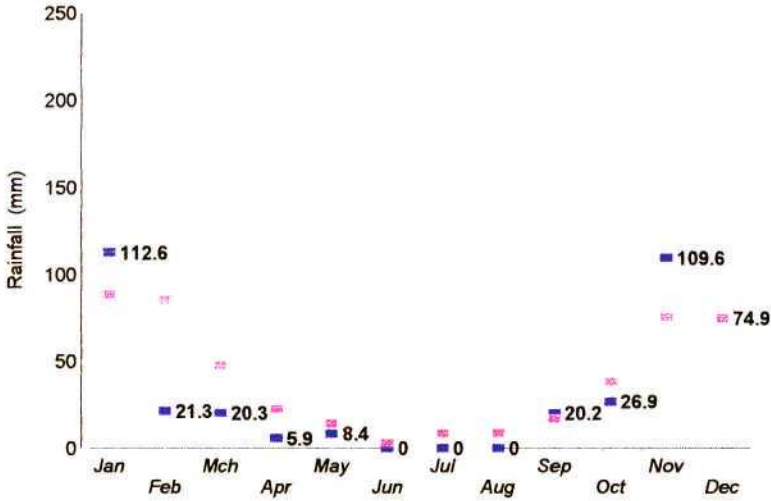
Figure 4.6 Total rainfall for 1997 was 400.1 mm. The average size for nesting females were 3.0 m TL, which was smaller than the females in 1998. The red line indicates the long term mean rainfall.
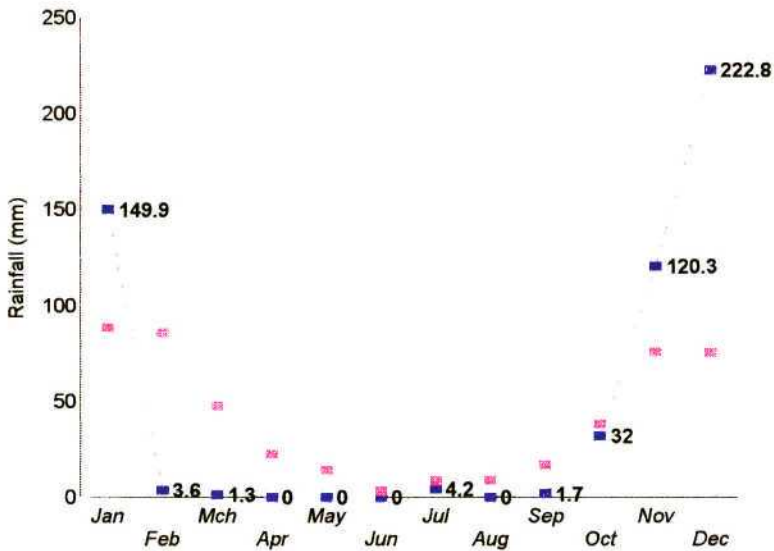
Figure 4.7 Total rainfall for 1998 was 535.8. The average size for nesting females were 3.5 m TL, which was larger than the previous season. The red line indicates the long term mean rainfall.

The only suggestion of communal nesting was found in 1995 and 1996 when six nests were located in an area of roughly 100 x 80 m. The availability of shade and access to a deep pool seemed to be the determining factors in selecting that specific site, as no other suitable nesting area was available for about 1 km both ways. It was obvious that every female had her own bush for shade as no two females shared a single bush. The shortest distance between two nests was 20 m in 1995 and 32 m in the 1996 season.

4.3.1.7 Size

The smallest breeding female observed along the Olifants River during the study period was 1.9 m TL and the largest female was 4.3 m TL. These measurements are well within the limits from the studies of Hutton (1984) and Leslie (1997). The details are summarized in Table 4.10. Only larger females nested during dry seasons whilst smaller females also nested during the wet season.

Table 4.10 Breeding sizes for females (TL) along the Olifants River for the study period.

	Smallest Female (m)	Largest Female (m)	Mean size (m)	SE*
1994	1.9	3.6	2.36	0.073
1995	2.6	4.3	2.49	0.072
1996	2.6	4.1	3.26	0.060
1997	2.1	3.7	2.71	0.065
1998	2.5	4.0	3.08	0.076
Mean	2.34	3.94	2.78	0.069
SE*	0.14	0.13	0.17	

* SE = Standard Error

There was a significant difference in the sizes of the breeding females between the two seasons in 1997 and 1998 (t = -2.43; p = 0.026). The larger females nested during the season with the higher rainfall (534 mm) in 1998. It was only smaller females that nested during the 1997 season when only 400 mm was recorded. This might indicate that the less experienced females or possibly the first time breeders nested in less than favourable conditions.

4.3.2 Eggs

Ten nests each for 1997 and 1998 were excavated and the eggs were measured. A total of 795 eggs were measured and weighed. Table 4.11 and 4.12 indicates the number of nests and eggs per nest for the period 1997 and 1998

Table 4.11 Nest data for the 1997 season.

1997	Total Eggs	Spoiled Eggs	Depth (cm)	Female (TL) m
Nest 1	54	3	21	3.4
Nest 2	20	5	27	3.1
Nest 3	49	4	27	2.5
Nest 4	39	0	23	2.9
Nest 5	43	3	25	2.1
Nest 6	4	1	11	3.1
Nest 7	30	30	23	3.6
Nest 8	46	2	31	3.5
Nest 9	38	1	49	2.9
Nest 10	45	5	20	3.2
Mean	36.8	5.4	25	3
SE	4.31	2.52	2.79	0.13

SE is the standard error.

Table 4.12 Nest data for the 1998 season.

1998	Total Eggs	Spoiled Eggs	Depth (cm)	Female (TL) m
Nest 1	30	2	37	3.6
Nest 2	59	4	31	4.1
Nest 3	34	0	40	3.2
Nest 4	48	1	39	2.7
Nest 5	37	4	34	3.1
Nest 6	61	5	43	3.9
Nest 7	34	3	38	3.9
Nest 8	43	2	36	3.4
Nest 9	50	1	39	3.4
Nest 10	31	0	31	3.9
Mean	42.7	2.2	36	3.5
SE	3.59	0.559	1.23	0.14

Although the mean nest size for 1997 was smaller than the 1998 season (37 vs 43 eggs per nest, respectively), it did not differ significantly (p > 0.05). Similarly, there were no differences in the number of rotten eggs between the two seasons (p > 0.05). However, there were significant differences in the depth of the nests (p < 0.01) and the TL of breeding females (p < 0.05) between the two seasons, with the larger females nesting in 1998. The deeper nests in 1998 can be explained by the physical ability of the larger females to dig deeper.

Table 4.13 and 4.14 summarises the physical measurements of eggs for the 1997 and 1998 seasons. There were significant differences in mean egg length (p = 0.05) and mean egg width (p < 0.05) but not mean egg mass (p > 0.05) between the two seasons. Larger and heavier eggs were produced by the larger females laying in 1998. Similar results were reported by Pooley (1969), Hutton (1984) and Webb *et. al.* (1987).

Table 4.13 Egg measurements for the 1997 season.

	Length	SE* (length)	Width	SE* (width)	Mass	SE* (mass)
Nest 1	79	0.27	51	0.1	127	0.71
Nest 2	79	0.62	49	0.42	110	2.69
Nest 3	75	0.23	51	0.17	111	0.77
Nest 4	76	0.35	49	0.13	109	0.58
Nest 5	75	0.31	49	0.13	106	0.49
Nest 6	75	1.1	47	0.47	102	1.22
Nest 7	Spoiled		Spoiled		Spoiled	
Nest 8	74	0.38	49	0.11	106	0.77
Nest 9	71	0.36	48	0.14	109	0.65
Nest 10	78	0.32	52	0.14	143	1.11
Mean	75.8	0.44	49.4	0.20	113.7	1.0

* SE = Standard Error

Table 4.14 Egg data for the 1998 season.

	Length	SE* (length)	Width	SE* (width)	Mass	SE* (mass)
Nest 1	84	0.46	53	0.34	125	0.53
Nest 2	81	0.31	52	0.10	122	0.27
Nest 3	81	0.31	50	0.12	121	0.26
Nest 4	79	0.27	50	0.12	122	0.51
Nest 5	74	0.48	48	0.25	123	0.72
Nest 6	77	0.20	53	0.13	127	0.57
Nest 7	77	0.17	55	0.19	124	0.14
Nest 8	75	0.24	49	0.17	118	0.19
Nest 9	77	0.21	46	0.14	121	0.18
Nest 10	80	0.23	67	0.11	124	0.18
Mean	78.5	0.28	52.3	0.16	122.7	0.35

* SE = Standard Error

There was a similar trend from the regression analyses between egg mass and length as well as egg mass and width. Both regressions showed that an increase in egg mass resulted in an increase in either egg width or length (Figures 4.9 and 4.10).

The clutch sizes were 40 (± 3.4) for 1997 (excluding Nest 6, as some disturbance probably occurred) and 42 (± 3.5) for 1998. A comparison of the data in Table 4.15 indicates that there is a significant difference ($p < 0.001$) in clutch size between South Africa, Uganda and Zimbabwe with the latter having the largest clutches. There is currently no individual nest data available for St. Lucia and Umfolozi. When the females are compared, a difference in median values indicated that there is a significant difference between the sizes of breeding (nesting) females for the three countries ($p < 0.05$). A pairwise comparison of sizes between females indicated: S.A. vs Zimbabwe females ($p < 0.05$), S.A. vs Uganda females (NS) and Uganda vs Zimbabwe (NS).
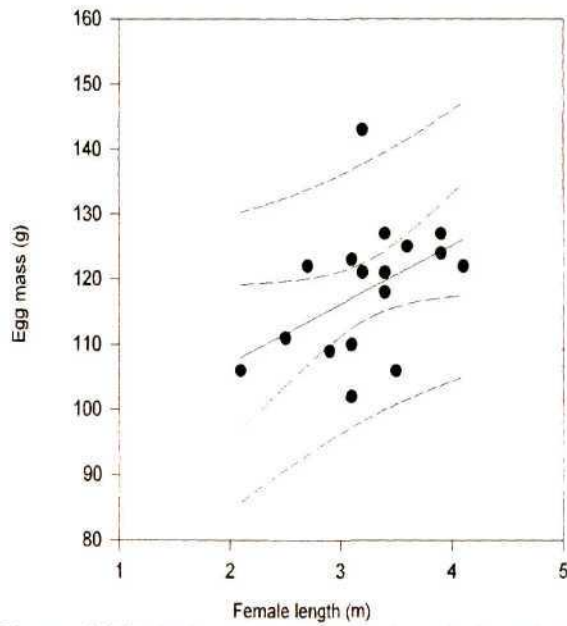
Figure 4.8 Relationship between female length and egg mass (r^2 = 0.215; p < 0.001). (- - -) 95 and 90% confidence intervals.
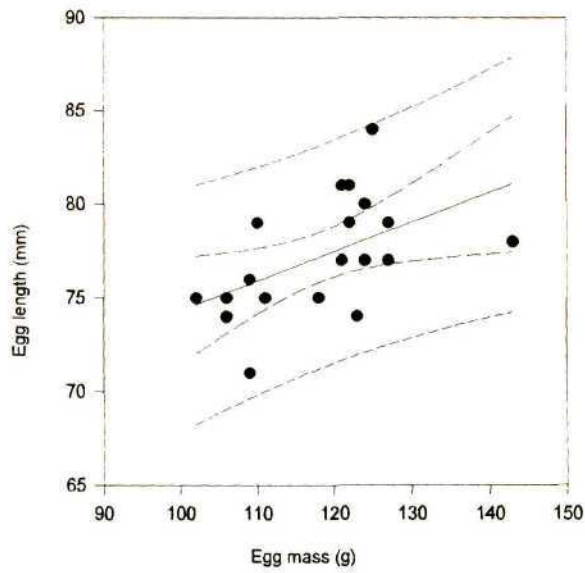
Figure 4.9 Relationship between egg mass and length (r^2 = 0.256; p < 0.001). (- - -) 95 and 90% confidence intervals.
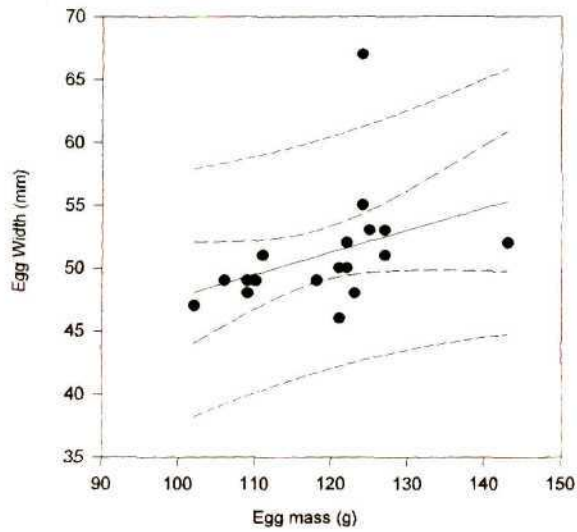
Figure 4.10 Relationship between egg mass and width ($r^2 = 0.154$; $p < 0.01$). (- - -) 95 and 90% confidence intervals.

Table 4.15 A comparison between clutch sizes and female TL in SA, Uganda and Zimbabwe (Millan *et. al., 1997)*. The figures for Uganda were compiled by Hutton (1984).

	Olifants River	Uganda	Ngezi - Zimbabwe	Umfolozi	St Lucia	Mean
Mean clutch size	39	49	54	47	45	47
SE* (Clutch size)	3.04	4.72	6.48			
Mean female TL (m)	3.29	2.72	1.73			2.58
SE* (female TL)	0.12	0.22	0.35			

* SE = Standard Error

4.4   DISCUSSION

The nesting ecology of *Crocodylus niloticus* in the Olifants River appears to be similar to that of closed systems (Hutton, 1984; Leslie, 1997). There are some minor differences which in some instances can be ascribed to environmental factors. The most significant of these, was the flood of February 1996. During the flood, the total geomorphology of the river changed. The last significant flood prior to 1996 was in 1976 with the cyclone " Emily". Ideal nesting sites i.e. sand, slope and

shade, before the flood were limited as a result of erosion. Over a period of 20 years, sand and silt were eroded away and deposited into the river, exposing the basalt mother formation and hard impenetrable clay formations. This influenced the placement of nests and to a certain extent limited the number of possible nesting sites in the study area.

After the flood of 1996, the majority of the study area was covered in sand and silt with long sandbanks in the riverbed (cf Figures 2.2 to 2.6 in Chapter 2). This resulted in an abundance of possible nesting sites. During the 3 year study period, after the flood, the effect of erosion and rain showers on the sand- and silt deposits were quite noticeable. The average depth of the mainstream decreased from about 1.5 m to < 0.5 m, and this had an adverse effect on the distribution and concentrations of crocodiles in the study area. A number of possible nesting sites were rendered unsuitable as a result of shallow water not offering adequate protection for the breeding females.

Pooley (1969) found that the distance from the nests to water in Kwazulu/Natal varied from 15 to 50 metres, and Hartley (1990) found that, despite a large variation ranging from 1 m to >80 m, the majority of nests were about 6m from the water in the Umfolozi Game Reserve. Similarly, Hutton (1984) noted the mean distance from water as about 6 m for the Ngezi population in Zimbabwe. Along the Olifants River, the mean distance to the water was 18.9 (±1.07) m, which compares favourably with the previous findings considering that the water level in the Olifants River constantly changes. Kofron (1989) indicated an initial range of 2.5 to 110 m from water when laid, but rising water levels later submerged all the nests for that specific season and the eggs subsequently drowned.

Kofron (1989) found that 97% of the nests during the 1984 season were initially in direct sunlight and 82% within 2 m of vegetation, whereas along the Olifants River, 19 of 33 nests (56%) were exposed to >6 hours of direct sunlight and 12 or 36% (n=33) nests for 3 - 6 hours of direct sunlight. It would appear that a combination of factors determine the placement of nests, such as exposure to direct sunlight, height above and proximity to water, soil type and shade (Cott, 1961; Graham, 1968; Hutton, 1984).

Nests from both the current and previous season were noted to indicate either the re-use of nesting sites or communal nesting (Cott, 1961; Pooley, 1969; Hutton, 1984; Hartley, 1990). Pooley (1969) suggested that Nile crocodiles do nest communally. The same indications were reported by Cott (1961) and Hartley (1990), but Hutton (1994) found that although the same nesting site was used as much as seven times in eight years, it was not by the same female. Graham (1968) observed nests as close as 1 m apart but never stated if this was due to limited nesting space or a preference for communal breeding. Communal nesting could then be seen as a possible response to limited breeding space or limited access to nesting sites and not so much as an instinctive behavioural pattern. Hutton (1984) supported this when he remarked that established breeding females still maintain home ranges and are free to nest in that area while smaller females are forced to leave the home range to breed. There is still confusion and uncertainty about the definition of communal nesting, but in the true sense of the word, this does not occur along the Olifants River. There are, however, indications that crocodiles will tolerate the presences of other nesting females.

The difference between communal nesting and nesting in a group is that in communal nesting the group would respond together to certain stimuli or threats and not as individuals. There is no evidence to suggest that nesting females will actively defend another female's nest in her absence, a phenomenon that does occur amongst birds. Birds that nest communally will respond to a threat as a unit, and this was not observed or noted amongst the crocodiles in the Olifants River. On the contrary, personal observations suggest that crocodiles respond individually to possible threats. Nesting in close proximity to one another have obvious advantages like increased observation against predators and increased awareness of approaching dangers. This was noted in a number of animal species including impala and zebra, and birds. If communal nesting, like in birds, exists amongst crocodiles in the Olifants River, more occurrences of this habit would have been noticed (at different locations along the river). However, this was not the case. The most likely reason for nesting together in a confined area appears to be a topographical one and not a behavioural pattern, as there were limited possible nesting sites in sectors D and G, which had the highest density of nests.

Incubation temperature determines the sex of the embryo (Chabreck, 1975; Bellairs, 1987; Webb *et.*

al. 1987; Games, 1988; Whitehead *et. al.* 1990). The crucial temperature seems to be 28.0 - 31.7°C

for females and 31.7 - 34.5 °C for males (Webb *et. al.* 1987; Leslie, 1997). Direct sunlight

contributes to the internal nest temperature, as much as 6 °C difference at 25 cm below the surface

(Leslie, 1997). The mean depth along the Olifants River for the 1997 and 1998 season was 250 and

360 mm respectively and this appears to be deeper than the findings in both KwaZulu-Natal (Hartley,

1990) and Zimbabwe (Hutton 1984). Hartley (1990) found the average nest depth 203 mm with 420

mm as the deepest and 15 mm as the shallowest nest. Pooley (1969) noted nests at between 275

and 450 mm deep and Hutton (1984) found that soil type did not influence the depth of nests, the

mean depth to the first egg was 164 mm. Exposure to direct sunlight is singled out as an important

factor in determining the location of a nest (Cott, 1961; Graham, 1968; Hartley, 1990), although the

availability of shade for the female also plays an important role (Cott, 1961; Hutton, 1984; Leslie,

1997). In dry seasons the mean soil temperature at 25 cm depth was higher than the mean air

temperature (Leslie, 1997). This situation was reversed during wet periods (Leslie, 1997). Nest

temperature not only influences the sex of the embryo but it significantly influences the incubation

period, survival of the embryos, body size and energy reserves (Hutton, 1984; Seymore *et. al.* 1994).

Hutton (1987b) stated that Nile crocodile eggs failed to hatch below 27 °C and Leslie (1997)

indicated that between 31 - 33 °C incubation temperature resulted in the shortest incubation period

whilst 34 - 35 °C produced the longest incubation period. Incubation time at 31 °C was 82 days, 77

days at 32 °C, 70 days at 33 °C and at 35 °C the incubation period was 80.5 days (Leslie, 1997).

The size at which sexual maturity in Nile crocodiles is attained varies for different populations and

appears to vary from one location to another over the species' distribution. The smallest breeding

female in the Olifants River was 1.9 m TL and the largest was 4.3 m TL, which were well within the

limits reported in the literature. Cott (1961) determined the size of males and females when they

reached puberty at various locations and the smallest males were 3.33 and 3.09 m TL for Zambia

and the Zambezi river respectively. In the Luangwa valley (Zambia) the smallest mature male was

2.9 m TL while the smallest mature female measured only 2.31 m TL, but only 50 % of the female

population were matured at 3.0 m TL (Hutton, 1984). Lake Victoria produced breeding females at

2.19 m TL (Cott, 1961) while Graham (1968) found matured males of 2.12 m TL and females as small as 1.8 m TL in Lake Rudolf (now Turkana). Hutton (1984), working on a high altitude population in Lake Ngezi in Zimbabwe, indicated that females of >2.85 m TL and a mass of 120 kg were matured. Individuals in this class were all > 35 years old. He measured the smallest breeding female at 2.65 m TL for the Ngezi population (Hutton, 1984). Kofron (1989) noted males and females to attain sexual maturity at 2.7 - 2.95 m and 2.62 - 2.87 m TL respectively. The range of age for mature males and females will vary from one region to another depending on food, temperature, population density and habitat, but in general females attain maturity at about 13 to 25 years and males from 11 to 23 years. The factors that determine the size or age at which crocodiles become mature are not fully known or understood, but life history parameters are closely linked with body size (Hutton, 1984) and this suggests that in animals with highly variable growth rates, size and mass rather than age will reflect reproductive parameters. Penned animals with rapid growth rates mature earlier than slower growing wild animals (Cody, 1974).

The nesting females in 1998 along the Olifants River were, on average, larger than in 1997 (Tables 4.11 and 4.12). Results from the Olifants River corresponds with the findings by Pooley (1969), Hutton (1984) and Webb et. al. (1987) that larger females produced larger eggs. The clutch size of 40 for 1997 and 42 for 1998 for the Olifants River were the smallest when compared to Zimbabwe (54 eggs/nest) (Hutton, 1984), 47 eggs per nest for Umfolozi Game reserve (Hartley, 1990) and 45 for St. Lucia Estuary (Pooley, 1969).

Both Hutton (1984) and Leslie (1997) found that females do not nest every year and this was found to be the case for A. mississippiensis (Rootes & Chabreck, 1993) and C. porosus (Webb, et. al., 1977). Nine adult females in Zimbabwe (Hutton, 1984) nested only 17 out of a potential 27 times over a period of three nesting seasons. The matured females nested only on 63% of the possible occasions. This is lower than Lake Rudolf (Graham, 1968) where an estimated 87.6% was attained. Data on the breeding females are not available for the Olifants River, a shortcoming that needs to be addressed. The breeding rate of the females will indicate their viability and the status of the breeding segment of the population. Similarly, Leslie (1997) determined that the proportion of breeding

females is lower during droughts than in wet seasons. Working on a female to male ration of 38.1%: 61.9% or 1.6:1 for the St. Lucia population, she calculated that over the past 12 years the proportion of females that nested varied from 13% to 34.1% (Leslie, 1997). Females fast during nest attendance (Cott, 1961) and this results in a reproductive cost for the females. Lance (1987) showed that reproducing females pay a heavy toll with respect to mineral and vitamin loss and as a result actually need to skip a nesting season to recover.   Hutton (1984) suggested that a ratio of male:female skewed towards females may be responsible for females skipping a nesting season. They cannot mate if there are too few adult males, but this might be an effect rather than a cause.

4.5   CONCLUSION

Statistically there are enough evidence to suggest that the original hypothesis: "There is no significant difference between the nesting habits of C. niloticus in "open" and "closed" systems",   should be accepted. The clutch size, egg mass, egg length and width from the Olifants River system equates favourably with findings in closed systems. The correlation between breeding females and eggs produced in terms of size and measurements, are similar to findings in Zimbabwe and KwaZulu-Natal. Two prominent dissimilarities were found. Firstly the sizes of breeding females in the Olifants River were smaller (1.9 m) and secondly, females in the Olifants River did not nest communally in the true sense of the word. They did however nest in close proximity to one another along the Olifants River. This can be ascribed to the geomorphological feature of the river, restricting available nesting areas at certain locations, and thus forcing females to nest near one another.

One previously unnoted aspect is that only larger females nested during dry periods and subsequently the nests were deeper. This could possibly have influenced the sex ratio of the hatchlings as deeper nests have lower internal temperatures, favouring female hatchlings. This deduction needs confirmation.

CHAPTER 5:

THE EFFECTS OF WATER QUALITY ON *Crocodylus niloticus*

5.1 INTRODUCTION

For the purpose of this study, pollution will be defined as any impairment of the suitability of water for any of its beneficial uses, by man-made changes in the quality and quantity of the water (Seymore, 1994). An estimated one million different pollutants have been introduced into natural water. Metals are one of these groups, and toxicity is determined by some 80 elements and their components. Zinc, copper, lead, cadmium, mercury, nickel and chromium are some of the most important metals causing pollution in water (Seymore, 1994).

Two particular categories of substances have a lasting detrimental effect on aquatic systems. Firstly, there are nutrients which may cause unrestricted biological growth, which can in turn lead to oxygen depletion (Maartens, 1994). The second category includes polycyclic aromatics, pesticides, radioactive matter and metals and are known as sparingly degradable synthetic chemicals (Seymore, 1994). Two factors contribute to the deleterious effects of metals. The fact that Metals cannot be destroyed through biological degradation and that metals tend to accumulate in the environment. In aquatic environments the accumulation is normally in the bottom sediments (Seymore, 1994).

A number of factors may influence the toxicity of metals, especially in aquatic environments, notably the temperature, pH and water hardness. Metals serve a purpose in nature, but it is only when a certain threshold is exceeded that the effects of metals become potentially detrimental to the environment. Copper and zinc are essential trace elements in living organisms while lead and cadmium serve no known biological function (Maartens, 1994). In elevated levels, all these metals can cause direct or indirect effects such as histological damage or a reduction in the survival, growth and reproduction of species (Maartens, 1994). Metals in aquatic environments can be found as soluble complexes in a dissolved state (hydrated ions and organic molecules) and/or in a particulate state as aggregates, coatings on particles or incorporated in organic particles. Insoluble complexes precipitate into bottom sediments. Chemical processes in water and sediments can influence the availability of metals to organisms, whilst water temperature and oxygen levels influence their absorption, particularly by fish species.

The objective of this study was to collect data on metal pollution in various tissue samples from Nile crocodiles residing at different locations in Kruger National Park. The aim was to determine whether there is a difference in pollution or accumulation in either different tissues from the same crocodile and or between crocodiles from different locations. No similar studies have ever been carried out in the KNP and consequently, these data are baseline data. The results of this part of the study cannot be compared or evaluated as no similar data exist because the range of metals tested for were very small and limited to reptile (crocodiles). Even though the initial objective was reached, no meaningful comparison to determine the degree of contamination, between crocodiles from the different locations in Kruger Park could be done.

5.2   MATERIALS AND METHODS

Two methods were used. Firstly, a literature study investigated the presence and effects of total dissolved solids (TDS) and metals in the Olifants River. Water quality values were obtained from the Department of Water Affair 1998 report. Secondly, various tissue samples from *C.niloticus* were collected and analysed to determine if there was an accumulation of metals in those tissues and to create a database of values found. Two previous research projects were conducted from 1991 to 1992 on the metal accumulation and concentrations in selected fish species in the Olifants River and the possible affects these metals had on the fish (Maartens, 1994; Seymore, 1994). The selected fish species were:

Barbus marequensis	-	Large-scaled Yellowfish
Clarias gariepinus	-	Common Catfish
Labeo rosae	-	Red-nosed Labeo
Oreochromis mossambicus	-	Redfin Tilapia

The literature review relied quite extensively on the findings of the two reports by Maartens (1994) and Seymore (1994) because these were recent studies specifically conducted in the Olifants River. It was argued that as each river system has its own unique combination of pollutants and water flow, data between rivers may not be comparable. No practical or physical research was done on any sediments and fish.

Blood and tissue samples from Nile crocodiles were obtained for analyses for possible
bioaccumulation of metals from three locations in Kruger National Park. During September 1997
six crocodiles of various sizes were shot in the lower Olifants River, all down stream of the Olifants
Camp. Two additional animals were sourced from the Sabi River (S 25 06.840 / E 31 54.612) on 26
and 27 September 1997, near Lower Sabi Restcamp, and another four were collected from the
Silverfish dam on the Shingwedzi river (S 23 13.026 / E 31 12.672) on 10 June 1998. A single
sample was also obtained from the Olifants River outside the Kruger National Park at Phalaborwa
(PMC). Due to financial constraints only the blood composition from this individual was
analysed(Table 5.4). As this was a single sample and part of the Olifants River it was grouped
together with the other Olifants River crocodiles. The crocodiles from the Sabi River and Silverfish
dam were immobilised by intramuscular injection of gallamine triothiodide (Flaxadill™), transported to
the field laboratory and then killed by a single shot through the brain. The seven samples from the
Olifants River were all shot with a rifle at relative close range in the river when sun basking. The
carcasses were recovered and transported to the field laboratory. The collection from the Olifants
River was deliberate and an attempt was made to collect a sample from each of the different size
classes (cf Chapter 3) used in determining movement. An attempt was made to gather base line
data on the effects of metal contamination on different crocodiles size classes, which might indicate
contamination over time.

Blood was collected from the jugular veins of those crocodiles shot in the Olifants River, but directly
from the bullet wounds of the immobilized crocodiles. Blood was collected in plain vacutainers with
and without fluoride. The vacutainers were kept on ice before and during transportation to the
laboratories at Medunsa and Onderstepoort in Pretoria, where they were centrifuged at 3000 g for 10
minutes. The supernatant was pipetted off and frozen without any additives.

All crocodiles were necropsied and duplicate samples of approximately 100 g of liver, muscle, kidney
and fat (when available) tissue were collected for metal analyses. When fat was available, about 50
g were collected and frozen. One set of body tissues was stored in 10% neutral buffered formalin for
histopathological examination while the other was kept on ice until it could be frozen in the

laboratory. A 50 mm section of the seventh rib was collected, cleaned of all muscle and connective tissue including the periosteum, and fixed in 70% ethyl alcohol. The ribs were analysed for possible mineral deficiencies.

Liver and kidney samples preserved in formalin, were analysed by means of the wet ashing technique. The samples were minced and dried overnight at 105^0 C. Nitric acid and a mixture of one part sulphuric acid to seven parts of perchloric acid, were added to the dried sample. The samples were then heated and once decomposition started, nitric acid was added until the sample was fully reduced. Afterwards all minerals, except phosphorus, were analysed, using the atomic absorption spectrophotometric method number 2.216 (Van Loon, 1980). Phosphorus was measured calorimetrically using the South African Bureau of Standards' specification 516 of 1957. The ribs were analysed for calcium, phosphorus, magnesium and fluoride to set a benchmark for future reference and in order to detect possible mineral deficiencies.

The frozen samples were thawed and wet mass determined. Tissues were then dried in an oven at 60^0 C for 24 hours, cooled in a desiccator and dry mass determined. One gram of each dried sample was placed in an Erlenmeyer flask and a mixture consisting of one part concentrated perchloric acid and two parts nitric acid was added (Van Loon, 1980; Houba *et.al.* 1983). Acid digestion was performed at temperatures ranging from 200 - 250^0 C until the samples were clear. After digestion, each sample was separately filtered, using acid resistant 0.45 µm filter paper. The volumes of the samples were increased to 50 ml with distilled water and metals and minerals determined by atomic absorption spectrophotometry.

All statistical calculations, analysis and graphs were done on either Jandel SigmaSstat for windows version 1, Statgraphics version 7 or Corel Quattro pro 8 with Windows 98 as the operating system. Simple linear regression analyses were done to establish the presences or absences of any relationships between crocodile size (TL) and metal values in some tissue samples. ANOVA was used to determine any significant differences between multiple comparisons while the Student's t-test was used for specific comparisons between two variables.

5.3   RESULTS

No similar references on the effects and concentration of metals in either the blood and/or organs of

C. niloticus could be found and therefore the results cannot be compared with known levels. It was

questionable whether any meaningful comparisons with other species of animals could be elicited,

as these results are unique to the Olifants River alone. The results are thus presented as baseline

data.

No seasonal patterns were found for metal concentrations in the water of the Olifants River

(Maartens, 1994; Seymore, 1994). Water analyses for 1997 and 1998 are included in Tables 5.1 and

5.2 and serve to reiterate the variable nature of water quality in the Olifants River. There appears to

be no visible seasonal pattern, except for increasing TDS levels during the winter (Seymore, 1994).

Invariably a number of the suggested values of the Department of Water Affairs (DWA) had been

exceeded albeit for short periods.   However, the accumulation of metals in the various tissue

samples taken from *C. niloticus* probably happened over a period of years. It is, therefore likely that

the published values (Table 5.1 and 5.2) of water quality might not be applicable. There inclusion

provides an indication of the water quality in the Olifants River for possible deductions. No similar

data were available for the Shingwedzi and Sabi Rivers.

Table 5.1 Water quality analysis for the Olifants River in 1998. DWA values refers to the maximum values laid down by the Dept of Water Affairs (DWA report 1998).

1998	Conductivity	TDS*	Ca	Mg	Cl	Na	K	Fe	pH	P	SO₄	NO₃	TSS
	mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
DWA values	120	800	100	100	100	100	50	1	7.5		250		<25
Jan	45	300	84	84	30	29	10	0.6	7.9	<0.2	92	<1	132
Feb	40	260	76	104	44	36	4	0.5	7.5	0.2	39	1	12
March													
Apr													
May	78	550	120	220	63	63	14	1.2	8.2	2	148	1	9
Jun	87	614	124	76	96	69	14	0.7	8.5	0.2	159	1	100
Jul	128	940	140	356	128	107	31	1.5	8.5	0.2	340	1	9
Aug	100	710	120	280	100	84	20	0.6	8.5	0.2	210	1	10
Sept													
Oct													
Nov													
Dec													
Average	79.7	562.3	111	186.7	76.8	64.7	15.5	0.9	8.2	0.5	164.7	0.8	45.3

*TDS = Total dissolved solids

Table 5.2 Water analysis for the Olifants River in 1997. DWA values refers to the maximum values laid down by the Dept of Water Affairs (DWA report 1998).

1997	Conductivity	TDS*	Ca	Mg	Cl	Na	K	Fe	pH	P	SO$_4$	NO$_3$	TSS
	mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
DWA values	120	800	100	100	100	100	50	1	7.5		250		<25
Jan	30	200	68	56	32	19	3	0.4	8.2	0.2	30	<1	798
Feb	39	250	60	78	30	35	4	0.5	8.1	<0.2	36	<1	15
March	54	360	80	132	20	56	14	0.4	7.8	<0.2	129	<1	15
Apr	39	250	104	116	40	30	4	0.6	7.7	<0.2	85	1	283
May													
Jun													
Jul	59	400	102	120	52	50	5	0.8	7.4	<0.2	87	<1	10
Aug	85	600	140	192	88	72	11	0.6	8.3	<0.2	131	<1	210
Sept	58	400	116	136	64	40	4	0.5	8.1	<0.2	51	0	5
Oct	63	400	160	220	68	57	6	0.5	8.6	<0.2	68	<1	6
Nov	48	320	104	68	28	35	5	0.6	8	0.01	98	<1	311
Dec	66	475	104	152	64	69	9	0.8	8.6	0.2	161	10	80
Average	54.1	365.5	103.8	127	48.6	46.3	6.5	0.6	8.1	0	87.6	1.1	173.3

*TDS = Total dissolved solids

5.3.2 Blood and tissue samples

Crocodiles were collected from three sources in KNP, the Olifants, Sabi and Shingwedzi Rivers.

Table 5.3 shows the details of the crocodiles used for blood and tissue collection.

Table 5.3 Details of crocodiles collected for tissue and blood samples.

Croc no.	Locality	Date	Sex	Size (m)
Silverfish 1	Silwervis dam	10/6/98	Female	2.8
Silverfish 2	Silwervis dam	10/6/98	Male	2.4
Silverfish 3	Silwervis dam	10/6/98	Female	3.2
Silverfish 4	Silwervis dam	10/6/98	Female	2.7
Olifants 1	Olifants River	23/9/97	Female	2.1
Olifants 2	Olifants River	23/9/97	Male	2.6
Olifants 3	Olifants River	24/9/97	Male	3.5
Olifants 4	Olifants River	25/9/97	Female	1.4
Olifants 5	Olifants River	25/9/97	Male	4.2
Olifants 6	Olifants River	2/3/97	Male	3.8
Sabi 1	Sabi river	26/9/97	Male	2.4
Sabi 2	Sabi river	27/9/97	Male	3.9
PMC	PMC mine	12/4/99	Male	3.9

It is possible that the composition of blood (Table 5.4) may be distorted due to the stress suffered by the individual animals (especially those darted with Flaxedil™), even though most crocodiles were killed with a single brain shot. For example, both Olifants 3 and PMC individuals, who had been kept in captivity for between 2 and 36 hours prior to being shot, had either elevated or lower levels for the majority of parameters measured when compared with the rest. Similarly Olifants 6 crocodile had to be shot twice as the first shot missed the brain, and the resultant stress can be seen in the elevated blood values in Table 5.4. Despite this, there were no significant differences between the three locations, Olifants, Sabi and Shingwedzi Rivers.

All the serum samples were slightly milky in appearance, probably due to cholesterol and triglycerides. However, these were not tested for. Despite some of the crocodiles being cachectic, there was no macroscopic difference in the turbidity of their serum.

Table 5.4 Blood parameters of collected crocodiles. SD = Standard deviation.

Parameter	TSP	ALB	GLOB	A/G	Gluc	Na	K	Ca	Mg	SIP	Urea	Creat	Cl
Unit	g/l	g/l	g/l		mmol/l	mmol/l	mmol/l	mmol/l	mmol/l	mmol/l	mmol/l	μmol/l	mmol/l
Silverfish 1	54.6	17.5	37.1	0.47	6.5	145	2.2	2.68	1.1	1.22	0.9	37	106
Silverfish 2	41.6	12.7	28.9	0.44	5.7	144	2.2	2.48	1.1	1.28	0.9	34	112
Silverfish 3	55.5	18.1	37.4	0.48	4.3	150	3.1	5.39	1.48	2.93	1.3	34	116
Silverfish 4	72.1	17.2	54.9	0.31	4.7	148	2.6	5.01	1.58	2.39	1.2	41	115
Range	41.6-72.1	12.7-18.1	28.9-54.9	0.31-0.48	4.3-6.5	144-150	2.2-3.1	2.48-5.39	1.1-1.58	1.22-2.93	0.91-1.3	34-41	106-116
Average	55.95	16.38	39.58	0.43	5.3	146.75	2.53	3.89	1.32	1.96	1.08	36.5	112.25
SD	12.5	2.48	10.95	0.08	0.99	2.75	0.43	1.52	0.25	0.84	0.21	3.32	4.5
Olifants 1	52.6	11.6	41	0.28	NA	136	4	2.65	0.91	1.52	0.1	70	93
Olifants 2	40.2	8.5	31.7	0.27	NA	145	4.4	2.75	1.39	1.68	0.6	65	114
Olifants 3	42.4	10.5	31.9	0.33	11.5	111	5.4	8.39	7.5	0.47	13.9	57	BD
Olifants 5	41.5	9.9	31.6	0.31	26	143	3.9	2.63	1.05	1.46	0.1	49	118
Olifants 6	63.9	14.3	49.6	0.29	5	160	4.3	2.93	1.16	1.27	0.8	68	124
PMC	66.6	14.8	51.8	0.29	3.5	160	5.6	3.14	1.56	0.67	1.1	157	136
Range	40.2-66.6	8.5-14.8	31.6-51.8	0.27-0.33	2.6-11.5	111-160	3.9-5.6	2.63-8.39	0.91-7.5	0.47-1.68	0.1-13.9	49-157	93-136
Average	51.2	11.6	39.6	0.3	5.6	142.5	4.6	3.75	2.26	1.18	2.77	77.67	117
SD	11.7	2.5	9.34	0.02	4.02	18.19	0.72	2.28	2.58	0.49	5.47	39.64	15.78
Sabi 1	38.6	8.3	30.3	0.27	6	145	4.3	2.46	1.24	1.63	0.6	110	89
Sabi 2	42.4	11.3	31.1	0.36	16.9	139	3.6	2.74	1.22	1.22	0.3	42	88
Range	38.6-42.4	8.3-11.3	30.3-31.1	0.27-0.36	6-16.9	139-145	3.6-4.3	2.46-2.74	1.22-1.24	1.22-1.63	0.3-0.6	42-110	88-89
Average	40.5	9.8	30.7	0.32	11.45	142	3.95	2.6	1.23	1.43	0.45	76	88.5
SD	2.69	2.12	0.57	0.06	7.71	4.24	0.49	0.2	0.01	0.29	0.21	48.08	0.71
Overall Range	38.6-72.1	8.3-18.1	28.9-54.9	0.27-0.48	2.6-16.9	111-160	2.2-5.6	2.46-8.39	0.91-7.5	0.47-2.93	0.1-13.9	34-157	88-136
Average	48.15	12.56	35.59	0.35	7.28	140.6	3.57	3.72	1.86	1.58	1.99	53.9	105.67
SD	11.63	3.46	9.19	0.08	4.32	12.6	1.12	1.8	1.82	0.67	3.83	36.47	14.99

This implies that, although the reptiles are not feeding, they may still be lipaemic. No references in the literature as to the presence or absence of urea in the blood could be found and the values obtained in this study should perhaps be treated with circumspect.

The only near similar blood values found were from a study in Australia (Millan *et al.*, 1997) on farmed yearling *C. porosus*. Comparisons between *C. niloticus* in KNP, and those reported by Millan *et al.* (1997) are shown in Table 5.5. Except for the Mg value which was significantly higher (df = 2; $p < 0.05$) in *C. niloticus* from KNP, there were no significant differences (df = 5; $p = 0.977$) between the blood parameters in crocodiles from KNP and the findings by Millan *et al.* (1997). However, it is difficult to draw any conclusions without a knowledge of the specific details of the populations, methodology and equipment used for analysis.

Table 5.5 Biochemical values (± s.e.) for yearling *C. porosus* and *C. niloticus* from Millan *et al.* (1997), and average values (± s.e.) for *C. niloticus* in Kruger National Park (KNP).

Parameter	Unit	*C.niloticus* in Kruger Park	*C.niloticus* (Millan)	*C.porosus* (Millan)
Total serum protein	g/l			
Albumin	g/l	12.56 ± 1.0	19	14 - 23
Globulin	g/l	35.59 ± 2.65	31	27 - 50
Glucose	mmol/l	7.28 ± 1.36	5.9 ± 0.9	4.5 - 12.1
Calcium	mmol/l	3.72 ± 0.52	2.97 ± 0.09	2.41 - 3.45
Magnesium	mmol/l	1.86[a] ± 0.52	0.9[b] ± 0.1	0.8 - 1.4[b]

[a,b] Significant difference ($p < 0.05$) between values with different superscripts.

The concentration of metals in the liver, kidney, muscle and fat tissue of crocodiles sampled are shown in Tables 5.6, 5.7, 5.8 and 5.9, respectively. Due to technical problems all samples could not be analysed. The Pb content from the Silwerfish Dam sample was significantly different from the Olifants River for kidneys (df = 6; $p = 0.001$) but not different for muscle tissue (df = 6; $p > 0.5$). Iron in the kidneys from the Olifants and Sabi Rivers samples was considerably higher (df = 5; $p < 0.05$) than those from Silverfish Dam while aluminium, chromium, manganese and lead were significantly lower (df = 5; $p < 0.05$).

Table 5.6 Values of liver samples collected in the Sabi and Olifants Rivers and Silverfish Dam.

	Al	Cu	Cr	Fe	Mn	Ni	Pb	Sr	Zn
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Silverfish 1	280	20.85	47.4	765.5	13.8	20.95	20.9	5.4	80.75
Silverfish 2	343	12.2	77.75	691.5	17.45	24.5	8.35	12.6	58.35
Silverfish 3	596	30.2	91.85	671.5	19.1	24.75	9.25	24.5	44.45
Silverfish 4	731	29.5	59	634.5	11.8	21.95	18.05	55.15	62.35
Range	280 - 731	12.2 - 30.2	47.4 - 91.86	634.5 - 765.5	11.8 - 19.1	20.95 - 24.75	8.35 - 20.9	5.4 - 55.15	44.45 - 80.75
Average	487.63	23.19	69	690.75	15.54	23.04	14.14	24.41	61.48
SD	212.22	8.47	19.71	55.14	3.33	1.88	6.28	21.95	14.97
Olifants 2	438.95	32.8	2.25	8965	0.1	NA	19.85	5.15	111.3
Olifants 3	311.2	35.35	16.75	16300	0.1	8.25	NA	5.35	86.7
Olifants 4	271	19.05	0.6	9490	0.15	NA	NA	7.55	128.75
Olifants 5	434.45	21.05	0.7	16650	0.1	NA	NA	8.15	75.85
Range	271 - 438.96	19.06 - 35.35	0.6 - 16.75	8965 - 16650	0.1 - 0.15	8.25	19.85	5.15 - 8.15	75.85 - 128.75
Average	363.9	27.06	5.08	12851.25	0.11	8.25	19.85	6.56	100.65
SD	85.67	8.2	7.82	4192.27	0.03	0	0	1.52	23.89
Sabi 1	158.2	37.7	BD	9450	0.1	BD	BD	9.05	176.5
Sabi 2	192.15	23.5	15.45	9405	0.1	7.3	BD	7.85	68.5
Range	158.2 -192.5	23.5 - 37.7	15.45	9405 - 9450	0.1	7.3	0	7.85 - 9.05	68.5 - 176.5
Average	175.18	30.6	15.45	9427.5	0.1	7.3	0	8.45	122.5
SD	24.01	10.04	0	31.82	0	0	0	0.85	76.37

BD = Below detectable   PPM = Parts per million   SD = Standard deviation

Table 5.7 Values of kidney samples collected in the Sabi and Olifants Rivers and Silverfish Dam.

	Al	Cu	Cr	Fe	Mn	Ni	Pb	Sr	Zn
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Silverfish 1	241.50	11.15	71.35	295.50	17.80	22.70	10.80	7.50	32.00
Silverfish 2	327.50	12.50	99.35	274.50	19.00	25.45	7.80	15.15	47.50
Silverfish 3	403.00	17.10	100.05	606.50	19.90	33.35	6.05	28.35	74.85
Silverfish 4	470.50	14.65	57.20	576.50	13.55	34.10	14.15	79.00	62.40
Range	241.5 - 470.5	11.15 - 17.1	57.2 - 100.05	274.5 - 606.5	13.55 - 19.9	22.7 - 34.1	6.05 - 14.15	7.5 - 79	32 - 74.85
Average	360.63	13.85	81.99	438.25	17.56	28.90	9.70	32.50	54.19
SD	98.58	2.60	21.25	177.59	2.81	5.69	3.56	32.17	18.54
Olifants 1	83.95	2.95	0.15	37.65	0.15	BD	BD	6.55	26.20
Olifants 2	37.65	3.85	BD	162.80	0.15	BD	BD	3.80	58.40
Olifants 3	22.50	4.65	18.00	546.00	0.10	8.05	BD	5.95	172.55
Olifants 4	288.75	8.88	1.88	998.75	0.25	BD	BD	15.50	118.50
Olifants 5	244.20	6.20	0.45	855.00	0.15	BD	BD	9.65	96.30
Range	22.5 - 288.75	2.95 - 8.88	0.15 - 18	37.65 - 998.75	0.1 - 0.25	8.05 - 8.05	BD	3.8 - 15.5	26.2 - 172.55
Average	135.41	5.31	5.12	520.04	0.16	8.05	BD	8.29	94.39
SD	122.78	2.33	8.62	419.03	0.05	0.00	BD	4.54	56.21
Sabi 1	34.95	3.55	BD	121.10	0.20	BD	BD	8.10	39.25
Sabi 2	46.60	3.45	0.70	141.45	0.10	BD	BD	7.90	93.45
Range	34.95 - 46.6	3.45 - 3.55	0.7 - 0.7	121.1 - 141.45	0.1 - 0.2	BD	BD	7.9 - 8.1	39.25 - 93.45
Average	40.78	3.50	0.70	131.28	0.15	BD	BD	8.00	66.35
SD	8.24	0.07	0.00	14.39	0.07	BD	BD	0.14	38.33
Overall: Range	22.5 - 470.5	2.95 - 17.1	0.15 - 100.05	37.65 - 998.75	0.1 - 19.9	8.05 - 34.1	6.05 - 14.15	3.8 - 79	26.2 - 172.55
Average	200.10	8.08	38.79	419.61	6.49	24.73	9.70	17.04	74.67
SD	162.57	5.06	43.34	318.63	8.92	10.55	3.56	21.66	43.47

BD = Below detectable   PPM = Parts per million   SD = Standard deviation

Table 5.8 Values of muscle samples collected in the Sabi and Olifants Rivers and Silverfish Dam.

	Al	Cu	Cr	Fe	Mn	Ni	Pb	Sr	Zn
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Silverfish 1	288.00	8.00	79.15	174.00	18.50	25.70	6.25	13.25	68.95
Silverfish 2	349.50	7.50	90.40	131.00	17.45	24.15	3.10	20.30	95.35
Silverfish 3	402.00	8.05	95.65	170.00	17.55	25.10	3.40	42.95	171.60
Silverfish 4	431.50	8.35	96.65	149.00	17.85	25.00	2.00	30.20	103.05
Range	288 - 431.5	7.5 - 8.35	79.15 - 96.65	131 - 174	17.45 - 18.5	24.15 - 25.7	2 - 6.25	13.2 - 42.95	68.9 - 171.6
Average	367.75	7.98	90.46	156.00	17.84	24.99	3.69	26.68	109.74
SD	63.06	0.35	8.02	19.95	0.47	0.64	1.81	12.89	43.75
Olifants 1	146.60	9.65	0.50	246.30	0.10	BD	BD	5.85	41.00
Olifants 2	49.70	9.65	BD	298.60	0.15	BD	BD	5.50	39.55
Olifants 3	343.20	14.20	13.30	720.00	0.10	9.25	20.25	6.60	35.60
Olifants 4	130.00	7.15	6.45	209.20	0.15	BD	BD	7.20	43.65
Olifants 5	66.70	11.85	18.95	524.00	0.15	11.35	BD	8.35	37.25
Range	49.7 - 343.2	7.15 - 14.2	0.5 - 18.95	209.2 - 720	0.1 - 0.15	9.25 - 11.35	20.25 - 20.25	5.5 - 8.35	35.6 - 43.65
Average	147.24	10.50	9.80	399.62	0.13	10.30	20.25	6.70	39.41
SD	116.94	2.65	8.04	216.84	0.03	1.48	0.00	1.13	3.15
Sabi 1	104.20	12.65	BD	643.50	0.05	BD	BD	8.35	45.90
Sabi 2	42.70	12.60	18.40	586.50	0.15	9.10	BD	8.00	43.40
Range	42.7 - 104.2	12.6 - 12.65	18.4 - 18.4	586.5 - 643.5	0.05 - 0.15	9.1 - 9.1	BD	8 - 8.35	43.4 - 45.9
Average	73.45	12.63	18.40	615.00	0.10	9.10	BD	8.18	44.65
SD	43.49	0.04	0.00	40.31	0.07	0.00	BD	0.25	1.77
Overall: Range	42.7 - 431.5	7.15 - 14.2	0.5 - 96.65	131 - 720	0.05 - 18.5	9.1 - 25.7	2 - 20.25	5.5 - 42.95	35.6 - 171.6
Average	214.01	9.97	46.61	350.19	6.56	18.52	7.00	14.23	65.94
SD	149.96	2.45	42.27	222.31	8.94	8.11	7.57	12.16	42.29

BD = Below detectable   PPM = Parts per million   SD = Standard deviation

Table 5.9 Values of fat samples collected in the Sabi and Olifants Rivers and Silverfish Dam.

	Al	Cu	Cr	Fe	Mn	Ni	Pb	Sr	Zn
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Silverfish 1	256.00	7.25	77.90	131.50	16.15	25.65	13.30	10.30	8.15
Silverfish 2	372.00	7.95	133.80	250.00	23.65	35.70	BD	19.85	14.20
Silverfish 3	395.50	7.05	81.55	136.50	15.65	23.65	6.80	34.25	9.15
Silverfish 4	447.00	8.25	128.25	234.50	19.45	39.60	5.35	28.45	13.20
Range	256 - 447	7.05 - 8.25	77.9 - 133.8	131.5 - 250	15.65 -23.65	23.65 - 39.6	5.35 - 13.3	10.3 - 34.25	8.15 - 14.2
Average	367.63	7.63	105.38	188.13	18.73	31.15	8.48	23.21	11.18
SD	80.74	0.57	29.74	62.85	3.69	7.72	4.23	10.45	2.97
Olifants 2	26.80	5.80	0.70	69.30	0.10	BD	1.90	5.75	12.00
Olifants 3	57.05	5.55	16.50	150.40	0.10	7.55	BD	5.60	61.75
Olifants 5	249.45	6.90	26.65	673.50	0.15	17.95	BD	9.25	8.60
Range	26.8 - 249.45	5.55 - 6.9	0.7 - 26.65	69.3 - 673.5	0.1 - 0.15	7.55 - 17.95	1.9 - 1.9	5.6 - 9.25	8.6 - 61.75
Average	111.10	6.08	14.62	297.73	0.12	12.75	1.90	6.87	27.45
SD	120.77	0.72	13.08	327.94	0.03	7.35	0.00	2.07	29.75
Sabi 2	55.60	6.50	30.30	292.00	0.15	20.55	BD	8.15	7.55
Overall: Range	26.8 - 447	5.55 - 8.25	0.7 - 133.8	69.3 - 673.5	0.1 - 23.65	7.55 - 39.6	1.9 - 13.3	5.6 - 34.25	7.55 - 61.75
Average	232.43	6.91	61.96	242.21	9.43	24.38	6.84	15.20	16.83
SD	167.87	0.95	51.08	189.12	10.23	10.81	4.77	11.02	18.32

BD = Below detectable   PPM = Parts per million   SD = Standard deviation

Figures 5.1 to 5.4 graphically shows the different metal values in the tissue samples collected from the various locations.
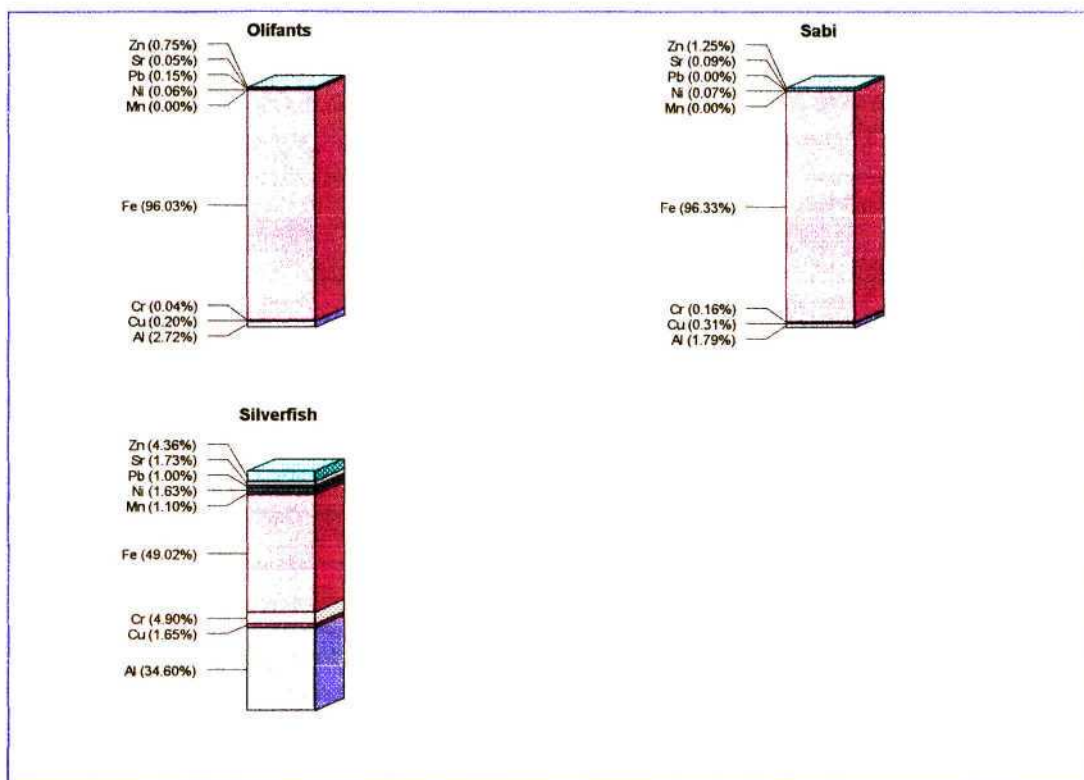
Figure 5.1 Metal values for liver samples taken from crocodiles in the Olifants and Sabi Rivers and Silverfish Dam. Values are expressed in percentages.
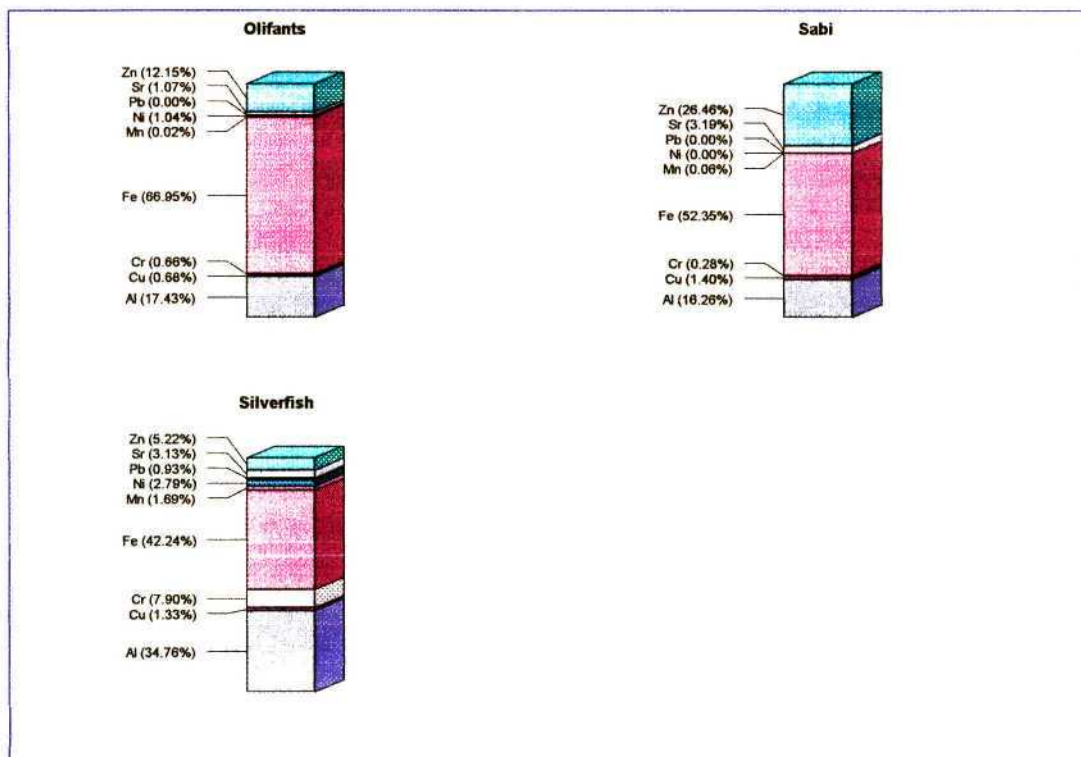
Figure 5.2 Metal values for kidney samples taken from crocodiles in the Olifants and Sabi Rivers and Silverfish Dam. Values are expressed in percentages.

Figure 5.3 Metal values for muscle samples taken form crocodiles in the Olifants and Sabi Rivers and Silverfish Dam. Values are expressed in percentages.

Figure 5.4 Metal values for fat samples taken from crocodiles in the Olifants and Sabi Rivers and Silverfish Dam. Values are expressed as percentages.

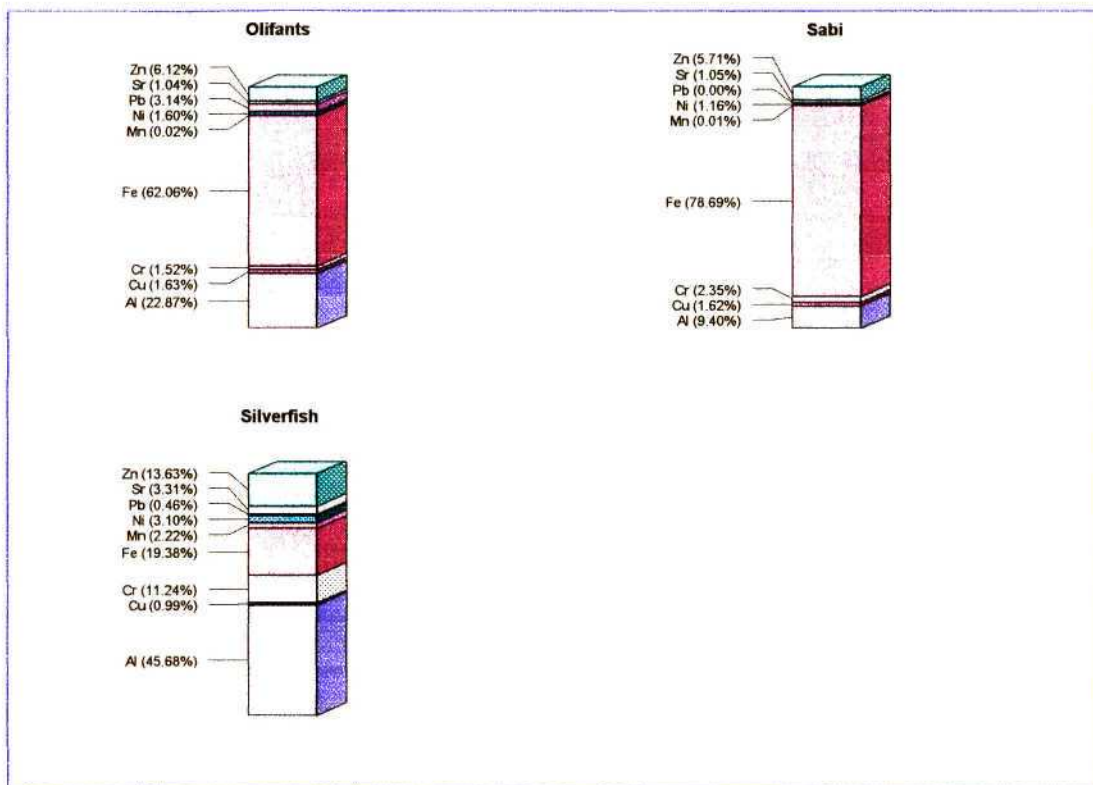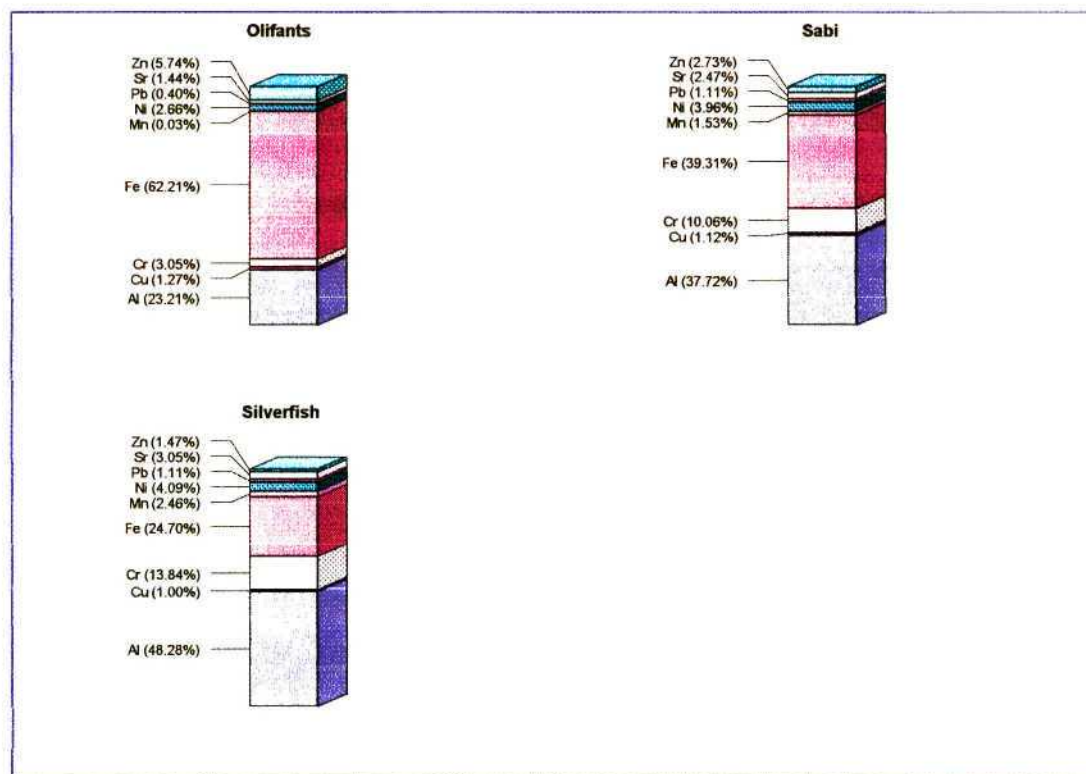Iron is the only metal that showed some relationship between accumulation in the muscle and size

(TL) of the crocodile (Figure 5.5). Although not significant ($p = 0.078$) and the goodness of fit is poor

($r^2 = 0.304$) there is a trend for larger crocodiles to have elevated levels of iron concentration in the

muscle samples. This in part, supports the suspicion that contamination of iron took place over a

period of time and that bioaccumulation has occurred in some tissue eg: muscle. However, the
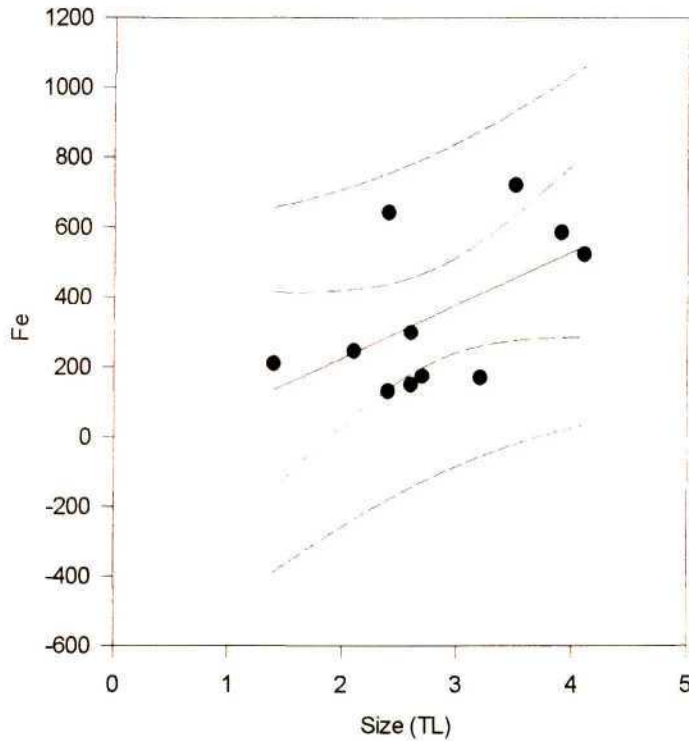
Figure 5.5 Relationship between size (TL) and iron (Fe)
concentration in muscle samples ($r^2 = 0.304$; $p = 0.078$).
(- - -) 90 and 95% confidence intervals.

converse relationship occurred within fat tissue (Figure 5.6). Smaller individuals tended to have

higher concentrations of Fe in their fat tissues. No indication of fat index or percentage fat to mass

was calculated and as such the smaller individuals could have had the same amount of iron but less

fat, and therefore a higher concentration, than larger crocodiles.

Aluminium in muscle tissue differed significantly between the three locations ($p < 0.01$) and in the

Olifants River, between muscle, liver and kidney samples ($p < 0.05$). Iron concentrations were

significantly different between locations ($p = 0.01$) and between liver, kidney, muscle and fat tissue

within the Silverfish Dam samples ($p < 0.01$).

Copper concentrations were similar between locations (p = 0.605), but differed significantly between liver, kidney, muscle and fat tissue in the Olifants River samples (p = 0.003).
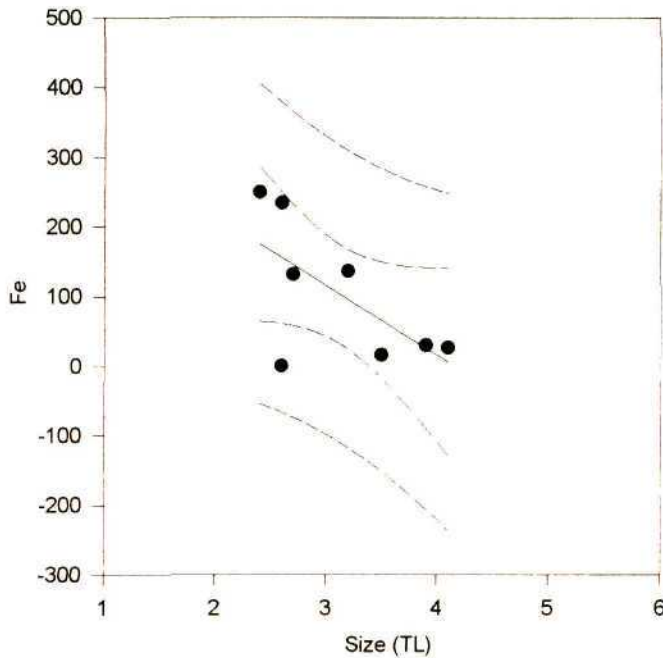

Figure 5.6 Relationship between size (TL) and iron (Fe) concentration in fat tissue (r^2 = 0.421; p = 0.081). (- - -) 90 and 95% confidence intervals.

In Table 5.10 the values of the various metal assays obtained in the survey are ranked. Iron was present in kidney, liver and muscle tissue, but occurred in especially high levels in the liver. Zinc and Al were the next most abundant, while the values of the other metals tested for fluctuated. The levels of Fe, Al and Zn, especially in those crocodiles from the Olifants River, are thought to be due to bioconcentration from an environment where the levels of them are seasonally high. Similar results have been obtained in fishes from several survey points in the Olifants River (Van Der Merwe et al. 1993; Van Vuren et al., 1994; Du Preez et al., 1997; Robinson et al., 1997).

Table 5.10 Comparison, ranked from 1 to 9, of the distribution of heavy metals in various organs of crocodiles from different locations in the Kruger National Park.

Metal	Liver			Kidney			Muscle			Fat		
	SF	O	S	SF	O	S	SF	O	S	SF	O	S[a]
Fe	1	1	1	1	1	1	2	1	1	2	1	1
Al	2	2	2	2	2	3	1	2	2	1	2	2
Zn	4	3	3	4	3	2	3	3	3	7	3	6
Cr	3	8	5	3	7	6	4	7	4	3	4	3
Sr	5	7	6	5	4	4	5	8	7	5	6	5
Cu	6	4	4	8	6	5	8	5	5	9	7	7
Ni	7	6[a]	7	6	5[b]	8	6	6[c]	6	4	5	4
Mn	8	9	8	7	8	BD	7	9	8	6	8	8
Pb	9	5[a]	9	9	BD	BD	9	4[b]	BD	8	9	9

SF   Silverfish Dam
O   Olifants River
S   Sabi River
[a]   Data of only one crocodile
[b]   Data of one crocodile; the remaining four's values were below detection
[c]   Averaged data of two crocodiles; the remaining one's values were below detection
BD   Below detection

5.4   DISCUSSION

The blood composition data obtained from the Nile crocodiles in the KNP fall within the ranges of those reported for Nile crocodiles occurring elsewhere (Foggin, 1987; Watson 1990; Stein 1996; Leslie 1997) as well as for other crocodilians, *Crocodylus acutus*, *Crocodylus porosus* and *Alligator mississippiensis* (Millan *et al*. 1997). This suggests that the crocodiles in KNP have no serious deficiencies or excess in blood composition.

The possible presence of pollutants, such as heavy metals, in water is reflected in the accumulation in, and effects on, aquatic animals. Once metals have accumulated in the tissues of fish, for example, they may cause biochemical, physiological, morphological and genetic transformations, which can ultimately influence specific performances, such as the ability to survive, develop, grow and reproduce (Nagel 1991). Although Nile crocodiles are less dependent on water for their existence than fish, pollutants may affect them indirectly as it may be acquired through ingestion of fish rather than absorption from the water.

With the exception of strontium, lead and possibly aluminium, the elements tested for in this survey are essential macro- or micronutrients in mammals but their role in biochemical and metabolic pathways in Nile crocodiles are poorly understood (Frye, 1991). Although these minerals and trace elements are more than likely required by reptiles (Frye 1991), their roles in the biochemical and metabolic pathways of Nile crocodiles are poorly documented and therefore cannot be meaningfully discussed. None of the sample sites chosen were classified as non-polluted and therefore no site could be used as a pollution-free control from which the effects of polluted water on crocodile ecology could be measured. The results do however, indicate that there were significant differences in heavy metal concentrations within body tissues between the three sample sites. These differences were also observed within individuals from the same location. The differences in the values of the metals in the frozen and formalinized tissues are difficult to explain, as they were collected at the same time, and from the same site in the respective organs. The same 10% neutral buffered formalin solution, prepared with distilled water, was used for all the preserved samples. The likely explanation for the difference is the possibility that residues of the various metals may have been present in the concentrated formaldehyde solution. The lack of any consistent trends in the accumulation of heavy metals between locations and within individuals from the same source, could be attributed to the small number of samples obtained and the variation in sample collection.

The inconclusive results obtained from the crocodile samples does not reflect the possible contamination of the Olifants River with heavy metals, nor the influence of the metals on the physiology of the crocodiles. Taking into consideration that bio-accumulation of especially Fe, Al and Zn has been reported in fish collected from the Olifants River, the metals in the various organs of the crocodiles, in all probability, will not be responsible for emaciation or mortalities in the foreseeable future.

CHAPTER 6:

CONCLUSIONS

The main study in the Olifants River was done over a period of five years, 1994 - 1998, with the radio telemetry only ending in 1999. The objectives of the study were to investigate possible movement(s) of adult crocodiles in the Olifants River, to collect data on nesting patterns, clutch size and egg measurements and to establish baseline data on the degree and effects of pollution on crocodiles

Movements of large adult crocodiles were monitored from 1994 to 1997 with a combination of three methods. The study area was covered on foot at an interval of four times per annum and total numbers of crocodiles were counted. Besides totals, the number of groups was noted as well. The second method was a series of spot counts at selected locations at 14 day intervals to obtain a higher resolution of fluctuations in numbers. Radio telemetry was the third method used.

The combination of this three methods produced results that strongly suggests a difference in behaviour between populations in large bodies of water and free-flowing rivers. Radio transmitters were fitted to adult crocodiles of both sexes and their movements were monitored over a period of 18 months. Many transmitters were lost but at the end of the study five transmitters were still active. Radio telemetry showed that some individuals remained static for the entire period, others moved away from the capture site to either return later or not at all. Movements over distances exceeding 15 km took place and it always coincide with high water levels.

This study showed that the current population of crocodiles in the Olifants River is unique with regards to movements of individuals. More than one period of movement was found, a seemingly large shift in numbers during December and two smaller movements during May and August of all study years. The major movement in December coincides with a high flow period in the river, and as such water level seems to play a significant role in determining/governing movement. Reproduction, defined as mating and nesting, is another possible factor that influenced movements. Mating occurred from late in July to the end of September, and was observed on various occasions. The

prerequisite for mating is a deep pool with slow flowing water. Again, water levels determined the locations of these pools and adults had to move to selected locations for mating. Sectors D and Gorge were significantly different from sectors A, B and C regarding total numbers. In terms of years, 1996 and 1997 differed from 1994 and 1995.

Nesting was seen during the last week of October till the end of January, and breeding females displayed aggressive behaviour toward their own species, irrespective of size and sex. This behaviour influenced numbers in the different sectors. The sectors with most nests, seemed to have fewer non-breeders.

Nesting data suggested that there was no significant difference between open and closed systems. Although clutch size, and egg measurements differed from closed systems, the difference was put toward environmental adaptations rather than behavioural differences. Crocodiles are renown for their ability to adapt to changing environments, and the differenced found in this study along the Olifants River can be explained and justified in terms of environmental factors. There was a significant difference in the sizes of nesting females for high and low rainfall periods. The objectives for this part of the study were achieved and the hypothesis of no difference was accepted.

Food was another factor that could have influenced movement, and although no data were collected on this aspect, indications are that it contributed substantially towards movements of both adults and juveniles.

Pollution and a possible accumulation of metals in various tissues were investigated but the degree of pollution in crocodiles was inconclusive, partly because of a lack of data. The results did show that there was a significant difference in heavy metal content between various tissue samples from the same crocodile and between crocodiles from different locations. However, it was again not possible to determine the effects of these metals on the physiology of crocodiles because of a lack of data. A more advanced study is required to determine the effects of pollution on the physiology of crocodiles.

Shortcomings that emanated from this study were:

▸ Home ranges and territories should be studied in more detail to determine their extent and size as this will aid in territory occupation and local movements of individuals.

▸ Radio telemetry should have included smaller individuals to indicate the dispersal and survival of juveniles and hatchlings.

▸ A larger sample of the population should have been caught to establish a possible ratio of males:females. This is important in determining the management actions and the monitoring of the total population in the Olifants River.

▸ More data should have been collected on nesting successes and numbers of hatchlings. The survival and dispersal of hatchlings in an open system is still largely unknown.

▸ A fat index should have been calculated from the individuals that were sampled.

The results from this study have brought the following concerns to the attention of management:

♦ The need to establish a TPC (Threshold of probable concern) for the population in the Olifants River.

♦ Movement during certain times of the year has been shown and therefore needs to be incorporated in an overall masterplan for the management of the species.

♦ Times and conditions for mating, nesting and movement were determined, and all management activities along water courses should be sensitized towards this.

♦ Highlight the need to investigate the degree of heavy metal pollution in the Olifants River and what effects these have on the crocodile population.

♦ Water quantity should be monitored more closely and at different locations along the river to minimise the influence of artificially controlled water levels.

♦ Monitoring of the survival and movements of adults must be done on an annual basis.

♦ It is strongly suggested that nests be counted annually. Nesting is an indication of the viability of the population and as such should be utilized by management.

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