The ecology and population dynamics of the Nile crocodile *Crocodylus niloticus* in the Flag Boshielo Dam, Mpumalanga province, South Africa

by

Petrus Johannes Botha

Submitted in partial fulfilment of the requirements for the degree of

Magister Scientiae (Wildlife Management)

at the

Centre for Wildlife Management

Faculty of Natural and Agricultural Sciences

University of Pretoria

Pretoria

January 2005

This work is dedicated to the memory of my late father,

I wish we could have shared this experience

The ecology and population dynamics of the Nile crocodile *Crocodylus niloticus* in the Flag Boshielo Dam, Mpumalanga province, South Africa

by

Petrus Johannes Botha

Supervisor: Prof W van Hoven

Centre for Wildlife Management

University of Pretoria

Pretoria

ABSTRACT

During the period January 2002 to November 2003 surveys were made of the Nile crocodile population in the Flag Boshielo Dam, Mpumalanga. The aim of these surveys was to estimate the size of the population and to determine the population structure based on size. The double-survey method was used to estimate the number of individual crocodiles in the population. The density in terms of biomass was compared to results of other studies on Nile crocodile populations in Africa. The size of every crocodile observed during spotlight counts and aerial surveys were estimated. This was used to group individual animals together in predetermined size classes. The number of crocodiles in each size class was expressed as a percentage of the total and used to establish the population structure.

The entire shoreline of the Flag Boshielo Dam was divided into 14 segments using easily recognisable reference points. The number of times that crocodiles were observed per size class in each segment was entered into an Excel spreadsheet. The spreadsheet functions allowed for the number of crocodiles observed per segment to be expressed as a percentage of the total number of animals seen. The GPS locations of every crocodile counted during night-counts were plotted on a GIS map of the Flag Boshielo Dam. Maps showing the dispersal patterns of crocodiles in the Flag Boshielo Dam could thus be compiled.

The number of times that crocodiles were observed per size class in each segment of shoreline over the total study period was noted and entered into a spreadsheet and grouped together by size class. Once grouped in this way, the frequency at which crocodiles were observed per segment of shoreline were determined and expressed as a percentage of the total number of animals seen, per size class, over the study period in that particular area. The data contained in the spreadsheet was manipulated to group together data of the colder months (May - August) and to group data together from the warmer months (January - April and September - December). The extent of any seasonal variation in dispersal of crocodiles in the Flag Boshielo Dam was determined by comparing the sets of data.

A total of 13 crocodiles were captured and VHF transmitters attached to their tail scutes. A further 2 crocodiles were captured and had GPS/GSM transmitters attached to the nuchal scales directly behind their heads. Radio tracking of these animals was done to establish their daily movements and to try and evaluate the size of their territories. The distribution data of the radio-tagged crocodiles were plotted and analysed with the ArcView 3.2 GIS software package. Range use analysis was achieved by using the *Spatial Analyst Extension* of ArcView 3.2 together with the *Animal Movement Analysis* extension.

Nest surveys were done each year from 2000 to 2004. Attempts were made to measure a number of environmental parameters at each identified nest. These included the estimated total length of the nesting female, the length of the hindfoot print (HF), the distance from the nest to water, the height of the nest above the water, the incline of the shoreline, estimated exposure of the nest to sunlight, height and species of vegetation near the nest and the type of substrate.

ACKNOWLEDGEMENTS

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

- My wife Joyce and daughter Elzahn for understanding my passion for Nile crocodiles and allowing me the freedom to follow the direction that my life took and also for their enjoyable company during many spotlight counts.

- The South African Veterinary Foundation and the members of their management, for awarding a grant to the project.

- The Centre for Wildlife Management at the University van Pretoria.

- The Wiplinger Bursary and the Koos du Plessis Bursary Fund for grants awarded to this project.

- The National Geographic Society for awarding a grant to purchase two GPS/GSM transmitters.

- GIMS, especially Messrs Charles Oosthuizen and Stuart Martin, for sponsoring the ArcView 3.2 GIS and Spatial Analyst Extension software.

- Mr Shane Nesbitt of Denichaud (Pty) Ltd for providing financial assistance to the project.

- Prof Wouter van Hoven for his valuable advice, extreme patience and encouragement beyond the call of duty.

- Prof Koos Bothma for valued support and for always asking about the project.

- Mrs Liset Swanepoel at the Centre for Wildlife Management for her support and long suffering patience to explain the University's many administrative procedures to me.

- Dr Brady Barr for sharing his capture technique and knowledge of crocodilians, for donating capture equipment and his ongoing interest and support of the project.

- Ms Andrea Nix of National Geographic Television for donating VHF transmitters and other equipment to the project.

- National Geographic Television.

- Dr Johan van den Berg for donating flying time to locate nests, do aerial surveys and radio tracking.

- Mr Douw "Swannie" Swanepoel for his valuable advice, for introducing me to crocodilians and for encouraging me to start this project.

- Mr Nico Coetzee for his selfless assistance during the many spotlight counts and the capture of crocodiles and for contributing his considerable knowledge of the Flag Boshielo Dam to the project.

- Mr Danie Wahl for kind permission to use the photos of the Flag Boshielo Dam and the Arabie Hengelparadys on page 12 and page 110.

- Dr Richard Fergusson and Dr James Perran Ross of the IUCN/SSC Crocodile Specialist Group for their valuable comments and advice on aspects of the project.

- Prof Remo Lobetti and Dr Kobus du Toit for their advice, assistance and support.

- Mr Bertus Homan who selflessly gave up his free time to assist with spotlight counts and with the capture of crocodiles to fit the GPS/GSM transmitters.

- Mr André Hoffman whose many welcome remarks and suggestions were incorporated into this study, for his encouragement and long hours spent with me during attempts to collect the stomach contents of crocodiles.

- My mother, my brothers Tony and Wiele and my sister Susan for their ongoing support, many late night discussions, encouragement and frequent enquiries into progress with the project.

- The Naude family for their keen interest in and much appreciated support of my project especially Mrs Dorothy Naude for her efforts to secure sponsorship for the project.

- Mr Peter van Niekerk of GT Auto Engineering in Marble Hall for custom manufacturing some of the capture equipment free of charge.

- Mr Albert Malan for allowing me the time to work on the project.

- Mr and Mrs Bruce and Lynette Esson of Cilabi who became true friends of the project.

- Oom Nic Doman (secretary of the Marble Hall Business Chamber) who supported the project at Business Chamber meetings.

- The Marble Hall Business Chamber for sponsoring repairs to the boat.

- Mr Kevin Bolton of K.J. Bolton Consultant the GPS Specialists.

- Mr André Treurnich and the Flag Boshielo Eco Tourism Company for allowing me access to the dam through their resort.

- Mr Frans Masilela and Mr Simon Mathaela for their assistance with launching and retrieving the boat from the dam.

- The many volunteers who assisted with spotlight counts during many late nights.

TABLE OF CONTENTS

List of tables

List of figures

CHAPTER 1

INTRODUCTION

Historically the larger aquatic vertebrates of South African rivers, particularly *Crocodylus niloticus* were relatively widespread. Crocodiles, like hippopotami (*Hippopotamus amphibius*) are important components of aquatic ecosystems because of their size and the amount of biomass tied up in their bodies (Davies and Day, 1998). Organic materials and nutrients are redistributed by Nile crocodiles in ecosystems but particularly so in small isolated water bodies (Davies and Day, 1998). Therefore, if crocodiles are removed from any system, the dynamics of nutrient recycling should be noticeably altered. As a group, crocodilians are of great antiquity with hundreds of fossil forms and three major radiations (Ross, 1998). Crocodilians are implicated in positive effects in their environments as “keystone species” that maintain the structure and function of ecosystems through their activities which include selective predation on fish species, recycling of nutrients and maintenance of wetlands in times of drought (King, 1988; Craighead, 1968).

The most recent revision of the taxonomy of crocodilians was undertaken by King and Burke (1997). They recognised 23 species of crocodilian arranged in three families i.e. Alligatoridae, Crocodylidae and Gavialidae. Appendix I shows the taxonomy of the Order Crocodilia in more detail. The Nile crocodile is among the largest and best known of all the crocodilians. Nile crocodiles are widely distributed throughout sub-Saharan Africa and Madagascar (Ross, 1998). Historical records indicate its range formerly extended into southern Israel, Jordan and the Comoros Islands (Ross, 1998). Nile crocodiles can be found in a wide variety of habitat types including lakes, rivers, freshwater swamps and even in brackish water environments.

Although the status of the Nile crocodile is relatively secure and abundant in southern and eastern Africa, where it is regarded as a species with a "moderate" need for the recovery of the wild population, it is greatly depleted in western Africa (Ross, 1998). The Status Survey and Conservation Action Plan of the IUCN Crocodile Specialist Group (Ross, 1998) states that among the 20 African countries where some indication of the status of *C. niloticus* is known, their numbers are considered to be severely depleted in six (30%), somewhat depleted in 12 (60%) and not depleted in two countries (10%). Two other species of crocodilian occur in Africa. They are the slender-snouted crocodile (*Crocodylus cataphractus*) and the dwarf crocodile (*Osteolaemus tetraspis*). There is much overlap in the distribution of these two species as both occur in Central Africa, West Africa and West-central Africa. Neither occurs in southern Africa.

Figure 1: Distribution of *Crocodylus niloticus* in Africa (Britton, 2004).

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

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

Aerial surveys during 1992 indicated that the *C. niloticus* population in the Flag Boshielo Dam seemed to prosper while the population in Loskop Dam had declined sharply (Jacobsen, 1992).

This was confirmed in 1993 when a survey by Kleynhans and Engelbrecht (1993) showed that the Flag Boshielo Dam (then known as the Arabie Dam) has the highest density of Nile crocodiles, in terms of numbers, per kilometre in the Olifants River between the Loskop Dam and the boundary fence of the Kruger National Park.

The Loskop Dam is situated about 85 km upstream from the Flag Boshielo Dam in the Olifants River. Jacobsen, (1988) suggested that the Flag Boshielo Dam (Arabie Dam) population of Nile crocodiles may very well be the last fairly large viable population that occurs outside an officially protected area in the former Transvaal Province of South Africa. In line with Jacobsen's view, Swanepoel (2001) states that the Flag Boshielo Dam population of Nile crocodiles is in his view, "a significant population that deserves to be protected".

The Department of Water Affairs and Forestry (DWAF) is planning to increase the height of the Flag Boshielo Dam by 5 meters starting in October 2005 (Department of Water Affairs and Forestry, 2003a). The resulting increase in the water level will undoubtedly have a serious effect on the numbers of crocodiles, their nesting ecology and their distribution in the Flag Boshielo Dam.

Important hypotheses regarding the status of the *C. niloticus* population in the Flag Boshielo Dam could not be tested against the data and information collected by various Nature Conservation Departments over the years. This was due to the existing data being unstructured and too unspecific to be of any value. The proposed increase in the height of the Flag Boshielo Dam by DWAF provided the opportunity to test the hypotheses that:

- The natural population of *C. niloticus* in the Flag Boshielo Dam presents a healthy population structure comparable to normal wild populations.

- The natural population of *C. niloticus* in the Flag Boshielo Dam shows seasonal movement within the impoundment and the inlet of the Olifants and Elands Rivers.

- The *C. niloticus* population in the Flag Boshielo Dam stays in a limited range and do not use the total surface area of the lake.

- Certain environmental parameters determine the choice of nesting sites by *C. niloticus* in the Flag Boshielo Dam.

The following aspects of the Nile crocodile in the Flag Boshielo Dam were researched in order to test the hypotheses:

- The number of crocodiles present.
- The population structure based on the size of individual crocodiles.
- The distribution of the crocodiles.
- The home-range of selected individual crocodiles.
- The seasonal distribution of the crocodiles.
- The size (therefore age) of breeding female crocodiles.
- The number of nests used by breeding females.
- The number of crocodile nests that hatch successfully.
- The environmental factors present at identified nests used by breeding females.

These objectives formed the basis of this study and the outcomes of the research into these objectives are discussed in the chapters that follow.

CHAPTER 2

STUDY AREA

Location

The Flag Boshielo Dam (24°49’05”S; 029°26’39”E) is situated about 25 km north-east of the town of Marble Hall (Clark, 1997) in the extreme north-western corner of South Africa’s Mpumalanga Province. On a wider scale, the dam is about 200 km north of Pretoria and about the same distance south-east of Polokwane (Pietersburg). Other local towns of interest in the general area of the Flag Boshielo Dam are Groblersdal and Middelburg.

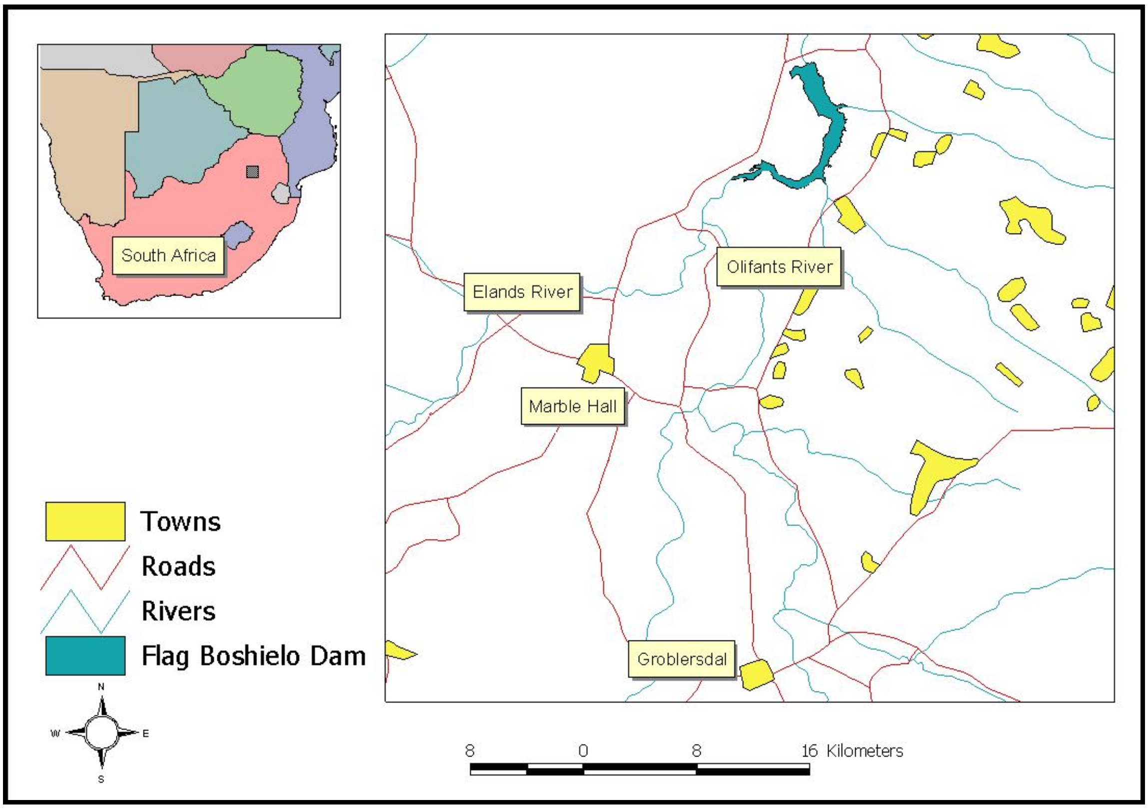

Figure 2: Locality of the Flag Boshielo Dam near Marble Hall in the Mpumalanga province of South Africa. The yellow polygons represent towns and villages.

Several large impoundments situated upstream from the Flag Boshielo Dam have a big influence on the water level of this dam. The biggest of these are the Loskop Dam, about 85 km upstream in the Olifants River, and also the Mkhombo Dam (Rhenosterkop Dam) which can be found about 70 km upstream in the Elands River.

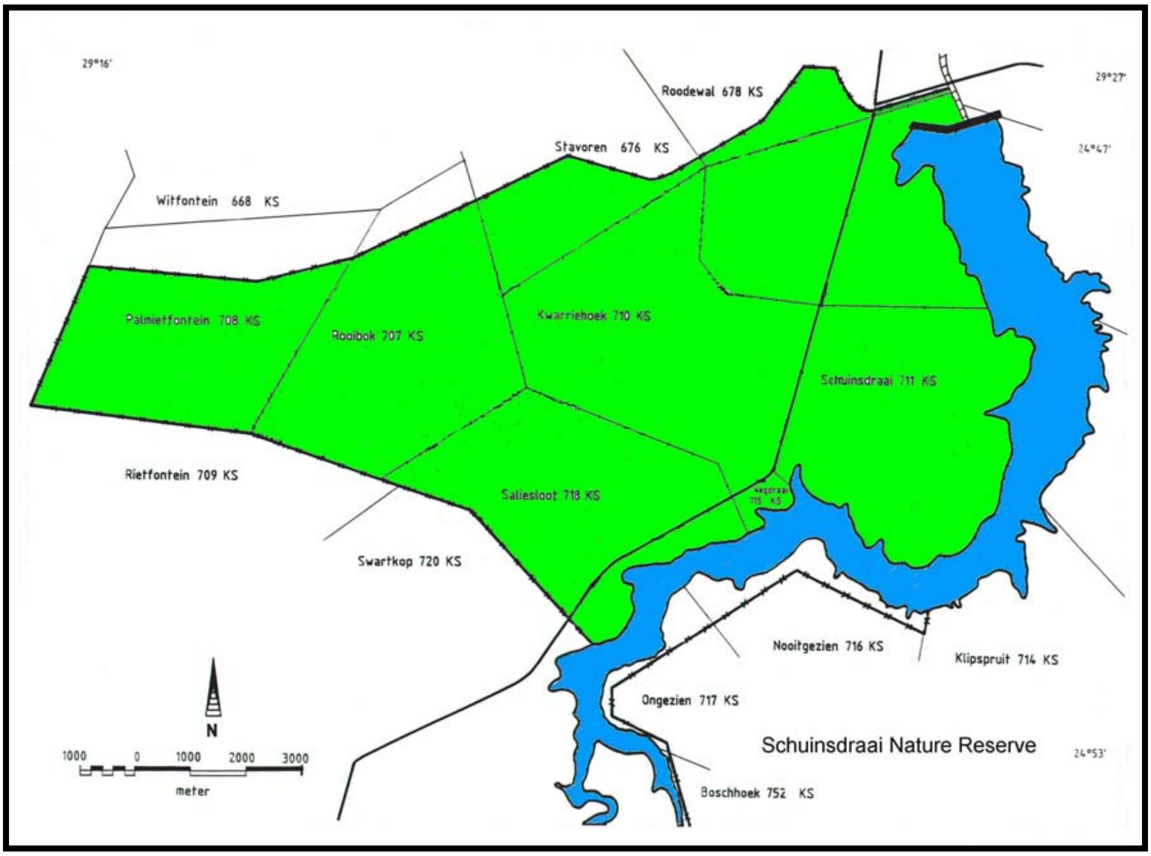

Figure 3: Map showing Schuinsdraai Nature Reserve (shown in green) in relation to the Flag Boshielo Dam (shown in blue)

The confluence of the Elands River with the Olifants River forms an important landmark at the inlet to the Flag Boshielo Dam. Several other small non-perennial streams also feed the dam but only for short times during periods of high rainfall. The western shore of the Flag Boshielo Dam forms part of the Schuinsdraai Nature Reserve, a 9037 ha provincial nature reserve. This means that the nesting sites and basking sites are protected to some extent but not the water where the crocodiles live and hunt.

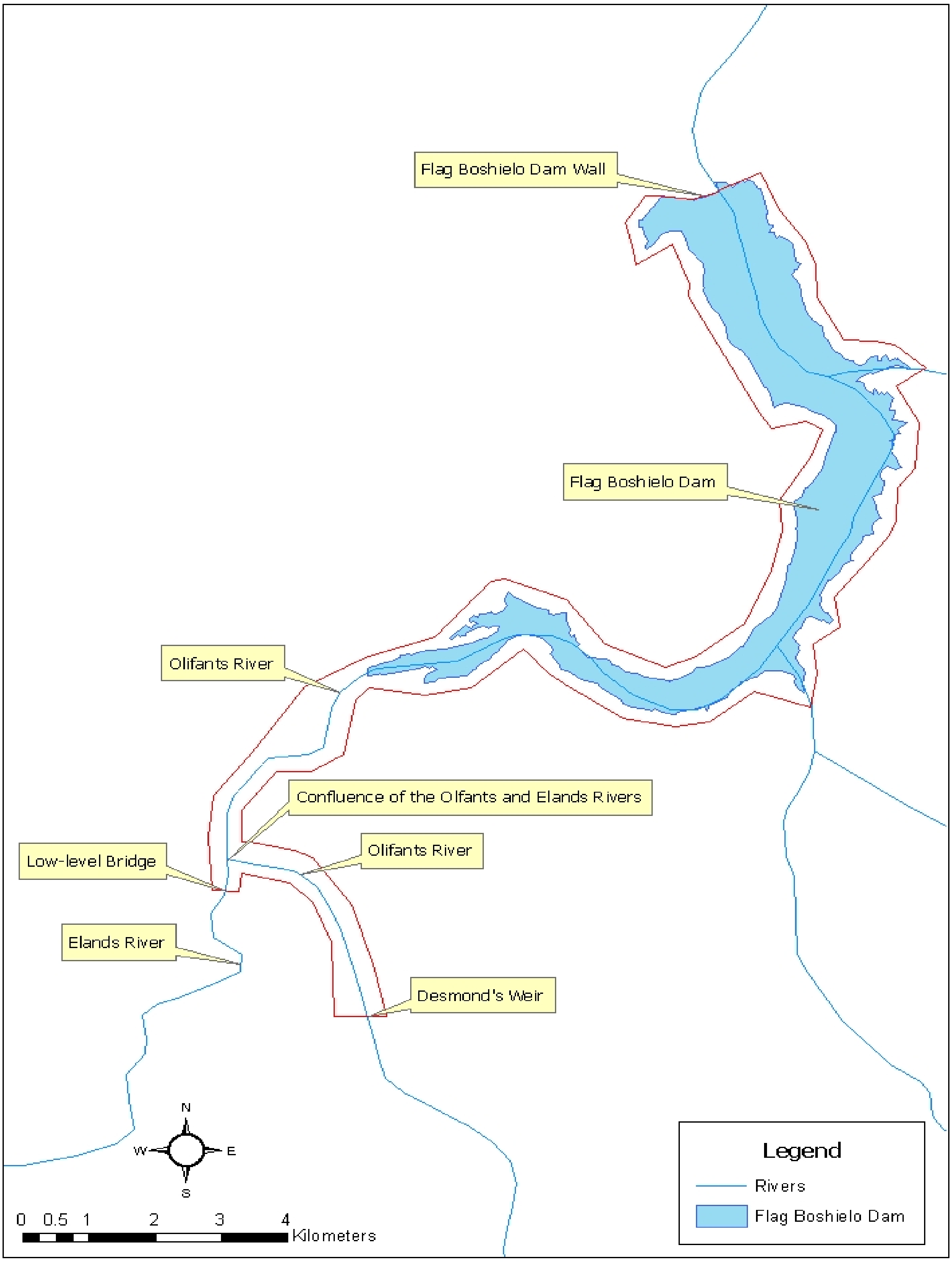

Figure 4: Map showing the boundaries of the study area in red. The study area included the whole of the Flag Boshielo Dam and one kilometre of the Elands River upstream of its confluence with the Olifants River and also 3.5 kilometres of the Olifants River upstream of its confluence with the Elands River.

The area where the study was concentrated can be described as the area that includes the whole of the Flag Boshielo Dam from the dam wall upstream to the confluence of the Olifants and Elands Rivers at the inlet to the dam. The study area also included the area about one kilometre upstream in the Elands River from its confluence with the Olifants River. This point was marked as roughly where the Elands River is crossed by the low level bridge on the Swartkop gravel road. The study area also extended for 3.5 km upstream in the Olifants River from its confluence with the Elands River to the weir known locally as Desmond's Weir. Both rivers become too shallow and rocky beyond these points to be negotiated safely by boat.

Climate

According to the South African Weather Service, the Flag Boshielo Dam falls within the Northern Transvaal climatic zone (Schulze, 1994). The climate of the Olifants River basin is described as semi-arid and hot with an average annual rainfall of 380 - 700 mm.

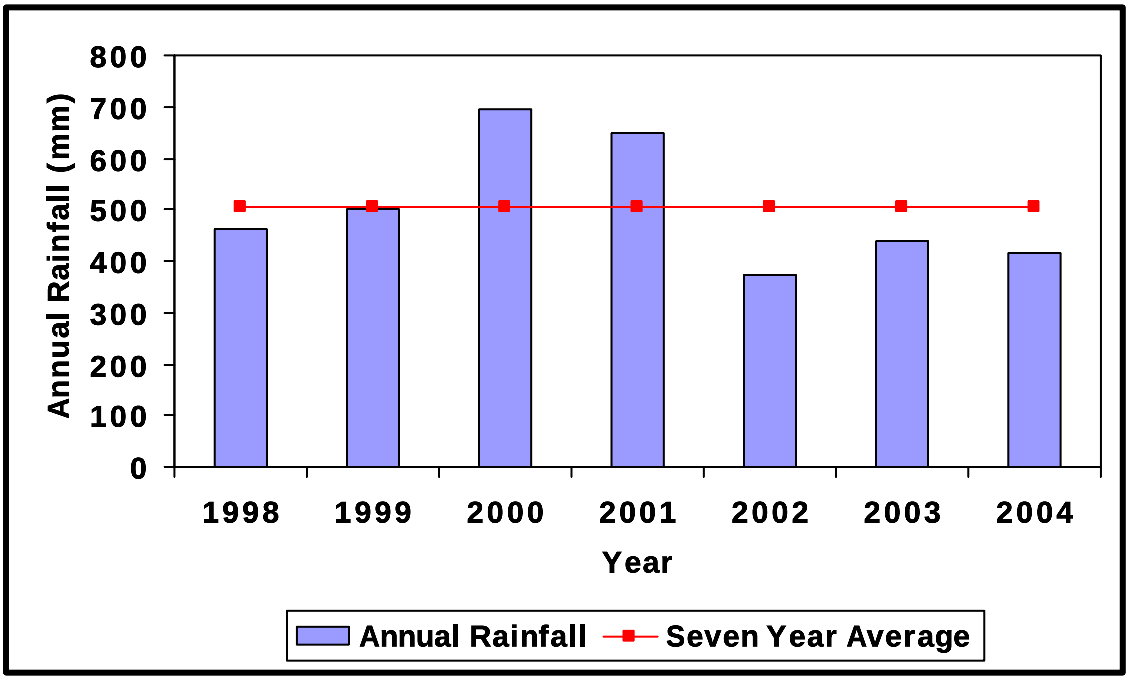

Figure 5: Annual rainfall measured in mm at the confluence of the Olifants and Elands Rivers in the Flag Boshielo Dam.

Thunderstorms are responsible for most of the rainfall in this region. The South African Weather Service describes the rainy season as starting in November with a peak in January. An important factor is that the rainfall is somewhat unreliable and that severe drought conditions occur in about 12% of all years (Schulze, 1994).

The warmest month is January while the coldest temperatures are measured during July. Daily maximum temperatures reported by Schulze (1994) are approximately 32°C during January and around 22°C during July. Extreme temperatures reported in the past are in the order of 42°C for January and 31°C for July (Schulze, 1994).

Schulze (1994) reported the average daily minimum temperatures for January as 18°C and 4°C for July while extremes can reach 8°C (January) and -7°C (July). In general summer days often are described as oppressively warm while some winter nights can be decidedly cold. Winds are mainly light to moderate and most often blow from a north-easterly direction.

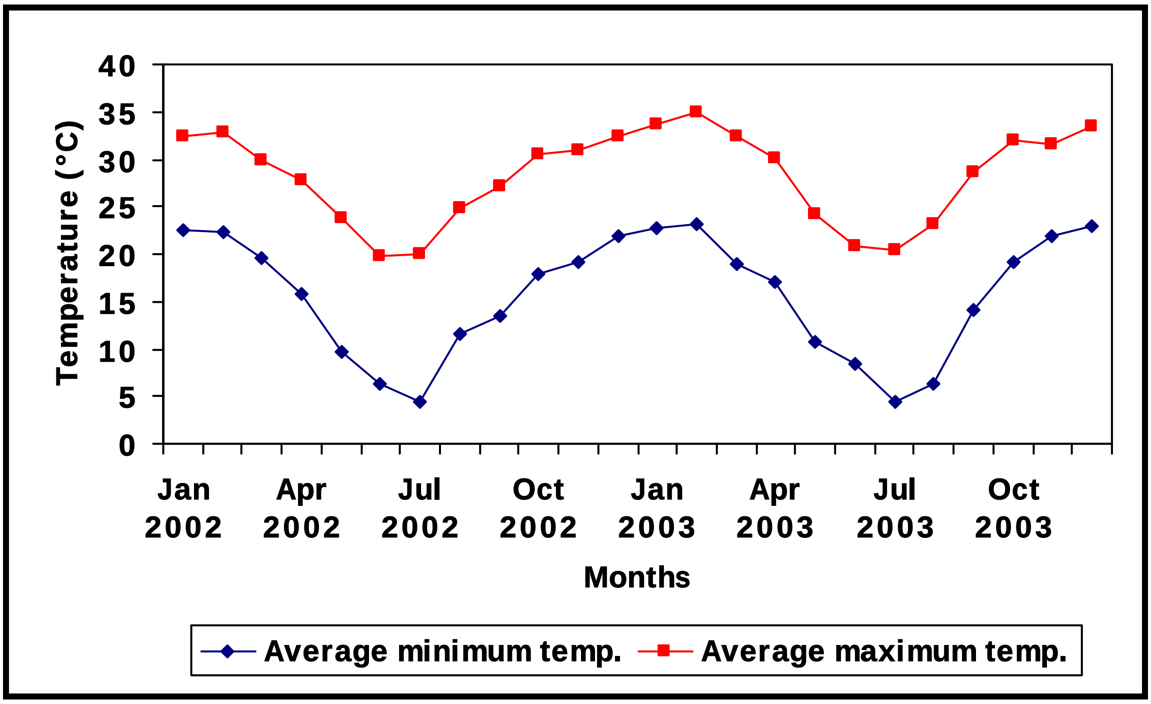

Figure 6: Mean monthly temperature (°C) for the period Jan 2002 to Dec 2004 measured at the confluence of the Olifants and Elands Rivers in the Flag Boshielo Dam.

Geology, soils and vegetation

In the central and southern Transvaal, the Archean granites and greenstone forms the basement to the Transvaal succession (Coetzee, 2001). The geology of the area where the Flag Boshielo Dam was built consist of these Archean granites and also rhyolites that was formed in excess of 2 500 million years ago. Other rock formations worth noting in the area occur to the west and south of the dam. These formations are part of the Transvaal succession and consist of orthoquartzite, dolomite, gabbro and shale (Department of Water Affairs and Forestry, 2003b). The soils in the wider area around the Flag Boshielo Dam are soils of the Glenrosa and Mispah types (Department of Water Affairs and Forestry, 2003b). Soils encountered in the immediate vicinity of the impoundment are described as red-yellow apedal freely drained soils (Department of Water Affairs and Forestry, 2003b).

The Flag Boshielo Dam is situated in the veld type described as Mixed Bushveld by Acocks (1975). Natural vegetation along the Elands and Olifants Rivers (and their tributaries) has been replaced by agricultural crops. Riparian vegetation in reasonable condition still exists in the upper reaches of the dam but downstream of the dam, most of the riparian vegetation has been removed. The vegetation along the western shore of the upper reaches of the dam is dominated by *Combretum erythrophyllum* and *Rhus gerrardii* which are typical riparian species (Department of Water Affairs and Forestry, 2003b). Other riparian species also present include *Salix mucronata*, *Ficus capreifolia* and *Maytenus heterophyla*. Some non-riparian species like *Acacia karroo, A. tortillis, A. galpinii, A. erioloba, Spirostachys africana,* and *Ziziphus mucronata* are also common along the western shore of the upper reaches of the dam. This indicates a possible degradation of the riparian vegetation in the upper reaches of the Flag Boshielo Dam. The active channel and some patches along the shore is colonised by *Phragmites*.

Description of the Flag Boshielo Dam

Construction of the Flag Boshielo Dam was completed in 1987 (Clark, 1997). The dam was originally known as the Mokgomo Matlala Dam but the name was later changed to Arabie Dam after the original farm on which the wall was built. However, during 2001 the name of the dam was once again changed, this time it became known as the Flag Boshielo Dam.

The existing dam is a composite structure and comprises a 770 m long earth embankment with a 455 m long roller compacted concrete gravity section across the riverbank (Department of Water Affairs and Forestry, 2003b). The dam has a central overflow spillway section with a four metre high and 200 m long earth embankment on the right bank which acts as an emergency break-section to protect the dam in case of extreme floods (Department of Water Affairs and Forestry, 2003b).

Figure 7: The Flag Boshielo Dam with outflow into the Olifants River and construction site visible across the Olifants River.

At full supply level, the shoreline of the Flag Boshielo Dam has a length of 65 km (Clark, 1997) but this may change often due to water abstraction and drought conditions. The full supply height of the Flag Boshielo Dam is given as 817 masl by Clark (1997). According to the Department of Water Affairs and Forestry (2003b), the Flag Boshielo Dam has a total catchment area of 23 712 km^2 and a current surface area of 1 285,2 ha. The net storage capacity of the dam at full supply level is 100 million m^3 giving a yield of 56 million m^3/a (Department of Water Affairs and Forestry, 2003b). After the dam has been raised by the proposed five metres, the storage capacity will increase to 188 million m^3 giving a yield of 72 million m^3/a (Department of Water Affairs and Forestry, 2003b).

Brief history of the Nile crocodile population in the Flag Boshielo Dam

Coetzee (1999) stated that some of the older inhabitants in the area allege that trek-farmers already encountered Nile crocodiles as early as 1940 in the Olifants River in the general area where the Flag Boshielo Dam is today. These farmers apparently described the area as “infested” with crocodiles. The land which currently forms the Schuinsdraai Nature Reserve was bought from farmers in 1985 to form part of the former Lebowa Homeland (Coetzee, 1999). After the area was fenced in by the Department of Agriculture the property was transferred to the Department of Development Aid who then managed it as a nature reserve (Coetzee, 1999). In this way the nesting areas of the crocodiles became part of the nature reserve and were protected almost by coincidence.

CHAPTER 3

GENERAL METHODS

Population surveys

The number of Nile crocodiles in the Flag Boshielo Dam was determined by doing regular counts of the crocodiles in the study area. There are several census techniques that are often used by researchers to determine the numbers of crocodiles in specific areas (Platt, 2000). The most widely used of these are foot-patrols, counts by boat and aerial censuses. Foot-patrols to count crocodiles are impractical in the Flag Boshielo Dam due to the length of the shore-line (65 km). Both aerial censuses and boat-based counts have their own negative aspects. Some of the problems associated with boat-based counts are that they are time consuming, expensive, often dangerous and restricted to habitats that allow easy boat access. Even with these problems in mind, the prohibitively expensive rates for hiring aircraft disqualified aerial censuses from becoming the method of choice. Importantly for this project, due to their small size, it is very difficult to the point of being almost impossible to count hatchlings in the water from any aircraft.

Therefore, boat-based counts were used to establish the number of Nile crocodiles in the Flag Boshielo Dam. An eight metre ski-boat fitted with two 40 hp Yamaha outboard motors was used for every count. The boat was always operated at an average speed of about 10 - 15 kph. The same route was always followed in such a way that the greatest number of crocodiles would be encountered early in the evening before observer fatigue sets in. The crew consisted of three persons, two were observers who spotted and counted the crocodiles (one of these persons also piloted the boat) while the third member of the team recorded the sightings on a datasheet.

Two standard 500 000 candlepower spotlights were used to spot crocodiles and counts normally started after sunset as soon as the light became dark enough to use the spotlights. When a crocodile was spotted, its total length (TL) was estimated by both observers. This estimation was based on experience gained from working with other crocodile experts, notably Mr D.G.J. "Swannie" Swanepoel (then a Senior Section Ranger in the Kruger National Park) on a number of crocodile counts and with Dr Brady Barr during a number of crocodile captures. Woodward and Moore (1993) commented on this method of size estimation saying that the ability of observers to detect crocodilians increases quickly with experience. Crocodiles were placed in categories based on their estimated TL. The categories being: crocodiles with a TL <40 cm were classed as current year's hatchling, >40 cm to 1.4 m TL were classed as small crocodiles, >1.4m to 2.1 m TL were classed as medium sized crocodiles, >2.1 m to 4.0 m TL were classed as large crocodiles and any crocodile >4.0 m TL were classed as extra large crocodiles. Crocodiles that submerged before size estimation could be made were noted as "unknown" length animals. The position of all crocodiles that was spotted including all "unknown" length animals were marked with a Garmin hand-held Global Positioning System (GPS). Twenty-eight counts were done in this manner before the level of the dam had dropped by a staggering 68.65% and further counts became impossible.

Spotlight counts were sometimes followed up with aerial counts early the following morning, roughly one hour after sunrise. It was not always possible to do the aerial surveys because the only affordable aircraft available was an Aquila Microlight aircraft equipped with a Rotax 582 engine. Flying these small aircraft is heavily dependant on good weather and clear skies for safe flying conditions. Counts that were completed were undertaken at a height of 150 to 200 feet while flying at a constant groundspeed of about 65 kph. The pilot acted as second observer during all flights and as with spotlight counts any crocodiles that were spotted had their total length estimated according to the same size classification and their positions were marked with the GPS.

Capture methods

Fifteen Nile crocodiles were captured using a modified version of the methods described by Chabreck (1965a), Kofron (1989a) and the Florida Fish and Wildlife Conservation Commission (2003). These animals were all captured for the specific purpose of attaching VHF or GPS/GSM transmitters in order to track their movements in the study area.

Animals identified for capture were approached with the boat and captured with a steel snare attached to a 12 mm climbing rope. The standard self-locking 3S-72" Thompson steel snares, supplied by Thompson Snares (Lynnwood, Washington, USA), were attached to the climbing rope by a steel coupling. The snare is kept open by stretching it over a Y-shaped frame attached to a four metre pole. The snare is positioned just behind the head of the crocodile and pulled tight. The self-locking mechanism on the snare prevents the crocodile from opening the snare and escaping. Crocodiles less than 2.1 m in TL were pulled onto the boat while bigger animals were pulled onto shore where transmitters were attached. All crocodiles caught were physically restrained without the use of narcotics and were released within 15 minutes of being caught.

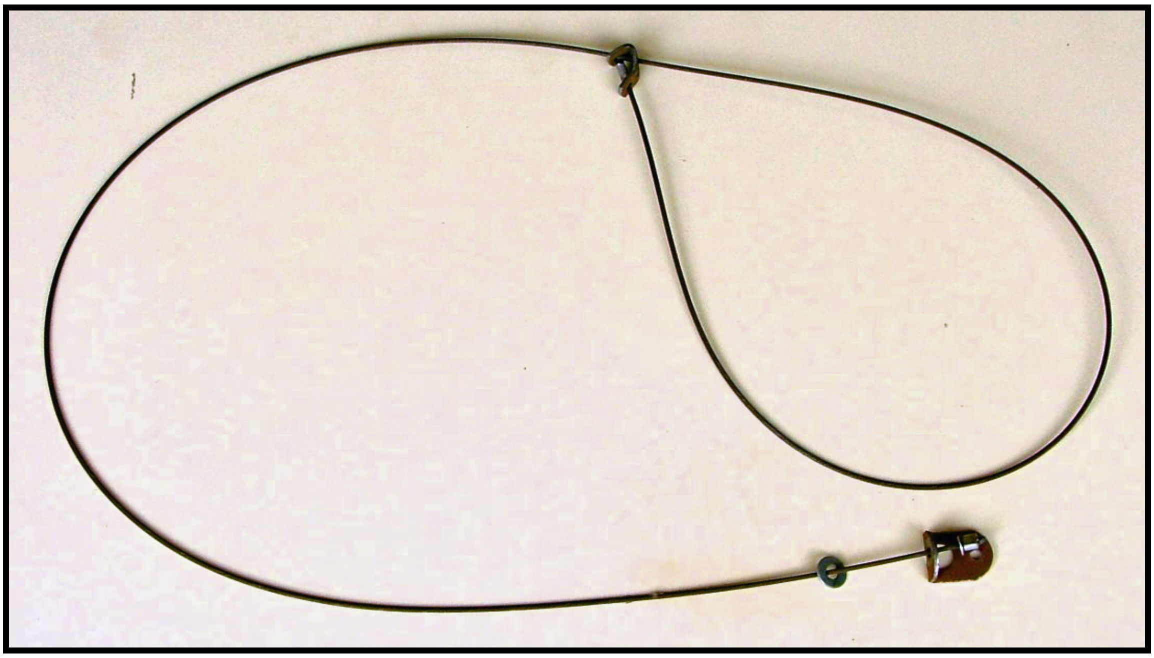

Figure 8: Self-locking 3S-72" Thompson steel snare supplied by Thompson Snares (Lynnwood, Washington, USA) used to capture Nile crocodiles for this study.

Radio telemetry

VHF transmitters were attached to 13 of the captured animals while Hawk 105 GPS/GSM transmitters were attached to another two crocodiles. The shape of a crocodilian head makes the use of radio collars impractical. The neck of an adult Nile crocodile is wider than its head and any radio collar attached around a crocodile's neck could easily be lost. Therefore, other methods of attaching the transmitters to the animals are often used in the case of crocodiles. The VHF transmitters were attached to the crocodiles by drilling holes through four of the scutes on the dorsal side of the tail. Some VHF transmitters had attachment points built into them through which cable ties were pulled to attach the transmitters to the tail scutes through the holes drilled into them. Transmitters that did not have the attachment points were placed inside a 12 - 15 cm length of 50 mm PVC pipe. The PVC pipe with the transmitter inside was then attached to the crocodile with cable ties in a crosswise manner to prevent the transmitter from falling out.

AVM Instrument Company (Colfax, California, USA) supplied the MP2 croc module custom application VHF transmitters. Animals fitted with these VHF transmitters were tracked with a directional antenna attached to a Telonics TR-4 receiver operating on the 148/152 MHZ frequency. Localities where crocodiles where found were marked with a GPS and then plotted on a Geographic Information System (GIS) map using the ArcView 3.2 GIS software.

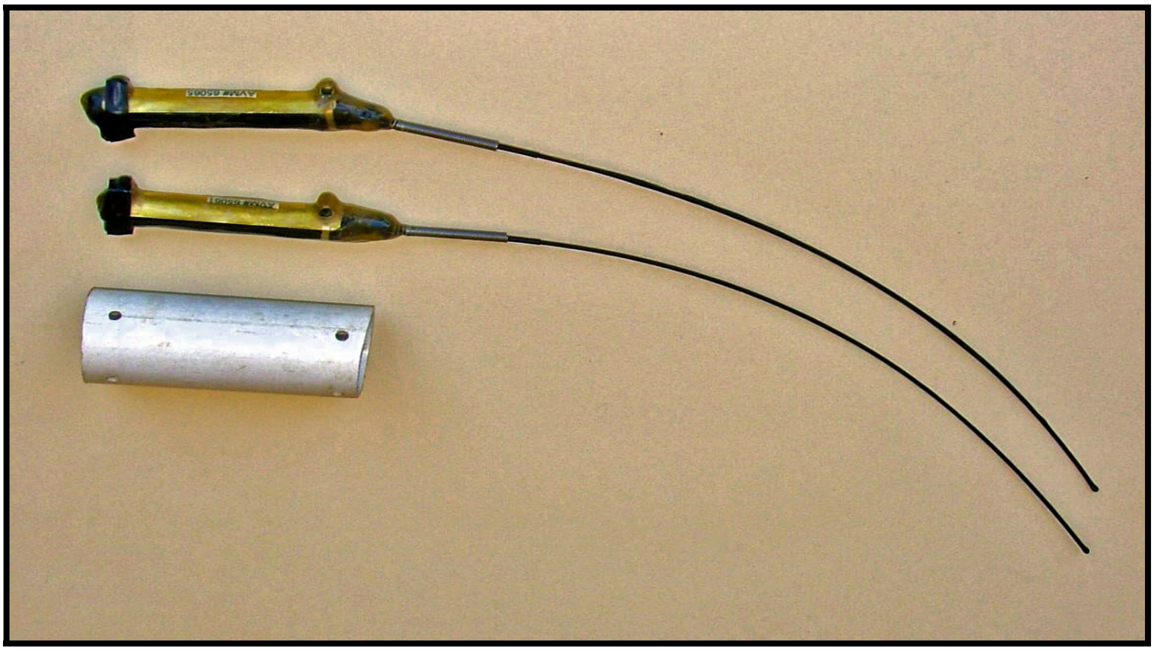

Figure 9: MP2 croc module custom application VHF transmitters supplied by AVM Instrument Company (Colfax, California, USA) shown with 15 cm PVC piping.

The Hawk 105 GPS/GSM transmitters were bought from Africa Wildlife Tracking (Pretoria, South Africa). These transmitters are totally encased in dental acrylic at manufacture and therefore quite robust. The unit determines the animal's position accurately and then sends the coordinates by SMS to a central database. At the same time the SMS is also forwarded to the researcher. Readings of the animal's position is taken at predetermined time schedules which can be reprogrammed while the animal is in the field. Data received and stored in the database can be downloaded via the internet with specialised Hawk software. Data can be displayed on a topographical map that comes with the software but it can also be downloaded as an Excel spreadsheet which can be imported into the ArcView GIS program. The destructive nature of the crocodiles made radio tracking almost impossible to achieve. Only four of the 13 transmitters made it through the summer and into winter before being destroyed by the crocodiles themselves.

Figure 10: Hawk 105 GPS/GSM transmitter that was used to track the movements of two adult Nile crocodiles in the Flag Boshielo Dam. Note the tabs with holes used for attaching the transmitter to the nuchal scales of a Nile crocodile.

The remaining nine transmitters were totally destroyed within an average of 17 days. Some transmitters lasted only two days before being completely destroyed by the crocodiles. All of the VHF transmitters including the protective PVC piping were broken beyond repair by being bitten into small bits and pieces. This problem was partially solved through the use of the Hawk 105 GPS/GSM transmitters which are more robust and can be programmed to gather a large amount of data over a relatively short period of time. The site of attachment was changed because it seems that crocodiles regularly receive bites on their tails where the transmitters then get in the way. Therefore the Hawk 105 GPS/GSM transmitters were attached to the nuchal scales directly behind the head. The attachment site was also changed in part because the GPS/GSM transmitters are too expensive to risk placing them on an animal in such a way that it may very well be lost within the first couple of days.

It was also important to attach the transmitter to the crocodile in a place where it was most likely to be above water most of the time to ensure maximum opportunity of achieving communication with GPS satellites and cellphone towers. Attachment was achieved by drilling small (4mm) holes through the nuchal scales and the transmitter attached with cable ties and stainless steel wire through holes in tabs built into the transmitter. All crocodiles tagged with transmitters were also tagged with colour coded Aussie Ear Tags manufactured by Milborrow. A series of three coloured tags was used to assign a unique colour code to each individual crocodile. The idea being that in the event of any transmitters failing, the tagged crocodiles could still be identified by their coloured tags and locations could still be recorded.

Figure 11: Coloured tags and VHF transmitter (inside white PVC piping) attached to an adult Nile crocodile with plastic cable ties through holes drilled in the tail scutes.

None of the batteries in any of the transmitters were changed since the units are sealed at manufacture and it was also considered to be to time consuming to search for and find one specific crocodile in the dam.

Figure 12: Adult Nile crocodile with VHF transmitter and colour coded tags attached to the scutes on the dorsal side of the tail.

Figure 13: Crocodile NGS 005 "Koos" with a Hawk 105 GPS/GSM transmitter attached to the nuchal scales directly behind his head instead of on the tail which is submerged in this picture.

Nesting surveys

Likely nesting sites were located along the shores of the Flag Boshielo dam and the inlets of the Olifants and Elands Rivers by a combination of methods. The areas were patrolled with an Aquila microlight aircraft equipped with a Rotax 582 engine. The aircraft was operated at a height of 150 - 200 feet at a groundspeed of about 65 kph. Nesting sites spotted from the air was marked with a GPS during the flight.

This was backed up by patrolling the same area on foot the next morning. The aerial survey was substituted by a boat-based survey at times due to the unavailability of the aircraft. During the foot patrols, the shoreline was followed at the waters edge and all trails leading into the bush was followed and examined.

The specific areas marked with the GPS during the aerial survey (or boat-based survey) was also located and examined. Once located, nests were positively identified by probing the hole with a 4 mm diameter metal rod to establish the exact location of the eggs.

Once located all possible nests were identified as active nests by probing and excavating the nest to establish the presence of eggs following Blake, 1974. The final exact position of the nest was then marked with the GPS to facilitate finding the nest again later and also to accurately plot the locality of the nest on a GIS map.

In an attempt to avoid predation, only selected nests were excavated during each season and a set of parameters regarding the characteristics of each egg was measured. All sand was removed from the nest, placing it on a piece of canvas next to the nest and taking care not to allow the sun to bake the sand dry. Eggs removed were marked with a pencil on the dorsal surface to indicate the side facing up. The eggs are never rotated, because this will rupture veins and arteries inside the egg causing the embryo to die. A set of parameters regarding the characteristics of each egg where then measured and recorded.

These are:

- The width and length of each egg measured with a vernier calliper.
- The weight of each egg measured with a set of electronic scales.
- Eggs were checked for banding indicating viability.

All eggs except for those found not to be viable were returned in reverse order (i.e. last out first back in) to the nest and covered with the sand removed form the nest.

All nests that were opened were revisited daily until it was established that the female was back at the nest and the nest had come to no harm.

A further set of environmental parameters was also measured and recorded at each confirmed nesting site. These are:

- The estimated length (TL) of the breeding female.
- The lengths of the hindfoot (HF) print to control the estimation of the TL against.
- The distance from the nest to the water (in metres).
- The height of the nest from the water (in metres).
- The estimated length of time that the nest is exposed to sunlight.
- The type of substrate in which the nest was dug (i.e. sand, soil or clay).
- The height and species of vegetation near the nest.

Unless stated otherwise, all statistics were calculated using the data analysis tool of MS Excel by following the procedures described by Koosis (1997) and also those described by Zar (1999).

CHAPTER 4

ESTIMATED NUMBER OF NILE CROCODILES IN THE FLAG BOSHIELO DAM

INTRODUCTION

Population surveys are normally done to achieve one of the following objectives (Bayliss, 1987).

(1) To determine distribution and abundance (i.e. where are the animals and how many are there?)

(2) To monitor changes in abundance and distribution (i.e. is the population increasing, decreasing or stable?)

Counts at night with spotlights are used throughout the world as a basis for evaluating crocodilian population trends (Wood, Woodward, Humphrey and Hines, 1985). These night counts represent a relative index of the total population because it is almost impossible to count every single crocodile in the population (Davis and Winstead, 1980; Bayliss, 1987). However, in most cases, systematic surveys do account for a major portion of the population (Woodward and Moore, 1993). The exact relationship between a count and the total population may be unknown but we either assume this relationship remain constant or that we can account for factors affecting the sighting proportion (Woodward and Moore, 1993). Therefore, any change in counts should reflect a proportionate change in the total population. Trend analysis of night-count data is often used to estimate the direction and rate of change in a population (Woodward and Moore, 1993).

Trend investigations evaluate the status of the population over time and measure the impact of management practises (e.g. harvesting, total protection, restocking etc.) on populations (Woodward and Moore, 1993). In the case of this study, the objective was to evaluate the status (distribution and abundance) of the crocodile population in the Flag Boshielo Dam over the period January 2002 to December 2003.

METHODS

The basic methods used to survey the number of crocodiles in the Flag Boshielo Dam have been described briefly in Chapter 3. To accurately determine the number of crocodiles in the Flag Boshielo Dam, night counts was conducted on a monthly basis from an eight metre fibreglass boat. The boat was piloted along a predetermined route along the shore of the dam. The shoreline and water surface is scanned with powerful spotlights and crocodiles are identified by their eye-shine. Once spotted, the animal was approached carefully sometimes even drifting in with engines off to estimate its total length and record its location with a GPS. All crocodiles observed were placed in one of the following categories based on their estimated TL: current year's hatchling (TL <40 cm), small sized crocodiles (>40 cm to 1.4 m TL), medium sized crocodiles (>1.4m to 2.1 m TL), large sized crocodiles (>2.1 m to 4.0 m TL) or extra large sized crocodiles (>4.0 m TL).

Animals that submerged before an estimation of the total length could be made were recorded as "unknown" length unless its total length could be estimated based on certain characteristics. Characteristics used to estimate the size of "unknown" length crocodiles includes factors such as habitat type, water depth, water swirl, mud trails, wakes and the intensity of the eye reflection (Woodward and Moore, 1993). Woodward and Moore (1993) suggest that despite its weakness, the approach to include "unknowns" is still superior to ignoring them in the analysis of different size classes. Webb and Messel (1979) showed a strong relationship between body size and wariness which has an important influence on the probability of detection.

The level of competence of the observers also has a definite influence on the success of the counts. Therefore, barring mechanical failures and bad weather, efforts were made to use the same trained observers for each count. Woodward and Marion (1978) reported that boat speed and light intensity affected counts. Therefore, the same set of spotlights was used at every count and the speed of the boat was kept at an average of between 10 and 15 kph. Crocodilians become less active under cooler conditions and spend more time under water (Smith, 1979). This behaviour ultimately reduces their probability of being counted during a night-count (Woodward and Marion, 1978; Hutton and Woolhouse, 1989). It has been shown that in the case of some crocodilians occurring in cooler regions, counts are closely correlated with water temperatures but at higher temperatures the correlation fades (Woodward and Marion, 1978). Therefore, because this correlation with temperature has already been established the water temperature of the Flag Boshielo Dam was not measured during any of the night counts. A total of 28 spotlight counts were done following this method during the period January 2002 to November 2003.

Aerial surveys were sometimes done on the morning following a night-count. This was however dependant on clear skies and clear weather since flights were undertaken in an Aquila Microlight aircraft equipped with a Rotax 582 engine. Aerial counts could unfortunately not be done on a regular basis because many flights had to be cancelled, especially during summer, when the air became to unstable to operate the aircraft. Counts that could be completed were undertaken at a height of 150 to 200 feet and at a constant groundspeed of about 65 kph. During all aerial surveys, the pilot also acted as a second observer.

Flights were always undertaken in the early morning about an hour after sunrise. It was found that at that time of the day many of the crocodiles were lying either on the shore or at least close to shore especially during winter to catch the first warmth of the sun after spending the night in the water. This behaviour made counting the crocodiles much easier than at night. As was done during night-counts, all crocodiles that were spotted had their total length estimated and their positions marked with the GPS. Size estimation from the air is much less complicated since most of the time one can see the entire body of the crocodile, even when it is just under the surface of the water. The fact that one has a birds-eye view from above is of great benefit since it allows one to compare body lengths of different crocodiles which are not always possible during boat-based counts. Therefore, total length estimation from an aircraft is considered more reliable. The biggest negative aspect though is still that hatchling, juvenile and even some small sized crocodiles are sometimes missed completely during aerial surveys. Bayliss (1987) considers the ability to obtain and/or improve precision of a population index one of the biggest advantages of aerial surveys.

RESULTS

Total number of crocodiles

Night counts provide a reasonable means of sampling crocodilian populations in many areas (Chabreck, 1966; Woodward and Marion, 1978) but the major problem with estimating population size from night-count data involves the estimation of the proportion of total animals which are actually seen (Nichols, 1987). This proportion probably varies from area to area and with environmental conditions (Woodward and Marion, 1978).

The average number of crocodiles counted in the Flag Boshielo Dam during the 28 night-counts came to a figure of 136.64 animals. However, as explained above, this figure does not take the influence of environmental factors and variations between different areas into account. Counting Nile crocodiles is often made more difficult by their seasonal migrations (Turner, 1977). Therefore, the double-survey method described by Magnusson, Caughley and Grigg (1978) was used to estimate the total number of crocodiles in the Flag Boshielo Dam population. Their method allow for two counts made by different survey methods to be used to calculate the estimated total crocodile population in an area. Both surveys must be mapped and the maps used to determine how many animals were found by both surveys (B), how many by survey 1 but not by survey 2 (S_1) and how many by survey 2 but not by survey1 (S_2).

The formula described by Magnusson *et al* (1978) is given below. In this formula, N = the estimated number of individuals in the population.

$$N = \frac{(S_1 + B + 1)(S_2 + B + 1)}{(B + 1)} - 1$$

By using the data from night-counts that was followed by aerial counts, the next morning the total size of the crocodile population in the Flag Boshielo Dam was estimated at 210.78 animals.

Magnusson *et al* (1978) also described a formula to estimate the number of crocodiles missed by both surveys. In this formula M = the number of individuals missed by both surveys.

$$M = \frac{S_1 S_2}{B}$$

Calculations based on this formula shows that an estimated 48.67 crocodiles were not seen by either of the surveys. This number makes up about 23.09% of the total population. The total number of crocodiles spans several size classes. It is important to group the animals is size classes since this gives an idea of the structure of the crocodile population in the Flag Boshielo Dam. When expressed as the arithmetic mean of each size class, the numbers were skewed in favour of the animals in the 2.1 to 4.0 m TL size class. The double-survey formula (Magnusson *et al*, 1978) corrected this bias. Table 1 below summarises the mean number of crocodiles estimated to be present in the Flag Boshielo Dam during the study period.

Table 1: The mean number of Nile crocodiles counted during night-counts in the Flag Boshielo Dam and the corrected estimates of the total number of crocodiles in each size class.

Survey method	**Size class (total length)**						**Total**
	0-40 cm	**40-140 cm**	**1.4-2.1 m**	**2.1-4.0 m**	**>4.0 m**	**Unsure**	
Night count mean	3.71	20.43	29.50	64.57	13.96	4.46	136.64
Double-survey estimate	0*	43.40	62.91	76.58	12.71	15.18*	210.78

* Due to the height of the aircraft no hatchlings were seen during aerial surveys while the high number of unsure size animals is possibly due to the groundspeed of the aircraft.

Population density

Population density is population size in relation to some unit of space; it is generally assayed and expressed as the number of individuals (or the population biomass) per unit area or volume (Odum, 1971). The effect that a population exerts on the ecosystem depends largely on the number of animals involved, in other words on the population density (Odum, 1971). There are definite upper and lower limits to species population sizes that are observed in nature (Odum, 1971).

It is known that certain animal species only tolerate a certain level of density, after which inherent social behavioural factors prevent further crowding, irrespective of whether there is sufficient food, shelter and water (Bothma, 2002). Absolute densities are not good for comparisons of crocodilian populations because their size structures could differ substantially (Hutton, 1984). The density of crocodilians is therefore better expressed in terms of biomass (Graham, 1968; Parker and Watson, 1970; Hutton, 1984). The expression of population densities in terms of biomass permits comparisons of data acquired in diverse ecological situations (Turner, 1977). Biomass of crocodilian populations is normally expressed as kilograms per kilometre of area. In the case of the Flag Boshielo Dam population the estimated average mass of crocodiles reported by Hutton (1984) together with the length of the shoreline as described by Clark (1997) was used to calculate the biomass of the population. The absolute density of the crocodile population in the Flag Boshielo Dam was calculated at 3.25 crocodiles/km of shoreline and the biomass came to 142.83 kilograms of crocodile/kilometre (kg/km) of shoreline.

DISCUSSION

There are some Nile crocodile populations in southern Africa that number more than 1000 individuals. In the areas with smaller populations, the Flag Boshielo Dam with an estimated 211 crocodiles compares well to the Pongola River with its 361 animals (Blake and Jacobsen, 1992), the Hluhluwe Rivers with their 238 crocodiles (Blake and Jacobsen, 1992), Lake Sibaya with its 112 animals (Combrink *pers. comm.*[1]) and the Olifants River from Loskop dam to the Kruger National Park (excluding Flag Boshielo Dam) with its 208 crocodiles (Kleynhans and Engelbrecht, 1993).

The absolute density of 3.25 crocodiles/km of shoreline in the Flag Boshielo Dam compares favourably to that of Lake Ngezi with 3.91 crocodiles/km (Hutton, 1984), the area above the Murchison Falls with 2.91 crocodiles/km (Parker and Watson, 1970) and the Umfolozi Rivers with 2.84 crocodiles/km (Blake and Jacobsen, 1992). In terms of biomass, the Flag Boshielo Dam has one of the highest values for smaller populations. The total biomass of 142.83 kg/km in the Flag Boshielo Dam is higher than the values for the rest of the Olifants River (Loskop Dam to the Kruger National Park), the Umfolozi Rivers and also the area above the Murchison Falls in Uganda.

Table 2 below, Compares the population numbers, absolute densities and biomass of the Flag Boshielo Dam Nile crocodile population with those of several other southern African Nile crocodile populations.

[1] Combrink, X: Threatened and Endemic Species Project, PO Box 398, St Lucia, 3936.

Table 2: Comparison of the population numbers, absolute densities and biomass of the Flag Boshielo Dam Nile crocodile population with those of several other southern African Nile crocodile populations.

Study area	Reference	Number of crocodiles	Length of shoreline (km)	Absolute density (crocs/km)	Estimated ave. mass (kg)	Estimated total mass (kg)	Biomass (kg/km)
Lake Turkana	Graham,1968	12439	927	13.42	26.098	324633.02	350.20
Murchison Falls (below falls)	Parker & Watson, 1970	1604	81	19.80	26.098	41861.19	75.3
Murchison Falls (above falls)	Parker & Watson, 1970	437	150	2.91	26.098	11404.83	76.03
Lake Ngezi	Hutton, 1984	125	32	3.91	44.000	5500.00	171.88
Umfolozi Rivers	Blake & Jacobsen, 1992	338	119	2.84	44.000	14872.00	124.97
Olifants River (excl. FBD)	Kleynhans & Engelbrecht, 1993	139	415	0.33	44.000	6116.00	14.74
Flag Boshielo Dam (FBD)	Current study	211	65	3.25	44.000	9284.00	142.83

CONCLUSION

The Flag Boshielo Dam population of Nile crocodiles show a relatively low total number of animals. It does however have a high absolute density and biomass but this should not be regarded as an extreme situation. Lake Ngezi is somewhat similar to the Flag Boshielo Dam with the exception that the water surface area is much smaller with a correspondingly shorter shoreline. Ngezi however shows higher values for both absolute density and biomass than the Flag Boshielo Dam.

CHAPTER 5

POPULATION STRUCTURE BASED ON THE SIZE OF INDIVIDUAL CROCODILES

INTRODUCTION

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

Nichols (1987) recommends that size structure rather than age class be used to develop models of crocodile populations. Most data on crocodiles are generally collected by size class and then converted to age class by application of growth curves. However, growth curves are generally considered to be difficult to estimate (Nichols, 1987).

Variables in crocodilian populations also seem more likely to be dependant on size rather than age. Predation mortality seems very likely to be a function of size with larger size classes being vulnerable to fewer potential predators. Similarly, reproduction may be more closely related to size than age in crocodilians. There is evidence that sexual maturity in American alligators (*Alligator mississippiensis*) is dependant on size rather than age (Whitworth, 1971; Joanen and McNease, 1975). Magnusson, Vliet, Pooley and Whitaker (1990) stated that alligators became sexually active at around 1.9 m (TL) but because males grow faster than females they reach this length at a younger age.

METHODS

Since the estimation of the size of individual crocodiles was done during the night-counts and aerial surveys, the methods are the same as those described in Chapter 3 and Chapter 4. Once the data were collected during counts, the number of individuals per size class was grouped together to determine the total number of individuals per size class per count. Five distinct size classes were developed to try and separate different age classes to describe hatchlings, small animals, those that have just reached maturity, those that form the breeding group and animals that are dominant in the population. The same size classes as discussed in earlier chapters were used and these can broadly be explained as animals less than 40 cm TL (hatchlings); animals longer than 40 cm but less than 140 cm TL (small animals); animals longer than 1.4 m but less than 2.1 m TL (just achieved maturity or about to achieve maturity); animals longer than 2.1 m but less than 4.0 m TL (breeding animals) and finally animals longer than 4.0 m TL (dominant animals).

RESULTS

The population structure of the crocodile population in the Flag Boshielo dam was based on the results of the double-survey estimate of the population size. Data showing the number of crocodiles per size class is summarised in table 3. Analysis of the population data based on the double-survey estimate of the population size indicates that the pre-reproductive group consist of 50.44% of the total number of Nile crocodiles present in the Flag Boshielo Dam.

The pre-reproductive group is formed by crocodiles with a total length less than 2.1 m. Based on the estimated population size, the pre-reproductive group of crocodiles consist of 42.36% of the estimated total number of Nile crocodiles in the Flag Boshielo Dam. The dominant animals in the over 4.0 m (TL) size class represented 6.03% of the total number of animals estimated to be in the population. Hatchlings which could not be counted during aerial surveys made up 2.72% of the mean number of crocodiles counted during all night-counts. Crocodiles of which the size could not be determined by any means represented 3.27% of the mean animals counted during night counts but this figure went as high as 7.20% of the estimated population size due to problems associated with counting crocodiles from the air.

Table 3: Number of Nile crocodiles per size class counted in the Flag Boshielo Dam, figures in brackets indicates percentage of the total.

Size class	**Night-count mean**	**Double-survey estimate**
Hatchling (< 40 cm TL)	3.71 (2.72)	-
Juvenile (year-old hatchlings)	7.89 (5.78)	-
Small (40 - 140 cm TL)	12.54 (9.17)	43.40 (20.59)
Medium (1.4 - 2.1 m TL)	29.50 (21.58)	62.91 (29.85)
Large (2.1 - 4.0 m TL)	64.57 (47.26)	76.58 (36.33)
Extra Large (> 4.0 m TL)	13.96 (10.22)	12.71 (6.03)
Unknown	4.46 (3.27)	15.18 (7.20)
Total	136.64 (100)	210.78 (100)

DISCUSSION

Only about 2 - 5% of hatchlings eventually survive to reach maturity (Pooley, 1969; Parker and Watson, 1970; Magnusson, Vliet, Pooley and Whitaker, 1990; Swanepoel, 2001). Therefore, the low percentage (6.12%) of hatchlings seen during the surveys is not unexpectedly low. Importantly the number of hatchlings observed does indicate that successful breeding is taking place in this particular population.

Night count data suggests that 5.78% of all crocodiles encountered was year-old animals, however this number will probably decline further before these animals manage to reach 2.1 m TL. This percentage compares well with estimates from studies done by Pooley (1969) and also by Parker and Watson (1970) which have shown that around only 5% of young crocodiles manage to reach maturity. Swanepoel (2001) states that cannibalism is the biggest cause of mortality amongst crocodiles in the 1.4 - 2.1 m TL size class.

Swanepoel (2001) suggests that the average survival rate of hatchlings in a healthy Nile crocodile population could be as high as 7 - 10%. Many observers agree that early mortality is considerable in crocodile populations (Turner, 1977). In the case of the Flag Boshielo dam population the 9.17% of crocodiles less than 140 cm TL encountered during night-counts therefore indicates that enough small crocodiles are probably managing to survive to adulthood in the Flag Boshielo Dam.

Medium sized crocodiles, i.e. those that will in all probability contribute to the population by producing next generations, represent an estimated 29.85% of all crocodiles in the current population.

This indicates a more even distribution of animals across the different size classes than the night-count data would suggest on its own and brings the pre-reproductive group of crocodiles in the Flag Boshielo Dam to 50.44% of the estimated total population.

The reproductive class comprise 42.36% of all crocodiles in the estimated total population of Nile crocodiles in the Flag Boshielo Dam. These are the animals in the 2.1 - 4.0 m and the over 4.0 m size classes.

The dominant animals in the population are represented by 6.03% of the individuals all of which is over 4.0 m in TL. Crocodiles this large are normally extremely wary and will submerge at the first sign of being approached. This behaviour may very well lead to fewer of them being counted during surveys which in turn will explain the low percentage of animals reported in this size class. However we can safely assume that between 6 and 10 % of animals in the population is larger than 4.0 m in TL.

Based on their extreme size these animals are probably mostly males. Both Hutton (1984) and Games (1990) showed through skeletochronology that males grow to much longer lengths than females do and that females are mostly absent in the over 4.0 m size class. Crocodiles in the 2.1 - 4.0 m size class were calculated to consist of 36.33% of the population. This group include the current breeding females and are the crocodiles that actively contribute to the production of new generations of crocodiles in the Flag Boshielo Dam.

The number of animals that could not reliably be placed in any specific size-class comes to an estimated 7.20% of the total population size.

CONCLUSION

The percentage of reproductive animals in the population is estimated at 42.36% of the total population size. This includes all animals in the range of 2.1 m to over 4.0 m in total length. Therefore, slightly less than half of the total population is responsible for reproducing the population. In contrast to this an estimated 50.44% of the total number of crocodiles in the population has a TL of less than 2.1 m. This is clearly shown below in Figure 14. These are animals not considered to actively contribute towards the reproductive process of the population. Analysis of nesting females shows that the smallest nesting female had a TL of 2.7 m (See chapter 9).

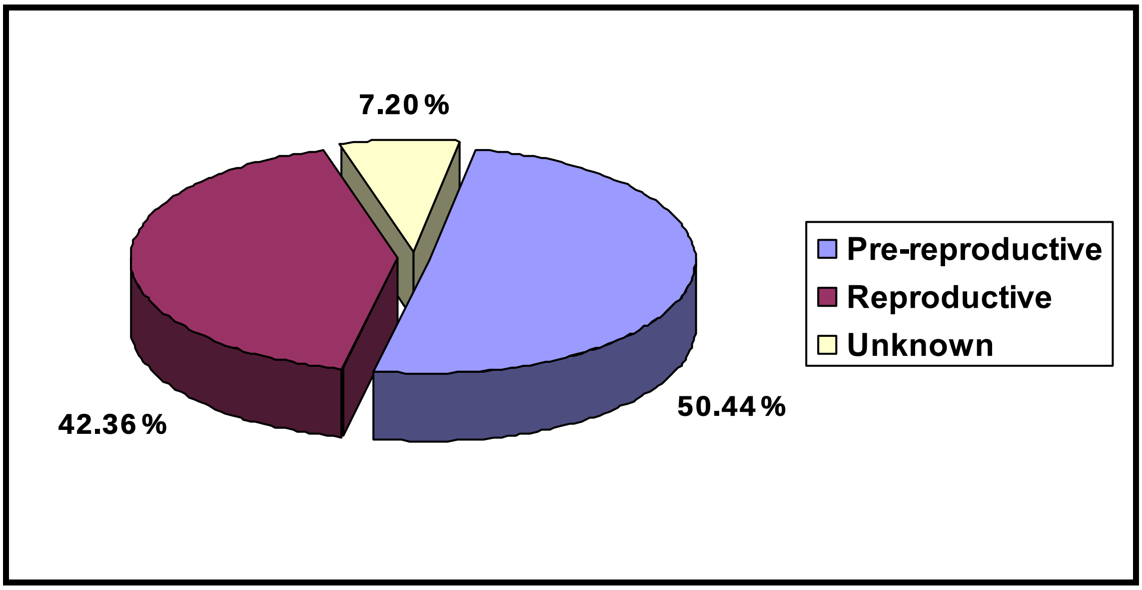

Figure 14: Structure of the Nile crocodile population in the Flag Boshielo Dam, based on the double-survey estimate, showing the percentage animals in the reproductive group against the percentage animals in the pre-reproductive group.

In a stable population, the rate of population growth decreases and approaches zero resulting in a structure where the pre-reproductive and reproductive age groups become more or less equal in size (Sutton and Harmon, 1973).

A stable population is characterised by a bell-shaped age pyramid indicating a moderate proportion of young to old (Odum, 1971; Ryke, 1978). Figure 15 below, shows the characteristics and form associated with a stable population proving the hypothesis that the natural population of *C. niloticus* in the Flag Boshielo Dam presents a healthy population structure comparable to normal wild populations. In this population the percentage of crocodiles in the 2.1 m to over 4.0 m TL groups represent a similar proportion of the total population size than the percentage of animals in the 40 cm - 1.4 m and 1.4 - 2.1 m TL size classes. The even distribution of age classes suggests a stationary population. The similarity between the reproductive and pre-reproductive age groups is indicative of a diminished growth rate in this population of crocodiles. This interpretation is supported by the somewhat higher than expected percentage of hatchlings, juveniles and small crocodiles seen together with the lower than expected percentage of large breeding animals.

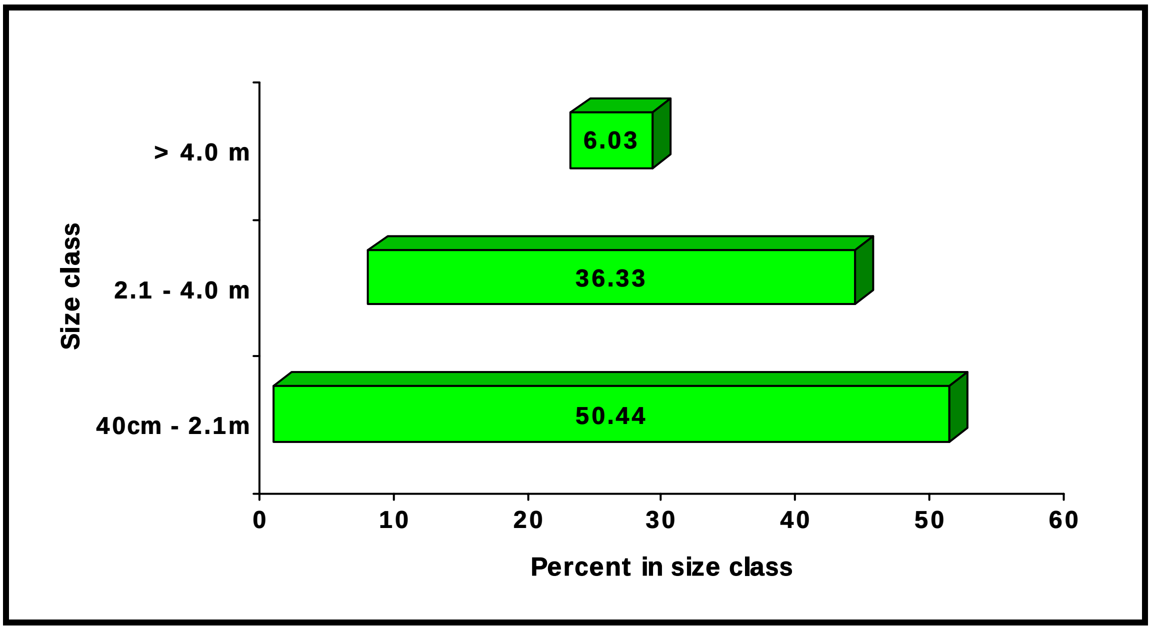

Figure 15: Age pyramid based on the double-survey estimate showing the percentage of crocodiles in each of the major size classes of the Nile crocodile population in the Flag Boshielo Dam. Crocodiles of unknown length (7.20%) are not shown in this graph.

CHAPTER 6

DISPERSAL OF NILE CROCODILES IN THE FLAG BOSHIELO DAM

INTRODUCTION

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

The movement of animals (dispersal) away from the area in which they spent the initial part of their lives is a particularly important phenomenon which has spatial and social elements (Hutton, 1984). Two categories of dispersal have been recognised by Howard (1960). These are: innate dispersal which can be described as spontaneous, random movements which are generally genetically dictated and environmental dispersal which is described as short directional movements to avoid unfavourable conditions. Innate dispersal has a negative impact by reducing the rate at which the population increases (Caughley, 1977). Environmental dispersal on the other hand, has been identified as an important regulating factor in many vertebrate populations (Grobler, 1978; Bunnell and Tait, 1981).

Hatchlings, young crocodiles and adult animals may all occupy distinct habitats which are appropriate for age and/or sex-specific activities. For example adult crocodilians require deep, open water for mating and the females require specific adequate sites for nesting. Similarly, young crocodilians require shallow water with abundant cover in which to feed. Hutton (1984) showed that changes in the home range behaviour of Nile crocodiles occur as they grow from juveniles through to reproductive status. Therefore, dispersal is the sum of all movements between the home ranges of successive size classes in the development of a hatchling to reproductive adult (Hutton, 1984). Effective management of crocodilian habitats requires a great deal of information regarding where and when crocodiles utilise various habitats. All of these requirements must be met if healthy, viable wild populations are to be maintained (Lang, 1987).

METHODS

The question whether the Nile crocodiles in the Flag Boshielo Dam dispersed over the whole of the lake or whether there are areas in the lake that is available to, but is seldom or never used, by the crocodiles needed answering. As at Lake Ngezi (Hutton, 1984) it became clear during the course of the night-counts that certain areas of the Flag Boshielo Dam were infrequently used by crocodiles. The shoreline of the Flag Boshielo Dam is divided along naturally occurring divisions into 14 segments. These segments were defined as follows:

- The Olifants River between Desmond's Weir and the confluence with the Elands River (distance of 3.45 km, both shores)
- The Elands River from the low-level bridge to the confluence with the Olifants River at the Fisheries station (distance of 1.0 km, both shores)

- Fisheries station to Pebble shore (distance of 2.01 km, both shores)
- Pebble shore to Nico's gully (distance of 1.50 km, both shores)
- Nico's gully to the Yellow container (distance of 1.85 km, both shores)
- Yellow container to Brady's Island (distance of 1.46 km, both shores)
- Brady's Island to the Old nests (distance of 2.45 km, both shores)
- Old nests to the Granite hills (distance of 2.04 km, western shore)
- Granite hills to the Matlala Road (distance of 3.85 km, western shore)
- Matlala Road to the Public camping-ground (distance of 4.65 km, western shore)
- Camping-ground to the Municipal resort (along the dam wall, distance of 1.50 km)
- Municipal resort to the Motsephiri stream (distance of 4.25 km, eastern shore)
- Motsephiri stream to the Puleng stream (distance of 6.65 km, eastern shore)
- Puleng stream to the Old nests (distance of 2.80 km, eastern shore)

The area referred to as the "Old nests" is the area where nature conservation officials marked a number of nests during the 1994/1995 nesting season.

The map in figure 16 shows the localities of the segments along the shores of the Flag Boshielo Dam.

The number of times that crocodiles were observed per size class in each segment was entered into an Excel spreadsheet. The spreadsheet functions allowed for the number of crocodiles observed per segment to be expressed as a percentage of the total number of animals seen. The GPS locations of every crocodile counted during night-counts were plotted on a GIS map of the Flag Boshielo Dam. Maps showing the dispersal patterns of crocodiles in the Flag Boshielo Dam were produced on computer with the ArcView 3.2 GIS program. Night-counts were conducted according to the standards and methods described in Chapter 3 and Chapter 4.

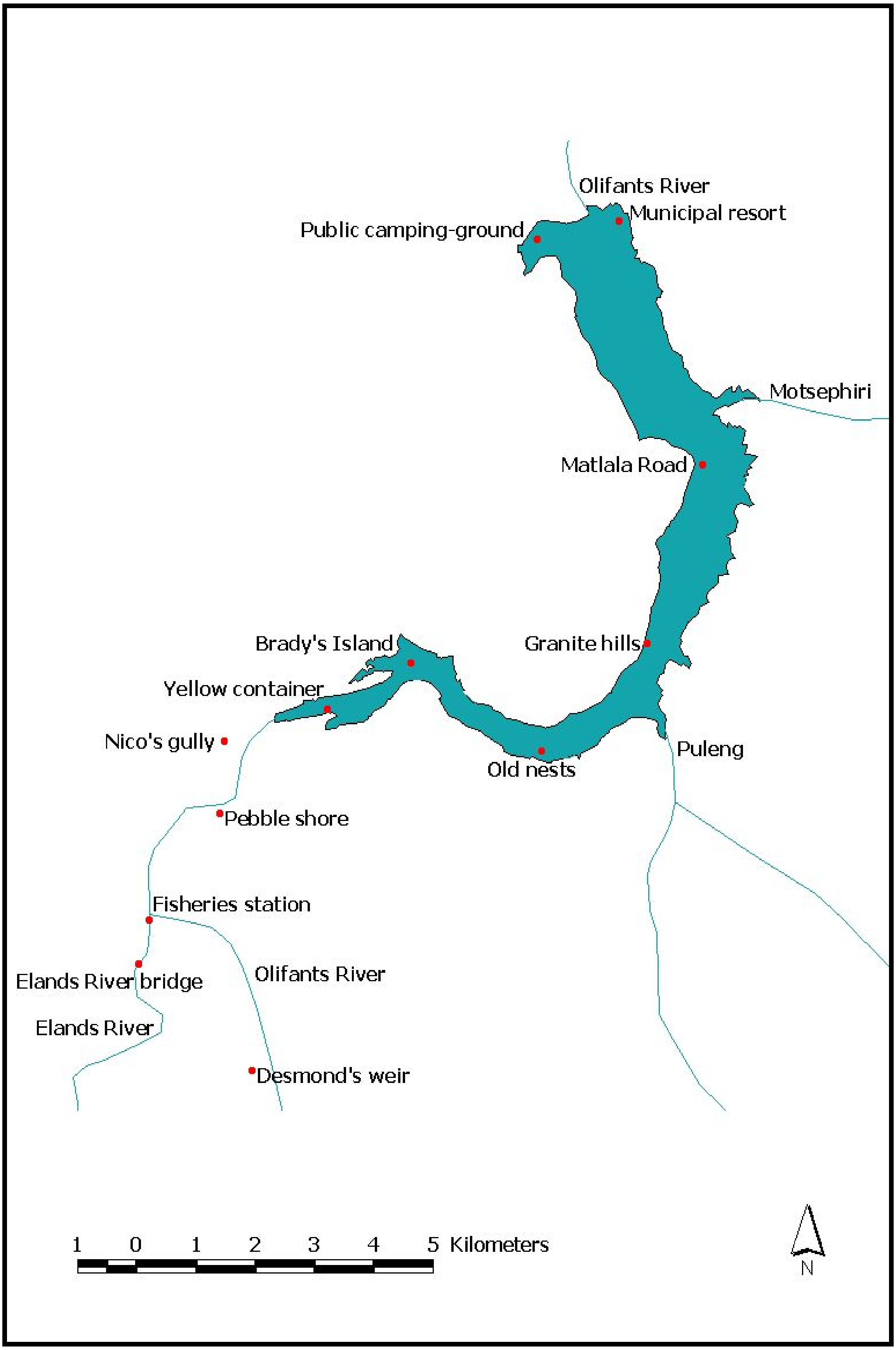

Figure 16: Flag Boshielo Dam showing the location of reference points used during the study to plot the dispersal of Nile crocodiles in the lake.

RESULTS

Hatchlings (Figure 17)

During 2002 hatchlings (< 40.0 cm TL) were encountered along the Olifants River and Elands River and also in the area stretching from Nico's gully to the Yellow container. A number of hatchlings were also found in the Fisheries station/Pebble shore area. Hatchlings in these areas represented 85.00% of all hatchlings seen during 2002. No hatchlings were found in the area between the Puleng stream and the Old nests. Similarly, no hatchlings were encountered in the area stretching from the Old nests past the Granite hills and up to the Matlala Road. The dam wall and the area between the Municipal resort and the Motsephiri stream also had no hatchlings. This pattern changed somewhat during 2003.

In 2003, the highest number of hatchlings (36.96%; *n* = 17) was seen in the area between the Motsephiri stream and the Puleng stream. The second highest number of hatchlings for 2003 was seen in the area between the Yellow container and Brady's Island (21.74%; *n* = 10). Hatchlings were also observed between Brady's Island and the Old nests (10.87%; *n* = 5). No hatchlings were found during 2003 in the area that runs from the Old nests past the Granite hills and up to the Matlala Road. This is exactly the same situation as was found during the 2002 season. In terms of distance, hatchlings were seen along an average of 26.32 km of the shoreline. This means that, on average, they used 40.49% of the total shoreline available to them. The biggest concentration of hatchlings in 2002 occurred in a core area over a distance of approximately 8.31 km. This distance increased to about 14.07 km in 2003. The length of the shoreline where hatchlings was never seen during 2002 was 14.44 km and during 2003 it was 11.84 km.

Juvenile crocodiles (Figure18)

The dispersal of “juvenile” crocodiles is addressed here because these animals are clearly survivors from the previous year’s hatchlings but are considered not to be quite big enough to be placed in the small size category.

Juvenile crocodiles dispersed in the Flag Boshielo Dam in much the same way during both the 2002 and the 2003 surveys. These animals were most often seen in the areas between the Fisheries station and Pebble shore and also from Pebble shore to Nico’s gully. They were also observed form Brady’s Island to the Old nests and in the area between the Motsephiri and Puleng streams. The only difference between the two years being that the grouping of crocodiles seen in the Pebble shore/Nico’s gully area during 2002 extended downstream towards the area around the Yellow container during 2003. This particular area was home to 55.90% (n = 57) of all juvenile crocodiles spotted during 2002 and 77.58% (n = 67) of all juveniles observed during 2003. Areas where juvenile crocodiles were never observed included the Granite hills/Matlala Road area, the Municipal resort/Motsephiri stream area, the dam wall and the Puleng stream/Old nests area. The length of the shoreline along which juvenile crocodiles were observed was on average about 32.51 km long. This translates into this size class of crocodile only using an average of 50.02% of the total shoreline available to them in the Flag Boshielo Dam. Most of the juvenile crocodiles were concentrated along a core of the shoreline that measured in total about 12.79 km in length. Correspondingly, juvenile crocodiles were never observed along areas of the shoreline measuring approximately 7.70 km in length.

Small sized crocodiles (Figure 19)

Small sized crocodiles (40cm - 140cm TL) were most abundant in the Brady's Island/Old nests area during 2002. This area, together with the area immediately upstream, stretching from the Yellow container to Brady's Island accounted for almost a third (32.91%; *n* = 51) of all small sized crocodiles observed during 2002.

By comparison, during 2003 the largest number of small sized crocodiles (29.73%; *n* = 44) was found in the areas around the Matlala Road. This is a move of about 6 km downstream from the areas frequented during the previous year. Areas where absolutely no small sized crocodiles were ever observed included the area of the dam wall as well as the area between the Municipal resort and the Motsephiri stream and also the area between the Puleng stream and the Old nests. Small sized crocodiles utilised an average of 33.94 km of the shoreline. Thus this size class of crocodile used about 52.21% of the shoreline available in the Flag Boshielo Dam for their activities. Except for the length of shoreline mentioned above, small sized crocodiles occurred in a core area with an average length of about 10.78 km of the total shoreline, while they were never observed along an average distance of 5.53 km of the shoreline.

Medium sized crocodiles (Figure 20)

Crocodiles in the medium size class (1.4 - 2.1 m TL) were most often spotted along the shoreline of the area stretching from the Yellow container to Brady's Island and downstream to the Old nests during 2002. This size class of crocodile also dispersed in the area between the Granite hills and the Matlala Road. In total 63.19% (*n* = 230) of all medium sized crocodiles spotted during 2002 occurred in these areas. During 2003, animals in this size class made a short move of about 1.5 - 2.5 km downstream.

This resulted in no medium sized crocodiles being observed in the area around the Yellow container and Brady's Island. Instead, they were located in the area stretching between Brady's Island and the Old nests past the Granite hills and the Matlala Road and on towards the area at the Public camping-ground. This area accounted for 69.03% (*n* = 233) of all medium sized crocodiles observed during 2003. The area in which medium sized crocodiles occurred in the Flag Boshielo Dam measured an average of 35.91 km of the available shoreline. This translates to a percentage of 55.25% of the available shoreline that was used by medium sized crocodiles during the study period. A smaller core area where this size class of crocodile were observed without exception measured 7.76 km during 2002 and extended to 12.96 km during 2003 ($\bar{x}$ = 10.36 km). Similarly, the area where medium sized crocodiles were never seen increased from 4.30 km in 2002 to 12.00 km during 2003 ($\bar{x}$ = 8.15 km). Apart from the area at the dam wall (Public camping-ground/Municipal resort) crocodiles in this size class were also absent from the area between the Puleng stream and the Old nests during both years. No medium sized crocodiles were seen in the area along the Olifants River during 2003. It must also be noted that during 2003, very few animals (0.51%; *n* = 2) were seen along the eastern shore of the dam in the area between the Municipal resort and the Motsephiri stream.

Large sized crocodiles (Figure 21)

The dispersal of large crocodiles (2.1 - 4.0 m TL) remained much the same for both survey years (2002 & 2003). The area where most of the large animals were seen was the area between Brady's Island and the Old nests. A total of 31.07% (*n* = 229) and 41.01% (*n* = 280) of all large animals seen during 2002 and 2003 respectively occurred in this area. Other important areas for the dispersal of large crocodiles were the areas between the Yellow container and Brady's Island and also between the

Granite hills and the Matlala Road. During 2002, 38.94% (*n* = 287) of all large crocodiles were seen in these two areas and during 2003 that percentage came to 38.48% (*n* = 262). During both 2002 and 2003, no large sized crocodiles were observed in the areas of the Olifants River and the Elands River nor were any large crocodiles seen in the area between the Puleng stream and the Old nests. The shoreline of the areas where large crocodiles were always observed is on average about 36.81 km long with a core area of 9.79 km in length where these crocodiles seem to concentrate. The distance of 36.81 km represents approximately 56.63% of the total shoreline available in the dam. At the same time no large sized crocodiles were ever observed along certain areas of the shoreline that measured an average of 10.88 km in length.

Extra large sized crocodiles (Figure 22)

Crocodiles in the extra large size class (> 4.0 m TL) were most often seen in the areas between the Yellow container and Brady's Island and also between Brady's Island and the Old nests. These areas were occupied by extra large sized crocodiles during both survey years. During 2002 about 56.89% (*n* = 95) of all extra large animals were observed in these two areas while that percentage decreased to 49.18% (*n* = 69) for the area during 2003. These percentages are still twice as high as those for the next most preferred areas. Animals in this size class were also frequently encountered in the area around the Fisheries station and downstream to Pebble shore and also in the area between the Granite hills and the Matlala Road. The number of crocodiles spotted in these four areas made up 79.05% (*n* = 132) of all extra large crocodiles spotted during 2002 and 73.77% (*n* = 103) of all extra large sized crocodiles observed during 2003. No crocodiles that could be classified in the extra large size class were ever observed in the following areas: the Olifants River, the Elands River, the area around the dam wall, the area between the Municipal resort and the Motsephiri stream and the area between the Puleng stream and the Old nests. These areas remained the same for both survey years. Crocodiles over 4.0m (TL) were routinely seen in areas along the shoreline that measured an average distance of about 31.06 km long with a core area of about 10.54 km where these animals seem to concentrate. The distance of 31.06 km converts to approximately 47.78% of the total shoreline available to crocodiles in the Flag Boshielo Dam. At the same time crocodiles of this size class were never observed along areas of the shoreline that all together measured an average of 13.00 km in length. The lengths of shore area used by Nile crocodiles in the Flag Boshielo Dam is summarised in Table 4 below.

Table 4: Length of shore areas used by Nile crocodiles in the Flag Boshielo Dam.

Size class	**Total length of shore occupied by crocodiles (km)**	**Length of shore where crocodiles were always seen (km)**	**Length of shore where crocodiles were never seen (km)**
Hatchling (<40 cm TL)	26.32	11.19	13.14
Juvenile (yearling)	32.51	12.79	7.70
Small (40 - 140 cm TL)	33.94	10.78	5.53
Medium (1.4 - 2.1 m TL)	35.91	10.36	8.15
Large (2.1 - 4.0 m TL)	36.81	9.79	10.88
Extra Large (>4.0 m TL)	31.06	10.54	13.00
Average	32.76	10.91	9.73
Standard Error	3.80	1.03	3.10
% of available shoreline	50.40	16.78	14.97

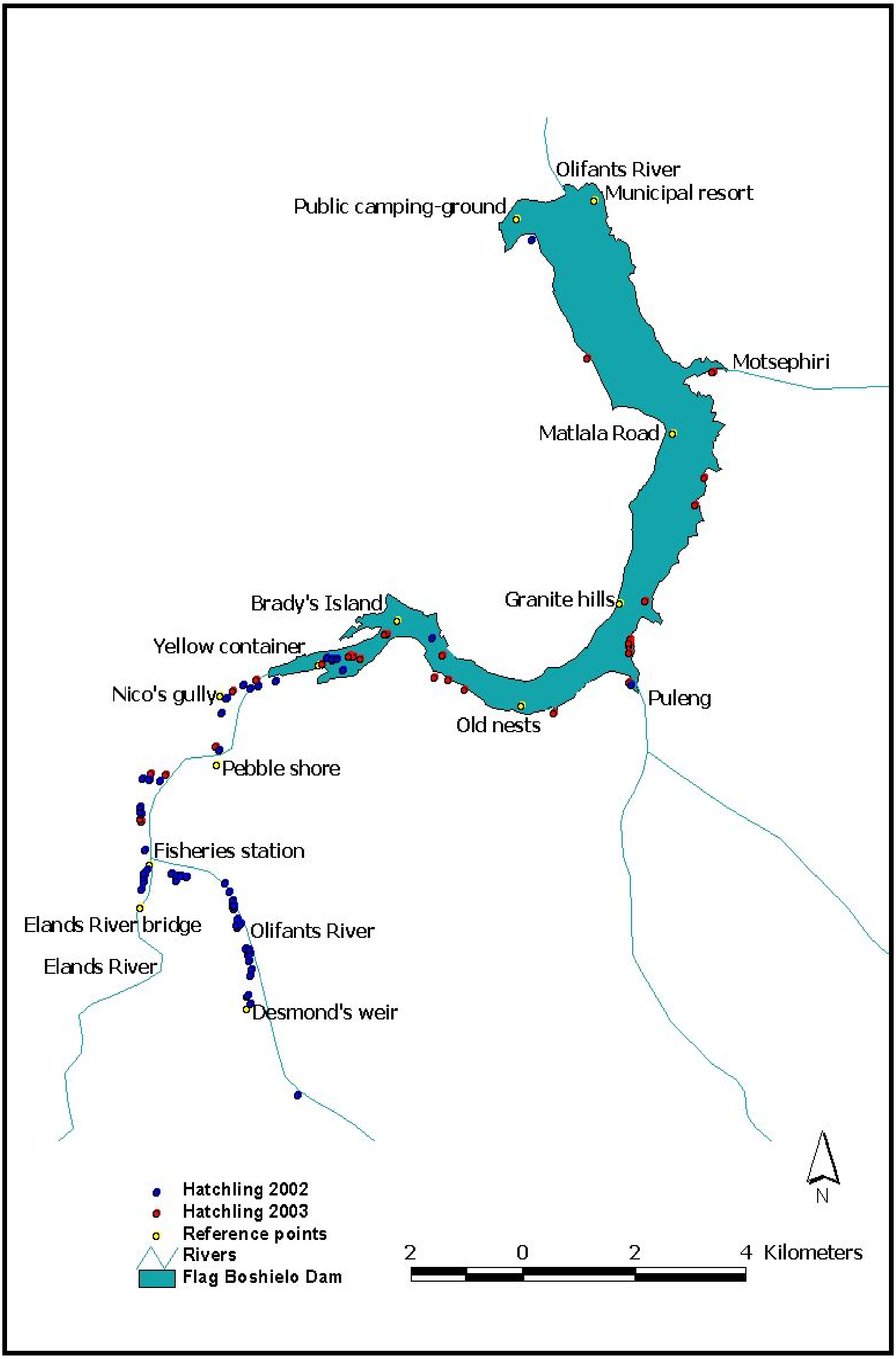

Figure 17: Dispersal of Nile crocodiles in the hatchling size class (< 40 cm TL) during 2002 and 2003 in the Flag Boshielo Dam.

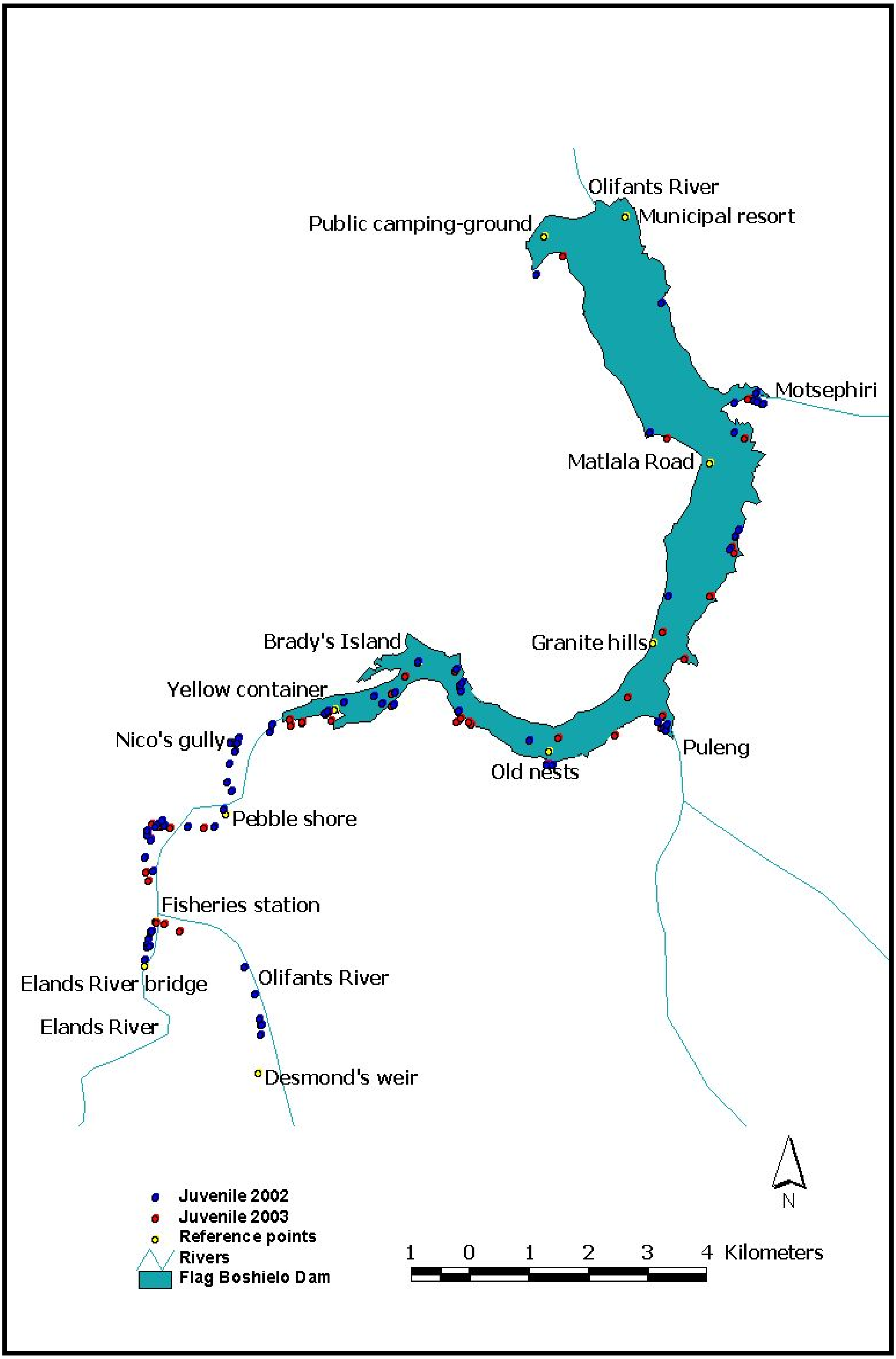

Figure 18: Dispersal of Nile crocodiles in the juvenile size class during 2002 and 2003 in the Flag Boshielo Dam.

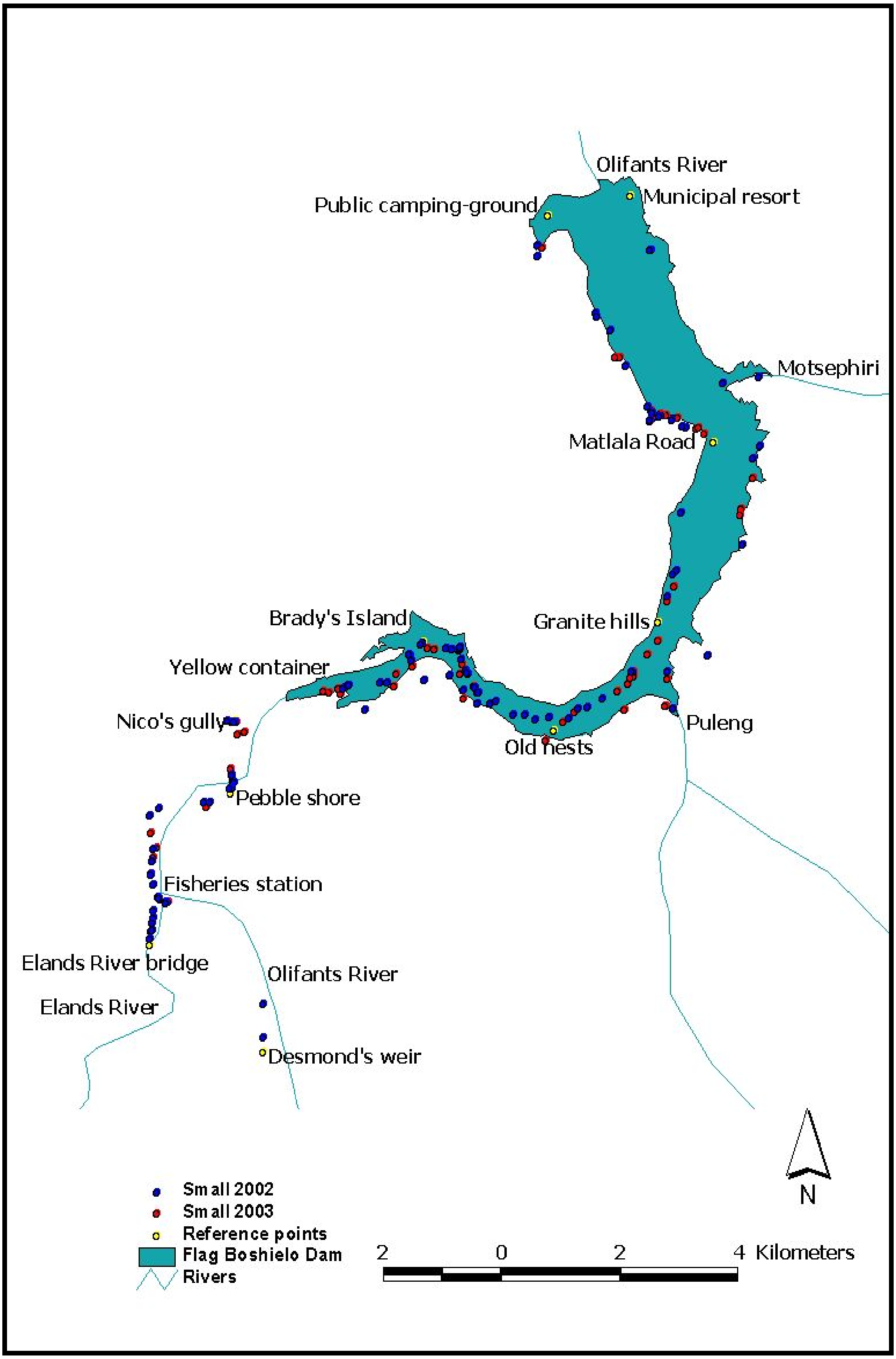

Figure 19: Dispersal of Nile crocodiles in the small size class (40 - 140 cm TL) during 2002 and 2003 in the Flag Boshielo Dam.

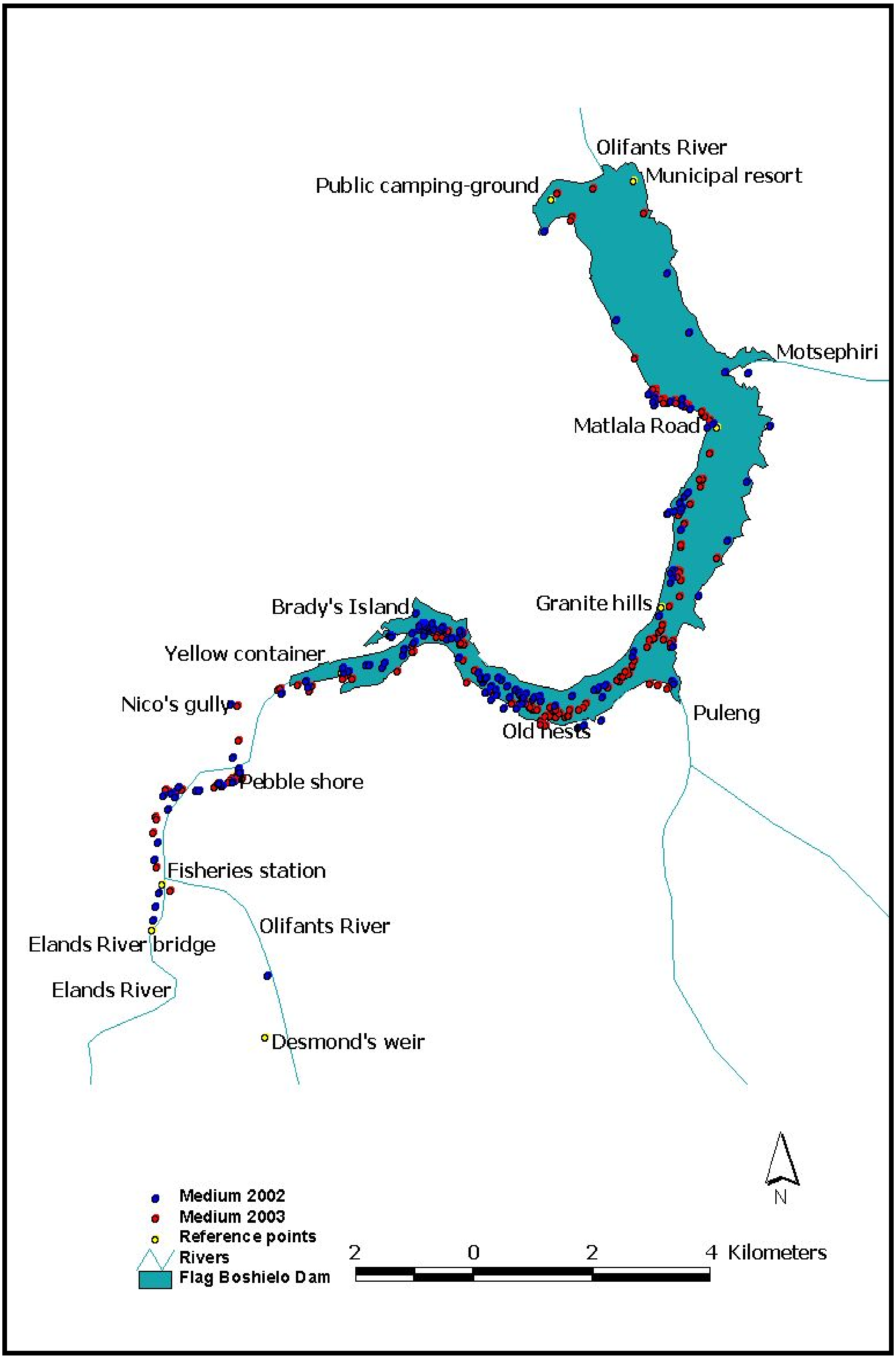

Figure 20: Dispersal of Nile crocodiles in the medium size class (1.4 - 2.1 m TL) during 2002 and 2003 in the Flag Boshielo Dam.

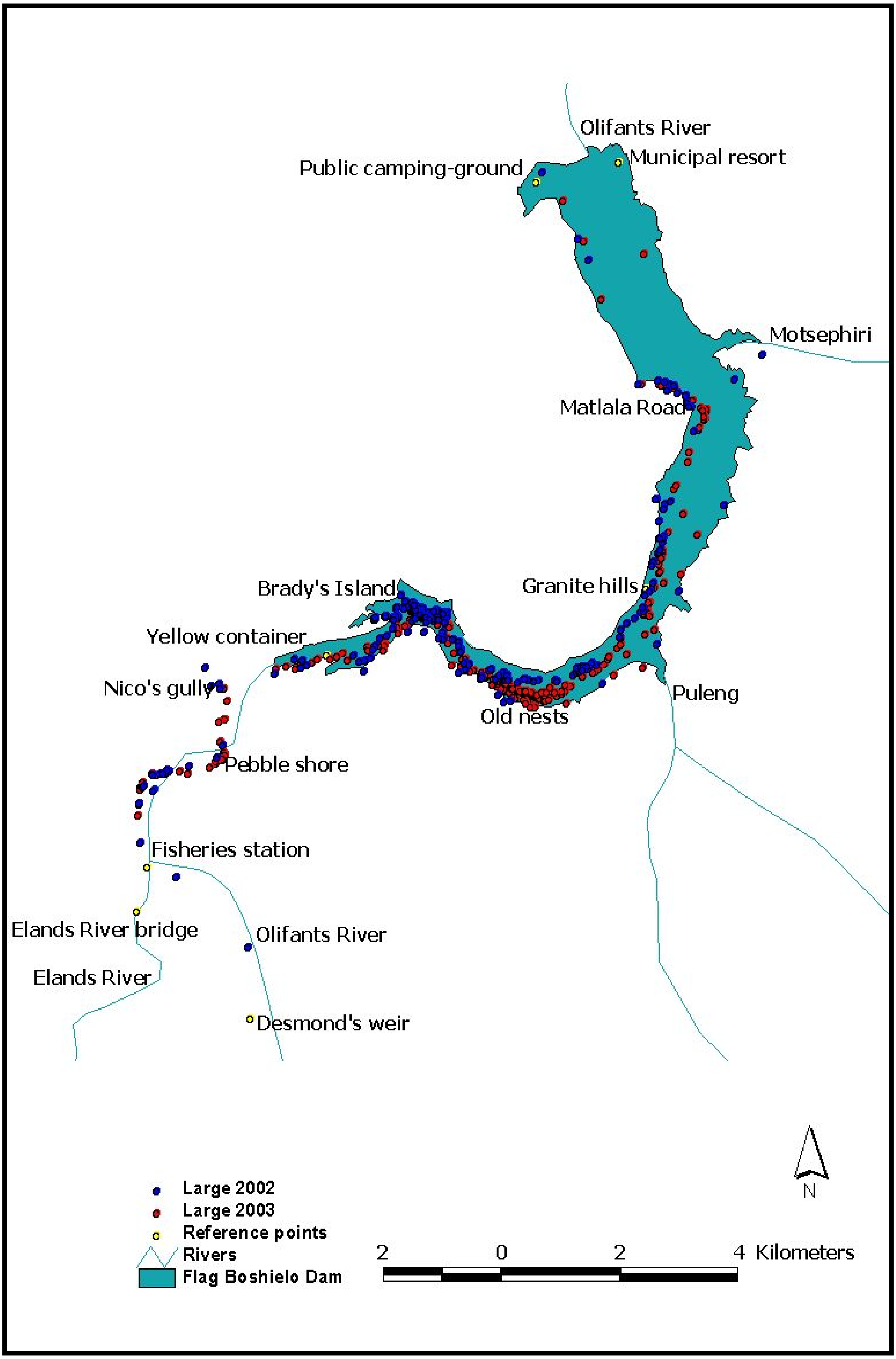

Figure 21: Dispersal of Nile crocodiles in the large size class (2.1 - 4.0 m TL) during 2002 and 2003 in the Flag Boshielo Dam.

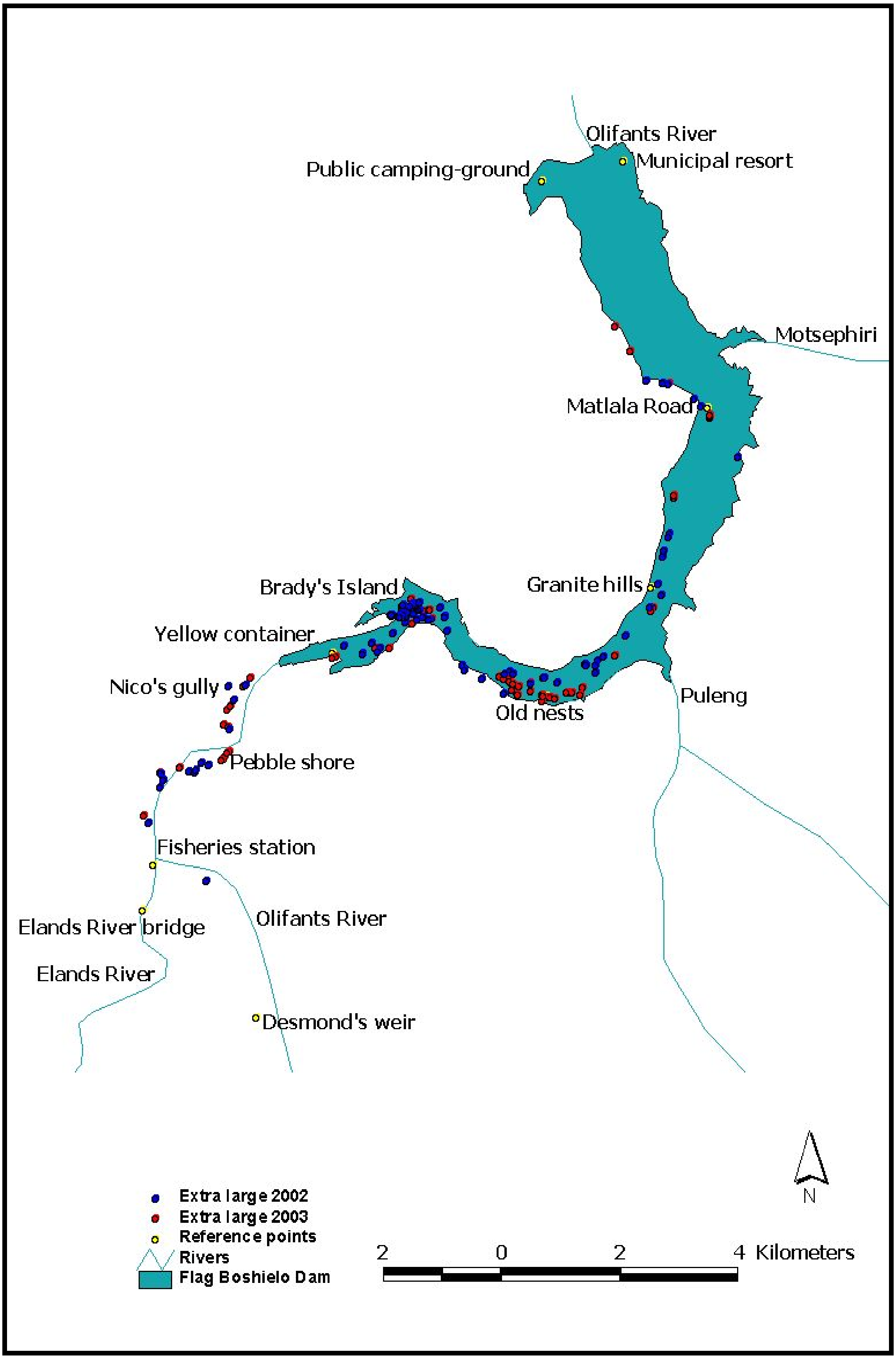

Figure 22: Dispersal of Nile crocodiles in the extra large size class (> 4.0 m TL) during 2002 and 2003 in the Flag Boshielo Dam.

DISCUSSION

The dispersal of hatchlings is dictated by the location of the nest. Therefore the location of hatchlings around the dam is predetermined by the success of the females in securing optimal nesting sites. Several authors have noted that female crocodiles do not nest at the same nesting site in consecutive years (Pooley, 1969; Hutton, 1984; Swanepoel, Ferguson and Perrin, 2000). It is likely that the nests of the second year were made by different females from the ones which made nests in the first year. It has been stated by Swanepoel (2001) that it is highly likely that female crocodiles only nest every other year in order to recover from the previous years nesting effort. This could explain the very different dispersal of hatchlings for the two years.

The area of shore where hatchlings were observed during 2003 is 5.76 km longer than the area observed during 2002. Due to heavy rains in the catchment area of the dam, a very high inflow of water was experienced during January 2003. This caused the level of the dam to rise by 7.98% in just two months. This sudden increase in water level came after the nests have hatched and increased the shoreline available to the hatchlings. The same effect has been reported on by Montague (1983) who described that juvenile crocodiles seek sanctuary away from large crocodiles when suitable habitats are made available by flooding. Chabreck (1965b) also determined that juvenile American alligators tend to disperse with increasing water levels while Pooley and Gans (1976) remarked that young crocodiles disperse to seek out pools and streams that are not inhabited by sub-adults or adults.

A large area along the centre of the dam was used by almost all the size classes as can be seen in Figures 17 - 22. This area between the Yellow container, Brady's' Island and the Old nests were particularly well used during 2002 with the exception of the hatchling and juvenile size classes. A severe drought affected the dam during the second half of 2003. The dam lost 45.34% of its water between January 2003 and November 2003. During this period the large and extra large animals remained in the area that stretched from the Yellow container to Brady's Island and on to the Old nests. This is the same areas where they were observed during 2002 before the drought. These areas are so situated that there was always water available in the old river course even at the height of the drought.

In 2003, the small and medium sized animals gave way to the large and extra large animals in this area while the small sized animals moved upstream to the adjacent area stretching from Nico's gully to the Yellow container. During the same period the medium sized animals moved downstream to the Matlala Road/Public camping-ground area. Hutton (1989) found that intermediate animals suffered when crocodiles from all size classes where forced together by drought condition at Ngezi. This could explain the move by these animals into areas that is not utilised by crocodiles under normal circumstances in the Flag Boshielo Dam. Before the drought, the Matlala Road/Public camping-ground area was not a preferred area for any of the size classes. No large and extra large animals were observed in any of these two areas during the dry season. It is worth noting that the Public camping-ground was closed the year before the drought and yet the crocodiles still did not make use of that area until they absolutely had to.

Some areas of the shore were never or only very seldom used by any crocodiles. It was not possible to explain the absence of crocodiles in certain areas of the Flag Boshielo Dam. One of the areas where crocodiles were only seen on very rare occasions is the area between the Public camping-ground and the Municipal resort. The embankment of the dam covers most of this area and perhaps therefore it is to be expected that very few crocodiles were observed here. The open water near the dam wall is less productive than the upstream areas. This is so because in the upstream areas, drowned riparian vegetation and old trees provides nutrients and nesting areas for fish and other prey animals. The area of the dam basin at the embankment is very deep and the water temperature is much colder than the river-like area upstream. Apart from the conditions being unfavourable to crocodiles there is also less fish in this area of the lake as a result of these conditions. Similarly, Montague (1983) suggests the absence of crocodiles in Lake Kopiagu may be attributed to the scarcity in forage fishes rather than to physical obstacles.

The next area that the crocodiles seemed not to use as much is the area from the Municipal resort to the Motsephiri stream. Crocodiles will take refuge in quiet areas when given the choice (Swanepoel, 2001). This means that they will avoid areas where there is much movement of humans, vehicles, livestock etc. The Municipal resort is a source of much movement of vehicles and humans. The resultant high noise levels almost certainly caused crocodiles to actively avoid this area.

The area between the Puleng stream and the Old nests also show a very low number of crocodiles. At first glance this is perhaps surprisingly so because this area is less than three km away from one of the highest populated areas in terms of crocodile numbers in the lake. The shore opposite the Puleng stream/Old nests area is between 500 and 640 meters away, and is also one of the more heavily utilised areas in the lake. The off-shore area between the Puleng stream and the Old nests is very shallow indeed, while the shore is exposed with very few rocks and little vegetation to provide shelter. The opposite shore however, has a clearly much higher incidence of rocks and vegetation. Hutton (1984) found in Zimbabwe that rocks, termitaria and other natural structures along the shore are important factors in the provision of shelter, basking and feeding sites. Thus the proximity of better suited habitat probably caused the crocodiles to ignore the Puleng stream/Old nests shore rather than the unfavourable habitat forcing them to find alternative habitat.

On average, crocodiles in the Flag Boshielo Dam utilises 32.76 km (50.40%) of the available shoreline for their daily activities, while they concentrate on about 10.91 km of shoreline with almost the same distance, 9.73 km along the shores of the Flag Boshielo Dam that is never utilised by crocodiles.

CONCLUSION

Separation of the hatchling and juvenile crocodiles from the larger size classes is evident. This concurs with the results reported from other Nile crocodile studies in Africa. Larger crocodiles used much of the available shoreline for their daily activities. The areas that were not utilised were those that provided inadequate shelter, basking and nesting sites and where prey species were harder to find as a consequence of the physical characteristics of the lake i.e. deep, open water near the embankment. Also the shore where human activities were highest showed the lowest number of crocodiles present in any area. No clear pattern of short range migration emerged from any of the size classes. Crocodiles did however adapt to the changing water level of the lake during the drought of 2003 by moving to areas which suited their requirements better. Table 4 clearly shows that about half (50.40%) of the available shoreline is used by crocodiles in the Flag Boshielo dam. Approximately 16.78% of shoreline is always used for activities such as basking and/or nesting by crocodiles while about 14.97% of the shoreline is never used by the crocodiles. Therefore, the hypothesis that the *C. niloticus* population in the Flag Boshielo Dam stay in a limited range and do not use the total surface area of the lake is true.

CHAPTER 7

SEASONAL MOVEMENTS OF NILE CROCODILES IN THE FLAG BOSHIELO DAM

INTRODUCTION

At the outset of this study the hypotheses was formulated that the natural population of *C. niloticus* in the Flag Boshielo Dam show seasonal movement within the impoundment and the inlet of the Olifants and Elands Rivers. Seasonal movements by crocodilians have been described by several authors in the past (Pooley, 1969; Goodwin and Marion, 1979; Hutton, 1989). In mammals, seasonal changes in range have been attributed to seasonal changes in the productivity of the environment (Harestad and Bunnell, 1979).

In southern Africa, the productivity of waters decreases during the cooler winter season (Allanson, 1982). This annual decrease in the productivity of the crocodile's environment must have an influence on its seasonal range. In addition, Hutton (1984) states that crocodiles are clearly also directly affected by seasonal temperature cycles through depression of their temperature sensitive metabolism. Pooley (1969) noted that the drop in water levels during the dry season in KwaZulu-Natal probably also triggered seasonal movement of Nile crocodiles to areas where permanent water is available in pans and rivers. The activity range and habitat preference of adult *Alligator mississippiensis* have been shown to change seasonally under both climatic and reproductive influences (Goodwin and Marion, 1979; Joanen and McNease, 1970, 1972). Research done by Hutton (1984) showed that a combination of social, energetic and environmental factors is important in explaining the range characteristics of Nile crocodiles.

Further, the diet of *C. niloticus* has been shown to change progressively with increased body length (Cott, 1961). Therefore, it is possible that crocodiles may adapt their range to suit hunting strategies which have evolved in response to energetic requirements (Hutton, 1984).

METHODS

The shoreline of the Flag Boshielo Dam was divided along naturally occurring divisions into 14 segments. These segments have already been described in Chapter 6 and were also used as a basis for calculating the extent of seasonal variation in the dispersal of Nile crocodiles in the Flag Boshielo Dam. The colder, winter months for the study area were identified from temperature data measured daily with a minimum-maximum thermometer at the Fisheries station. The number of times that crocodiles were observed per size class in each segment of shoreline over the total study period was noted and entered into a spreadsheet. These observations were made during spotlight-counts which were conducted according to the standards and methods described in Chapter 3 and Chapter 4. The spreadsheet allowed observations to be grouped together by size class. Once grouped in this way, the spreadsheet functions allowed for the frequency at which crocodiles were observed per segment of shoreline to be expressed as a percentage of the total number of animals seen, per size class, over the study period in that particular area. The data contained in the spreadsheet was manipulated to group data of the colder months (May - August) together and also to group data from the warmer months (January - April and September - December) together. This effectively divided the calendar year into three groups of four months each with the coldest months set in the second third of the year. By comparing the sets of data to each other the extent of any seasonal variation in dispersal of crocodiles in the Flag Boshielo Dam could be determined.

A total of 13 crocodiles were captured and VHF transmitters attached to the scutes on their tails (see chapter 3 for methods). A further 2 crocodiles were captured and had GPS/GSM transmitters attached to the nuchal scales behind their heads (see chapter 3 for methods). Most of these animals were in the 2.1 - 4.0 m TL size class with two animals in the > 4.0 m TL size class. Radio tracking of these animals was done to establish their daily movements and to try and evaluate the size of their territories. However the tracking of these animals also gave some insight into their seasonal movements.

RESULTS (Table 5 and Figure 23)

Hatchlings

As was to be expected, hatchlings (< 40.0 cm TL) showed a dramatic decline in the percentage of observations over the span of one year. An average of 70.40% (*n* = 106) of all hatchlings observed throughout the study was seen during the period January to April. During the cooler months (May to August) the average frequency at which hatchlings were observed in the lake declined to around 28.77%. In the last third of the year (September to December) very few hatchlings were seen and those that were, represented an average of 0.84% of all hatchlings observed throughout the study period. No variation in the distribution of this size class of crocodile became evident. These animals stayed in or very close to the general area where they were hatched. At no time were hatchlings observed in areas in the lake where they were not observed during the preceding months. Hatchling crocodiles were concentrated in no discernable pattern in the following areas: Olifants River, Brady's Island, Motsephiri stream. The animals remained static in these areas but their numbers declined from summer to winter and back to summer again.

Small sized crocodiles

In the case of small sized (40.0 cm-1.4 m TL) crocodiles, the frequency of observations made over the entire study period showed that these animals increased their numbers slightly in the lake during the warmest time of the year. Animals in this size class form the prepubertal, subdominant group in crocodilian society. The highest frequency (35.78%) at which small crocodiles were encountered in the lake occurred during the September to December period (n = 302). The average frequency of observation during winter was 33.64%. During 2002, crocodiles of this size class moved from Brady's Island up to the Fisheries station in winter and back to the Brady's Island area the next summer, thus avoiding the river like area near the Fisheries station during the breeding and nesting season. However during the 2003 drought, these crocodiles were frequently observed over the large area between the public camping area, the Puleng stream, the Old nests and the Yellow container areas. They therefore avoided the Brady's Island area which became a preferred nesting site during the 2003 drought.

Medium sized crocodiles

Medium sized crocodiles (1.4 - 2.1 m TL) showed an increase in their numbers during the winter period between the months of May and August. During this time an average of 40.52% of all observations of medium sized crocodiles were made (n = 702). This is as much as 16.30% higher than the frequency at which medium sized crocodiles were observed in the Flag Boshielo Dam during summer time.

The medium sized group of crocodiles formed three distinct groupings. The first group concentrated in the Yellow container area but moved downstream to the adjacent Brady's Island area during the 2003 drought. The second group preferred the Brady's Island area but moved downstream to the adjacent Granite hills area during the 2003 drought while the third group was concentrated around the Granite hills area but moved slightly downstream to the Matlala Road area during the 2003 drought.

Large sized crocodiles

The highest average frequency (42.59%) at which large crocodiles (2.1 - 4.0 m TL) was observed during the study period occurred during the cool months between May and August (*n* = 1419). This figure represents an increase of 12.17% in the frequency of observations over those made during the January to April period and also an increase of 15.59% over the percentage of times that large crocodiles were observed during the months between September and December. Results from radio tracking support these visual observations. Telemetry locations of crocodiles tracked during different seasons show a definite movement into the lake during winter and upstream into the river during summer (See figures 24, 25, and 26).

Five distinct groups of large sized crocodiles each concentrated around a specific area in the dam. These areas being the area around the Fisheries station, the area around the Yellow container, Brady's Island, the area near the Granite hills and the area around the Matlala Road. No real movement of the groups took place but as explained above the increase in numbers during winter certainly indicated an influx of large crocodiles into the dam during the cold months and out again during the breeding and nesting season.

Extra large sized crocodiles

Extra large sized crocodiles (> 4.0 m TL) showed a pattern similar to that of the large sized crocodiles. The frequency at which extra large crocodiles were observed in the lake also increased substantially during the winter period (May to August). The average percentage observation for this group was 39.41% (*n* = 307).

As in the case of large crocodiles, this represented a much higher frequency of observation than during the warmer months (January to April and September to December). The winter frequency at which extra large crocodiles were observed was 7.77% higher than the frequency of observations during January to April and it was also 10.45% higher than the frequency of observations during the September to December period.

The number of crocodiles with a TL of > 4.0 m in the Flag Boshielo Dam was estimated at between 12 and 14 individuals (see chapter 5). Possibly due to these low numbers only one group in this size class formed in the dam. Individuals from this group concentrated around the Yellow container, Brady's Island and the Fisheries station. During the 2003 drought this group moved downstream and stayed in the area around the Old nests. As was found with the large crocodiles (2.1 - 4.0 m TL) these animals did not move about much but the increase in numbers explained above indicates an influx of animals with a TL of > 4.0 m into the dam during winter and out again during the breeding and nesting season.

Table 5: Observations of selected Nile crocodiles expressed as percentage of times observed during warm and cold periods in the Flag Boshielo Dam.

Crocodile	**Sex**	**TL**	**Average % observed in lake**		
		(m)	**Jan-Apr**	**May-Aug**	**Sep-Dec**
FBD010	♂	3.60	28.57	42.86	28.57
FBD011	♂	3.00	40.00	40.00	20.00
FBD012	♀	3.04	14.29	85.71	0*

* Crocodile moved into the Olifants River upstream of Desmond's weir during the nesting season. This area is outside the study area and could not be reached by boat, due to access being blocked by the weir, to attempt radio tracking of these individuals.

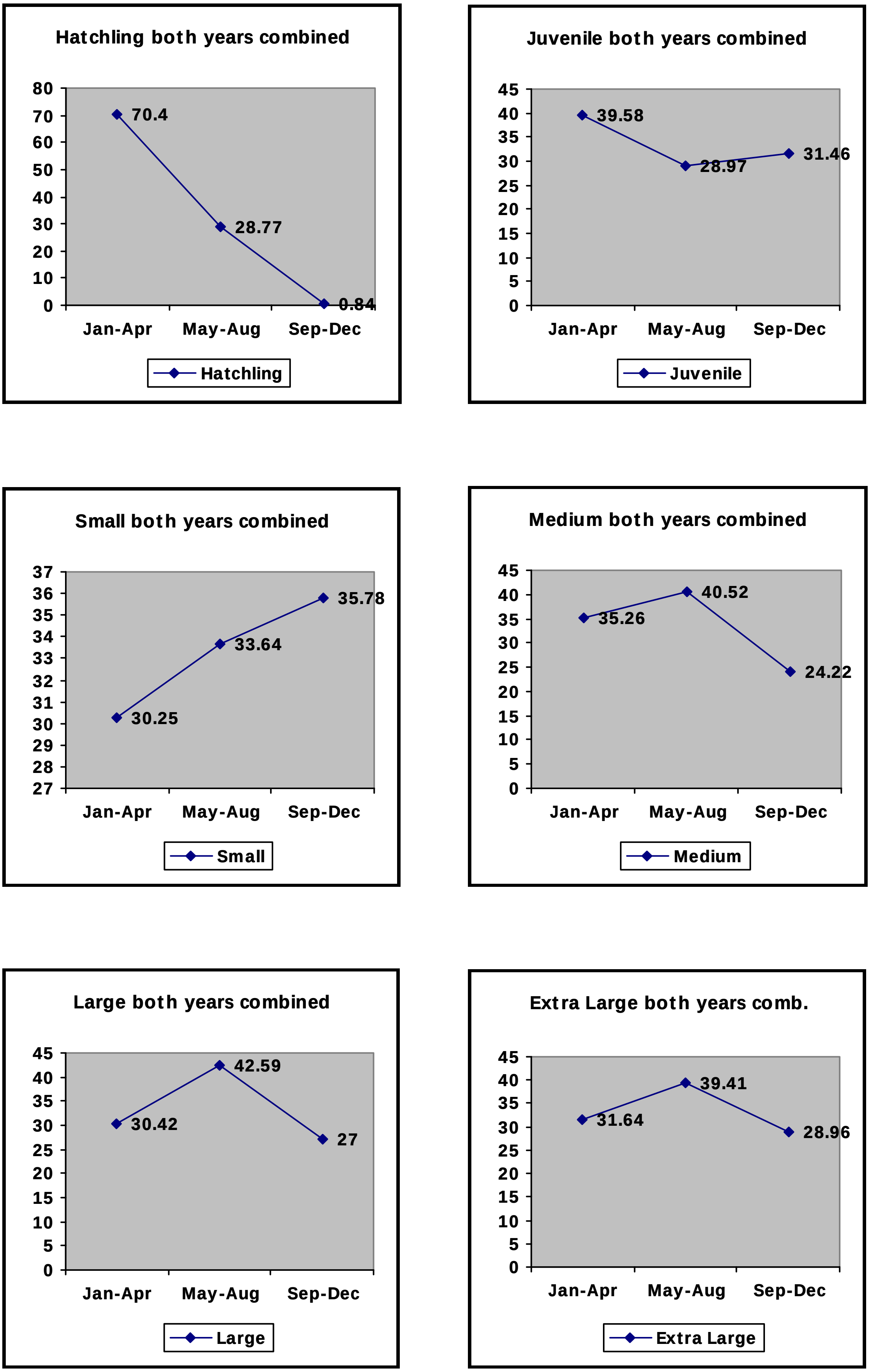

Figure 23: Percentage occurrence of crocodiles per size class during warm and cold months of the year in the Flag Boshielo Dam.

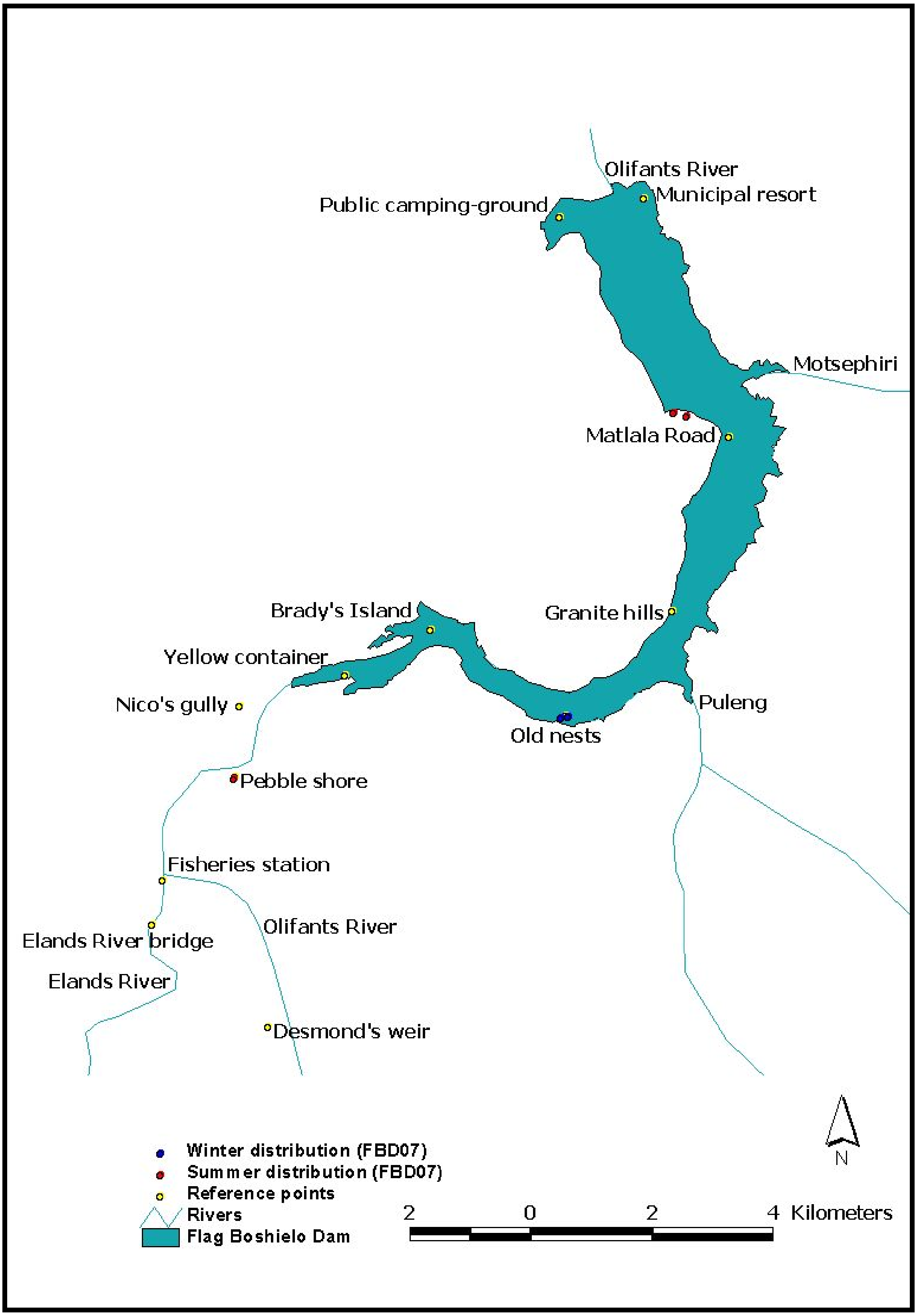

Figure 24: Summer and winter distribution of a single large Nile crocodile (FBD07) in the Flag Boshielo Dam determined by means of radio tracking with a VHF transmitter. The winter distribution was more heavily utilised in terms of the number of times that this particular animal was spotted in a specific area of the dam.

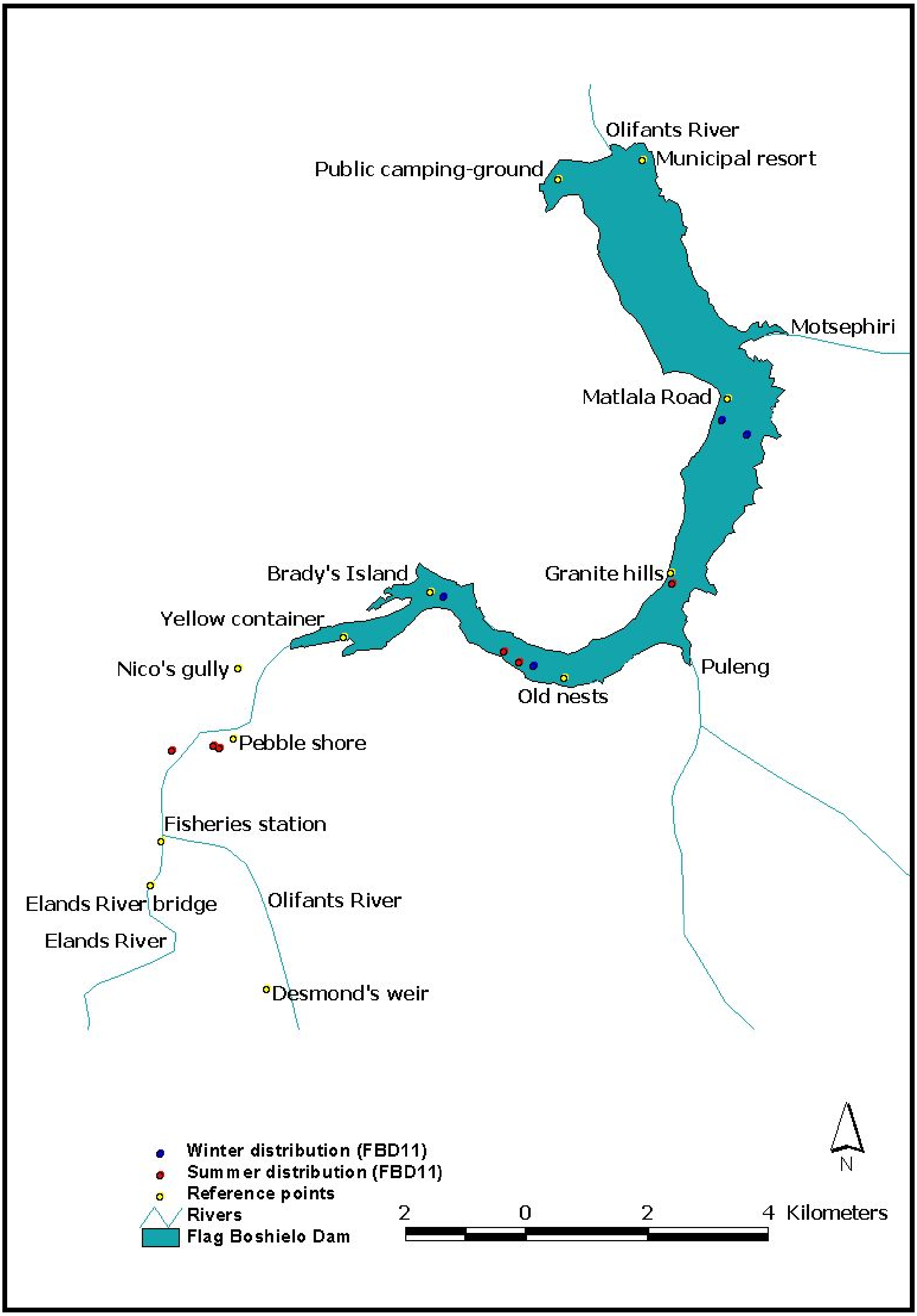

Figure 25: Summer and winter distribution of a single large Nile crocodile (FBD011) in the Flag Boshielo Dam determined by means of radio tracking with a VHF transmitter. This animal shows a distinct preference for areas inside the lake during winter time.

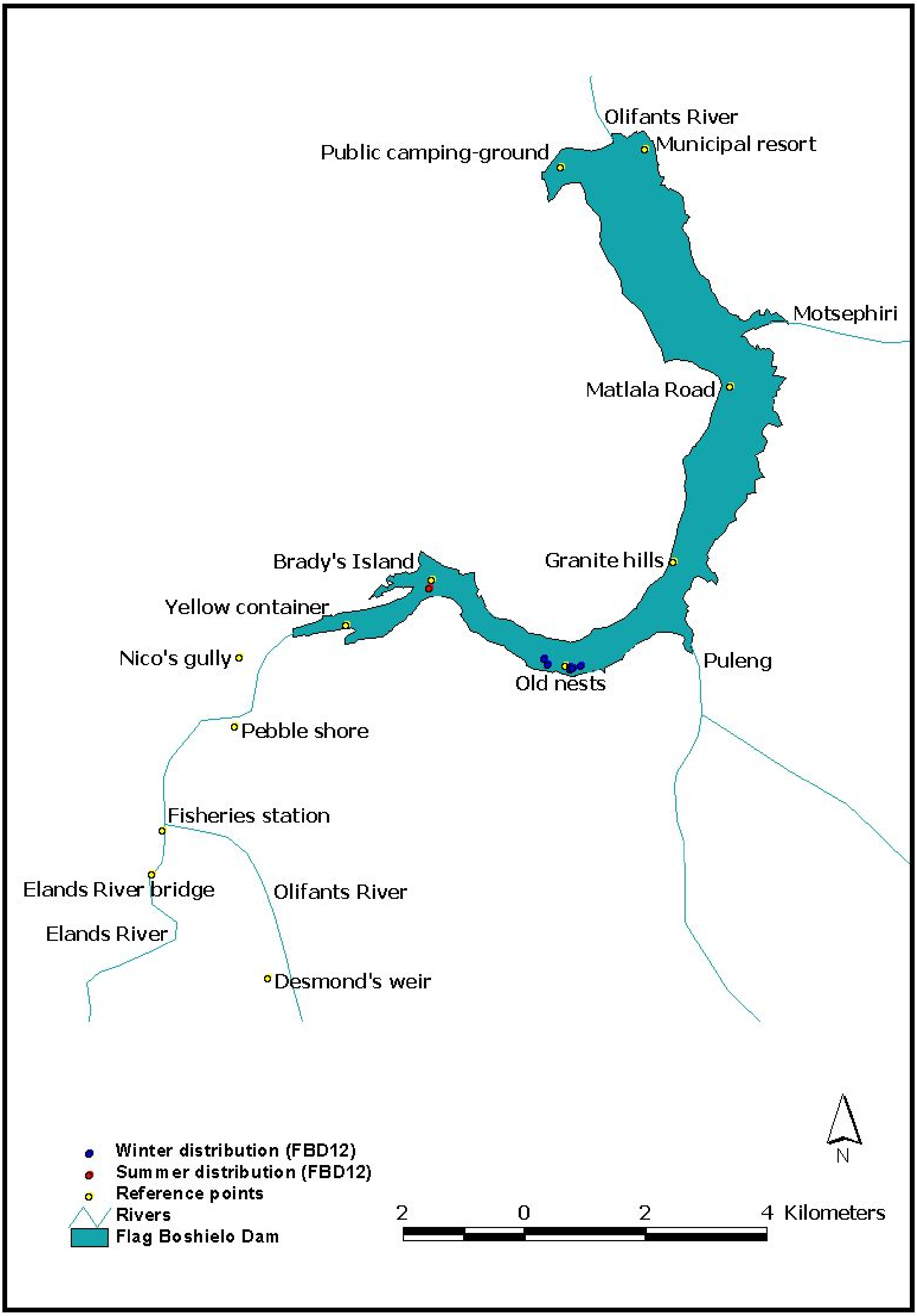

Figure 26: Summer and winter distribution of a single large Nile crocodile (FBD012) in the Flag Boshielo Dam determined by means of radio tracking with a VHF transmitter. This animal also shows a distinct preference for areas inside the lake during winter time.

DISCUSSION

Hatchlings showed no real seasonal movements in the Flag Boshielo Dam. The biggest numbers of this size class was observed during the second half of the summer. This is the period January to April. The reason for this is that eggs from nests in this particular population regularly start hatching during January. As was expected the numbers of hatchlings declined sharply during winter and continued to decline during the first half of summer (September - December). Several authors agree that early mortality is relatively great in crocodilian populations, with mature populations enjoying high life expectancies. Turner (1977) reports that about 20-30% of hatchling *C. porosus* and *C. siamensis* die within their first year of life. Cott (1961) refers to "heavy mortality in the egg, newly hatched and adolescent life stages". Modha (1967) commented on "very considerable" infant mortality in Lake Turkana. During his study in Zululand, Pooley (1969) estimated the number of young Nile crocodiles that reach maturity at no more than 5%. According to Turner (1977) the survivorship curve of Parker and Watson also indicates that about 5% of Nile crocodiles in Lake Victoria survived to the age of 15 years.

Figure 23 show that the percentage occurrence of crocodiles less than 1.4 m TL increased during the first half of summer (September to December). Although this was only a slight increase, it may still be attributed to the fact that the nesting season commences during this time of year. The larger crocodiles and particularly the breeding females probably forced these smaller animals out of the areas where they had lived since being hatched. This movement by smaller animals away from the river-like areas of the dam, where nesting takes place, would be consistent with sub-dominant behaviour. It is widely known that female crocodiles actively compete for and defend optimal nesting areas (Pooley, 1976; Swanepoel *et al,* 2000).

Modha (1967) observed that large male crocodiles in Lake Turkana apparently patrolled the beach near nesting sites and that no sub-dominant crocodiles were to be seen in that particular area. Breeding female crocodiles in Lake Ngezi was found to maintain home ranges and also nested in that particular area (Hutton, 1984). Hutton (1984) also described how breeding females actively forced smaller females out of the home range to breed elsewhere in Lake Ngezi. A socially organized system where juvenile and sub-dominant animals were displaced by breeding females when they re-invade prime breeding grounds annually is described by Hutton (1984). The movement of young, sub-dominant crocodiles in the Flag Boshielo Dam concurs with the social system described by Hutton (1984). Because of their small size, these animals have to disperse more widely than bigger animals in an effort to find a safe spot to live in. They make use of a much wider area than the larger animals do and therefore the observation percentage shows only a slight increase over the figures for the winter period.

The percentage observations made for large crocodiles are very similar for both summer periods (i.e. Jan - Apr and Sep - Dec). Exactly the same situation was found in the case of extra large crocodiles. In both size classes the percentage of times that these animals were observed inside the lake during winter was much higher than the percentage observations made during summer. This indicates a migration into the dam during the cool period and out of the dam during the warmer periods. This would place the large crocodiles in the river-like part of the dam and the inlets of the Olifants and Elands Rivers where nesting takes place during the breeding season. The influx of both large and extra large crocodiles during the cooler months could be due to environmental factors such as the availability of suitable basking sites during winter. The winter months is traditionally considered to be the dry period of the year when no or very little rainfall is received in the area around the Flag Boshielo Dam.

This together with extraction of water for irrigation and maintenance of the ecological reserve of the river downstream from the dam causes a significant lowering of the water level during winter. The effect of this sometimes dramatic lowering of the water-level is that reliable stretches of water situated near suitable sandbanks are only available inside the dam basin. Since the availability of water for thermoregulation is of great importance to large crocodiles, they must migrate to where basking sites with access to deep water is available.

Another possible factor that must be considered is the abundance of prey in the dam during winter as opposed to the river-like areas. It is acknowledged that food intake of crocodilians is considered to be minimal during winter months and it has also been shown that adult crocodiles will not eat when their body temperature falls below a fixed threshold (Pooley, 1976; 1990). However, adult crocodiles were observed on several occasions actively pursuing and catching prey during the winter months in the Flag Boshielo Dam. It is therefore possible that the winter temperatures although lower than the rest of the year, is still warm enough to trigger hunting behaviour in these animals and that they could perceivably select areas where they can easily catch prey while spending less energy than in other areas such as the rivers.

Radio tracking by means of VHF transmitters was also attempted as a possible method to determine any seasonal movement by crocodiles in the Flag Boshielo Dam. As reported in Chapter 3, the destructive nature of the crocodiles made this almost impossible to achieve. Only four of the 13 VHF transmitters made it through the summer and into winter before being destroyed by the crocodiles. The remaining nine VHF transmitters were totally destroyed within an average of 10.92 days. The transmitter that lasted the longest took 19 days before it was destroyed.

Data of some of the VHF transmitters although admittedly low in volume, can be used in support of visual observations. The GPS/GSM transmitters unfortunately proved too unreliable to obtain long-term data regarding the movements of the tagged crocodiles. Data collected from crocodile FBD011, FBD012 and FBD07 showed clearly that their winter distribution was concentrated inside the dam basin while summer distribution was concentrated in the river-like areas (χ^2 = 2.00; df = 1; P < 0.050). This pattern is clearly shown in figure 25 and also in figure 26. Crocodile FBD07 while smaller than both FBD011 and FBD012 still shows the same distribution pattern. Figure 24 clearly shows that this crocodile preferred to live in the dam basin during the colder period of the year and then moved away during the summer period. The movement into the area north of the Matlala Road is possibly due to this crocodile's small size. It was measured at 2.60 m TL while the total lengths for both FBD011 and FBD012 where recorded at over 3.0 m. It is commonly known that smaller crocodiles will actively avoid bigger ones especially during the mating and breeding seasons.

The only other transmitter that lasted long enough to give decent readings was the one attached to crocodile FBD010. Unfortunately this transmitter was lost after only 5 days but it continued to transmit signals while being washed about in the shallows where it came off the crocodile. Therefore the distribution data was not correct and could not be used.

CONCLUSION

Migration of animals between the dam basin and the inlets/river-like areas of the lake was found to exist. This migration however seem to be size related. Hatchling sized animals showed no seasonal movement at all. These animals stayed put in the general area where they were hatched and then showed a marked reduction in numbers.

This substantial loss of hatchlings has been reported in the past by several authors (Cott, 1961; Modha, 1967; Pooley, 1969; Parker and Watson, 1970; Turner, 1977) and it is therefore not considered out of the ordinary.

Small sized crocodiles (40 - 140 cm TL) seemed to be displaced during the September to December period of summer. The percentage occurrence of these animals inside the dam basin increased during this period. A simultaneous decrease in the sightings of this size class was noted in the rivers and river-like areas of the lake during this same period of summer. This increase in sightings in one area of the lake together with a decrease of sightings in another area at the same time suggests migration of animals rather than loss due to predation as is the case with hatchlings.

Large and extra large sized crocodiles showed an unmistakable migration out of the lake during summer and back into the dam basin during winter. The observations for these animals were higher during winter than summer which supports the hypothesis that migration takes place between the dam and the rivers. It is not quite clear why the larger animals move into the lake during the winter but this may well be due to environmental factors. The availability of basking sites in close proximity to deep pools of water could attract these animals into the lake during winter time. This is traditionally the dry season and water in the river can at times become no more than a trickle. Together with the availability of suitable basking sites, access to prey animals during winter may also be a factor. Large Nile crocodiles were observed showing hunting behaviour during the cooler months of the year when they are in fact supposed to minimise food intake (Pooley, 1976; 1990). Movement by this size class of crocodile into the rivers during summer coincide with the nesting season. Large females actively compete for and defend prime nesting sites. This competitive behaviour is known to force smaller crocodiles out of the areas where they have been living since they have hatched. This migration of the smaller animals is consistent with sub-dominant behaviour and concurs with the social system described by Hutton (1984).

In summary, the hypotheses that the natural crocodile population of the Flag Boshielo Dam show seasonal movement within the impoundment and the inlet of the Olifants and Elands Rivers were proved to some extent. Hatchlings showed no form of seasonal movement while small sized crocodiles showed some migration possibly due to being forced out of their areas by larger breeding animals. Large and extra large crocodiles however, showed an unmistakable migratory pattern of movement into the lake during winter and out into the rivers during the summer when mating and breeding takes place. Crocodiles in the large and extra large size classes (2.1 - >4.0 m TL) were seldom seen outside the dam in winter while they were observed both inside and outside of the dam in summer. None of the size classes showed any sign of localised migration patterns between areas within the dam.

CHAPTER 8

SIZE OF TERRITORIES USED BY NILE CROCODILES IN THE FLAG BOSHIELO DAM

INTRODUCTION

The distinction between home range and territory is not always very clear. Hutton (1984) suggests that a territory involves a fixed space with elements of defence, exclusion and dominance. Burt (1940) defined home range as the area, usually around a home site, over which an animal normally travels in search of food. Territory on the other hand was defined by Burt (1940) as the protected part of the home range, be it the entire home range or only the nest. The size of the home range may vary with sex, possibly age and season while population density may also influence the size of the home range to coincide closely with the size of the territory (Burt, 1940). In later studies, Owen-Smith (1977) described territoriality as a strategy used by individuals to secure a disproportionate share of each resource which has potential significance to genetic success. Home range strategies affect life history processes such as growth and survival of individuals in a population (Jewell, 1966).

Howard (1960) defined dispersal as the movement an animals makes from its point of origin to the place where it reproduces or would have reproduced if it had survived and found a mate. This definition implies that dispersal only occurs on one occasion in the life of an animal. In the case of crocodiles it has been shown that home range behaviour changes a number of times as the animal grows from juvenile to reproductive size (Hutton, 1984).

METHODS

Various methods can be used to analyse and present home range data (Anderson, 1982, Hutton, 1989) but many of these do not give satisfactory results when used to estimate the activity range of crocodilians. The minimum convex polygon would present problems with the interpretation of outlying points in a linear range such as a river or dam (Hutton, 1989). The harmonic mean home range technique (Dixon and Chapman, 1980) may accurately describe the shape of the home range but according to Hutton (1989) it does not indicate true centres of activity. Hooge and Eichenlaub (1997) consider the Jennrich-Turner home range technique to be seriously flawed in its dependence on a bivariate distribution of locations.

Because of its advantages, the Kernel method of range size and use analysis is sometimes used rather than the more traditional methods. The Kernel technique determines the range size and use in terms of the relative amount of time spent by an animal in the different areas of its range (Worton, 1987, 1989; Seaman and Powell, 1996), and gives a good indication of patterns of range use and size (Worton, 1995). This is often referred to as the utilisation distribution (Van Winkle, 1975).

MP2 croc module custom application VHF transmitters were attached to 13 Nile crocodiles while Hawk 105 GPS/GSM transmitters were attached to another two crocodiles. The shape of a crocodilian head makes the use of radio collars difficult and impractical. Three crocodiles were radio-tagged during August 2002; two animals were radio-tagged during September 2002 with a further five radio-tagged during October 2002. One crocodile was also radio-tagged during each of the following months: November 2002, February 2003 and August 2003. Animals fitted with VHF transmitters were tracked with a directional antenna attached to a Telonics TR-4 receiver operating on the 148/152 MHZ frequency. Localities where crocodiles were found were marked with a GPS and then plotted on a Geographic Information System (GIS) map using ArcView GIS software.

The GPS/GSM transmitters functioned independently and therefore no daily tracking of crocodiles tagged with these transmitters was necessary. These transmitters were preset to take a GPS reading every four hours which was sent as a text message by cellphone to the central database. The data was then downloaded from the database and imported into the ArcView GIS via the internet to plot the activity range of the crocodiles concerned. Readings of the crocodiles position could however, only be taken if the crocodile was actually on the surface or at least just below the surface of the water at the time when the reading was to be taken. This never became a problem, since crocodile NGS 004 transmitted 331 readings before the unit shut down.

The distribution data of the radio-tagged crocodiles were plotted and analysed with the ArcView 3.2 GIS software package. Range use analysis was achieved by using the *Spatial Analyst Extension* of ArcView 3.2 together with the *Animal Movement Analysis* extension which was specifically developed by Hooge and Eichenlaub (1997) for analysing animal movements. Five percent outliers were removed from the data by running the outlier removal routine of the Animal Movement Analysis extension software. This produced results that were much more in line with the linear shape of the crocodile's habitat. The 50%, 75% and 95% utilisation distribution were then calculated for each crocodile using the Kernel home range routine of the same software package. The 50% utilisation distribution is considered a reliable estimate of an animal's centre of activity while the 95% utilisation distribution is accepted as an estimate of its total range size excluding outlier distribution points (Mizutani and Jewell, 1998).

The Kernel home range analysis routine of the Animal Movement Analysis extension produce results in the form of a polygon shapefile for each probability percentage while it also displays the calculation of each probability. The shapefile was then turned into a contour map showing the different probabilities in colour. The 50% utilisation distribution is considered a reliable estimate of an animal's centre of activity while the 95% utilisation distribution is accepted as an estimate of its total range size excluding outlier distribution points (Mizutani and Jewell, 1998).

RESULTS

Large enough samples of radiolocation data could only be collected from four crocodiles over the period that they were radio-tagged. These are crocodiles NGS 004 (3.00 m), NGS 005 (4.10 m), FBD 05 (3.27 m) and FBD 12 (3.04 m). The problem of radio tracking a large number of crocodiles successfully was also encountered during other studies (Hutton, 1984).

Crocodile NGS 004 (Tables 6, 7, 8, 9 and Figure 27)

The GPS/GSM transmitter on crocodile NGS 004 (♀; 3.0 m TL) had sent a total of 331 sets of coordinates by the time it shut down. These confirmed that the animal had a small centre of activity near Pebble shore. The total size of this area was estimated at 0.04 km^2. This particular crocodile also moved about in the area behind (upstream) of Desmond's Weir and the estimated total size of this range is approximately 0.82 km^2 in extent. These two home ranges are situated approximately 4.56 km apart. During the winter months (May and June) this crocodile left its territory and maintained a smaller area near Brady's Island (0.16 km^2) while also maintaining a centre of activity (0.03 km^2) near the Old nests area. This "winter range" of this crocodile is about 4.25 km downstream from the territory at Pebble shore which in turn is about 4.56 km downstream from the Desmond's Weir territory. The average size of this crocodile's centre of activity is 0.05 km^2 while the average size of the home range is 0.26 km^2. The activity centres of this crocodile's range are situated along a total of 3.50 km of shoreline.

Crocodile NGS 005 "Koos" (Tables 6, 7, 8, 9 and Figure 28)

The GPS/GSM transmitter attached to "Koos" (NGS 005) sent 25 sets of coordinates to the database before shutting down. All attempts to get the transmitter up and running again failed and no further data could be collected from this crocodile. This particular crocodile was a male with a TL of 4.10 m making him one of the dominant males in this population and was named "Koos". This crocodile spent most of his time in an area of approximately 0.54 km^2 situated near the Old nests with a second range of approximately 0.44 km^2 near Brady's Island. During the winter months this crocodile moved downstream to the area near the Granite hills where he stayed in an area approximately 0.42 km^2 in size. This "winter range" of crocodile NGS 005 is a distance of 2.38 km downstream from the Old nests. The average size of the centre of activity of crocodile NGS 005 is 0.09 km^2 while the average size of the home range is approximately 0.28 km^2. The activity centres of this crocodile's range are situated along a total of 3.25 km of shoreline.

Crocodile FBD 05 (Tables 6, 7, 8, 9, and Figure 29)

Crocodile FBD 05 (♂; 3.27 m TL) had a VHF transmitter attached to the scutes on his tail. Only eight radiolocations were made before the transmitter stopped working. The crocodile was later seen without the transmitter which had obviously been broken off and was lost somewhere in the dam. However from the little data that was collected it seems that this male crocodile, which is much smaller than "Koos", maintained a very small centre of activity of approximately 0.04 km^2 near Brady's Island. His total range extended for about 0.19 km^2. Unfortunately no radiolocations were made during the winter months. The average size of the centre of activity for FBD 05 is 0.04 km^2 while the average size of the home range is 0.10 km^2. The activity centres of this crocodile's range are situated along approximately 650 m (0.65 km) of shoreline.

Crocodile FBD 12 (Tables 6, 7, 8, 9 and Figure 30)

Crocodile FBD 12 is a female crocodile with a TL of about 3.04 m. She also had a VHF transmitter attached to the scutes on her tail and unfortunately only 10 radio contacts could be made before the transmitter stopped working. This animal had a centre of activity estimated to be about 0.05 km^2 in size and situated in the general area of the Old nests with a total range size of approximately 0.26 km^2. The average size of this crocodile's centre of activity is 0.03 km^2 while the average size of the home range is 0.13 km^2. The activity centres of this crocodile's range are situated along approximately 790 m (0.79 km) of shoreline.

Table 6: Difference in size and length of home range between male and female radio tagged Nile crocodiles in the Flag Boshielo Dam. The 50% utilisation represents the animal's core area of activity while the 95% utilisation represents the total range size, excluding outlier distribution points.

Gender	Number	Mean size of area utilised			Mean length
	of locations	50%	75%	95%	of territory
Males (NGS 005; FBD 05)	33	0.08 km² (80 m²)	0.09 km² (90 m²)	0.23 km² (230 m²)	0.56 km (560 m)
Females (NGS 004; FBD 12)	341	0.05 km² (50 m²)	0.10 km² (100 m²)	0.23 km² (230 m²)	0.39 km (390 m)

***** Figures were converted to meters and square meters and are given in brackets.

Table 7: Home range sizes of Flag Boshielo compared to home range sizes at Lake Ngezi**,** Zimbabwe.

Lake Ngezi (Hutton, 1984)			Flag Boshielo Dam		
Crocodile No.	**No of radiolocations**	**Home range area (km²)**	**Crocodile No.**	**No of radiolocations**	**Home range area (km²)**
N 18	11	0.164	NGS 004	331	0.52
N 203	60	0.120	NGS 005	25	0.47
N 209	56	0.262	FBD 05	8	0.19
N 80	151	0.799	FBD 12	10	0.26
Average	**69.5**	**0.311**	**Average**	**93.5**	**0.36**

Table 8: Kernel estimation of range sizes (km²) showing the average size of range and centre of activity of selected Nile crocodiles in the Flag Boshielo Dam at different percentages of utilisation. The 50% utilisation represents the animal's core area of activity while the 95% utilisation represents the total range size, excluding outlier distribution points.

Crocodile No.	Sex	Total length of crocodile	No. of locations	Length of territory	Mean range size at different % of utilisation			Total home range size
					50%	75%	95%	
NGS 004	♀	3.00 m	331	3.50 km	0.05 km²	0.11 km²	0.26 km²	0.52 km²
NGS 005 "Koos"	♂	4.10 m	25	3.25 km	0.09 km²	0.12 km²	0.28 km²	0.47 km²
FBD 05	♂	3.27 m	8	0.65 km	0.04 km²	0.04 km²	0.10 km²	0.19 km²
FBD 12	♀	3.04 m	10	0.79 km	0.03 km²	0.07 km²	0.13 km²	0.26 km²

Table 9: Kernel estimation of sizes (km²) of home range and territories of selected Nile crocodiles in specific areas in the Flag Boshielo Dam at different percentages of utilisation. The 50% utilisation represents the animal's core area of activity while the 95% utilisation represents the total range size, excluding outlier distribution points.

Area	Mean length of territory	Total length of territory	Mean size of area utilised			Total size of area utilised		
			50%	75%	95%	50%	75%	95%
Desmond's Weir	0.24 km	0.72 km	0.10 km²	0.12 km²	0.41 km²	0.10 km²	0.24 km²	0.82 km²
Pebble shore	0.16 km	0.32 km	0.01 km²	0.02 km²	0.02 km²	0.02 km²	0.03 km²	0.04 km²
Brady's Island	0.92 km	3.66 km	0.07 km²	0.12 km²	0.39 km²	0.26 km²	0.71 km²	1.57 km²
Old nests	0.35 km	2.46 km	0.05 km²	0.09 km²	0.15 km²	0.18 km²	0.45 km²	1.08 km²
Granite hills	0.52 km	1.03 km	0.10 km²	0.16 km²	0.21 km²	0.10 km²	0.16 km²	0.42 km²
Average	0.43 km	1.63 km	0.06 km²	0.10 km²	0.23 km²	0.13 km²	0.31 km²	0.78 km²

Figure 27: Kernel estimation of the range of crocodile NGS 004 in the Flag Boshielo Dam during 2002 - 2004 showing the 50%, 75% and 95% utilisation distribution.

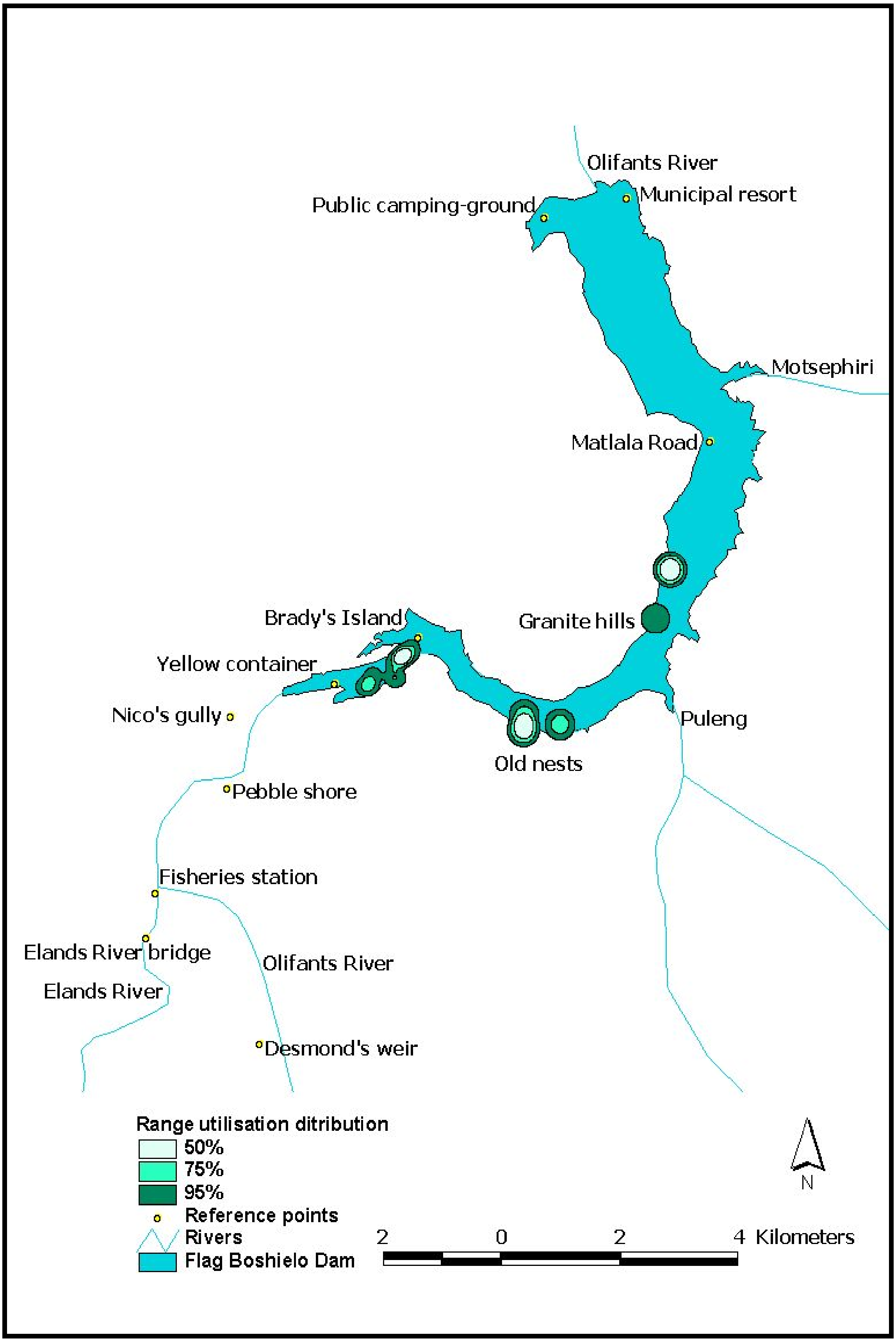

Figure 28: Kernel estimation of the range of crocodile NGS 005 "Koos" in the Flag Boshielo Dam during 2002 - 2004 showing the 50%, 75% and 95% utilisation distribution.

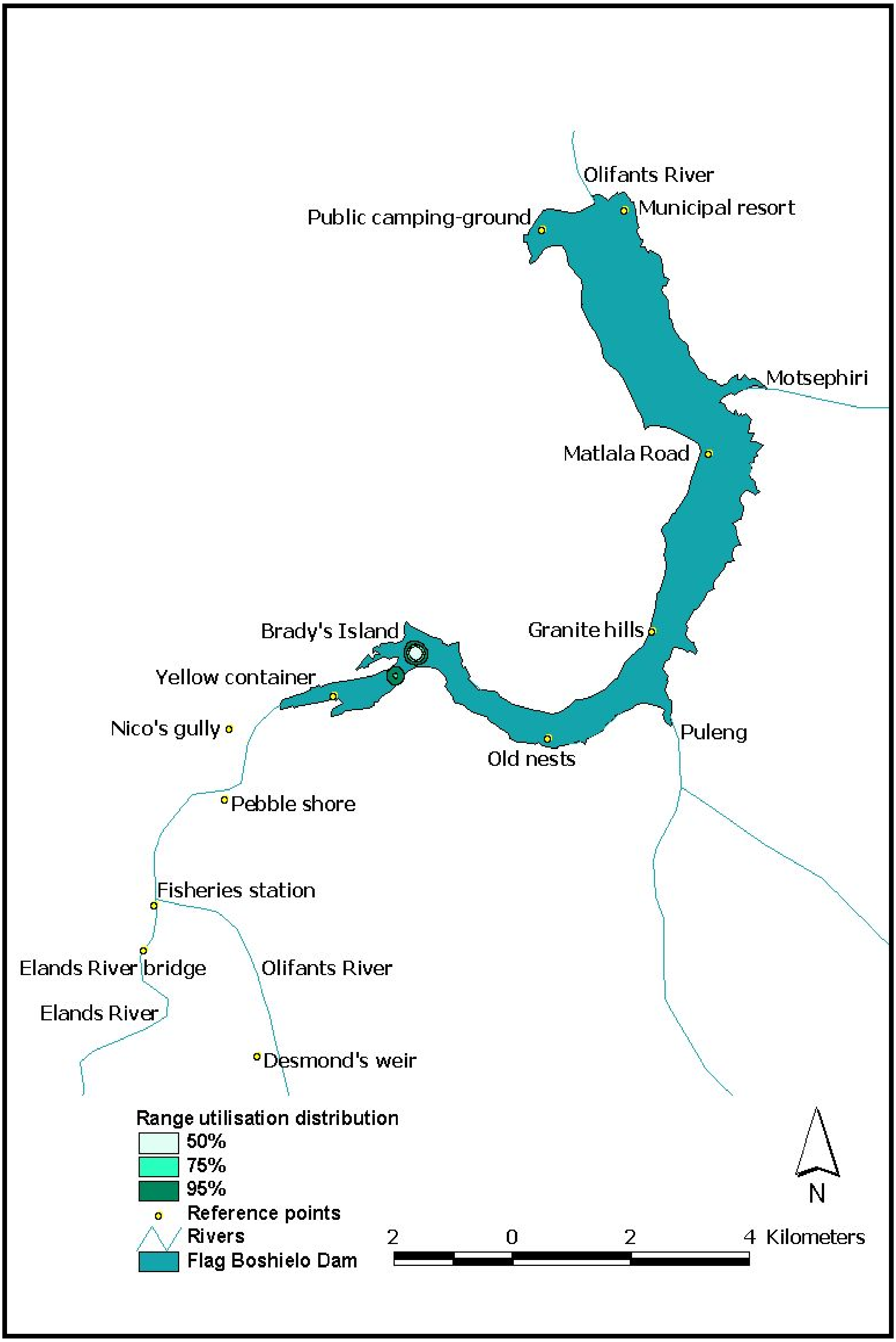

Figure 29: Kernel estimation of the range of crocodile FBD 05 in the Flag Boshielo Dam during 2002 - 2004 showing the 50%, 75% and 95% utilisation distribution.

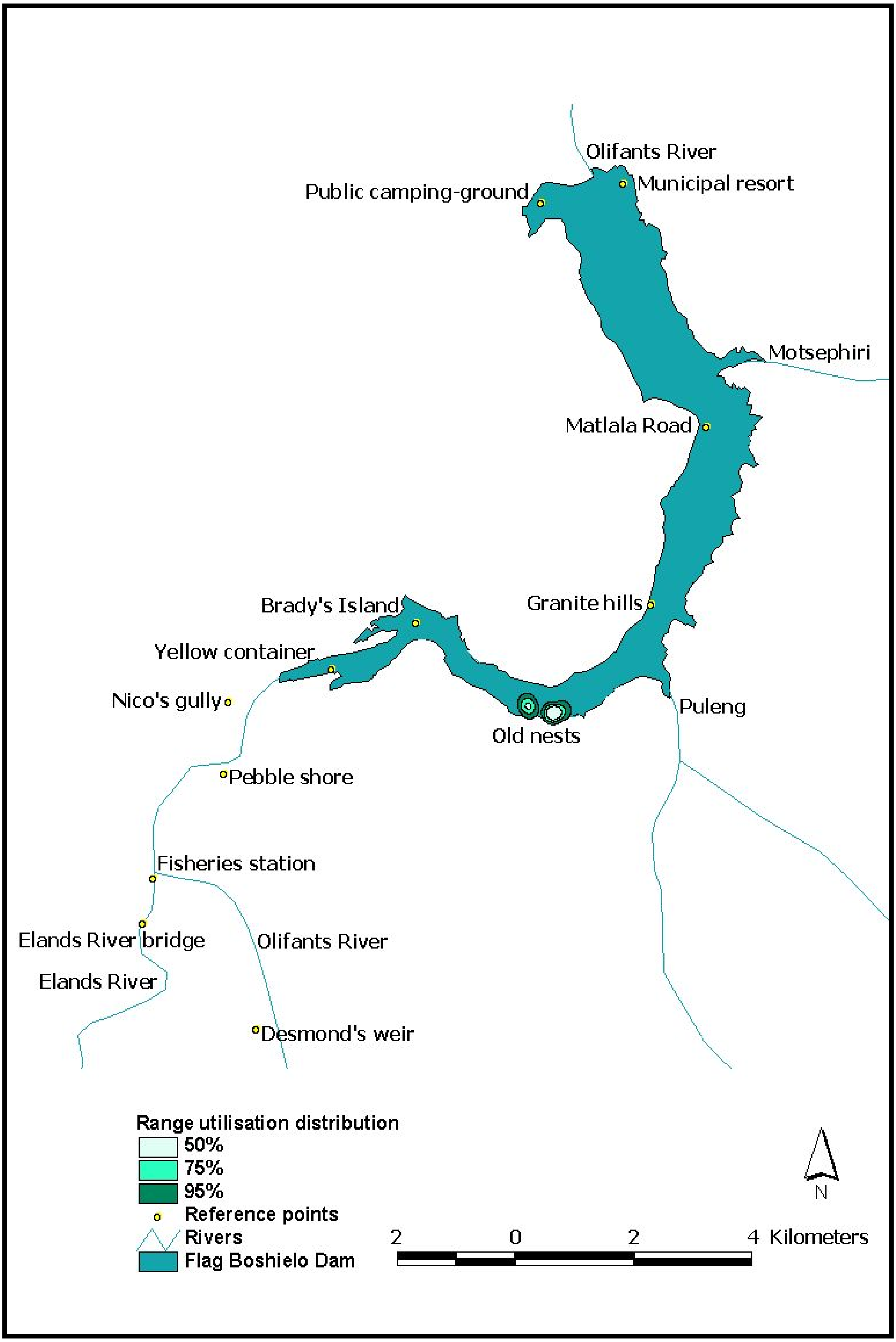

Figure 30: Kernel estimation of the range of crocodile FBD 12 in the Flag Boshielo Dam during 2002 - 2004 showing the 50%, 75% and 95% utilisation distribution.

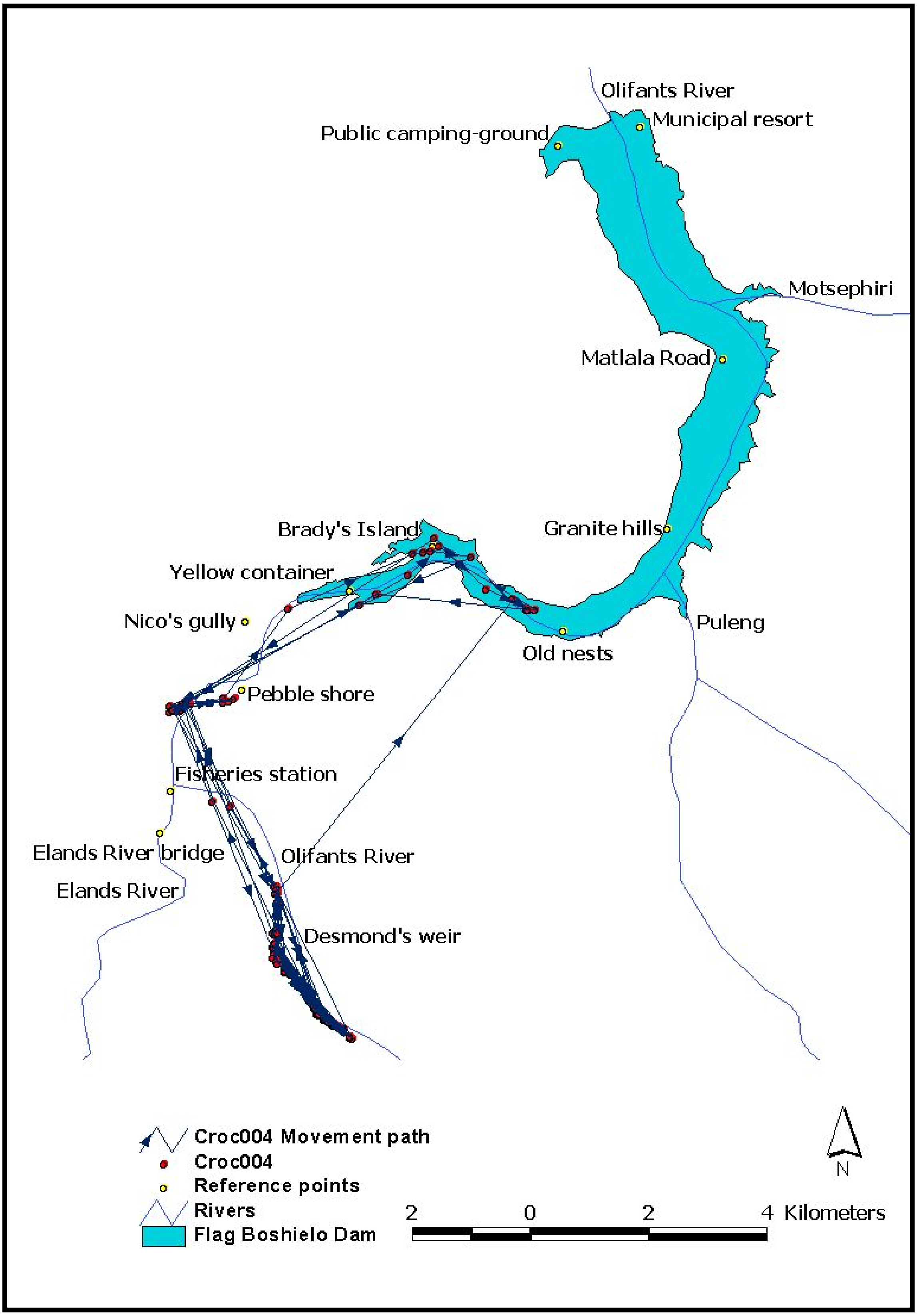

Figure 31: Movement path of crocodile NGS 004 in the Flag Boshielo Dam. The Animal movement analysis tool (ArcView 3.2) does not take the linear characteristics of a river into account, thus showing some movements across large areas on land to connect outlier points. These movements across land should be ignored.

DISCUSSION

Modha (1967) measured the territory of crocodiles in Lake Turkana and expressed the size thereof in linear distance (m) rather than in area (km^2). He observed the Lake Turkana crocodiles moving through territories that ranged from 60 m to 230 m in length. The Flag Boshielo Dam is a much smaller and narrower lake where the average size of all centres of activity came to between 0.06 km^2 and 0.23 km^2. The average home range size is approximately 0.36 km^2 which can be compared to the average home range size of 0.31 km^2 found by Hutton (1989) in Lake Ngezi, Zimbabwe. The minimum sizes that compare well to those found in Lake Turkana and also in Lake Ngezi suggest that there is a minimum size of territory that crocodiles need in order for them to fare reasonably well. Based on the results of this study given in tables 8 and 9 the size of that area is estimated to be approximately 0.06 km^2 (60 m^2) in the Flag Boshielo Dam.

Variation in the size of territories is evident with the average size ranging between 0.03 km^2 and 0.09 km^2 (table 8). Although the sample size was small, it was noticeable that male crocodiles had bigger territories than females while males also maintained longer territories than females (table 6). Hutton (1989) also found that mature female crocodiles have small home ranges. The two female crocodiles maintained a centre of activity with an average size of approximately 0.05 km^2 and an average home range of approximately 0.23 km^2. In contrast the two males had a somewhat larger centre of activity with an average size of approximately 0.08 km^2 whilst the average home range of approximately 0.23 km^2 is the same as the females. A fair amount of overlapping in home range seem to occur between individual crocodiles as evidenced by all the tagged crocodiles having some claim to the Brady's Island/Old nests area. It was however never clear whether these were defended against other crocodiles. Hutton (1989) found no overlapping of home ranges in Lake Ngezi.

The utilisation of a large area upstream of Desmond's Weir was a little unexpected. It has long been argued that this weir is an obstruction that heavily influences the distribution of crocodiles in the Flag Boshielo Dam and the Olifants River. Crocodile NGS 004 was caught and tagged on 12 March 2004 near Pebble shore and spend the next three days in the same general area. The crocodile then suddenly moved upstream and one day later he had travelled 4.56 km to the area at Desmond's Weir. During his stay in this area this crocodile eventually even travelled as far as 2.28 km beyond Desmond's Weir upstream into the Olifants River. Crocodile NGS 004 then stayed behind the weir for the next 24 days before moving back downstream to the territory where he was caught (Pebble shore). This crocodile moved freely back and forth over (or around) the weir until the transmitter stopped working. Therefore weirs in rivers probably do not limit the movements of crocodiles as much as it was expected to do. Similarly crocodile NGS 005 "Koos" stayed in the Old nests area where he was caught for one day and then moved 2.86 km upstream to Brady's Island where he moved up and down for the next five days. Koos then moved 5.24 km back downstream past the Old nests to settle in the Granite hills area. Unfortunately the transmitter broke down shortly after this move and no further data was collected. This confirms the possibility that crocodiles quickly move away from the site where they were captured or had perhaps been harassed (e.g. by watercraft) to settle in areas much further away for quite some time before returning to their original territory.

A strong correlation (r = 0.92) was found between the total length of the crocodiles and the size of their territories indicating that home range behaviour do indeed change as the crocodile grows from juvenile to adult size.

CONCLUSION

The Nile crocodiles in the Flag Boshielo Dam seem to establish home ranges that vary on average between 0.03 km² to about 0.28 km² in the case of an animal in the > 4.0 m TL size class. The average size of territories (0.06 km²) compare well to that found in other crocodile populations (Modha, 1967, Hutton, 1989), which indicates that individual crocodiles need at least a minimum size of territory in order for them to fare reasonably well. In the Flag Boshielo Dam that distance seem to be approximately 0.06 km² which converts to about 60 m².

Male crocodiles had bigger territories and range sizes than the females. Radio telemetry results gathered indicates that in the Flag Boshielo Dam, the centres of activity of male crocodiles are on average 23.08% larger than that of female crocodiles. The results also indicate that the average length of the male territories is 17.90% longer than those of female crocodiles in the Flag Boshielo Dam. Amongst the male crocodiles, "Koos" has a substantially bigger territory and range than the much smaller FBD05. "Koos" is a dominant male and member of the > 4.0 m TL size class. Crocodile NGS 004 spent much of its time behind Desmond's Weir which suggests that obstructions such as weirs in rivers do not present a particular problem to crocodiles in the 2.1 - 4.0 m TL size class. This is probably also true for smaller crocodiles. Finally, a strong correlation was found to exist between the length of the crocodile and the size of its territory. The crocodiles showed interesting behaviour in the way that they moved out of the area where they where captured and into other areas as far as 2.86 km and even 6.83 km away from the capture site before returning to the original area again. Overlapping of home ranges seems to exist as evidenced by all the tagged crocodiles having some claim to the Brady's Island/Old nests area.

CHAPTER 9

NESTING ECOLOGY OF NILE CROCODILES IN THE FLAG BOSHIELO DAM

INTRODUCTION

An attempt was made to establish the nesting patterns of female Nile crocodiles in the Flag Boshielo Dam. This was achieved by measuring the physical placement of nests in relation to the immediate environment, estimating the size of nesting females, determining the physical attributes of the eggs and by accurately mapping preferred nesting areas in the Flag Boshielo Dam. While historical figures seem to indicate that the Flag Boshielo Dam population of Nile crocodiles prospered (Swanepoel, 2001) the population in the Loskop Dam has declined sharply since the early 1980's (Jacobsen, 1992). In view of this decline of the Loskop Dam population, Jacobsen (1988) suggested that the Flag Boshielo Dam population of Nile crocodiles may be the last fairly large viable population that occurs outside an officially protected area in the former Transvaal Province of South Africa. This suggestion is supported by surveys done by Kleynhans and Engelbrecht (1993) in the area of the Olifants River between the Loskop Dam and the boundary fence of the Kruger National Park. Their study has shown that the highest number of Nile crocodiles per kilometre of shoreline occur in the Flag Boshielo Dam.

METHODS

Possible nesting sites were located along the shores of the dam and also along the inlets of the Olifants and Elands Rivers by a combination of methods. The areas concerned were surveyed using an Aquila microlight aircraft equipped with a Rotax 582 engine and flying at a height of 150 - 200 feet, travelling at a ground speed of approximately 65 kph. Any nesting site spotted from the air was marked with a handheld GPS during the flight. The same areas were then ground-truthed on foot the following morning. The aerial survey was at times substituted with a boat based survey due to unavailability of the aircraft or unfavourable weather conditions. An eight meter fibreglass-hull catamaran ski boat powered by twin 40 hp Yamaha outboard motors was used for all boat based surveys. The average speed at which boat surveys were carried out was between 10 and 15 kph.

Possible nests were spotted from the water and the location marked with a GPS. As for the aerial surveys, all boat based surveys were also confirmed on foot the following day. During these foot patrols the shoreline was walked and in addition to locating the GPS marked nests any trails and footpaths leading from the water and showing signs of crocodile presence e.g. footprints, tail marks etc was followed to establish if any nests were possibly located at the end of the trail. This was considered a method of making sure that no nesting sites was overlooked. Once located all possible nests were identified as active nests by probing and excavating the nest to establish the presence of eggs following Blake, 1974. Nests thus identified were marked with the GPS to be plotted on a GIS map later. Although most nests were found, a small percentage of nests were missed in some years as shown by the appearance of hatchlings. Therefore the number of nests recorded in each year must be taken as the minimum number of nests.

A set of environmental characteristics were recorded at each active nesting site. These included the estimated total length of the nesting female, the length of the hindfoot print (HF), the distance from the nest to water, the height of the nest above the water, the incline of the shoreline, estimated exposure of the nest to sunlight, height and species of vegetation near the nest and the type of substrate.

The size of the nesting female was estimated by using a standard pair of 8x42 binoculars. This estimated size was controlled against the measurement of the hindfoot print. The print of the hindfoot was measured in cm and multiplied by a factor of 1:14 where HF is <150 mm and 1:13.5 where HF is >150mm (Hutton, 1987a).

The distance from water is crucial to the survival of hatchlings (Swanepoel *et al*, 2000) because they are most vulnerable to attacks from predators from the time of hatching until they can reach the relative safety of the water. The distance of each nest to the nearest water was measured with a standard 30 m measuring tape. This was done at the start of the nesting season.

Nest height above water is an equally important factor as flooding of nests during the incubation period accounts for many nest mortalities (Hartley, 1990; Hutton, 1984; Pooley, 1969). The height of the nest above water was measured using string stretched from the nest opening to a 3 m aluminium pole marked at 50 cm intervals. The pole was held in position at the waters edge by an assistant and the string pulled straight along a carpenter's square set against the pole to ensure that both the pole and the string was level at all times. The height of the nest above water was read where the string touched the pole.

The incline of the slope is also regarded as an important factor in the accessibility of the nest to the female (Swanepoel *et al.* 2000). The exact incline was calculated by using the cotan function of distance over height converting radians into degrees (Swanepoel *et al.* 2000).

Exposure of the nest to direct sunlight was estimated by observing each nest during early morning and late afternoon. The time was noted when the nest became exposed to direct sunlight in the morning and also when it was no longer exposed to direct sunlight in the late afternoon. Based on these observations the number of hours of direct exposure to sunlight was calculated.

Hutton (1984) deemed exposure to direct sunlight as one of the most important factors in the choice of a nesting site by the female crocodile. Crocodile eggs incubated at below 27°C develop so slowly that the embryo eventually dies whilst eggs incubated at temperatures above 36°C fail to develop at all (Hutton, 1984). These thermal tolerances are dependant on local environmental factors and may vary accordingly (Leslie, 1997). The importance of direct sunlight for the successful incubation of crocodile eggs and sex ratios of the emerging hatchlings has been reported by several other authors (Blake and Loveridge, 1992; Lang and Andrews, 1994; Leslie, 1997).

The height and species of vegetation around nesting sites was also noted. The importance of vegetation lies in the shade that it will cast over the nest causing it to cool down. Vegetation also provides shade for the female crocodile that has to regulate her body temperature while guarding the nest against predators. Pooley (1969) noted that soil temperatures in direct sunlight became intolerably high, thus shade becomes important for the survival of the female crocodile. However, too much shade over the nesting site may alter the incubation temperature which will affect sex ratios in the nest while roots of overgrown vegetation may impede the female in her efforts to dig a suitable egg chamber (Leslie and Spotila, 2001).

The shape of the egg chamber is often influenced by the type of substrate (Kofron, 1989b). The type of substrate in which nests was made in the Flag Boshielo Dam was classified into three broad categories, these being sand, soil and clay. Swanepoel *et al.* (2000) defined sand as being coarse loosely-packed river sand, soil was defined as alluvial deposits on floodplains next to the river and clay was defined as any substance that stuck to a metal rod when probed. Nile crocodile nests have been reported in a variety of soil types in the past (Hutton, 1984; Pooley, 1969).

The contents of the nests were also examined and a number of characteristics were recorded. Only selected nests were opened because of the danger that the activities at the nest may attract predators which could then destroy the nest. Once positively identified as an active nest and all environmental characteristics were recorded, sand was removed from the nest to expose the egg chamber. Care was taken to place the sand on a canvas and not to let the sand dry out in the baking sun.

The eggs were removed, taking care not to rotate any of them. Rotation of the eggs may cause veins and arteries to rapture which will cause the death of the embryo. A pencil was used to number each egg according to its position in the nest thus ensuring that eggs were placed back into the nest in the same order that they were removed. At the same time the numbering also indicated the dorsal surface of each egg to ensure that it could be placed back into the egg chamber with the right side up. The width and length of each egg was measured to the nearest millimetre using a pair of vernier callipers. The mass of each egg was determined by using a battery operated Krups electronic scale.

Eggs were examined for banding to determine the fertility of each egg. Hutton (1984) describes the development of banding in crocodile eggs as follows: "At the time of laying crocodile eggs are enveloped in mucus and beneath this the eggs are uniform in texture and appearance. The mucus breaks down within 48 hours by which time each developing egg has an opaque spot at the point where the embryo is attached to the shell membrane. This mark grows around the equator of the egg and also moves toward the poles causing the band to be broader on the upper side of the egg than on the lower side. At about 60 days the band reaches the poles of the egg which then again acquires a uniform appearance." Only fertile eggs form opaque bands of which the width of the banding reflects the development of the chorio-allantoic membrane and the underlying embryo (Fergusson, 1982, 1985; Hutton, 1984). Therefore, eggs were considered to be infertile if the shell was unbanded and of a uniform colour. All eggs considered to be infertile were removed from the clutch and later discarded. Once all data were collected the eggs considered to be fertile were returned to the egg chamber in the same order they were removed and the sand returned to the nest. The depth to the first egg and to the bottom of the chamber was noted and maintained as closely as possible when eggs where returned to the nest. Nests opened in this manner were revisited for a couple of consecutive days to confirm that the female had not abandoned the nest and that it had not been predated.

Unless stated otherwise, all statistics were calculated using the data analysis tool of MS Excel together with procedures described by Koosis (1997) and also those described by Zar (1999).

RESULTS

A total of 21 nests were located, measured and marked during this study. The average number of nests located per year was 5.25, which corresponded well with the number of nests reported by Nature Conservation Officials for the 1993 to 1996 nesting seasons (Coetzee, 1994, 1996).

The average clutch size was 39.2 eggs per nest with an average of 6.8 infertile eggs per nest and an average of 32.4 fertile eggs per nest. The average clutch size of 32.9 eggs per nest corresponds to the average of 39.0 found in the Olifants River, Kruger National Park (Swanepoel *et al.* 2000). The average number of infertile eggs per nest (6.8 eggs) and the average number of fertile eggs per nest (32.4 eggs) found in nests at the dam is also comparable to the average number of infertile eggs (5.4 eggs) and fertile eggs (33.6 eggs) per nest found in the Kruger National Park by Swanepoel *et al.* (2000).

The average depth of crocodile nests at the Flag Boshielo Dam was 27.0 cm while this figure was 25.0 cm in the Kruger National Park (Swanepoel *et al.* 2000). However, the number of nests found in the Flag Boshielo Dam came to an average of 5.25 nests per year. Swanepoel *et al.* (2000) reported an average of 50 nests per year for the Kruger National Park while Hartley (1990) reported an average of 21.3 nests per year in the Umfolozi Game Reserve. Meaningful comparison of these averages is difficult to achieve and therefore the average number of nests per area was converted to reflect the number of nests per kilometre of shoreline. In terms of nests per kilometre, the Flag Boshielo Dam population has a significantly lower number of nests than that found in the Kruger National Park, the Umfolozi Rivers and Lake Ngezi (see table 10).

When comparing different crocodile populations, the use of biomass is preferred as this permits comparisons of data acquired in diverse ecological situations (see chapter 4).

Table 10: The number of Nile crocodile nests per kilometre found in the Flag Boshielo Dam compared to crocodile populations found elsewhere in southern Africa.

Area	Mean number of nests in area	Length of shoreline	Mean number of nests per kilometre
Flag Boshielo Dam	5.25	65 km	0.085
Kruger National Park	50.00	31 km	1.612
Umfolozi Rivers	21.30	100.24 km	0.212
Lake Ngezi	9.50	29.5 km	0.322

Location of nesting sites (Figure 32)

The Olifants River flows in a westerly direction at the point just before it enters the Flag Boshielo Dam. No nests were found along this east/west section of the river. The majority of nests were however found along the western shore of the narrow river-like area that forms part of the dam. A statistically significant preference for nesting along the western shore of the dam was found to exist ($\chi^2 = 6.06$; $df = 1$; $P < 0.025$).

All nesting took place within an area of 13.17 km out of the possible 65 km total length of the shoreline. This converts to only 20.26% of the shoreline being used for nesting purposes. Nests along the western shore made up 71.43% while those along the eastern shore represented 28.57% of all nests found. Table 10 summarises the percentage occurrence of nests along both shores of the dam.

No sign of communal nesting was observed. The two nests closest to each other were approximately 85.97 m apart while the greatest distance between any two nests was 5869.10 m. This occurred in 2001 when the dam was at 102% of its capacity and overflowed. On average, the nests were located at approximately 1135.40 m from each other but if one discount the long distance between nests in 2000 then the average distance come down to approximately 771.27 m between neighbouring nests.

A negative correlation was found to exist between the water level in the dam and the number of nests per season (r = -0.49; P = 0.5028). The highest number of nests was located when the dam was at 31% (n = 6) of its capacity while the lowest number of nests was found when the dam was at 102% (n = 3) of its capacity.

Table 11: The percentage occurrence of *C. niloticus* nests per year along both shores of the Flag Boshielo Dam.

Year	No of nests (Western shore)	No of nests (Eastern shore)	Total number of nests
2000	3	0	3
2001	2	4	6
2002	6	0	6
2003	4	2	6
Total	15	6	21
Percentage	71.43	28.57	100

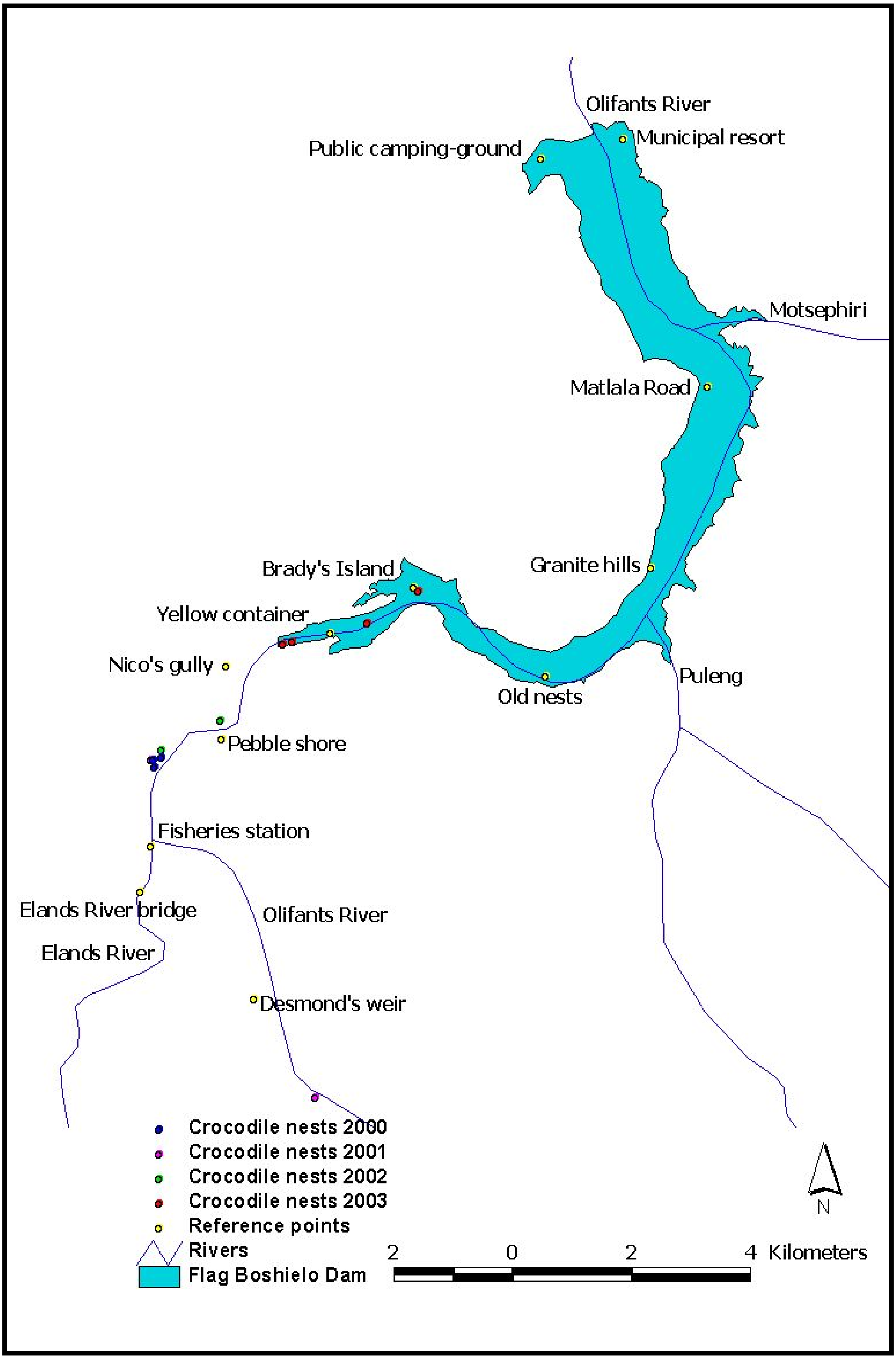

Figure 32: Nile crocodile nesting areas in the Flag Boshielo Dam. Note that nesting is confined to the upper-reaches of the dam, inlets and rivers.

Egg characteristics

Due to the low number of nests and the increased risk of predation only selected nests were excavated to examine, measure and weigh the eggs (n = 196). The mean clutch size (39.2 eggs/nest) is small when compared to 54 eggs/nest found in Zimbabwe (Hutton, 1984) and the 47 eggs/nest found in Umfolozi Game Reserve (Hartley, 1990). It does however correspond to the mean clutch size of 39.0 eggs/nest found in the Kruger National Park (Swanepoel *et al.* 2000). The average width of eggs was approximately 48.60 mm while the average length was approximately 72.06 mm. The average mass of eggs from the excavated nests was 97.14 g. In the Kruger National Park the heavier eggs were laid by the bigger females (Swanepoel *et al.* 2000) this was also found to be true of the Flag Boshielo Dam crocodile population (see table 11) and also concurs with the findings of Pooley (1969), Hutton (1984), Webb, Sack, Buckworth and Manolis (1983) all of whom reported that larger females produced larger eggs.

Table 12: Size of breeding female, egg characteristics and clutch size of *C. niloticus* measured during the 2000 - 2003 nesting season in the Flag Boshielo Dam.

Nest no	Size of female (m)	Clutch size (No of eggs)	Average width of eggs (mm)	Average length of eggs (mm)	Average mass of eggs (g)
1/2001	4.19	43	51.89	74.10	115.63
4/2002	3.11	16	47.75	69.69	89.94
1/2003	3.11	26	46.79	73.18	90.54
2/2003	3.51	71	48.15	74.00	99.50
3/2003	3.24	40	48.40	69.35	93.00
Average	3.43	39.2	48.60	72.06	97.72

Size of nesting female

The smallest female Nile crocodile that nested in the Flag Boshielo Dam during the 2000 to 2003 nesting seasons had a TL of 2.70 m. During this same period the largest female found at a nesting site measured 4.19 m (TL). The average size of nesting females was established at approximately 3.33 m (TL) (n = 21). Statistical testing of the linear regression showed that there was no significant relationship between the size of nesting females and the level of the dam (r = 0.20; P = 0.4905; r^2 = 0.0404).

Height above and distance to the water

The height of nests above water and distance from the water individually seem not to be significant factors in the choice of a nesting site. For instance topography greatly determines the distance from water while the height above water is heavily influenced by floods and drought conditions. It stands to reason that the distance to water will increase when the water level (height above water) drops lower and vice versa. The maximum height above water, measured during the drought of 2003, was 6.0 m while the minimum height above water was measured at 1.0 m. The mean height of nests above the water was calculated at 3.07 m. The maximum distance of any nest from the water was also measured during the drought of 2003 and came to 25.55 m while the minimum distance from the water was 3.0 m. The mean distance of nests from the water was calculated to be 11.72 m.

Half of the nests (50.00%) were between 3 - 8 m from the water followed by a smaller group of nests (35.71%) which were between 23 - 28 m from the water with 14.29% of the nests situated between 8 - 13 and 13 - 18 m from the water. In this instance the following formula, $k = 1 + 3.3 \log_n$ was used to calculate the class width.

The relationship between height above and distance to water proved to be significant (r = 0.952; P = 0.02; r^2 = 0.906). This relationship indicates that the majority of the nests made over a four year period were dug in areas with a similar slope (incline).

Incline of the slope

All nests excavated by crocodiles were situated in shoreline areas with a steep slope. The average incline of the slope where nests were excavated was approximately 72.10° with a minimum incline of about 60.00° and a maximum of 79.98°. No nests were found in areas with a more flat incline which would be easier for the female to negotiate. No significant difference could be found to exist between the inclines of nesting sites in the Flag Boshielo Dam. The same situation was also mentioned by Swanepoel *et al.* (2000) in the Kruger National Park. However as was mentioned in the previous section the significant relationship between height above and distance from water indicates that the incline of the slope have some influence on the choice of nesting site by breeding female Nile crocodiles in the Flag Boshielo Dam.

Exposure to direct sunlight

Most of the nests (52.38%; n = 11) received > 6 hours but < 8 hours of direct sunlight per day. Several of the nests (42.86%; n = 9) received < 6 hours of direct sunlight each day while one nest (4.76%) received < 4 hours of direct sunlight per day. This nest was located in a dense bed of *Phragmites australis* that was approximately 4.0 m tall and grew very close to the nest. This tall vegetation reduced the number of hours that the nest was exposed to direct sunlight but the nest still hatched successfully. Evidence of predation was found at all nests that did not survive.

Height and species of vegetation

The vegetation along the shores of the Flag Boshielo Dam can be described as sparse which is typical of a shoreline along the waters of an impoundment with a fluctuating water level. A total of 42 trees/shrubs from 15 species were recorded in close proximity to *C. niloticus* nests and five of these were most frequently found namely: *Melia azedarach* (21.43%), *Phragmites australis* (19.05%), *Acacia karroo* (11.90%), *A. erioloba* (9.52%), and *A. galpinii* (7.14%). The remaining 10 species occurred in low numbers but together they accounted for 23.81% of the vegetation around nesting sites. No clear pattern was found for the occurrence of vegetation near nesting sites and specific species of vegetation appear not to be selected as part of the nesting site criteria. Apart from three *A. galpinii* trees which were approximately 15 m tall, all the other species had an average height of just over 3.0 m.

Type of substrate

Over the four year period of the study, the majority of nests (95.24%) were dug in alluvial soils. Only one nest in the Olifants River, at the inlet to the dam was excavated in course river sand. No nests were found in clay soils.

DISCUSSION

The nesting ecology of the Nile crocodile in the Flag Boshielo Dam seems to be similar to that described by Hutton (1984) at Lake Ngezi, Zimbabwe, Swanepoel *et al.* (2000) in the Kruger National Park and in KwaZulu Natal by Hartley (1990) and Leslie (1997). The drought conditions that prevailed during 2003 totally changed the environment of the crocodiles. Water levels dropped dramatically and exposed nesting habitats that have not been available for at least 10 years. The low number of nests when the dam is at full supply level confirms that the high water level restricts access to nesting areas. This theory was proven when the number of nests doubled as soon as the water level dropped below 70% of the dam's capacity. Localised migration to follow the receding waters was evident but many pools formed in the channel of the Olifants River where nesting females where able to remain.

A holiday resort and large commercial farms are situated along the shore of the Olifants River just before it enters the dam. No nests were found along this bank of the river although Nature Conservation Officers recall that this area was once a prime nesting habitat before the holiday resort was established (Coetzee *pers. comm.*[2]). The noise generated by visitors and boat traffic with the associated wave action from boating probably caused nesting females to avoid this area when nesting.

Figure 33: Holiday resort and commercial farming activities developed in the riparian vegetation along the right-hand bank of the Olifants River at the inlet to the Flag Boshielo Dam in what was once prime nesting habitat for Nile crocodiles.

[2] Coetzee, N.J.: PO Box 142, Kiepersol, 1241.

During the study period, a second holiday resort was developed on the eastern shore of the dam in an area which is also used by subsistence framers to graze livestock. The majority of nests (71.43%) where located along the western shore of the dam which borders the Schuinsdraai Nature Reserve. A similar situation was reported by Hutton (1984) where the clear majority of nests (80.23%) were found along the southern bank of Lake Ngezi. The soils of the eastern shore of the Flag Boshielo Dam have been compacted by people and livestock forming hard impenetrable banks. In contrast the banks of the western shore, where no visitors are allowed in the Nature Reserve, are in almost pristine condition which makes for ideal nesting conditions.

Figure 34: Eastern shore of the Flag Boshielo Dam showing severe erosion by livestock causing unfavourable nesting conditions for crocodiles.

Communal nesting has been observed by Cott (1961), Pooley (1969), Hutton (1984) and Hartley (1990). However the concept of communal nesting is still not clearly defined e.g. Graham (1968) observed nests as close as 1 m apart but he did not state whether this was due to limited nesting space or perhaps because of a preference for communal nesting. In the Flag Boshielo Dam no nests were ever observed in close proximity to each other. In the context of this project "close proximity" was taken as at least one body length of the nesting crocodile concerned away. However the shortest distance between two nests was approximately 85.97 m apart which does not constitute "close proximity".

It has already been established that crocodiles in the Flag Boshielo Dam prefer to nest in a very limited area of less than a quarter (20.26%) of the available shoreline. These limited nesting grounds should have led to some sort of communal nesting but didn't. Swanepoel *et al.* (2000) argues that communal nesting is environmentally induced rather than genetically determined. The findings of this study support the theory that communal nesting is not an instinctive behavioural pattern. Hutton (1984) described that females maintain home ranges and nest in that particular area while smaller females are forced to leave the home range and breed elsewhere. The absence of communal nesting in the Flag Boshielo Dam is possibly due to the maintenance of home ranges by breeding females.

The distance of 5869.10 m measured between the nests in 2000 underlines the situation that suitable nesting habitat disappears when the dam is at full capacity. Nests were much closer ($\bar{x}$ distance = 771.27 m) and also more abundant when the alluvial slopes were exposed once the water level dropped below 70% of capacity. The average number of nests per kilometre of shoreline in the Flag Boshielo Dam is significantly lower at 0.085 nests/km than that of the Kruger National Park (1.612 nests/km), the Umfolozi Rivers (0.212 nests/km) and Lake Ngezi (0.322 nests/km).

The mean clutch size (39.2 eggs/nest) in nests around the Flag Boshielo Dam corresponded favourably with those found in the Kruger National Park (39.0 eggs/nest) by Swanepoel *et al.* (2000). Both Hutton (1984) and Hartley (1990) however found substantially higher clutch sizes at Ngezi and the Umfolozi Rivers respectively. A significant difference between the size of clutches from South African, Ugandan and Zimbabwean crocodile populations have been shown by Swanepoel *et al.* (2000). According to Swanepoel *et al.* (2000) the difference in median values for these populations indicates that there is a meaningful difference in the size of the nesting females from the three countries.

Mature female crocodiles in the Luangwa Valley of Zambia were measured at 2.31 m TL while a nesting female in Lake Victoria was measured at 2.19 m TL (Cott, 1961). Graham (1968) reported that nesting females as small as 1.80 m TL were present in Lake Turkana (then Lake Rudolf) while Hutton (1984) found a nesting female at Lake Ngezi with a TL of 2.65 m. When viewed against this background the smallest breeding female encountered in the Flag Boshielo Dam at 2.70 m TL seems not to be extraordinarily small. The largest female found in attendance at a nest measured 4.19 m which is well within the norm for a mature female crocodile as is the average length of nesting females (3.33 m TL). Near same correlations was found between the size of the nesting female en the weight of eggs laid during years with high rainfall (r = 1.01) and between the size of the nesting female and the weight of eggs laid during low rainfall (r = 1.02). Therefore it seems fair to accept that prevailing wet or dry conditions does not trigger nesting behaviour in any specific size class of female crocodile in the Flag Boshielo Dam. In the Kruger National Park, Swanepoel *et al.* (2000) found a significant difference in the size of breeding female during drought conditions compared to breeding seasons with high rainfall.

The level of the water in the Flag Boshielo Dam has an undeniable influence on the height above and distance from the water to the nest. These factors change constantly with prevailing flood or drought conditions. Extensive variation in the distance from the nests to the water was reported in KwaZulu Natal. Pooley (1969) reported figures ranging from 15 - 50 m while Hartley (1990) described distances ranging between 1 and >80 m from the water. Hutton (1984) calculated a mean distance from water of 6.0 m for the crocodile population at Ngezi, Zimbabwe while Swanepoel *et al.* (2000) mentioned a mean distance from the water of 18.9 m in the Kruger National Park. The mean distance of nests from the water in the Flag Boshielo Dam was found to be approximately 11.72 m. This variation in distances from widely distributed crocodile populations indicates that the distance from water and height above water when viewed on their own may not be of much importance to crocodiles. However, the relationship between these two factors were found to be statistically significant (r = 0.952; P = 0.02; r^2 = 0.906). This relationship indicate that the majority of nests made over a four year period in the Flag Boshielo Dam where dug in areas with almost the same slope (incline). A similar relationship between height above and distance to water was also found in the Kruger National Park by Swanepoel *et al.* (2000) where the majority of nests over a five year period were excavated on slopes with a near similar incline.

The incline preferred by nesting female crocodiles in the Flag Boshielo Dam is quite steep. The average incline was found to be approximately 72.10° and no nests were excavated on slopes with an incline of less than 60°. The variety of height above and distance from water coupled with a clear preference for steep slopes indicate that nesting crocodiles may select for a particular spot on the slope (incline) rather than for a particular distance or height above the water. The steep slopes allow quick movement of the hatchlings to the safety of the water thereby minimising their exposure to predation. Even though the female would require more energy to crawl up a steep bank to reach the nest, the safety of the hatchlings rather than her own energy needs seem to be the overriding factor here. The main channel in the Flag Boshielo Dam is extremely deep in places and provides deep enough water for crocodiles to submerge in during drought conditions, which would not be the case in an open river system. The effect of this deep channel during the drought of 2003 was that deep pools was available for nesting females to stay behind and guard their nests while non-nesting crocodiles had to follow the receding water downstream.

In crocodilians, many turtles and some lizards, the temperature experienced by the embryo in its egg is a major determinant of hatchling sex, a type of environmental sex determination referred to as temperature-dependant sex determination (TSD) (Lang, 1990). Incubation temperature is the major determinant of hatchling sex and the temperature that produces a 1:1 sex ratio under constant temperature incubation has been termed the "pivotal temperature". Exposure to direct sunlight has been singled out as an important factor in choosing the best position for the nest to achieve the pivotal temperature and to produce a 1:1 sex ratio (Cott, 1961; Graham, 1968; Hartley, 1990). The majority of nests in the Flag Boshielo Dam (52.38%) received more than 6 hours of direct sunlight per day while 42.86% of the nests received less than 6 hours of direct sunlight per day and one nest (4.76%) received less than 4 hours of direct sunlight per day. All nests survived and hatched successfully except for those lost to predation. The high exposure times of direct sunlight experience by nearly all (95.24%) of the nests in the Flag Boshielo Dam underlines the importance of exposure of the nest to direct sunlight. Although exposure to direct sunlight is extremely important, the incubation temperature is considered to be the factor which determines the overall success of the nest. According to Leslie (1997) the incubation temperature of a crocodile nest is affected by the soil type and its ability to retain heat.

Unlike some of the other reptiles, crocodilians have a restricted range of incubation temperatures from about 28 - 34°C (Fergusson, 1985; Webb and Smith, 1987).

Incorrect incubation temperatures have been shown to affect the probability of crocodile and alligator embryos to survive (Webb and Smith, 1984, Lang, Andrews and Whitaker, 1989). It can also influence body size (Webb, Beal, Manolis and Dempsey, 1987; Allsteadt and Lang, 1995), hatchling pigmentation patterns (Deeming and Fergusson, 1989) and post hatchling growth rates (Hutton, 1987b; Webb and Cooper-Preston 1989). At the lower threshold of 28°C *Alligator mississippiensis* develop completely but fail to hatch (Lang and Andrews, 1994). Chinese alligator (*Alligator sinensis*) and dwarf caiman (*Paleosuchus trigonatus*) eggs survive poorly below 27°C (Chen, 1990; Magnusson, Lima, Hero, Sanaiotti and Yamakoshi, 1990) while Hutton (1987) found that Nile crocodile eggs that incubate below 27°C also fail to hatch.

Vegetation plays an important role in the nesting ecology of Nile crocodiles. Too much or too little shade may jeopardise the success of the nest. Very small differences of 0.5 - 1.0°C in the incubation temperature can result in markedly different sex ratios (Lang, 1990; Leslie, 1997). Vegetation is also important in providing shade for the nesting female (Cott, 1961; Hutton, 1984; Leslie 1997). Vegetation does not overgrow nesting sites in the study area and can in fact be described as sparse which is typical of vegetation around a large impoundment such as the Flag Boshielo Dam. The average height of vegetation near nests was 3.94 m but all nests (except those that were predated) hatched successfully. Where vegetation becomes to overgrown near nesting sites the soil temperature can be as much as 5.0 - 6.0°C lower which may even prevent embryonic development in the eggs (Leslie and Spotila, 2001).

The dominant soil type in the preferred nesting area of the Flag Boshielo Dam is alluvial deposits. All nests except for one were dug in this type of soil. The average depth of nests in the Flag Boshielo area was measured at 270 mm. This is deeper than the average of 202.8mm recorded in KwaZulu Natal (Hartley, 1990) and the average of 164 mm measured in Zimbabwe (Hutton, 1984). It does however compare favourably to the average depth of 250 mm recorded in the Kruger National Park by Swanepoel *et al.* (2000). As was discussed earlier, all nests except those that suffered predation hatched successfully. It is accepted that the ability of the soil type to retain heat has a profound effect on the success of the nest. Therefore, since 95.24% of the nests were excavated in the alluvial soil type the hypothesis is that this type of soil is what the females select for and that it is the restricted occurrence of this type of soil that results in the small size of the area preferred for nesting in the Flag Boshielo Dam. A similar situation was described by Hutton (1984) in Lake Ngezi. He found a significant increase in the use of sand deposits which appeared to be due to preferential choice of sandy sites rather than simple reflection of the increased availability of sand.

CONCLUSION

The size of nesting females in the Flag Boshielo Dam is not out of the ordinary when compared to other crocodile populations while the contents of the nests correspond with those found in the Kruger National Park in the same river system. The crocodiles however show a clear preference (71.43%) for the western shore of the lake for nesting and then only for a small proportion (20.26%) of the available habitat. The average number of nests/km in the Flag Boshielo Dam is significantly lower than that in the Kruger National Park, the Umfolozi Rivers and in Lake Ngezi.

Variation in the height above and distance from the water to the nest indicates that these elements on their own are not important factors in selecting a nesting site. A significant relationship does however exist between the height above and distance to the water. This relationship indicates that nests are positioned in such a way that the incline (slope) is the important factor possibly to aid in minimising exposure of hatchlings to predation by allowing quick access to the water. Successful nests received > 6 hours of direct sunlight per day. Together with exposure to direct sunlight the ability of the soil to retain heat is also of great importance to the survival of the nests. Soil type can influence the internal temperature of the nest which has a direct influence on the success of the nest. In the Flag Boshielo Dam, all but one of the nests where excavated in the same soil type which was alluvial soils deposited on the river banks.

Figure 35: Typical nesting site with access to deep pool of water. This photo was taken during the drought of 2003 when the dam dried up leaving only pools of water in the preferred nesting area.

Since other soils is available for nesting but were not used there is surely a clear preference for these alluvial soils. This explains the limited distribution of nests, since the crocodiles in the Flag Boshielo Dam seem to only nest where alluvial soils occur. This preferential choice of sites with a sandy soil type was also found in Lake Ngezi by Hutton (1984). It therefore seems fair to accept that these alluvial soils can retain heat to such an extent that the survival of the nest is ensured. The low number of nests could be due to a combination of factors. The tendency of females to defend territories at the nesting grounds together with an already limited available area where the alluvial soils occur can result in there being just too little space for all female crocodiles to nest successfully. The distribution of hatchlings supports the hypothesis that successful nesting does not take place in other areas around the lake. Vegetation is also an important factor but in terms of providing shade to the nest and the female crocodile but no clear pattern for selection of any specific plant species could be identified. In summary, the clear preference for nesting along the western shore, the doubling in the number of nests when the dam is at 70% of its capacity, the 95.24% occurrence of nests in alluvial soils and in areas that receive > 6 hours of direct sunlight daily, the importance of the incline (slope) indicated by the relationship between height above and distance to water certainly proves the hypothesis that the choice of a nesting site in the Flag Boshielo Dam is influenced by certain environmental parameters.

CHAPTER 10

MANAGEMENT IMPLICATIONS

Introduction

Crocodiles pose some difficult problems for conservationists. The larger species, of which the Nile crocodile is one, is often regarded as dangerous and unattractive by people who live near these animals. Some crocodilians species can be given complete protection in protected areas and in captivity. However, there are crocodilian species that require a different approach to the problem of protection. This is especially true where humans live in close proximity to crocodiles. In general, crocodilian populations become threatened in direct proportion to the proximity and density of human populations (Ross, 1998). The real and perceived costs of people living near crocodiles must be offset in some way that will be acceptable to both the community and conservationists. This has often been achieved through the process of sustainable use. Examples of successful programmes can be found in such diverse countries as Papua New Guinea, Venezuela, Zimbabwe, USA and Australia.

Sustainable use has become a key element in the conservation of crocodilian species (Jenkins, 1993; Ross, 1998). Sustainable use of crocodilians may provide economic incentives to encourage people to maintain crocodilians and their habitats in a natural state. However, the individual characteristics of different countries make some techniques more feasible and more effective than others.

Background to management recommendations

Jacobsen (1992) argued that the Middle Olifants River should be declared a protected natural environment in order to control development along the river. This never happened and as a result development along the river took place in an uncontrolled manner with huge impacts on the crocodile's nesting grounds. The raising of the Flag Boshielo Dam now gives us a rare second opportunity to correct this oversight. The Department of Water Affairs and Forestry will purchase land along the shoreline of the new dam. This is done to accommodate possible flooding in the future. The official policy of DWAF is not to allow any development within this so-called "purchase-line" and therefore, should result in the permanent closure of the holiday resort next to the Olifants River at the inlet to the dam.

Once all properties within the purchase line have been procured by DWAF, management of these areas should be carried over to the relevant Nature Conservation Authority with specific instructions that the "no development" policy remain in place. This one single administrative procedure will make historical nesting grounds situated between Desmond's Weir and the old Fisheries station, that have been unavailable to the crocodiles for the last 10 years, immediately available again. The currently available protected nesting grounds will also be doubled by this one action.

Sustainable use is often rightly seen as a method to secure the continued existence of crocodile populations. However, exploitation of crocodile populations is usually focussed on those life stages where high mortality has the least effect on the population which is the reason why it is usually the eggs, hatchlings and adult males that are targeted for sustainable harvesting (Ross, 1998). It needs to be established which parts of the population can be utilised and to what extent. This biological study pointed out that the eggs, hatchlings and adult males are the life stages where very low numbers exist. Further exploitation of these life stages will without doubt threaten the population.

Monitoring of the population should continue at least over the medium term to establish whether the nesting effort stays the same or increases with the increase in available nesting area. The undertaking by DWAF to fund monitoring of the crocodile population during the construction phase of the dam must be honoured by them.

A detailed study of the Nile crocodile's diet in the Flag Boshielo Dam should be undertaken as a matter of urgency to establish if diet is the factor that makes crocodiles prefer to stay in the Flag Boshielo Dam rather than living in other dams in the general area.

Zoning of nesting areas as out of bounds to visitors and their boats is currently not feasible because the holiday resort upstream in the Olifants River allows the public access to the water behind the nesting areas. Boats then travel through the nesting areas on their way to the angling sites all the time disturbing nesting females. The closure of the holiday resort on the Olifants River as explained above will create the opportunity to zone the Olifants and Elands Rivers as wilderness areas not open to recreational use by visitors and boats. Access to these areas under the control of trained and certified guides but depending on the carrying capacity for boats and the time of year can be considered to allow people the opportunity to view crocodiles in their natural environment.

Concession should be made along the eastern shore of the lake for bona fide members of the local community and their livestock to gain access to the water of the dam. This shore should not form part of the excluded wilderness area to be set aside as a refuge for the crocodile population.

The Status Survey and Conservation Action Plan of the IUCN Crocodile Specialist Group (Ross, 1998) mentions that despite the optimistic expectations that enlightened self interest would ensure good compliance with regulations, effective enforcement is still necessary to ensure compliance with laws and regulations. Nature Conservation officers must be instructed by their Heads of Department to maintain high visibility in the Flag Boshielo Dam. They must prosecute any person found harming crocodiles, destroying nests, littering in basking areas, chasing crocs away from basking areas and making fires for barbeques etc. The denial of responsibilities by Nature Conservation Authorities for the Flag Boshielo Dam just because it is situated across the provincial border between two provinces should stop immediately. This situation must be resolved as a matter of urgency and the relevant Nature Conservation authority should accept its responsibility and regard their duties in the Flag Boshielo Dam with the same seriousness as they do tasks in other areas of their province.

This population of crocodiles should be acknowledged by people residing in local communities. The community in the area along the eastern shores of the lake have been living with these crocodiles for ages. A worrying trend is that people are now using gillnets to catch more fish. The fish are then sold for economic gain. If this is allowed to continue unabated, the crocodiles will surely loose this competition for the natural resource. The only possible outcome to this situation is that crocodiles will start causing damage to livestock and property. To add to the problems, the people in the surrounding towns seem to have an attitude that they have first priority to any area in the dam and the crocodiles are fair game in this situation. Many people have access to boats and thus there is no place on the lake where the crocodiles can find peace and solitude. During the course of this study alone five crocodiles ranging in size from1.50 m to 4.10 m were killed by people on boats. Of these animals, one was shot from a boat, three was hit by boats and one was harassed to death by anglers trying to catch the animal with a fishing pole. These are attitudes that, if allowed to continue will only get worse in future.

Management recommendations

The following management recommendations are based on knowledge gained from this study and should be implemented to ease the possibility of conflict between humans and crocodiles and to secure the long term survival of the Nile crocodile population in the Flag Boshielo Dam:

- Management of all areas within the purchase line to be transferred from DWAF to the relevant Nature Conservation Authority.

- No development to be allowed within this purchase line area in accordance with existing official DWAF policies.

- All future developments along the banks of the Olifants and Elands Rivers must go through the environmental assessment process to establish their potential impacts on the crocodiles.

- Monitoring of the population and nesting effort must continue during the construction phase of the new dam wall and DWAF must honour their undertaking to fund this part of the monitoring.

- Monitoring of the population must continue for at least the next 5 years after completion of construction to monitor any increase or decrease in numbers and nesting efforts.

- A dietary study must be undertaken to determine on which prey animals the Nile crocodiles in the Flag Boshielo Dam depend for survival. Loss of these prey animals (e.g. due to over fishing) may jeopardise the continued existence of the crocodile population.

- The areas surrounding the dam must be zoned, taking the behavioural requirements of the crocodile population into account. The area from the yellow container to Desmond's weir must be zoned as a wilderness area with no access to private boats and/or other vehicles. Zoned areas must be handed over to the relevant provincial conservation authorities to enforce the zoning and the relevant conservation legislation.

- Guided tours under control of a trained and certified guide may be allowed into this area depending on the time of year (not during nesting season). These should be regulated to ensure minimum impact on the environment and particularly on the crocodile population.

- All basking, nesting and nursery areas (including the Brady's Island and old nests areas) must be out of bounds to visitors and must be protected by enforcing the relevant conservation legislation.

- Fishing and holiday resorts must be situated along the shores of the open water i.e. the area between the granite hills and the dam wall.

- Sustainable exploitation can only be considered after long term monitoring of the population, and a scientifically sound biological study have been undertaken to determine the feasibility of this strategy.

- Nature Conservation Authorities must take responsibility for law enforcement in the Flag Boshielo Dam and maintain a high level of presence in the dam in order to discourage unlawful behaviour by visitors to the area.

- Negative behaviour by communities around the dam must be curtailed. The setting of gill nets for commercial fishing can only lead to a reduction of the food source of the crocodiles and entrap crocodiles leading to higher martalities. This will in turn lead to confrontation between humans and crocodiles.

- Negative behaviour by visitors on boats must be dealt with in strong terms. Any harassment, disturbing, catching, shooting at or killing of crocodiles etc can never be condoned and any person guilty of this type of behaviour must be prosecuted by Nature Conservation Officers.

- The impact of all types of watercraft must be determined to avoid overcrowding of watercraft on the waters of the Flag Boshielo Dam, since overcrowding will certainly disrupt the natural daily activity patterns of crocodiles and other wildlife.

- A way must be found for the people of surrounding villages and towns to take pride in the crocodile population, such as donating a percentage of the money earned from guided tours and entrance fees to the community and should also be used to finance the monitoring programme.

SUMMARY

Crocodilians are seen in positive terms in their environments as “keystone species” that maintain the structure and function of ecosystems through their activities which include selective predation on fish species, recycling of nutrients and maintenance of wetlands in times of drought. Although the status of the Nile crocodile is relatively secure and abundant in southern and eastern Africa, where it is regarded as a species with a “moderate” need for the recovery of the wild population, it is greatly depleted in western Africa. Crocodilians are threatened by many human activities. Most significant of these is the destruction or alteration of the wild habitat. Commercial over-exploitation and indiscriminate killing have resulted in many crocodilian species suffering a decline in numbers and reductions in distribution. Surveys have shown that the Flag Boshielo Dam (then known as the Arabie Dam) has the highest density of Nile crocodiles, in terms of numbers, per kilometre in the Olifants River between the Loskop Dam and the boundary fence of the Kruger National Park.

The proposed increase in the height of the Flag Boshielo Dam by DWAF provided the opportunity to test the hypotheses that:

- The natural population of *C. niloticus* in the Flag Boshielo Dam presents a healthy population structure comparable to normal wild populations.
- The natural population of *C. niloticus* in the Flag Boshielo Dam show seasonal movement within the impoundment and the inlet of the Olifants and Elands Rivers.
- The *C. niloticus* population in the Flag Boshielo Dam stay in a limited range and do not use the total surface area of the lake.
- Certain environmental parameters determine the choice of nesting sites by *C. niloticus* in the Flag Boshielo Dam.

A total of 28 spotlight counts were done during the period January 2002 to November 2003. Aerial surveys were done on the morning following a night-count however this was not always possible because the aircraft were influenced by local weather conditions. Based on the spotlight counts, the total number of crocodiles in the Flag Boshielo Dam population was estimated by using the double-survey method. By using the data from night-counts that was followed by aerial counts the population in the Flag Boshielo Dam was estimated at 210.78 animals. Absolute densities are not good for comparisons of crocodilian populations because their size structures could differ substantially, therefore the density of crocodilians is better expressed in terms of biomass. The absolute density of the crocodile population in the Flag Boshielo Dam was calculated at 3.25 crocodiles/km of shoreline and the biomass came to 142.83 kilograms of crocodile/kilometre (kg/km) of shoreline. The Flag Boshielo Dam has one of the highest biomass values for smaller populations. The figure of 142.83 kg/km is higher than the values for the rest of the Olifants River (Loskop Dam to the Kruger National Park), the Umfolozi Rivers and the area above the Murchison Falls in Uganda.

Variables in crocodilian populations seem more likely to be dependant on size rather than age and therefore size structure rather than age class is used to model crocodile populations. Small sized crocodiles (including juveniles) made up 20.59% of the population but this percentage will decline before these animals manage to reach 2.1 m TL. Medium sized crocodiles, i.e. those that will in all probability contribute to the population by producing next generations, represent 29.85% of the animals in the current population. Crocodiles in the 2.1 - 4.0 m size class were calculated to make up 36.33% of the population. This group include the current breeding females.

The dominant animals (>4.0 m TL) in the population are represented by 6.03% of the individuals in the population. Reproductive animals in this population are estimated to be approximately 42.36% of the total population.

The way in which crocodilian size classes are dispersed is of crucial importance because the adult animals are several orders of magnitude heavier and longer than hatchlings. Separation of the hatchling and juvenile crocodiles from the larger size classes is evident. Larger crocodiles used much of the available shoreline for their daily activities. The areas that were not utilised were those that provided inadequate shelter, basking and nesting sites and where prey animals were harder to find as a consequence of the physical characteristics of the lake i.e. deep, open water near the embankment. Also the shore where human activities were highest showed the lowest number of crocodiles present in any area. No clear pattern of short range migration emerged from any of the size classes. Crocodiles did however adapt to the changing water level of the lake during the drought of 2003 by moving to areas which suited their requirements better.

In southern Africa, the productivity of waters decreases during the cooler winter season. This annual decrease in the productivity of the crocodile's environment must have an influence on its seasonal range. Migration of animals between the dam basin and the inlets/river-like areas of the lake was found to exist but seem to be related to body size. Hatchlings showed no form of seasonal movement while small sized crocodiles showed some migration possibly due to being forced out of their areas by larger breeding animals. Large and extra large crocodiles however, showed an unmistakable pattern of movement into the lake during winter and out into the rivers during the summer when mating and breeding takes place. Crocodiles in the large and extra large size classes (2.1 - >4.0 m TL) were seldom seen outside the dam in winter while they were observed both inside and outside of the dam in summer. None of the size classes showed any sign of localised migration patterns between areas within the dam.

In the case of crocodiles it has been shown that home range behaviour changes a number of times as the animal grows from juvenile to reproductive size. In the Flag Boshielo Dam the average size of all centres of activity that was measured came to between 0.06 km^2 and 0.23 km^2. The average home range size is approximately 0.36 km^2 which can be compared to the average home range size of 0.31 km^2 found in Lake Ngezi, Zimbabwe. The minimum sizes that compare well to those found in Lake Turkana and also in Lake Ngezi suggest that there is a minimum size of territory that crocodiles need in order for them to fare reasonably well. Based on the results of this study the size of that area is estimated to be approximately 0.06 km^2 (60 m^2) in the Flag Boshielo Dam. A fair amount of overlapping occurs between individual crocodiles as evidenced by all the tagged crocodiles having some claim to the Brady's Island/Old Nests area. Although the sample size was small, it was noticeable that male crocodiles had bigger territories than females. The two female crocodiles maintained a centre of activity with an average size of approximately 0.05 km^2 and an average total range of approximately 0.23 km^2. In contrast the two male had a somewhat larger centre of activity with an average size of approximately 0.08 km^2 with an average total range of approximately 0.23 km^2. A strong correlation (r = 0.92) was found between the total length of the crocodiles and the size of their territories indicating that home range behaviour do indeed change as the crocodile grows from juvenile to adult size. The crocodiles showed interesting behaviour in the way that they moved out of the area where they where captured and appeared almost to "recover" in areas as far as 5.24 km away from the capture site. It is also clear that obstructions such as weirs in rivers do not present a particular problem to crocodiles > 3.0 m TL. This is probably also true for smaller sized crocodiles.

The average number of nests/kilometre of shoreline found in the Flag Boshielo Dam came to about 0.085 nests/km while an average of 1.612 nest/km of shoreline were reported in the Kruger National Park with 0.212 nests/km of shoreline in the Umfolozi Game Reserve and about 0.322 nests/km of shoreline in Lake Ngezi. When comparing different crocodile populations, the use biomass is preferred as this permits comparisons of data acquired in diverse ecological situations. The clutch size and egg size (width, length and mass) corresponded well to that found in the Kruger National Park.

A clear preference for nesting in a small proportion (20.26%) of the available habitat along the western shore of the lake was found to exist. A significant relationship exists between the height above and distance to the water which indicates that the incline (slope) is the important factor in choosing a nesting site.

All but one of the nests where excavated in alluvial soils deposited on the river banks which explains the limited distribution of nests. All nests hatched successfully except those that were predated upon. The successful nests received > 6 hours of direct sunlight per day. The distribution of hatchlings supports the hypothesis that successful nesting does not take place in other areas around the lake. The tendency of females to defend territories at the nesting grounds together with an already limited available area where the alluvial soils occur can result in there being just too little space for all female crocodiles to nest successfully.

This study pointed out that the nests (eggs), hatchlings and adult males are the life stages where very low numbers of individuals were found to exist. Exploitation of these life stages will without doubt place the existing population under even more pressure. The area from the yellow container to Desmond's weir must be zoned as a wilderness area with no access to private boats and/or other vehicles. Monitoring of the population must continue and a detailed study of the Nile crocodile's diet in the Flag Boshielo Dam should be undertaken as a matter of urgency to establish if diet is the factor that makes crocodiles prefer to stay in the Flag Boshielo Dam rather than living in other dams in the general area.

OPSOMMING

Krokodille word erken as diere wat die struktuur en funksies van die ekosisteem onderhou deur middel van hulle aktiwiteite soos selektiewe predasie van vis spesies, die hersirkulering van voedingstowwe en die onderhoud van vlei-agtige gebiede in tye van droogte. Die algemene gevoel is dat wilde populasies van Nylkrokodille in Suidelike- en Oos-Afrika n matige behoefte aan herstel het. In Wes-Afrika is hulle egter grootliks uitgeroei. Krokodille word bedreig deur menslike aktiwiteite veral die vernietiging van hulle habitat. Kommersiële oorbenutting en onoordeelkundige jag metodes het veroorsaak dat baie krokodil spesies se getalle en verspreiding skerp afgeneem het. Opnames in die Olifantsrivier tussen die Loskopdam en die Nasionale Krugerwildtuin het aangedui dat die Flag Boshielodam (toe nog bekend as die Arabiedam) die hoogste digtheid van krokodille in terme van aantal diere per kilometer het.

Die beoogde verhoging van die Flag Boshielodam het die geleentheid gebied om die volgende hipotese te toets:

- Die natuurlike *C. niloticus* populasie in die Flag Boshielodam toon n gesonde populasie struktuur in vergelyking met ander natuurlike krokodil populasies.
- Die natuurlike *C. niloticus* populasie in die Flag Boshielodam toon n patroon van seisoenale migrasie binne die dam en die inlope van die Olifants- en Elandsriviere.
- Die natuurlike *C. niloticus* populasie in die Flag Boshielodam leef binne n beperkte gebied en gebruik nie die totale oppervlak van die dam nie.
- Die keuse van n nesgebied word beinvloed deur sekere omgewingsfaktore.

n Totaal van 28 nagtellings is gedoen tussen Januarie 2002 en November 2003. Waneer moontlik is lugtellings gedoen die oggend na die vorige aand se nagtelling. Lugtellings was egter baie beinvloed deur plaaslike weersomstandighede en dit was dus nie moontlik om n lugtelling na elke nagtelling te doen nie. Die geskatte aantal Nylkrokodille in die Flag Boshielodam is gebaseer op die sogenaamde dubbele opname metode wat gebruik maak van nagtelling data wat opgevolg is deur n lugtelling die volgende oggend. Volgens hierdie metode word geskat dat daar ongeveer 210.78 Nylkrokodille in die Flag Boshielodam leef. Absolute digthede word nie dikwels gebruik om krokodilpopulasies met mekaar te vergelyk nie omdat daar groot verskille in die struktuur van verskillende populasies kan wees. Daarom word die digtheid van krokodilpopulasies meestal in terme van biomassa uitgedruk. In die Flag Boshielodam is die digtheid van die krokodilpopulasie ongeveer 3.25 krokodille/km oewer maar die biomassa is 142.83 kg/km oewer. Hiervolgens het die Flag Boshielodam een van die hoogste biomassa waardes vir n klein populasie krokodille. Die biomassa waarde is hoër as die van die res van die Olifantsrivier (tussen Loskopdam en die Nasionale Krugerwildtuin) asook die Umfoloziriviere en ook die gebied bokant die Murchison Watervalle in Uganda.

Veranderlikes in krokodilpopulasies is waarskynlik meer afhanklik van liggaamsgrootte as wat dit is van ouderdomme. Daarom word die grootte-struktuur verkies om krokodil populasies te modeleer. Die klein grootte krokodille (wat jaaroud diere insluit) het ongeveer 20.59% van die populasie uitgemaak maar hierdie persentasie sal afneem voordat die diere 2.1m in totale lengte kan bereik. Medium grootte krokodille maak ongeveer 29.85% van die totale populasie uit. Hierdie is die diere wat in die toekomstige generasies tot die populasie moet bydra. Daar is bereken dat krokodille in die 2.1 - 4.0 m TL klas ongeveer 36.33% van die totale populasie uitmaak. Hierdie groep sluit die huidige broeiwyfies in. Dominante diere oor 4.0 m TL, het ongeveer

6.03% van die populasie uitgemaak. Die reproduktiewe groep in hierdie populasie maak ongeveer 42.36% uit van die totale aantal krokodille.

Die verspreiding van diere oor die grootte klasse is van groot belang in n krokodil populasie omdat die volwasse diere n hele aantal grooteordes swaarder en langer is as klein krokodilletjies. Skeiding tussen klein tot eenjaaroue diere en groter krokodille kom duidelik na vore. Die groter krokodille het die meeste van die beskikbare oewers gebruik vir hulle daaglikse aktiwiteite. Gebiede wat nie gebruik is nie is gebiede wat onvoldoende beskerming bied asook waar onvoldoende rus en nesgebiede voorkom. Gebiede waar prooidiere moeiliker is om te vind is ook vermy soos bv die diep, oop water naby die damwal. Oewers waar baie menslike aktiwiteite gebeur het die laagste verspreiding van krokodille gehad. Geen kort afstand migrasie patrone is geidentifiseer nie maar die krokodille het wel by veranderende watervlakke gedurende die droogte van 2003 aangepas deur te verskuif na gebiede wat beter aan hulle vereistes voldoen het.

Die produksie van waters in Suidelike-Afrika neem af gedurende die winter maande. Hierdie jaarlikse afname in die produktiwiteit van die krokodil se omgewing het n invloed op krokodille se seisonale gebiede. Migrasie van groter krokodille het plaasgevind tussen die damkom en die inlope van die Olifants- en Elandsriviere. Geen migrasie van klein krokodilletjies (< 40 cm TL) is waargeneem nie maar krokodille in die groteklas 40 - 140 cm TL is geforseer om uit gebiede uit te migreer waar groter diere wou nes maak. Diere in die 2.1 - 4.0 m TL klas en die in die > 4.0 m TL klas het n defnitiewe migrasie in die dam in gehad gedurende die winter maande en weer uit in die riviere in met die aanbreek van somer om daar te paar en nes te maak.

In die Flag Boshielodam is die aktiewe gebied van krokodille se tuisgebiede tussen 0.06 km² en 0.23 km² groot. Die gemiddelde grootte van tuisgebiede is ongeveer

0.36 km² wat vergelykbaar is met die 0.31 km² wat in die Ngezi-meer in Zimbabwe gevind is. Minimum groottes vir tuisgebiede in die Flag Boshielodam stem ooreen met tuisgebiede in ander krokodil bevolkings elders in Afrika. Dit dui aan dat krokodille n minimum grootte habitat nodig het om te oorleef en in die Flag Boshielodam is daardie grootte ongeveer 0.06 km² (60 m²). n Mate van oorvleuling is gevind in die gebiede waar krokodille hulle tuisgebiede handhaaf. Hierdie stelling word ondersteun deur die feit dat alle gemerkte krokodille aanspraak gehad het op die Brady Eiland/Ou Neste gebiede. Ten spyte van die klein monstergrootte was dit steeds opmerklik dat manlike diere groter gebiede onderhou as wat vroulike diere doen. Die twee vroulike diere was aktief in n gemiddelde gebied van 0.05 km² met n gemiddelde tuisgebied grootte van ongeveer 0.23 km². In teenstelling hiermee was die manlike diere aktief in n gebied met n gemiddelde grootte van ongeveer 0.08 km². Die sterk korrelasie (r = 0.92) tussen die lengte van die krokodille en die grootte van hulle gebiede bevestig dat hulle gedrag ten opsigte van tuisgebiede verander soos hulle ontwikkel van onvolwasse tot volwasse diere. Interessante gedrag is geopenbaar toe die krokodille die gebiede waar hulle gevang is verlaat het en hulself in gebiede so ver soos 5.24 km weg gaan vestig het. Dit het ook duidelik geword dat obstruksies soos keerwalle in riviere nie n betekenisvolle invloed het op die verspreiding van krokodille in die > 3.0 m TL nie. Dit is waarskynlik ook die geval vir kleiner krokodille.

Daar word gemiddeld 0.085 neste/km oewer in die Flag Boshielodam gemaak terwyl daar n gemiddeld van 1.612 neste/km oewer in die Nasionale Kruger Wildtuin gemaak word met n gemiddeld 0.212 neste/km oewer in die Umfolozi Wildtuin gevind is en n gemmiddeld van 0.322 neste/km oewer in die Ngezi-meer het. Krokodil populasies kan egter eerder met mekaar vergelyk word deur biomassa te gebruik aangesien dit die probleem van onbekende veranderlikes uitskakel.

Die nesgrootte en eiergrootte (wydte, lengte en massa) stem wel ooreen met data uit die Nasional Krugerwildtuin uit. n Duidelike voorkeur is gevind vir nesmaak op die westelike oewer in n klein deeltjie (20.26%) van die beskikbare habitat. Daar is ook n betekenisvolle verwantskap tussen die hoogte bo die water en die afstand van die water af waar die nes gemaak word. Hierdie verwantskap dui daarop dat die helling van die oewer n belangrike faktor is in die keuse van n nesplek in die Flag Boshielodam. Steil oewers maak dit waarskynlik makliker vir die pas uitgebroeide krokodilletjies om vinnig in die water te kom. Die vermoë om die water vinnig te bereik verminder hulle kwesbaarheid vir roofdiere. Slegs een nes is nie in die alluviale grond wat op die oewers neergeset is gemaak nie. Alle neste (behalwe die wat deur predatore geplunder is) het suksesvol uitgebroei. Neste wat suksesvol uitgebroei het, het direkte sonlig vir meer as 6 ure per dag ontvang. Die verspreiding van klein krokodilletjies ondersteun die hipotese dat daar slegs in gebiede met alluviale gronde gebroei word. Die gedrag van wyfiekrokodille om hulle nesgebiede te verdedig tesame met die klein gebied waarin die alluviale gronde voorkom lei waarskynlik tot die probleem dat daar gewoon net nie genoeg plek is vir al die wyfies om suksesvol te broei nie.

Die huidige studie dui aan dat die aantal neste, aantal klein krokodilletjies en aantal groot bul krokodille baie laag is. Benutting of versteuring van hierdie groepe sal veroorsaak dat die populasie onder nog meer druk geplaas word. Die gebied tussen die geel vraghouer en Desmond se keerwal moet as n wildernisgebied gesoneer word met geen toegang vir private bote en ander voer- en vaartuie nie. Monitering van die populasie moet voortgaan en n gedetaileerde studie van die Nylkrokodil se dieet in die Flag Boshielodam moet dringend gedoen word. Daar moet bepaal word hoe belangrik die dieët is in die behoud van hierdie krokodil populasie en of dit die beperkte beskikbaarheid van alluviale grond is wat die bevolking beheer.

REFERENCES

ACOCKS, J.P.H. 1975. Veld types of South Africa, second edition. *Memoirs of the Botanical Survey of South Africa.* 40. Department of Agricultural Technical Services. Pretoria.

ALLANSON, B.R. 1982. The energy base of aquatic systems in South Africa. *Journal of the Limnological Society of Southern Africa.* 8(2), 47-53.

ALLSTEADT, J. and LANG, J.W. 1995. Sexual dimorphism in the genital morphology of young American alligators. *Herpetologica.* 51(3), 314-325.

ANDERSON, D.J. 1982. The home range: A new non parametric estimation technique. *Ecology.* 63, 102-112.

BATCHELOR, G.R. 1992. Van dam tot dam. *Fauna & Flora.* 48, 22-29.

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

BLAKE, D.K. 1974. The rearing of crocodiles for commercial and conservation purposes in Rhodesia. *Rhodesia Science News*. 8(3), 315-324.

BLAKE, D.K. and JACOBSEN, N.H.G. 1992. The conservation status of the Nile crocodile (*Crocodylus niloticus*) in South Africa. In: *Conservation and utilisation of the Nile crocodile in South Africa - Handbook on crocodile farming.* Edited by G.A. Smith and J. Marais. The Crocodilian Study Group of Southern Africa.

BLAKE, D.K. and LOVERIDGE, J.P. 1987. Observation on the behaviour of Nile crocodiles *Crocodylus niloticus* in captivity. In: Wildlife management: Crocodiles and alligators. Edited by G.J.W. Webb, S.C. Manolis & P.J. Whitehead. Surrey Beatty, Chipping Norton.

BOTHMA, J du P. 2002. Important ecological principles and conservancies. In: *Game ranch management.* Edited by J du P. Bothma. Van Schaik Publishers, Pretoria.

BRITTON, A. 2004. Crocodilians natural history & conservation. http://www.crocodilian.com/ (15 June 2004).

BUNNELL, F.L. and TAIT, D.E.N. 1981. Population dynamics of bears, implications. In: *Dynamics of large mammal populations*. Edited by C.W. Fowler and T.D. Smith. John Wiley and Sons. Wiley-Interscience, London.

BURT, W.A. 1940. Territoriality and home range concepts as applies to mammals. *Journal of Mammalogy.* 45, 346-352.

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

CHABRECK, R.H. 1965a. Methods of capturing marking and sexing alligators. *Proc. Ann. Conf. Southeastern Assoc. Game and Fish Comm*. 17, 47-50.

CHABRECK, R.H. 1965b. The movement of alligators in Louisiana. *Proc. Ann. Conf. Southeastern Assoc. Game and Fish Comm*. 19, 102-110.

CHABRECK, R.H. 1966. Methods of determining the size and composition of alligator populations in Louisiana. *Proc. Ann. Conf. Southeastern Assoc. Game and Fish Comm*. 20, 105-112.

CHEN, B. 1990. The past and present situation of the Chinese alligator. *Asiatic Herpetological Research.* 3, 129-136.

CLARK, J. 1997. Kapasiteitsbepaling van Arabiedam, Internal Report, Department of Water Affairs and Forestry, Pretoria.

COETZEE, L.L. 2001. Genetic stratigraphy of the Paleoproterozoic Pretoria Group in the Western Transvaal. M.Sc. dissertation, Rand Afrikaans University, Johannesburg.

COETZEE, N.J. 1994. Krokodilnesmonitering 1993/1994. Unpubl. Report, Transvaal Chief Directorate of Nature and Environmental Conservation, Pretoria.

COETZEE, N.J. 1996. Krokodilnesmonitering 1995/1996. Unpubl. Report, Transvaal Chief Directorate of Nature and Environmental Conservation, Pretoria.

COETZEE, N.J. 1999. Status van die krokodil populasie in die Arabiedam. Unpubl. Report, Transvaal Chief Directorate of Nature and Environmental Conservation, Pretoria.

COTT, H.B. 1961. Scientific results of an enquiry into the ecology and economic status of the Nile crocodile (*Crocodylus niloticus*) in Uganda and Northern Rhodesia. *Trans. Zool. Soc. Lond*. 29, 211-356.

CRAIGHEAD, F.C. 1968. The role of the Alligator in shaping plant communities and maintaining wildlife in the Southern Everglades. *Florida Nat.* 41:2-7, 69-74, 94.

DAVIES, B and DAY, J. 1998. *Vanishing Waters*. University of Cape Town Press, Cape Town.

DAVIS, D.E. and WINSTEAD, R.L., 1980. Estimating numbers of wildlife populations. In: *Wildlife management techniques manual*. Edited by S.D. Schemnitz. The Wildlife Society, Washington D.C.

DEEMING, D.C. and FERGUSON, M.W.J. 1989. The mechanism of temperature dependant sex determination in crocodilians: a hypothesis. *Amer. Zool.* 29, 973-985.

DIXON, K.R. and CHAPMAN, J.A. 1980. Harmonic mean measure of animal activity areas. *Ecology*. 61, 1040-1044.

FERGUSON, M.W.J. 1982. The structure and composition of the eggshell and embryonic membranes of *Alligator mississippiensis*. *Trans. Zool. Soc. Lond.* 36, 99-152.

FERGUSON, M.W.J. 1985. Reproductive biology and embryology of the crocodilians. In: *Biology of the Reptilia, Volume 14*. Edited by C. Gans, F.S. Billett and P.F.A. Maderson. John Wiley and Sons, New York.

FLORIDA FISH AND WILDLIFE CONSERVATION COMMISION. 2003. *Public waters alligator harvest training and orientation manual*. Florida, USA.

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

GOODWIN, T.M. and MARION, W.R. 1979. Seasonal activity ranges and habitat preferences of adult alligators in a North-central Florida lake. *Journal of Herpetology.* 13(2), 157-164.

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

GROBLER, J.H. 1978. Population dynamics of sable in Rhodesia. D.Phil. thesis, University of Rhodesia.

HARESTAD, A.S. and BUNNELL, F.L. 1979. Home range and body size a re-evaluation. *Ecology*. 60, 389-402.

HOOGE, P.N. and EICHENLAUB, B. 1997. *Animal movement extension to ArcView. ver. 1.1.* Alaska Biological Science Centre, U.S. Geological Survey, Anchorage, AK, USA.

HOWARD, W.E. 1960. Innate and environmental dispersal of individual vertebrates. *American Midland Naturalist*. 63, 152-161.

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

HUTTON, J.M. 1987a. Morphometrics and field estimation of the size of the Nile crocodile. *Afr. J. Ecol.* 25, 225-230.

HUTTON, J.M. 1987b. Incubation temperatures, sex ratios and sex determination in a population of Nile crocodiles (*Crocodylus niloticus*). *Journal of Zoology*. 211, 143-155

HUTTON, J.M. 1989. Movements, home range, dispersal and the separation of size classes in Nile crocodiles. *Amer. Zool.*, 29, 1033-1048.

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

JACOBSEN, N.H.G. 1988. The Nile crocodile. In: South African Red Data Book - Reptiles and Amphibians. *South African National Scientific Report No 151*. Edited by W.R. Branch. CSIR, Pretoria.

JACOBSEN, N.H.G. 1992. Conservation plan. *Crocodylus niloticus*. Unpubl. Report, Transvaal Chief Directorate of Nature and Environmental Conservation, Pretoria.

JENKINS, R.W.G. 1993. Sustainable use of crocodilians - conservation benefits. *Proceedings of the 2nd regional meeting of the Crocodile Specialist Group, Darwin, Australia. Species Survival Commission of IUCN.* IUCN. Gland, Switzerland.

JEWELL, P.A. 1966. The concept of home range in mammals. *Symp. Zool. Soc. London.* 18, 85-109.

JOANEN, T. and McNEASE, L. 1970. A telemetric study of nesting female alligators on Rockefeller Refuge, Louisiana. *Proc. Ann. Conf. Southeastern Assoc. Game and Fish Comm.* 24, 175-193.

JOANEN, T. and McNEASE, L. 1972. A telemetric study of adult male alligators on Rockefeller Refuge, Louisiana. *Proc. Ann. Conf. Southeastern Assoc. Game and Fish Comm.* 26, 252-275.

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

KING, F.W. 1988. Crocodiles: Keystone wetland species. In: *Wildlife in the Everglades and Latin American wetlands.* In: *Proceedings of the First Everglades Nat. Park Symposium.* Miami.

KING, F.W. and BURKE, R.L. (eds.) 1997. Crocodilian, Tuatara and Turtle species of the world: An online taxonomic and geographic reference. Association of systematics collections, Washington D.C. http://flmnh.ufl.edu/natsci/herpetology/tutcroclist/ (7 April 1997).

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

KOFRON, C.P. 1989a. A simple method for capturing large Nile crocodiles. *Afr. J. Ecol.* 27, 183-189.

KOFRON, C.P. 1989b. Nesting ecology of the Nile crocodile *Crocodylus niloticus*. *Afr. J. Ecol.* 25, 225-230

KOOSIS. D.J. 1997. *Statistics, 4th ed.* John Wiley & Sons, New York.

LANG, J.K., ANDREWS, H.V. and WHITAKER, R. 1989. Sex determination and sex ratios in *Crocodylus palustris*. *Amer. Zool.* 29, 935-952.

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

LANG, J.W. 1990. Sex determination. In: *Crocodiles and Alligators*. Edited by C.A. Ross. Merehurst Press, London.

LANG, J.W. and ANDREWS, H.V. 1994. Temperature dependant sex determination in Crocodilians. *Journal of Experimental Biology*. 270, 28-44.

LESLIE, A.J. 1997. The ecology and physiology of the Nile crocodile, *Crocodylus niloticus*, in Lake St Lucia KwaZulu Natal, South Africa. PhD Thesis. Drexel University, Philadelphia.

LESLIE, A.J. and SPOTILA, J.R. 2001. Alien plant threatens Nile crocodile (*Crocodylus niloticus*) breeding in Lake St. Lucia, South Africa. *Biol. Cons.* 98(3). 347-355.

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

MAGNUSSON, W.E., LIMA, A.P., HERO, J., SANAIOTTI, T.M. and YAMAKOSHI, M. 1990. *Paleosuchus trigonatus* nests: sources of heat and embryo sex ratios. *Journal of Herpetology*. 24(4), 397-400.

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

MIZUTANI, F and JEWELL, P.A. 1998. Home range and movements of leopards on a livestock ranch in Kenya. *J. Zool. Lond.* 244, 269-286.

MODHA, M.L. 1967. The ecology of the Nile crocodile (*Crocodylus niloticus* Laurenti) on Central Island, Lake Rudolf. *East. Afr. Wildl. J.* 5, 74-95.

MONTAGUE, J.J. 1983. Influence of water level, hunting pressure and habitat type on crocodile abundance in the Fly River drainage, Papua New Guinea. *Biological Conservation*. 26, 309-339.

MROSOVSKY, N. and PIEAU, C. 1991. Transitional range of temperature, pivotal temperatures and thermosensitive stages for sex determination in reptiles. *Amphibia-Reptilia*. 12, 169-179.

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

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

OWEN-SMITH, N.E. 1977. On territoriality in ungulates and an evolutionary model. *Q. Rev. Biol.* 52, 1-38.

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

PLATT, S.G. 2000. An expedition into central Rakhine State, Myanmar. Report to Wildlife Conservation Society, Bronx, New York.

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

POOLEY, A.C. 1990. Food and feeding habits. In: *Crocodiles and Alligators*. Edited by C.A. Ross. Merehurst Press, London.

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

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

RYKE. P.A.J. 1978. *Ekologie, beginsels en toepassings.* Butterworth. Durban.

SCHULZE, B.R. 1994. Climate of South Africa, Part 8. Report No WB 28, Weather Buro, Department of Environmental Affairs, Pretoria.

SEAMAN, D.E. and POWELL, R.A. 1996. An evaluation of the accuracy of kernel density estimators for home-range analysis. *Ecol.* 77, 2075-2085.

SMITH, E.N. 1979. Behavioural and physiological thermoregulation of crocodilians. *Amer. Zool.* 19, 239-247.

SOUTH AFRICA. DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 2003a. Olifants River Dam: Reliable water supply for economic development. Media release by Minister Ronnie Kasrils, 19 February 2003. Pretoria.

SOUTH AFRICA. DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 2003b. Raising the Flag Boshielo Dam, Scoping Report Volume 1. Pretoria.

SUTTON, D.B. and HARMON, N.P. 1973. *Ecology: selected concepts.* John Wiley and Sons. New York.

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

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

TURNER, F.B. 1977. Dynamics of populations. In: *Biology of the Reptilia, Volume 7*. Edited by C. Gans and D.W. Tinkle. Academic Press, London.

Van WINKLE, W. 1975. Comparison of several probabilistic home-range models. *J. Wildl. Manage.* 39, 118-123.

WEBB, G.J.W. and COOPER-PRESTON, H. 1989. Effects of incubation temperature on crocodiles and the evolution of reptilian oviparity. *Amer. Zool.* 29, 953-971.

WEBB, G.J.W. and MESSEL, H. 1979. Wariness in *Crocodylus porosus*. *Aust. Wildl. Res.* 6, 227-234.

WEBB, G.J.W. and SMITH, A.M.A. 1984. Sex ratio and survivorship in the Australian freshwater crocodile, *Crocodylus johnstoni*. In: *The structure, development and evolution of reptiles*. Edited by M.W.J. Ferguson. Academic Press, London.

WEBB, G.J.W. and SMITH, A.M.A. 1987. Life history parameters, population dynamics and the management of crocodilians. In: *Wildlife management: crocodiles and alligators*. Edited by G.J.W. Webb, S.C. Manolis and P.J. Whitehead. Surrey Beatty and Sons, Chipping Norton.

WEBB, G.J.W., BEAL, A.M., MANOLIS, S.C. and DEMPSEY, K.E. 1987. The effects of incubation temperature on sex determination and embryonic development rate in *Crocodylus johnstoni* and *C. porosus*. In: *Wildlife management: crocodiles and alligators*. Edited by G.J.W. Webb, S.C. Manolis and P.J. Whitehead. Surrey Beatty and Sons, Chipping Norton.

WEBB, G.J.W., SACK, G.C., BUCKWORTH, R and MANOLIS, S.C. 1983. An examination of *Crocodylus porosus* nests in two Northern Australian freshwater swamps with an analysis of embryo mortality. *Aust. Wildl. Res.* 10, 571-605.

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

WOOD, J.M., WOODWARD, A.R., HUMPHREY, S.R. and HINES, T.C. 1985. Night counts as an index of American alligator population trends. *Wildl. Soc. Bull.* 13, 262-273.

WOODWARD, A.R. and MARION, W.R. 1978. An evaluation of factors affecting night-light counts for alligators. *Proc. Annu. Conf. Southeastern Assoc. Fish and Wildl. Agencies*. 32, 291-302.

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

WORTON, B.J. 1987. A review of models of home-range for animal movement. *Ecol. Model.* 38, 277-298.

WORTON, B.J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. *Ecol.* 70, 164-168.

WORTON, B.J. 1995. Using Monte Carlo simulation to evaluate kernel-based home-range estimators. *J. Wildl. Manage.* 59, 794-800.

ZAR, J.H. 1999. *Biostatistical analysis, 4th ed.* Prentice Hall, New Jersey.

APPENDIX I

BRIEF DESCRIPTION OF THE TAXONOMY OF THE ORDER CROCODYLIA

(KING AND BURKE, 1997)

Class Reptilia

Order Crocodylia

Family Alligatoridae

Alligator mississippiensis (American alligator)

Alligator sinensis (Chinese alligator)

Caiman crocodilus (spectacled caiman) includes *C. c. crocodilus, C. c. fuscus, C. c. apaporiensis*

Caiman latirostris (broad-snouted caiman)

Caiman yacare (yacaré)

Melanosuchus niger (black caiman)

Paleosuchus palpebrosus (dwarf caiman)

Paleosuchus trigonatus (Schneider's smooth-fronted caiman)

Family Crocodylidae

Subfamily Crocodylinae

Crocodylus acutus (American crocodile)

Crocodylus cataphractus (African slender-snouted crocodile)

Crocodylus intermedius (Orinoco crocodile)

Crocodylus johnsoni (Australian freshwater crocodile)

Crocodylus mindorensis (Philippine crocodile)

Crocodylus moreletii (Morelet's crocodile)

Crocodylus niloticus (Nile crocodile)

Crocodylus novaeguineae (New Guinea crocodile)

Crocodylus palustris (mugger)

Crocodylus porosus (saltwater crocodile)

Crocodylus rhombifer (Cuban crocodile)

Crocodylus siamensis (Siamese crocodile)

Osteolaemus tetraspis (dwarf crocodile)

Subfamily Tomistominae

Tomistoma schlegelii (tomistoma)

Family Gavialidae

Gavialis gangeticus (gharial)