POPULATION SURVEY OF *CROCODYLUS NILOTICUS* (NILE CROCODILE) AT LAKE SIBAYA, REPUBLIC OF SOUTH AFRICA

by

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PREFACE

The work described in this dissertation was carried out at the Centre for Environment and Development, University of KwaZulu-Natal, Pietermaritzburg, from July 2002 to December 2004, under the supervision of Mr Jan Korrûbel.

These studies represent original work by the author and has not otherwise been submitted in any form for any degree or diploma at any other university. Where use has been made of the work of others it is duly acknowledge in the text.

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James Perran Ross

Dedicated to the loving memory of my mother

Lucia Combrink (1941 – 1992)

ABSTRACT

The Greater St Lucia Wetland Park (GSLWP) World Heritage Site, is one of the most important remaining protected areas for the conservation of *Crocodylus niloticus* (Nile crocodile) in the Republic of South Africa. Although crocodiles are present at low densities in some of the wetlands throughout the GSLWP, at Kosi Bay and Lake Sibaya, the majority is found at Lake St Lucia. Concern about the status of the crocodile population at Lake Sibaya prompted a quantitative assessment of the present situation to direct appropriate management action to secure the future viability of this population. Due to the complex nature of crocodile surveys, and the paucity of available scientific literature in South Africa, a literature review of global crocodilian survey techniques provided the basis for a survey strategy to determine an index of relative abundance of the crocodile population at Lake Sibaya.

The population was estimated in 2003 through aerial and spotlight surveys and nest surveys were conducted in 2003 and 2004. The highest count during the 2003 aerial surveys was 36 crocodiles, suggesting a decline of 66% during the past 13 years in the population index based on earlier surveys. Sixty five crocodiles were counted during the spotlight surveys, 72% more than the highest aerial count (excluding hatchlings), which indicates the importance of using a combined survey approach. A correction factor of 1.72 was calculated for future aerial surveys and the population is estimated at 112 crocodiles, with a variance of 22.49 and standard error of 4.47.

Three nests were found during the 2003 nest survey, but none during 2004. Crocodiles rarely produce every year in the wild, and the Lake Sibaya population might display a low reproductive frequency, similar to the nearby Lake St Lucia population. Sixty three potential nesting areas were identified and evaluated in terms of their relative suitability for nesting. These sites could play an important role in increasing the population to support a sustainable use programme at Lake Sibaya.

Despite legal protection, the population is clearly under threat as a result of direct and secondary pressures. To secure the future viability of this population, I recommend that Ezemvelo KZN Wildlife develop an integrated crocodile management plan through collaboration with The Greater St Lucia Wetland Park Authority and the local communities

adjacent to Lake Sibaya, where the conservation and increase of crocodiles will benefit the communities that are dependent on the lake for their daily livelihoods. The likely alternative might be extinction of this important predator from the largest freshwater ecosystem in South Africa's first World Heritage Site.

OPSOMMING

Die Groter St Lucia Vleiland Park (GSLVP), Wêrelderfenisgebied is een van die belangrikste oorblywende bewaringsgebiede vir die bewaring van *Crocodylus niloticus* (Nyl krokodil) in die Republiek van Suid-Afrika. Alhoewel krokodille teenwoordig is in sommige van die vleilande in die GSLVP, by Kosi baai en die Sibaya meer, word die meeste krokodille aangetref in die St Lucia meer. Kommer oor die status van die krokodil bevolking in die Sibaya meer het gelei tot 'n kwantitatiewe ondersoek na die huidige stand van die populasie met die oog om relevante bestuurs aanbevelings te maak ten einde die toekoms van die krokodilbevolking te verseker. As gevolg van die kompleksitiet van krokodil sensus tegnieke en die skaarsheid van enige wetenskaplike literatuur oor hierdie onderwerp in Suid Afrika, het 'n wêreldwye literatuur oorsig van krodidil sensus tegnieke die fondament gevorm van 'n sensus strategie om 'n relatiewe index van die krokodilbevolking in die Sibaya meer te bepaal.

Gedurende 2003 is die krokodilbevolking bepaal deur middel van lug sensusse, naglig sensusse per boot en te voet en krokodilnes sensusse is uitgevoer gedurende 2003 en 2004 om meer insig te verkry in die broeikomponent van die bevolking.
Die meeste krokodille wat op een slag gedurende die 2003 lug sensusse getel is, was 36, en dit veronderstel 'n afname van 66% die afgelope 13 jaar in die bevolkings index, gebaseer op vorige lug sensusse. Vyf en sestig krokodille is getel gedurende die naglig sensusse, 72% meer as die hoogste lugsensus (uitgesluit pasgebore krokodille), wat die belangrikhied van 'n gekombinerde sensus benadering beklemtoon. 'n Korreksie faktor van 1.72 is bereken vir toekomstige lug sensusse en die bevolking word beraam op 112 krokodille, met 'n variansie van 22.40 en 'n standaardfout van 4.47.

Drie krokodilneste is gevind gedurende 2003, maar geen nes is opgespoor gedurende die 2004 sensus nie. Krokodille broei selde elke jaar in natuurlike omstandighede, en die Sibaya bevolking kan moontlik 'n natuurlike lae voortplantings frekwensie vertoon, net soos die naby geleë krokodil bevolking in die St Lucia meer. Drie en sesting potensiëele broei areas is geïdentifiseer en geëvalueer in terme van hul relatiewe geskiktheid as broei gebiede. Hierdie broei areas kan 'n belangrike rol speel in die groei van die krokodil bevolking om 'n program te onderstuen gebaseer op die volhoubare benutting van krokodille by die Sibaya meer.

Ondanks wetlike beskerming, word die krokodil bevolking bedreig as gevolg van direkte en indirekte faktore. Om die toekomstige oorlewing van krokodille by die Sibaya te verseker beveel ek aan dat Ezemvelo KZN Wildlife 'n geïntegreerde bestuursplan ontwikkel saam met die Greater St Lucia Wetland Park Authority en die plaaslike gemeenskap wat teenaan die meer woon, waar die bewaring en groei in die krokodilbevolking ekonomies voordelig sal wees vir die gemeenskappe wat afhanklik is van die meer vir hul daaglikse bestaan. Die waarskynlike alternatief is die uitsterf van hierdie belangrike roofdier in die grootste varswater ekostelsel in Suid-Afrika se eerste Wêrelderfenisgebied.

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CHAPTER 1
INTRODUCTION

1.1 RATIONALE

The natural distribution of the Nile crocodile in Africa expands over 40 countries, and overall it is not threatened, having a relatively secure status in southern and eastern Africa (Ross 1998). Although South Africa was once host to a large crocodile population occurring in all the estuaries, rivers and lakes in the eastern half of the country where the climate was suitable, today their range and numbers are confined to a few waterbodies and eastward flowing rivers south of the Limpopo river extending to the Tugela River in KwaZulu Natal. The only secure populations occur in the Kruger National Park, Ndumu Game Reserve and Lake St Lucia (Blake and Jacobsen 1992) and less than 8 500 wild crocodiles survive in the RSA today (Marais and Pooley 1991). As a result of extirpation over much of its former range in South Africa and current problems of habitat destruction, the Nile crocodile has been listed in the South African Red Data Book as Vulnerable (Jacobsen 1988; Branch 1998).

In December 1999, the Greater St Lucia Wetland Park (See Fig 1.1), consisting of 16 legally protected areas of 289 376 ha (Porter, Sandwith and Bainbridge 1998) was listed as South Africa's first World Heritage Site as a result of, amongst others, criterion no. iii (World Heritage criterion for the listing of a potential site as a natural World Heritage Site)

"superlative natural phenomena of exceptional natural beauty and aesthetic importance", with special mention of the basking and nesting sites of *C. niloticus*.

The Greater St Lucia Wetland Park consists of a myriad wetlands, small lakes and rivers as well as three main waterbodies; Lake St Lucia, Kosi Bay and Lake Sibaya. Crocodiles are present at low densities in some of the wetlands throughout the GSLWP, at Kosi Bay and Lake Sibaya, but the majority is found at Lake St Lucia. Although the crocodile population at Lake St Lucia appears to be stable (Blake 1990; Leslie 1997), a cause for concern is the apparent decline of crocodiles in most of the other lakes and wetlands inside the boundary of the Greater St Lucia Wetland Park, for instance at Lake Sibaya.

Lake Sibaya, (See Fig. 1.1) is South Africa's largest freshwater lake, and host to the second largest crocodile population within the Greater St Lucia Wetland Park. For many years conservationists have expressed their concern with regards to the status of crocodiles at Lake Sibaya (Pooley 1976; Bruton 1979a; Blake 1990; Mountain 1990; Thorbjarnarson 1992) as well as the lack of population and breeding information during the past decade.

Although the water surface of Lake Sibaya is a legally protected area (KwaZulu-Natal Provincial Ordinance 15 of 1974, KwaZulu Nature Conservation Act No. 29 of 1992, KwaZulu-Natal Nature Conservation Management Act no. 9 of 1997) and listed as a Ramsar and World Heritage Site, the surrounding land is state land and held in trust by three tribal chiefs (Kyle and Ward 1995). Unemployment is widespread and many community members are dependent on the lake for daily resource utilisation. The amaThonga people have lived around Lake Sibaya for centuries (Bruton 1979) and human-crocodile conflict has led to increased negativity from the community. This resulted in pressure on the crocodile population in the form of unregulated harvesting and killing of crocodiles as well as disturbance of crocodile nesting areas (Bruton 1979; Ward 1985; Kyle & Ward 1995), especially the past decade (Kyle 2003 pers. comm.).

In the light of the present situation, an integrated crocodile management plan is required to address the apparent decline in the crocodile population as well as to deal with the fears, concerns and possible opportunities for the local communities living adjacent to Lake Sibaya.

The first component for such a management plan should be a quantitative population survey, to assess the population structure, distribution, density, and investigate factors affecting breeding. Quantifying the status of a crocodile population is complex and subject to various sources of bias and uncertainty (Games et al. 1992). It is therefore imperative that a throughout review on global crocodilian techniques should be undertaken in order to select the best possible survey strategy at Lake Sibaya.

1.2 RESEARCH AIM

To review global crocodilian survey techniques in order to conduct a population survey of *C. niloticus* at Lake Sibaya.

1.3 PRIMARY RESEARCH OBJECTIVE

To estimate the *C. niloticus* population through aerial and spotlight surveys and investigate breeding for 2003 and 2004.

1.4 SECONDARY RESEARCH OBJECTIVES

- To investigate the types of crocodilian surveys (total or sample), the best technique (direct or indirect) to use and the effect that survey bias (visibility bias and environmental factors) could have on the results of the survey.
- To collate historical survey information on *C. niloticus* at Lake Sibaya
- To document and compare the relative distribution and estimate size structure of the crocodile population.
- To evaluate potential nesting areas and investigate factors affecting breeding
- To calculate a correction factor for future aerial surveys, using data obtained from spotlight counts.
- To propose management recommendations for the crocodile population at Lake Sibaya.

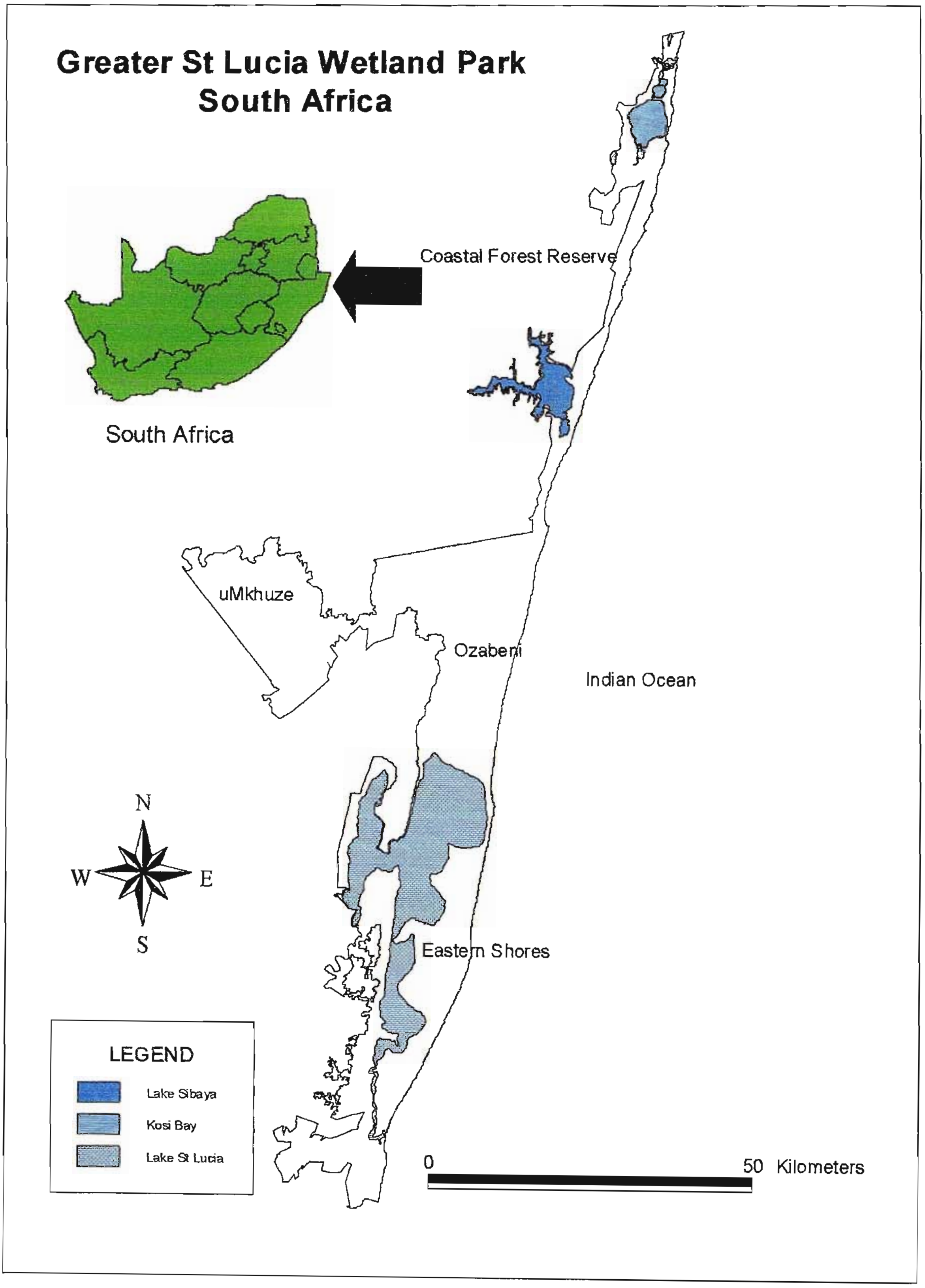

Figure 1.1 The Greater St Lucia Wetland Park, consisting of 16 legally protected areas was listed as South Africa's first World Heritage Site in 1999.

1.5 METHODOLOGY - COMPONENT A & B

Due to the complex nature of crocodile surveys, and the paucity of available scientific literature in South Africa, a literature review of global crocodilian (Crocodylinae, Alligatorinae and Gavialinae) survey techniques was an important first step to gain insight into factors pertaining to crocodilian surveys in general (types, techniques and bias) so as to employ the most appropriate survey strategy for Lake Sibaya (see Fig's. 1.2 & 1.3). Figure 1.3 highlights the major factors in global crocodilian surveys, and each component is separately explained in the literature review (Component A). fAs a result of the similarity in survey techniques between the different crocodilian species in the global survey literature, the term *Crocodilian(s)* will be used for most of Component A, referring to crocodiles, caimans, alligators, and gharials. At the same time, historical survey data for Lake Sibaya was collated to facilitate a better understanding of the present situation (see Fig. 1.2) and the outcome of these two processes (Component A) was distilled into an appropriate survey strategy for Lake Sibaya.

Component B (fieldwork and paper) consisted of a combination of three aerial surveys, two nest surveys (2003 and 2004), seven spotlight surveys from a boat and two spotlight surveys on foot (see Fig. 1.2). The aim was to assess the crocodile population status at Lake Sibaya and to propose management recommendations. Shortly after completion of the fieldwork, an abstract of the preliminary results was submitted and accepted for the 17th Working Meeting of the IUCN Crocodile Specialist Group in Darwin, Australia. A research paper (Component B) outlining the results has been prepared in the required style format for publication in the South African Journal of Wildlife Research.

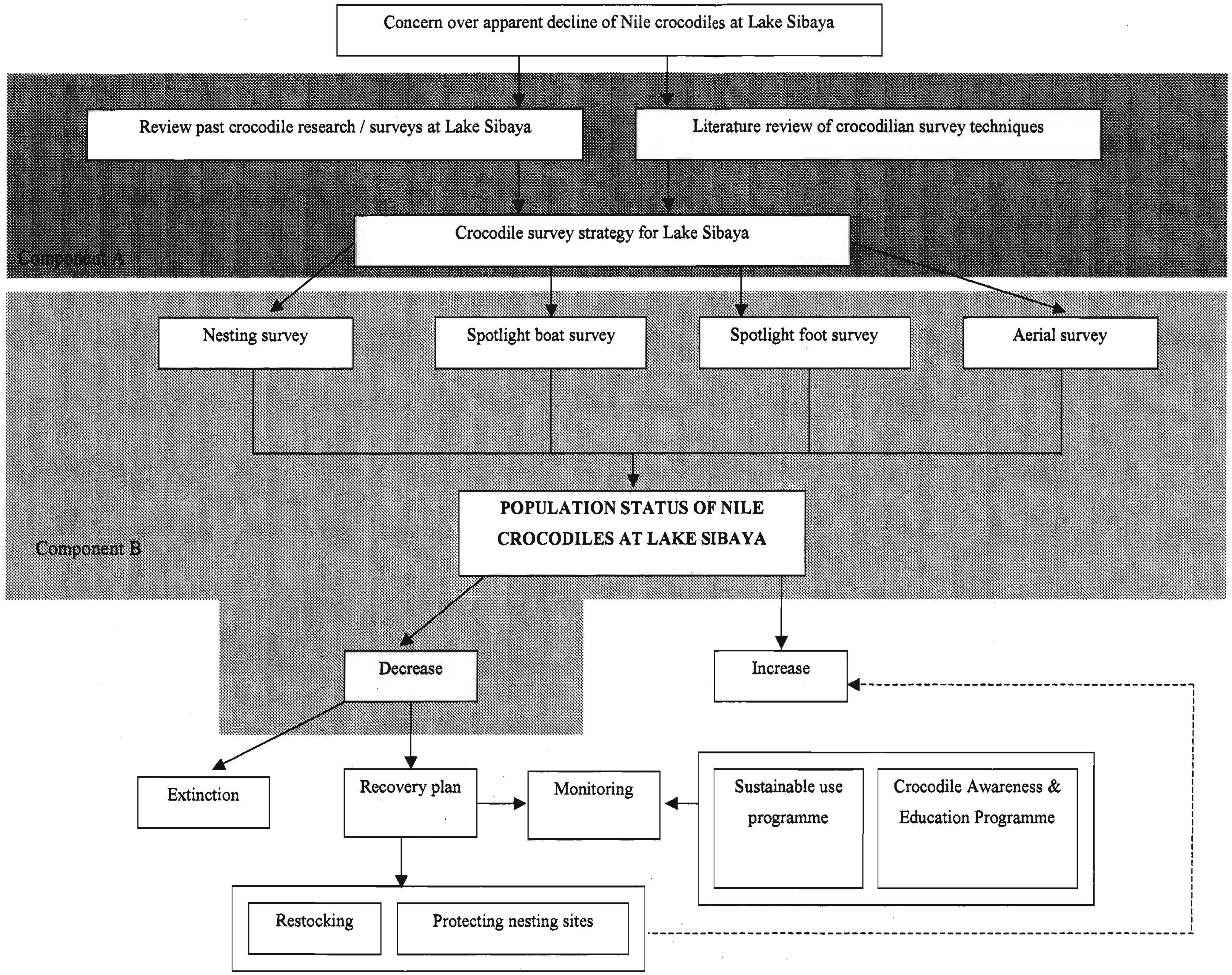

Figure 1.2 Outline of Component A (dark grey) & Component B (light grey) within the broader framework (white).

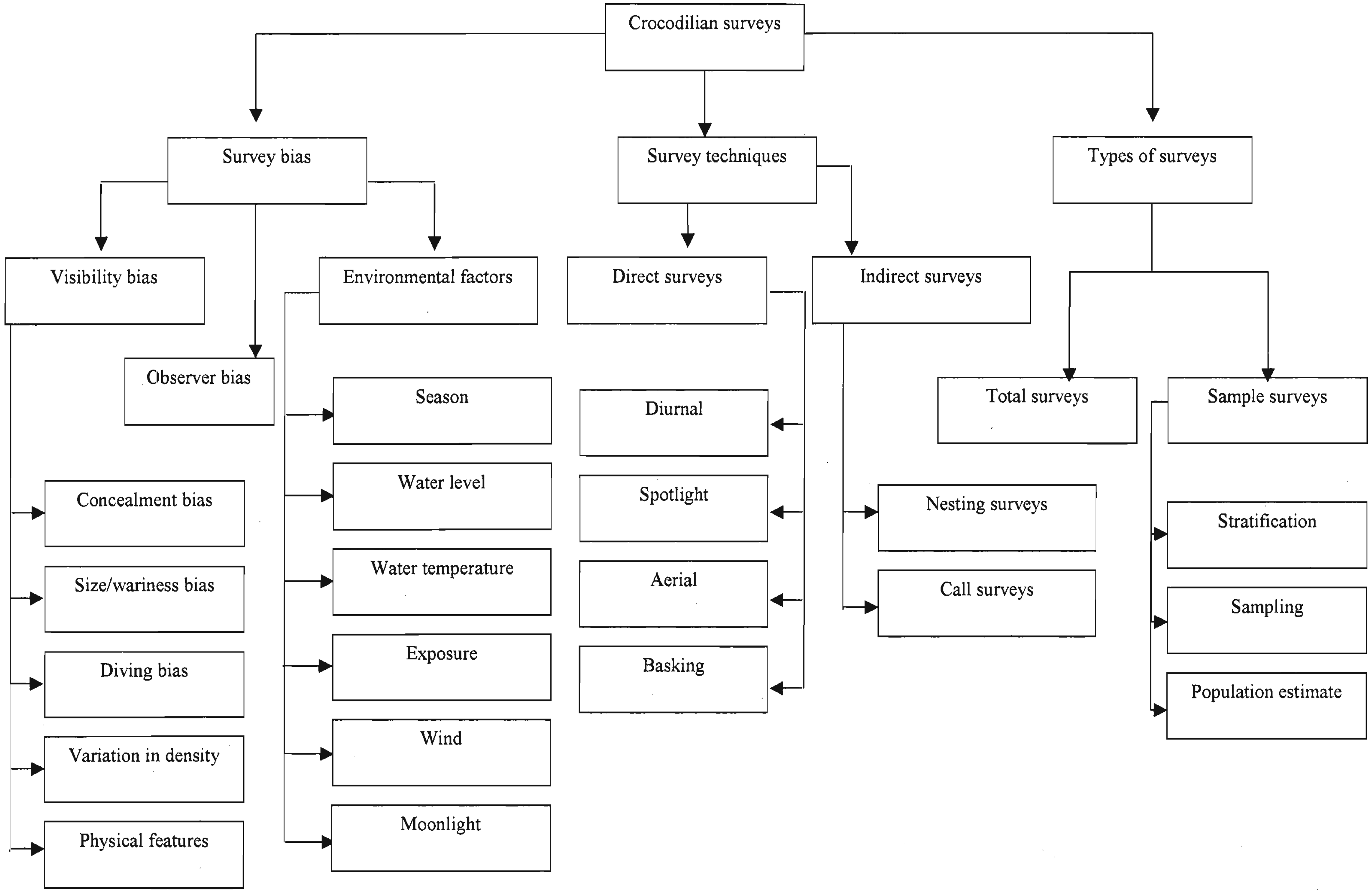

Figure 1.3 A schematic presentation of Crocodilian surveys, as discussed in Component A.

CHAPTER 2
BACKGROUND INFORMATION

2.1 STUDY ORGANISM

Crocodilians (crocodiles, caimans, alligators, and gharials) are prominent and widespread occupants of tropical aquatic habitats where they occur (Ross 1998). They are important predators (Taylor and Blake 1987) and play an imperative ecological role in aquatic environments as keystone species, influencing lower trophic levels and furthermore maintaining ecosystem structure and function by the nature of their activities. These include selective predation on natural prey species, recycling nutrients and the maintenance of wet refuge areas during times of drought (Ross 1998).

Crocodilians are so well adapted to their aquatic environment that they have had little incentive to change during the past 65 – 200 million years (Messel 1977; Marais and Pooley 1991). However, as a result of the commercial value of crocodilian hides, many species have been exploited for more than a century. That, as well as the more recent problem of habitat loss, has almost led to the extinction of a number of crocodilian species (Thorbjarnarson 1992). Since the early 1970's increased protection and strong regulations in the skin trade benefited many species and populations of once overexploited species have showed a remarkable recovery (Ross 1998). This recovery led to a re-evaluation during 1996 by the IUCN and of the 23 named species of crocodilians, four are listed are Critically Endangered, three as Endangered, three as Vulnerable, three as Data Deficient and the balance, amongst others, the Nile crocodile, as Lower Risk (Ross 1998).

Today, sustainable use programmes are imperative in crocodilian conservation programmes (Thorbjarnarson 1992) and although some species still require a protectionist approach for their survival, the majority of species will only benefit from innovative approaches where the benefits outweigh the cost to local people living with crocodiles (Ross 1998).

Of the three crocodile species found in Africa, only the Nile crocodile has established itself in the eastern half of the subcontinent (Blake and Jacobsen 1992). Due to the pressure of commercial hunting and widespread eradication programmes in the first half of the previous century (Thorbjarnarson 1992), the numbers of this species have been dramatically reduced almost everywhere throughout its former distribution (Cott and Pooley 1972). Although legal protection in the early 1970's resulted in significant recoveries of the Nile crocodile over some of its former range (Groombridge 1987), Loveridge (1980) warned that the status of Nile crocodile populations throughout southern Africa are not unconditionally secure, due to a lack of adequate permanent protection for large populations in prime habitat. The destruction of suitable nesting sites also played a major part in the decline of crocodiles from areas in which they were formerly found (Leslie 1997).

The South African Red Data Book classifies the conservation status of the Nile crocodile as Vulnerable (Jacobsen 1988; Branch 1998) and the species is listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (Mulder 1992). Today, only three secure wild populations of Nile crocodiles are to be found within the borders of the RSA: the Kruger National Park, Lake St Lucia and Ndumu Game Reserve (Taylor and Blake 1987).

Threats to the survival of the Nile crocodile in South Africa have been documented as habitat destruction through farming development, killings of crocodiles by farmers in rivers or dams on or adjacent to their property, illegal killings for medicinal purposes, construction of dams in rivers, wetland transformation, pollution of rivers (Pooley 1969) conflict with people, habitat loss, and degradation of lakes, estuaries and rivers (Blake and Jacobsen 1992), human population growth, uncontrolled water removal for agricultural and other uses (Jacobsen 1991), industrial development (Marias and Pooley 1991), the destruction of nesting sites by trampling and disturbance of livestock (Ward 1985, 1986b; Jacobsen 1991) and effects of exotic invasive vegetation, such as *Chromolaena odorata*, on breeding sites (Leslie and Spotila 2001). Blake and Jacobsen (1992) expressed concern that in South Africa the remaining crocodile populations outside protected areas are threatened and in urgent need of protection. They also believe that certain populations inside legally protected areas are declining as a result of direct and secondary human activities.

2.2 STUDY AREA

2.2.1 Introduction

Lake Sibaya, South Africa's largest natural fresh water lake (Kyle and Ward 1995) is situated on the seaward margin of the low-lying Moçambique Coastal Plain of Eastern Maputaland, in the province of KwaZulu-Natal (see Fig. 1.1, p. 7). The lake floor is bedded on tertiary marine deposits overlying Cretaceous to Palaeocene sediments (Kyle and Ward 1995) and the eastern shore lies less than a kilometre from the Indian Ocean, but is separated from the sea by a series of high forested sand dunes. The lake surface is approximately 20 m above mean sea level and the bottom of the lake extends to nearly 20 m below sea level. With no connection to the sea, the lake level fluctuates in response to the dynamic balance between inflow and outflow (Hill 1979). The main source of inflow consists of surface and subsurface drainage together with direct rainfall, and outflow is regulated by means of seepage to the sea and evaporation (Mountain 1990). The surface area of the lake is rainfall dependent and a variation of between 54 km^2 (1930's) to 77 km^2 (1975) has been recorded. The lake has a mean depth of 10.9 m (Kyle and Ward 1995).

Tinley (1976), who conducted the first ecological survey of Lake Sibaya in 1958, noted that: "the lake is roughly circular with large bays in the northern and southern ends, with a large 'channel' entering into the main lake from the west. The western lake (see Fig. 8.1) is remarkable in formation, having long, narrow inlets and hidden bays, and many long and rounded peninsulas." Hill (1979) notes that the lake can be divided into five regions (see Fig. 8.1): The largest region is the Main Basin, which represents 56 - 59% of the total area per volume, with some of the deepest water. In the southern areas two small subsidiary regions are found, the South Eastern and South Western Basins, containing approximately 9% of the lake area. The remaining two areas are the dendritic Northern and Western Arms, making up 12 and 20% of the lake area respectively. The shoreline length fluctuates with increasing or receding water levels and in 1977 it measured 127.2 km (Hill 1979) compared to 135.7 km in 2003, measured from a digital aerial photograph in ArcView GIS 3.2.

2.2.2 Historical scientific research

There is no evidence of scientists visiting Lake Sibaya prior to 1900, and Bruton (1980a) mentions that the threat of tropical diseases and general inaccessibility could have been the major reasons. During 1906 and 1907 some fish were collected, but the Tongaland expeditions from 1947 to 1949 highlighted the research potential of this area (Bruton 1980a).

Tinley (1976) conducted the first ecological survey of Lake Sibaya in 1958 and during 1965 an expedition of Rhodes University visited the lake, which led to the establishing of a research station by the Rhodes University Institute of Freshwater Studies (Bruton 1980a). This station was flooded during the mid 1970's and subsequently removed. As a result, research by this Institute at Lake Sibaya came to an end.

2.2.3 Conservation importance

Bruton (1979) described the lake as a unique independent ecosystem that may once have supported large breeding populations of hippopotami and Nile crocodiles. Eighteen fish species occur in the lake and feeder streams. The fauna reflects a marine origin and have a close affinity to tropical forms. Twenty-two frog and eight reptile species are associated with the lake (Bruton 1980a). Of the 279 bird species recorded in the area, 60 are closely associated with the lake for breeding, feeding and roosting (Bruton 1979a). Seven reptile, 27 bird, six mammal and 16 plant species that occur in the lake system are listed as Red Data (threatened) species, including the only known population of *Vanilla roscheri*, a climbing orchid (Kyle and Ward 1995).

Because of this diversity and ecological importance, Lake Sibaya was designated a Ramsar Wetland of International Importance in 1991. Although the land surrounding Lake Sibaya is tribal land, the water surface area was proclaimed a Nature Reserve in 1994, in terms of the KwaZulu Nature Conservation Act No. 29 of 1992 (Kyle and Ward 1995). In December 1999, the water surface area of Lake Sibaya was proclaimed, together with the rest of the Greater St Lucia Wetland Park, as South Africa's first World Heritage Site.

2.2.4 Local amaThonga communities

The amaThonga people have lived around Lake Sibaya for centuries, even though the area is known for being low lying, unhealthy, inclement and not well-suited for agriculture or stock farming. Their livelihood consists mainly of fishing, hunting, snaring, the utilisation of indigenous fruits and vegetables and shifting agriculture. Crops planted around the lake include sweet potatoes, maize, groundnuts, potatoes and bananas (Bruton 1980b). Extensive cultivation has occurred in most of the catchment area and drainage lines entering the lake system (Kyle and Ward 1995) and many important wetland areas have been transformed to cultivated fields (pers. obs.). Although some community members keep cattle and goats, it is principally for ceremonial purposes and not for protein (Bruton 1980b).

As a result of their affinity with fishing and their dependence on water, the amaThonga have settled predominantly near the sea, rivers and lakes. According to Bruton (1979), their fishing methods vary according to the nature of the nearby water source, and at Lake Sibaya they fish throughout the year, using hand lines, rod and line as well as 'umono' valve baskets that are used on their own, or with the aid of reed barricades and trenches to direct fishes into the trap.

Sometimes fishermen will walk into the clear water up to a depth of 1.5 m and fish for long periods during the day (pers. obs.). Fishermen seem to be aware of the favoured basking sites of crocodiles as well as their distribution in close proximity to preferred fishing areas. Although attacks by crocodiles on dogs, goats and calves (pers. obs.) do occur in the lake, there is no evidence of an attack by a crocodile on a person in recent memory.

As a consequence of their way of life, the amaThonga community adjacent to Lake Sibaya perceive crocodiles as a threat to their subsistence way of life and to their livestock. Without any incentive to protect crocodiles or perceived benefit from having them in the lake, it is not surprising that numerous records exist where either crocodiles were killed by the community or nests destroyed (Bruton 1979a; 1980a, Ward 1985; 1986, Ward 1990, Kyle and Ward 1995).

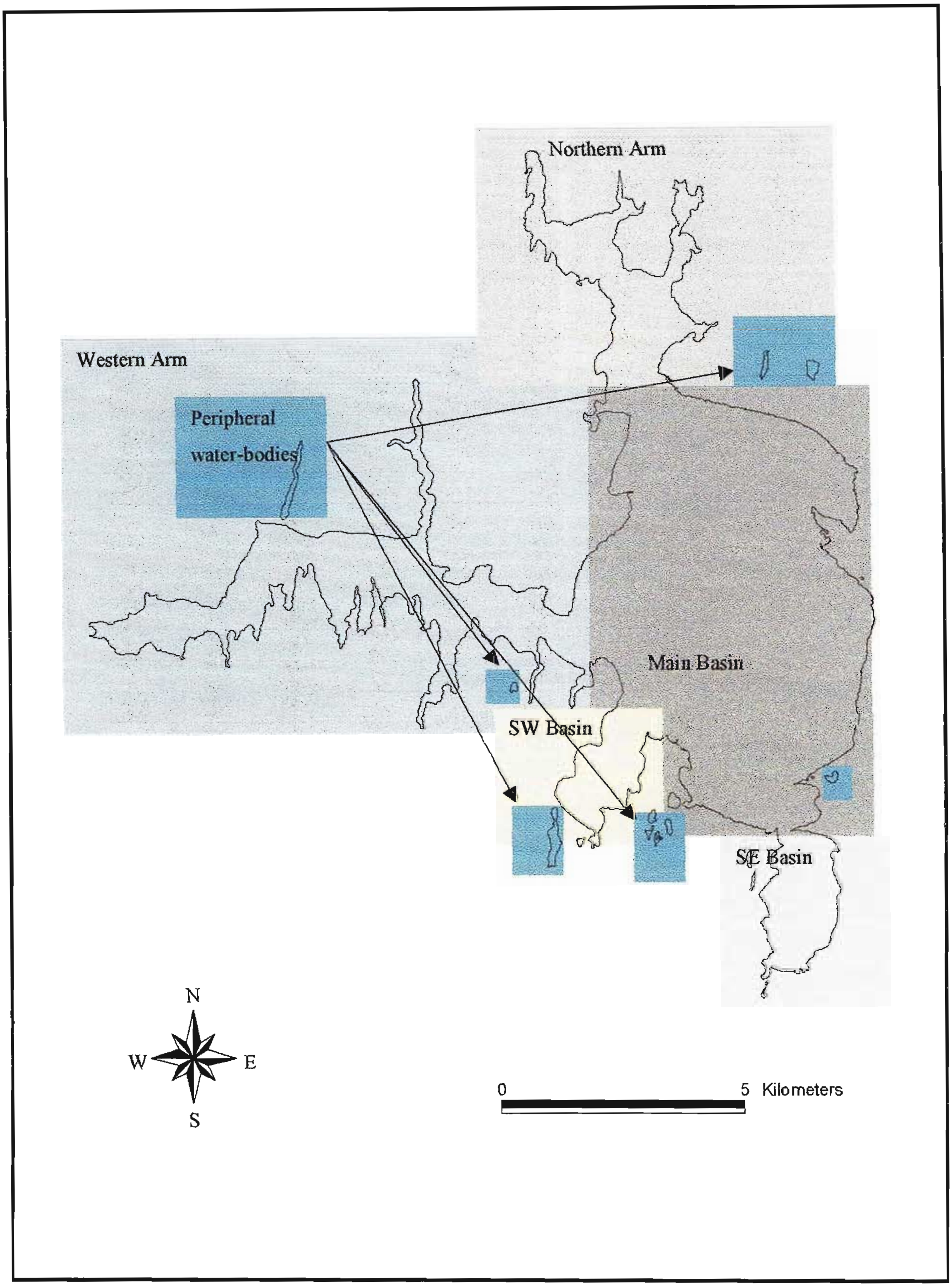

Figure 2.1 The five main regions of Lake Sibaya, as well as some of the peripheral water-bodies adjacent to the lake.

To manage growing human-crocodile interactions will always be complex and difficult, but Bruton (1979:307) states that: "there is a strong case for retaining breeding populations of the Nile crocodile in Lake Sibaya, despite the potential threat to human lives. The crocodile plays an important role as a predator of tertiary consumers, especially *Clarias gariepinus* (Sharptooth catfish), and as a scavenger". He also emphasises the fact the lake is of great conservation importance due to the reduced range of the Nile crocodile in Africa and that besides the ecological role of the Nile crocodile, its presence could play an important part in tourism to Lake Sibaya and surrounds.

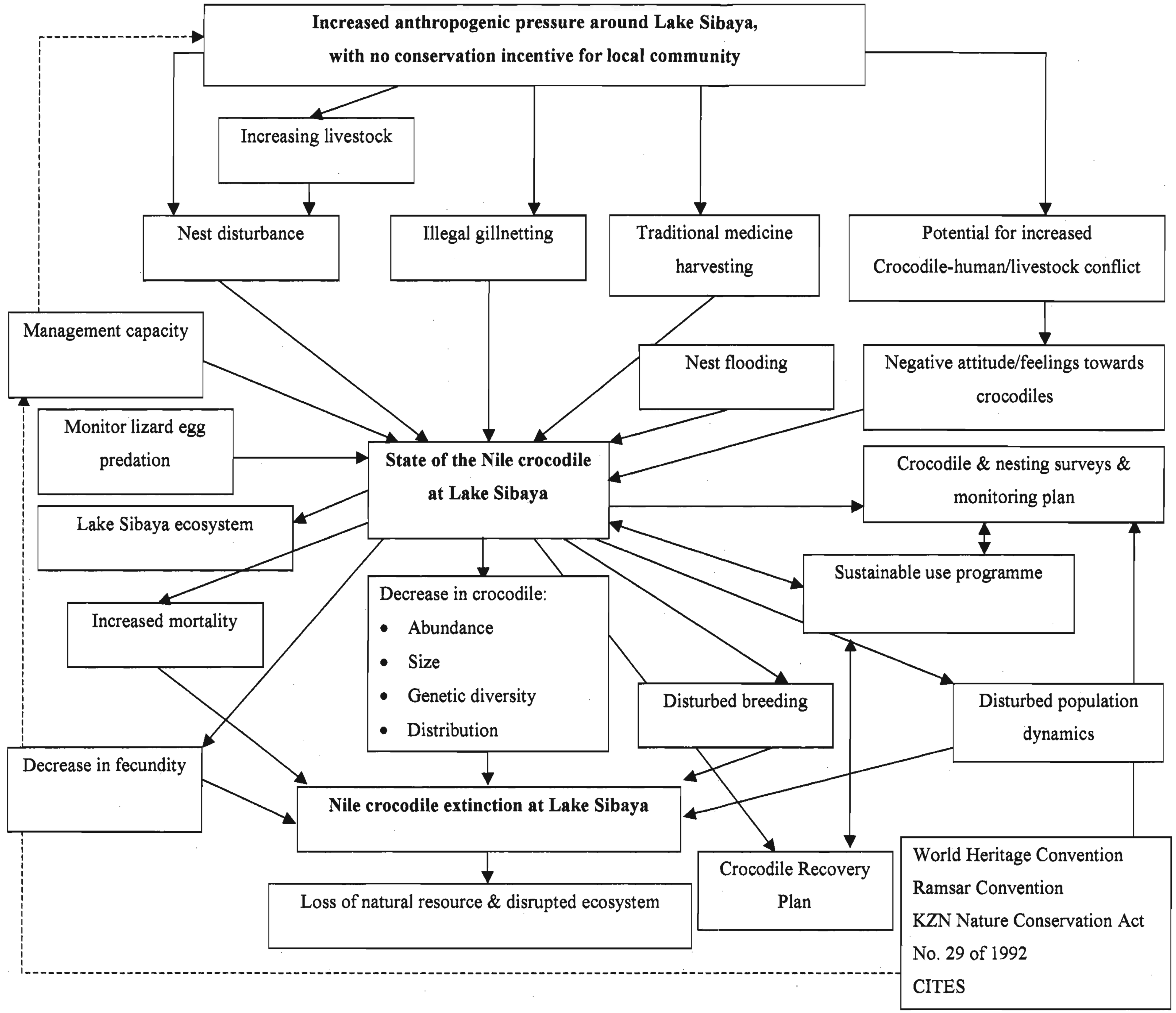

Figure 8.2 State of the Nile crocodile at Lake Sibaya.

CHAPTER 3

HISTORICAL CROCODILE SURVEYS AT LAKE SIBAYA

3.1 INTRODUCTION

While the Nile crocodile has been studied in Lake St Lucia, among others, the late AC Pooley (MSc thesis 1982) and AJ Leslie (PhD thesis 1997), no extensive research on the Nile crocodile has ever been conducted at Lake Sibaya (Bruton 1979a). Ken Tinley, an ecologist of the former Natal Parks Board (now Ezemvelo KZN Wildlife), was probably the first scientist to document Nile crocodiles at Lake Sibaya during an ecological field survey in 1958. In his report he mentioned that: "large numbers of crocodiles inhabit the lake, and the surrounding lesser lakes and pans. Some specimens are of an extremely large size, probably up to 20 feet (6 m) in length. Several of their nesting sites were observed in various parts of the area, such as the Western and Northern Lake, Etsheni Bay and the Mabibi pans" (Tinley 1976:21). From the late 1950's the population has apparently decreased and since the 1970's conservationists have expressed their concern as to the status of the crocodile population at Lake Sibaya (Pooley 1976; Bruton 1979b; Blake 1990; Mountain 1990; Thorbjarnarson 1992).

3.2 AERIAL SURVEYS

During July 1985 Dr S Kyle, the late MC Ward and P Phelan from the KwaZulu-Natal Bureau of Natural Resources surveyed Lake Sibaya for crocodiles in a Bell Jet ranger helicopter. A total of 67 animals (See Figure 9.1) were counted (Ward 1985). In July 1986 a second survey was conducted under similar environmental conditions and 75 crocodiles were counted (Ward 1986a). As both were total surveys, covering the entire shoreline, but with only one helicopter, it was not possible to calculate the precision of these surveys.

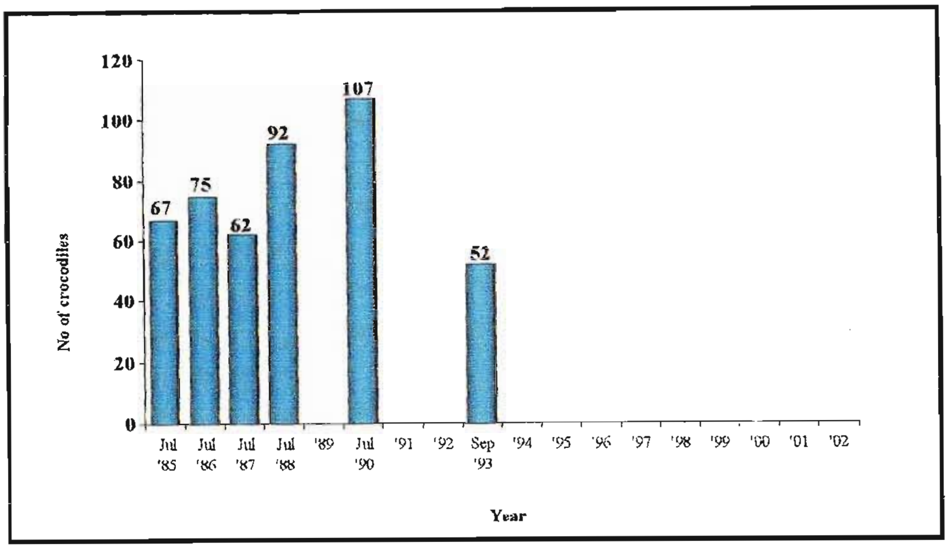

Figure 3.1 Aerial surveys (1985 – 1993) at Lake Sibaya.

During July 1987, 62 crocodiles were counted and for the 1988 and 1990 surveys the number of crocodiles observed were 92 and 107 respectively (Ward 1987, 1990). The September 1993 survey resulted in 52 crocodiles counted (Ward 1993), which suggests an unnatural decline in the population index, given the similarity in survey methodology for the 1990 survey where 107 crocodiles were counted. The difference in the month of survey (September instead of July) would probably not account for such a large variance in crocodiles encountered.

3.3 SPOTLIGHT SURVEYS

The first attempt to survey crocodiles at Lake Sibaya occurred in 1970 when Prof. Mike Bruton conducted a spotlight count from a slow boat and recorded 35 crocodiles over 1 metre in length (Bruton 1979a). He repeated the count in 1973 and observed 43 crocodiles, but he mentioned that these figures were probably underestimates. He estimated the population inhabiting the lake system at approximately 60 individuals (Bruton 1979a; 1980), which must have been a considerable underestimate, given the 30 nests he counted in 1970, which is indicative of at least 30 breeding females, given the possibility that not all nests were found during the survey.

3.4 NEST SURVEYS

Bruton (1979; 1980a) recorded 30 nesting sites in 1970 (see Fig. 9.2) including a communal nesting site of 18 nests (11 close together and 7 peripheral) in the Western Arm of the lake. Despite *Veranus niloticus* (Nile monitor) predation, he observed high nesting success for the 1970/71 breeding season. As a result of cattle disturbance, illegal harvesting, Nile monitor predation and increased lake levels, none of the communal nests hatched during the 1971/72 breeding season, with a total of 12 nests found during that survey (Bruton 1979a).

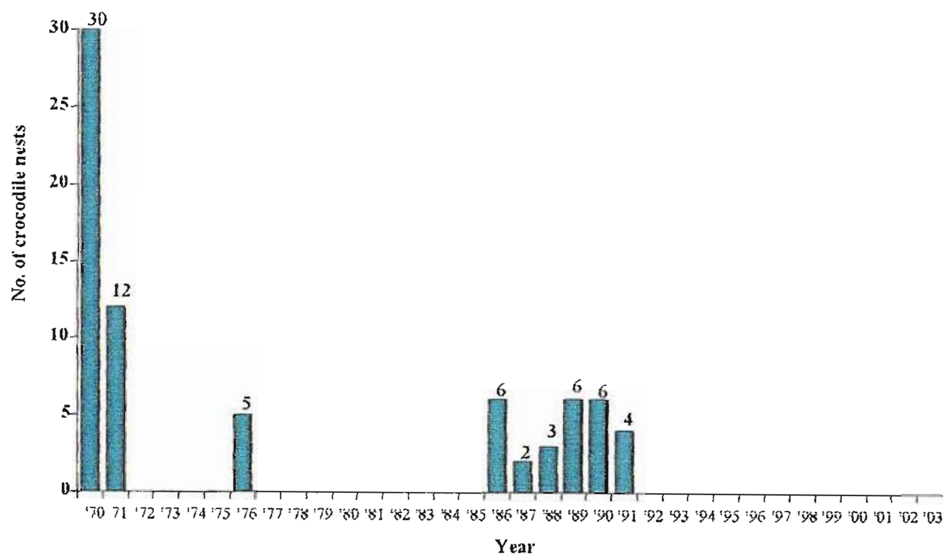

Figure 3.2 Nile crocodile nesting sites recorded 1970 – 2002.

During 1975 the lake level increased to its highest level in more than 30 years (Pitman and Hutchison 1975 cited in Bruton 1979a) and many crocodile nesting sites were subsequently flooded. Only three of the original 30 nests were used during 1975 (Bruton 1979a).

During 1985 it was decided that in addition to the aerial surveys, a crocodile nest survey would be carried out. Six nests were found for the 1985/86 breeding season, of which two were predated (Ward 1986b). Nest surveys continued between 1986 and 1990, but no surveys have been carried out since then.

Given the nesting data for the past 34 years, it seems that the breeding segment of the crocodile population at Lake Sibaya has decreased to such an extent, that without management intervention, the Lake Sibaya population faces likely extinction in the future.

CHAPTER 4
CROCODILIAN SURVEYS

4.1 OBJECTIVES

Knowledge of the size or density and structure of an animal population is usually a prerequisite to effective management (Chabreck 1966; Games, Zolho and Chande 1992; Caughley and Sinclair 1994). Leopold (1933 cited in Chabreck 1966) advocated this many years ago; he believed a population survey to be the first important step in the management of a species. Primack (2000) emphasised the importance and urgency of regular surveys and continuous monitoring efforts, especially for species of high conservation status (e.g. rare or threatened) or species of special concern (e.g. sustainable use programmes).

The contemporary reality is that very few protected areas in developing countries have sufficient funds for surveys and monitoring programmes, especially for less charismatic species, such as crocodiles. This is mainly the result of general financial constraints which force conservation agencies to use available funds for more "urgent' priorities. This situation could be exacerbated by a lack of trained staff, equipment and very little or no knowledge of the appropriate survey methods.

Prior to any survey, management should be explicit with regards to the objectives of the survey, as this will determine the appropriate methodology (Caughley 1977; Eberhardt 1978; Caughley and Sinclair 1994). Caughley (1977) identified three fundamental objectives of wildlife management:

- Conservation – the management of a small or declining population in order to increase density.
- Harvesting – the sustainable use of a population.
- Control – the management of a population that is either too dense or has an unacceptably high rate of increase. The objective would be to stabilise or reduce its density.

These management objectives should be based on quality survey information regarding the status (size and structure) of the population, and that requires some measure of abundance (total number of animals) (Bayliss 1987; Games, Zolho and Chande 1992). A management information system should include abundance, structure, distribution and movements within the population (Norton-Griffiths 1978), as well as the level of threat or pressure to the population. Although information on the absolute total numbers would always be the ideal, Caughley and Sinclair (1994) state that in reality a survey or census of wild animals would always be an estimate of the total population size or density.

Population size may be estimated either directly through a total or a sample survey, or by indirect means such as a mark-recapture experiment or a nesting survey. Caughley (1977) argued that absolute estimates are normally unnecessary luxuries and that most ecological problems could be dealt with through indices of density. A population index in itself is not a direct estimate of the population size or density, but has a proportional relationship to them, such as the number of crocodiles encountered during spotlight surveys. Indices derived from surveys are especially useful for comparative analysis between surveys and between areas (Caughley and Sinclair 1994) although in many situations indices are site specific and comparisons are not possible, or should be treated with caution.

In conclusion, the intention of a crocodilian survey would thus be either to determine abundance or to measure abundance over time (monitoring).

4.2 ABUNDANCE

Caughley (1977) explained that the term abundance refers either to the number of animals in a population (absolute abundance), the number of animals per unit area (absolute density) or comparing the absolute density to another area (relative density). He further notes that although the absolute abundance seems superior to estimates of absolute or relative density, it has limited use in wildlife management. However, it can be used, for instance to determine the proportion of a population to be removed during a harvesting programme (Caughley 1977; Graham 1987).

4.3 MONITORING

If the objective of management is to measure abundance over time, either a population index (Taylor and Neal 1984; Woodward and Moore 1993), or a measure of relative abundance will suffice (Hutton and Woolhouse 1989; Woodward and Moore 1995). The purpose of measuring abundance, or relative abundance over time (monitoring) is to have access to objective information on which to base timely management actions should a decline in the number of crocodilians in a population be detected (Stirrat, Lawson, Freeland and Morton 2001). In a monitoring programme, an absolute measure of abundance is mostly too expensive to justify the time and resources required (Caughley 1977).

The success of a crocodilian monitoring programme will depend largely on the assumption that the trend of relative abundance is linear on absolute density (Caughley 1977) and that this trend is stable over time (Bayliss 1987), so that changes in the index will be a reflection of actual changes in the population. Graham (1987) notes that for such changes to be detectable, precise estimates are needed.

Stirrat et al. (2001) argued that it is neither physically possible nor practical to detect a relatively small change, for instance 10% per annum in a monitored population, whether the change was sudden or gradual. The time required to detect a small change should be relevant to the species's biology and life history, and the relevant parameter is the generation time, defined as the mean time between the birth of the parents and the birth of their offspring. For example, an estimate of the average age of sexual maturity for the Nile crocodile is 18 years (Craig, Gibson and Hutton 1992). So the *a priori* value of maximum time to detect the required 10% change per annum in the monitored population was chosen as half the generation time, which is approximately nine years. The detection time would allow for management regimes to be adjusted well before crocodiles born at the beginning of the period reach sexual maturity.

Relative indices of abundance can be extremely powerful when comparing different crocodilian populations within a given country or region, but also to evaluate and monitor various countries and river systems in and over time. The key to temporal and spatial comparisons is ridged standardisation of survey techniques (Bayliss 1987). If bias (error) varies from one survey to the next, the trend in the number of crocodilians counted, measures something different than the trend in the size of the population (Seber 1982 cited in Moore 1991.

4.4 DETERMINING ABUNDANCE

Determining abundance requires some definition of the boundaries of the population. For most animal populations boundaries are very difficult to define, but crocodilians may be unusual in that their habitat usually clearly defines their boundary at the margin of a lake or wetland, thereby removing a major limitation of most survey programmes. But even these boundaries are porous as crocodiles move across them through immigration and emigration (Ross 2004 pers. comm.).

Hutton (1989) found at Lake Ngezi in Zimbabwe, that crocodiles less than 2.2 m have small and localised home ranges, while the largest males and non-breeding females had no specific centre of activity. Although most of the breeding females were restricted to the Ngezi River, where all breeding occurred, he found that a few females moved into the main part of the adjacent lake. One radiotagged juvenile (approximate size of 1.0 m) moved a considerable distance from the Ngezi River towards the main lake, moved back again and at a size of about 1.1 m and returned to the lake to take up a home range with other intermediate size crocodiles (Hutton 1989). He also recorded seasonal movements of the home range of a radiotagged adult male within the Ngezi River and the main lake.

In most instances, the definition of the boundary will be a function of the scale of the study, which is determined by the management objectives (Bayliss 1987). At the micro level the resolution of scale could focus on a specific site or could include an entire region or county at the macro level. Caution should be taken when comparing population surveys at different scales, as the precision of information between them might be entirely different (Polisar 2002).

Important decisions about survey boundaries and scale of resolution should be made by the field researcher at the outset of the study, taking into account factors like the size and movements of the animal, constraints such as the duration of the study and other logistical restrictions. The likely effect of these decisions need to be acknowledged and made explicit in survey design and analysis.

4.5 MEASURING ABUNDANCE

Crocodilian abundance can be measured in one of three ways (adapted from Bayliss 1987):

4.5.1 Absolute abundance

This is the total number of crocodilians in a specific area within the limits of a defined boundary. The best example of absolute abundance of a population would be the number of crocodilians on a crocodile or alligator farm. Due to the influence of visibility and observer bias on the accuracy of a survey, absolute abundance for wild crocodilian populations is seldom known.

4.5.2 Absolute density

This is the true density of crocodilians in a specific area, for instance a lake. If a lake of 10 000 ha with a shoreline of 150 km is inhabited by a known number of 350 crocodiles at a specific time, the crocodile density for the lake at that time would be 0.035 crocodiles per hectare or 2.33 crocodiles per/km of shoreline. It is thus evident that absolute density has a spatial component also expressed in the results.

4.5.3 Index of relative abundance

Crocodilian density is most often expressed in terms of an index. If the exact number of crocodilians in the population was observed during a total count, the density could have been expressed as an index of true abundance, but due to visibility and observer bias, not all crocodilians were detected and the density could only be an index of relative (true abundance unknown) abundance. For instance, if 254 crocodiles were seen during 10 spotlight surveys on random sample transects covering a total shoreline distance of 80 km's, subsequent to habitat stratification, the index of relative abundance for the lake is 3.18 crocodiles/km.

4.6 DENSITY

Most literature on crocodilian surveys refers to density, but in the strictest sense, the term is used inaccurately in this context and the concept requires further discussion. The average crocodilian density (number of crocodilians per unit area or volume) is a more convenient measure of comparison than abundance (the number of crocodilians in a given area) (Eberhardt 1978). However, crocodilian density is usually expressed as a ratio or encounter rate of the number of crocodilians per kilometre of route travelled (Parker and Watson 1970; Bayliss et al. 1986; Bayliss 1987; Leslie 1997; Games and Severre 1999; Thorbjarnarson, Platt and TunKhaing 2000; Platt and Thorbjarnarson 2000; Stirrat et al. 2001). Survey route length is often estimated from the shoreline or water's edge, but may also be river length measured down its centre. The rationale for this is a function of the life history of all crocodilian species.

Crocodilians are predators of the water's edge, inhabiting shorelines rather than open water, so that crocodilian habitat could be characterised as linear as opposed to occupying a surface area (O'Brien and Doerr 1986). Parker and Watson (1970) also found that crocodilians are partial to shoreline and shallow water, not frequenting deep offshore waters. The reason for surveying only the land-water interface (shoreline and waters edge) is based on the assumption that if the crocodilian is not out of the water and concealed by bank vegetation or submerged as the observer passes, the animal will be detected.

Polisar (2002) cautioned that strictly speaking, it is incorrect to refer to crocodiles/km as "density" or "abundance", as density could only be measured for a unit area such as ha or km^2 and abundance is an estimate of the number of crocodiles in a given area. He proposes that the best term to use for crocodiles/km is an encounter rate or an index of abundance. But he foresees problems in using encounter rates (crocodiles/km) from single transects for the purpose of extrapolation to the whole area for the use of comparing populations. For instance, care should be taken when comparing the encounter rate of 10 crocodiles/km for a small lake with a similar encounter rate for an extensive river system, as they clearly have two very different crocodile populations. He furthermore advises that encounter rates for survey routes along a very narrow river, for instance, 25 m wide and another river 1.5 km wide will not be comparable. He also cautions that the shape of the shoreline and the distance travelled influence encounter rates when comparing two routes where one has a complex interdigitated shoreline and the other a smooth planar one, keeping in mind that although the boat travelled the same distance for the two transects, the length of the shoreline is different. He concludes that as long as conditions and survey techniques are strictly standardised, the encounter rate trend of crocodiles/km over time should be a true measure of crocodile abundance and allows reasonable inferences about population trajectory and the effects of management actions (Polisar 2002).

CHAPTER 5
TYPES OF SURVEYS

5.1 TOTAL SURVEYS

Total surveys, also referred to as a systematic search (Collinson 1985), a complete census, or a total count, are types of surveys where the objective is to count every animal in the defined area. Two assumptions are important: firstly, that the animals are relatively sedentary and secondly, that the survey is executed in such a short time as to preclude any significant movement or change (e.g., mortality or recruitment) in the population (Caughley 1977).

The rate at which the total survey area could be covered is an important consideration when deciding if either a total survey or a sample survey for a given area should be used. If the area to be surveyed is extremely large, the rate at which the observers can proceed through the survey area with acceptable levels of counting accuracy while minimising the effect of observer bias is such that it becomes extremely expensive, time-consuming and impractical to attempt a total survey (Norton-Griffiths 1978; Games, Zolho and Chande 1992).

A total survey is a non-sampling strategy, which as the name implies, does no involve any kind of sampling and their application and analysis does not concern probability statistics (Lancia, Nichols and Pollock 1996). Because this method commands no arithmetic analysis apart from adding and the results are easily interpreted, it is thus not surprising that total surveys used to be very popular in wildlife management due to their attractive simplicity (Caughley and Sinclair 1994).

The main disadvantage of total surveys is the high cost (Bayliss 1987; Caughley and Sinclair 1994) and, as explained above, the time involved compared to a sample survey (Norton-Griffiths 1978). Another disadvantage is that precision, or the statistical estimate of the error, cannot be calculated for a total survey (Graham 1987) in the absence of the double/tandem count mark-resight technique, which makes comparisons between total surveys difficult.

This apparent limitation can be overcome by dividing the total area into similar strata, and then calculating the mean density for each stratum. However, in certain instances this method could prove to be impractical, if for instance the shoreline habitat is extremely diverse or if the density is very low. Total surveys have the advantage of gaining an insight into the relative distribution of the species throughout the area. One of the major problems with sample surveys is that the density of the sample is extrapolated to the total area, which could result in an inaccurate estimate, because of the naturally uneven distribution of crocodilians through the total area.

Notwithstanding their limitations, total surveys have an important place in crocodile surveys (Caughley and Sinclair 1994) and have been used, especially in smaller rivers and lakes (Hutton 1992) and where the crocodilian density is extremely non-randomly distributed.

5.2 SAMPLE SURVEYS

In many areas throughout the world, crocodilian populations may range over such large areas that under normal circumstances it would be impractical to include the entire area in the survey (Games, Zolho and Chande 1992). Instead, only a sample of the total area is selected, surveyed for crocodilians or evidence of their presence and through a process of extrapolation an estimate of the total number of crocodilians in the whole area is made from the number of observations in the sample survey (Norton-Griffiths 1978; Collinson 1985; Games, Zolho and Chande 1992). Unless the survey area is relatively small, sample surveys provide a more efficient use of resources (Graham 1987).

The problem with sampling is that most statistical models assume that animals are randomly distributed, for instance, if 25% of a lake's shoreline was surveyed, it should contain 25% of all crocodilians in the lake (Norton-Griffiths 1978). Experience has shown that animals usually reflect a clumped distribution (Caughley 1977; Norton-Griffiths 1978), which is also true for crocodilians (Graham 1987). Numerous studies have shown that crocodilian density is far from evenly distributed throughout the survey area, and that this could change between areas. Densities ranging from 1 crocodile/km to 112.5 crocodiles/km have been observed on the shores of Lake Turkana (Graham 1969 cited in Graham 1987).

5.2.1 Stratification

Prior to the selection of sample areas for the survey, the variation in natural crocodilian distribution should be accounted for through a process called stratification. Stratification divides the survey area of inconsistent crocodilian density into a number of strata within which the crocodilian density per strata is relatively uniform (Norton-Griffiths 1978; Caughley 1977, 1979; Caughley and Sinclair 1994; Graham 1987). Strata usually represent homogeneous and distinct habitat types and are biologically important in the analysis phase in determining the effect of habitat on indices and spatial distribution (Caughley 1977; Wood, Woodward, Humphrey and Hines 1985; O' Brien and Doerr 1986).

Parker and Watson (1970) divided the shoreline into four habitat categories: "Swampy", "Sandy", "Hard Compacted Shoreline" and "Cliffs or Very Deep Slopes". Each stratum, for instance Sandy or Swampy, could be seen as a distinct survey area, where independent sample transects could be taken within each of the strata and the results subsequently combined at the end (Norton-Griffiths 1978; Caughley and Sinclair 1994). The crocodilian density for transects of similar strata should have a low variance, and the overall sampling error will be reduced (Norton-Griffiths 1978).

The process of stratification increases the precision of the estimate because variance in crocodilian density is now a function of the variance of samples within similar strata as opposed to comparing sample density across dissimilar strata (Caughley 1977). This important pre-sampling process gives the most accurate estimate of mean crocodilian density for the total area. Caughley (1977) notes that stratification presupposes knowledge of the distribution of crocodilians within the area to be surveyed. If possible, the first component of the survey should be a pilot survey where an approximate estimate of density will be made. That will allow for the proportional allocation of sampling transects per stratum, based on the relative density of crocodilians for each stratum.

Games (1992) recommends that in order to calculate the coefficient of variance (CV), which is the standard error as percentage of the estimate (Graham 1987) for the purpose of monitoring, a river or lake perimeter should only be divided into subsections if it proves impossible to do a double observer count. In that case sub-divisions could be used to determine the CV, but he recommends that surveys be kept to the broader areas of river sections, because of the effect of observer and visibility bias in the narrower segments.

Caution should be taken when similar shore habitats are stratified together, as there might be other influences, for instance salinity levels that could influence crocodilian density in seemingly similar shore habitats.

5.2.2 Sampling

The percentage of the length of a stratum that is sampled is known as the sampling fraction. Sampling fraction influences the coefficient of variance (CV) directly, and in surveying for crocodilians the objective should be to increase the sampling fraction within the limits of the budget (Graham 1987). He also suggests that each stratum should be divided into as many as possible sample transects rather than only a few large ones.

The various strata in the survey area are divided into sampling transects that cover the whole area without overlapping. For instance, if a lake is to be surveyed, the sampling transects will consist of sections of shoreline at the land-water interface. If a river is to be surveyed, the sample area of the river will be divided into non-overlapping sections (Caughley and Sinclair 1994). The sample transect routes that will be surveyed should be chosen to cover as many of the different habitat types as possible so as to include all segments of the population and to have sample transects that are as nearly representative of the total population as possible (Chabreck 1966). The sample transects could now be surveyed either by plane, boat, vehicle or on foot, and all crocodiles seen counted (Caughley 1977). Tests should be conducted for each transect as some will require more replications than others in order to produce the same degree of confidence in the estimate of the mean number of crocodilians/km (Wood et al. 1985). The mean density of crocodilians taken per sample unit (crocodilians/km) is taken as an estimate of the mean density of crocodilians on sampled and unsampled units combined, thus extrapolating the density to the entire area (Graham 1987). The confidence that can be placed in the estimate number of crocodilians for the entire population is calculated from the variation in crocodilian density between the sampled units (Caughley 1977).

5.2.3 Estimating the population from a sample survey

In order to analyse a sample survey with sample areas of either equal or different sizes, Jolly's method, as outlined in Graham (1987) is regarded as generally acceptable.

$\hat{Y}$ = estimated population

y = number of crocodiles for a given sample

z = sample length in km

Z = stratum length in km

$d = y/z$, crocodile sample density

The population Y is then estimated as $\hat{Y} = Z\bar{d}$

The population variance is estimated as Var $(\hat{Y}) = [Z^2 / n]\, S^2_d$ where Z = the total length surveyed and n = the number of sample transects.

The sampling variance is as follows: $S^2_d = [(\sum d^2 - (\sum d)^2) / n] / [(n-1)]$

Where d = density (crocodiles/km) of the sample transects and n = number of sample transects.

The standard error of the population estimate $(\hat{Y})$ is the square root of the variance, and the (CV) of the population estimate $(\hat{Y})$ is the standard error divided by the population estimate $(\hat{Y})$ x 100.

CHAPTER 6
BIAS

6.1 ACCURACY AND PRECISION

Estimates of crocodilian surveys could be influenced by two kinds of bias, namely the accuracy and the precision of the survey (Graham 1987). Accuracy is a measure of how close a survey estimate lies to the number of crocodilians in the population (Sokal and Rohlf cited in Collinson 1985). An accurate estimate of a crocodile population, for instance 230 crocodiles in a lake, is one that is very close to the true total, for instance 234 crocodiles, but it may have wide confidence limits. So if the survey were to be repeated the following week, only 180 crocodiles might be counted as a result of using, for instance, a different or untrained crew of observers (observer bias) during a cold and rainy day (environmental effect on visibility bias) for the survey.

The accuracy error then is the difference between the estimate of either the sample survey or the total survey and the true number of crocodilians in the population, or an indication of the proximity of the estimate to the actual number of crocodilians in the population (Graham 1987). In most wildlife surveys the estimates are usually biased downwards as a result of animals not being seen during the survey (Bayliss 1987). This is especially true for crocodilian surveys, where an important part of their life history is centred around concealment. This specific kind of bias or error is a form of visibility bias. The accuracy of an estimate could be improved by anticipating and correcting the sources of visibility bias that are invariably present in crocodilian counts (Graham 1987).

Precision refers to the size of deviations from the mean of multiple surveys on the same population, for instance the variation of the mean density of crocodiles (encounter rate/km) over various survey transects or survey dates. The precision of the estimate is especially valuable when comparing the same survey routes either in close replication or on an annual basis. It provides information on the 'repeatability' or the similarity of repeated survey estimates, for instance, if the same survey is conducted over the same distance - how similar or dissimilar were the results.

As explained earlier, in order to calculate precision the survey area must be either divided into samples or subsections where mean densities can be recorded, or a double count mark-resight method must be employed. Failing to do that in a total count would result in an estimate without a precision value, which would be difficult to compare. Graham (1987) mentions this as being the main disadvantage of total surveys.

A common measure of precision is the 95% confidence limits of the survey estimate (Cochran 1963 cited in Collinson 1985) and can be used to determine whether two estimates are statistically different, for instance, comparing a microlight aerial survey with a spotlight survey at night for the same transect(s). "Confidence levels are measured from the standard error and measure the range of uncertainty around an estimate. Only if their confidence limits do not overlap can two estimates be taken as significantly different" (Graham 1987: 78). Precision is also known as the random variation among the number of crocodilians counted, and the statistical measure of precision is the sampling error (Graham 1987; Caughley and Sinclair 1994) normally shown as the mean estimate plus its standard error (Graham 1987).

The precision of an estimate can be improved by identifying sources of variation (Wood et al. 1985) and reducing the variation between counts (Graham 1987) by rigid standardising of the survey procedures, or by stratification. If the methodology used for each survey is consistent, the component of variability due to the sampling methods can be minimised (Stirrat et al. 2001).

6.2 TYPES OF SURVEY BIAS

6.2.1 Visibility Bias

Both direct crocodilian survey techniques (i.e. aerial and spotlight surveys), and indirect techniques (i.e. nest surveys), are plagued by visibility bias. Visibility bias is a function of either the crocodilian, or a sign of its presence, not visible to the eye of observers and thus not counted during a survey (Caughley 1977; Seber 1977; Bayliss 1987; Marsh and Sinclair 1989). There is clear evidence that not all animals are visible during the survey and that this bias could account for as much as 30 - 40% of the total animals present, but not seen (Seber 1977). Caughley (1977) presented data from a wide range of wildlife surveys, illustrating that between 12 – 61% of animals present are often not observed during aerial surveys.

Ramos, de Buffrenil and Ross (1994) conducted a quantitative aerial survey over a large part of the southeastern portion of the Zapata Swamp in Cuba and found that more than 88% of crocodiles present (ratio of aerial survey density to mark recapture density) were not detected from the air, due to the limited sightability of crocodiles.

A mark-recapture experiment in South Carolina suggested that approximately 75% of the adults present are not sighted on an average night count within typical habitats (Taylor and Neal 1984).

There is little value in estimating the total number of crocodilians in a population if visibility bias is not corrected for (Games 1992). Currently, the only method of doing that is by either a mark-recapture/resight experiment (not normally part of a standard crocodilian survey) or by augmenting aerial survey data with correction factors obtained in a spotlight survey for the same area. It must be noted that for various reasons, e.g. heavily wooded terrain, complex, shallow waterways, restricted visibility, personal safety, difficulty of navigating through swamps at night (Ramos, de Buffrenil and Ross 1994) manpower required, shallowness, tidal variation, danger of hippopotami (Leslie 1997) shallow rivers and hippopotami spotlight counts at night are sometimes impossible.

6.2.1.1 Concealment bias

Concealment bias is responsible for probably the most significant effect on visibility bias and the accuracy of the survey estimate. Vegetation on the banks of rivers, swamps or lakes may obscure crocodilians present in the survey area from the observer's view biasing the results of the survey (Messel, Vorlicek, Wells and Green 1981). Concealment bias will always have a downward effect on the total estimate of the population. Bayliss et al. (1986) found that the probability of observing a crocodile decreases with increased vegetation on the banks. Woodward, Rice and Linda (1996) believed that vegetation density might affect the visibility of alligators, especially when they are submerged.

6.2.1.2 Size and wariness bias

The size of a crocodilian influences its visibility bias (Bayliss et al. 1986) on two accounts, but in different directions. During aerial surveys, the size of the crocodilian is positively correlated with its probability of detection, so if the visibility bias is held constant an increase in size will lead to a decrease in observer bias (the error of not seeing crocodilians that are visible in the field of view). Hatchlings are very difficult to detect during aerial surveys (Bayliss et al. 1986; Bayliss 1987) and Parker and Watson (1970) found that crocodiles of less than 1.83 m were easily missed from the air.

The opposite is true during spotlight surveys. Woodward, Rice and Linda (1996) found that alligators longer larger than 2.4 m tend to make up a significantly greater proportion ($p<0.05$) of total counts during aerial surveys than during spotlight surveys. During spotlight surveys, the size of a crocodilian is negatively correlated with its probability of detection as a result of the wariness or shyness of the animal, which influences the visibility bias. This negative relationship is so strong that Webb and Messel (Bayliss 1987) and Woodward et al. (1992 cited in Woodward and Moore 1993) showed that the size of the crocodilian could be used to index its wariness. In a downstream river section Bayliss et al. (1986) found that the probability of detecting hatchlings was 69%, compare to only 15% for crocodiles larger than 3 m.

It is possible that a similar size-wariness relationship might apply to the Nile crocodile (Graham 1987). The effect of wariness on visibility bias and the relationship of the wariness with other factors causing visibility bias are most important (Bayliss 1987).

Due to the relationship between visibility bias, the size and wariness of the crocodile and its probability of detection, spotlight surveys should be adjusted for differential visibility due to size, otherwise they would be inconsistent and unreliable in monitoring programmes (Bayliss 1987).

6.2.1.3 Diving bias

As part of their life history, crocodilians spend a certain proportion of time under water (Woodward and Moore 1993, 1995) and if that coincides with the time that the observer surveys the area, the crocodilian would not be detected and subsequently not counted. It must be noted that there could be exceptions, such as in the clear waters of Lake Sibaya in South Africa, where submerged crocodiles have been observed in the shallow parts of the lake during aerial surveys (pers. obs.). Spotlight surveys conducted in Florida revealed that more than 65% of alligators were submerged during an average survey (Woodward and Linda 1993 cited in Woodward and Moore 1995).

Hutton and Woolhouse (1989) found that at Lake Ngezi in Zimbabwe under the most favourable survey conditions, when the water level was low with little vegetation and other cover, that on average only 63% the population was seen during spotlight surveys. This suggests that the proportion of crocodiles under water at any given time could be at least 37%. A similar statistic of diving bias (38%) was recorded for the estuarine crocodile in the open rivers in the Northern Territory of Australia (Bayliss et al. 1986).

Graham (1987) suggests that more research is needed to determine whether this statistic of diving bias is a population specific parameter, or if could be applied to other species and other areas as well. It is evident that diving bias can only be accurately calculated if the total number of crocodiles in the study area are known (Hutton and Woolhouse 1989; Bayliss 1986; Graham 1987) and the only method available to quantify this bias is by a mark-recapture/resight experiment.

In cetaceans' surveys, an approach widely used is to independently estimate average dive times and dive intervals from which the average amount of time and the average proportion of the total population at the surface at any given moment can be estimated. This estimate can be combined with the estimated time that any given section of the habitat is within view of the surveyors (a function of survey speed and habitat form) to generate a diving bias correction factor. This has most probably never been attempted with crocodilians (Ross 2004 pers. comm.).

6.2.1.4 Quantifying visibility bias

The extent of visibility bias in spotlight surveys can be quantified by conducting a mark-recapture experiment to determine the total population, and then using spotlight surveys to determine the proportion of the population absent in each of the habitat types during these spotlight surveys at night (Bayliss 1987). This proportion is essentially the sighting fraction for the specific habitat type in the population. The average sighting fraction is a reflection of the visibility variance of crocodiles between dissimilar habitats. Sighting fractions calculated for a specific habitat type or population with a specific age-size distribution should preferably not be extrapolated to other habitats and populations.

Although mark-recapture techniques have been widely used to estimate the population size of crocodilians (Rice and Linda 1996; Hutton and Woolhouse 1989). Bayliss (1987) found that certain assumptions, especially the assumption of homogeneity of capture probabilities are often violated. It is therefore believed that mark-resight methods (where a resighting qualifies as a recapture), tend to provide more reliable population estimates (Rice and Linda 1996; Bayliss 1987).

Estimates of crocodilian populations through surveys will always suffer from the error of visibility bias, which could vary between populations and even within the same population between successive counts. Currently, only the use of a mark-recapture or mark-resight experiment can quantify the effect of diving and concealment bias, which generally accounts for the largest proportion of visibility bias on crocodilian surveys. Due to the technical nature and the costs involved, mark-recapture experiments are not generally used on standard crocodile surveys (Graham 1987).

6.2.2 Variation in density

Harris (1986) showed that when the behaviour or habitat use of a specific species varies with the density of the species, the probability of seeing the animal becomes a function of its density. He uses the example where animals at low densities occupy preferred habitats where they are easily observed, but as the density increases surplus animals are forced to frequent sub-optimal habitats where sightability is lower. For this specific species the expected counts will be a decreasing function of density. This bias could influence counts in the opposite direction for a species that prefers thick vegetated habitat under low-density conditions. Because of the difficulty in measuring this phenomenon, its influence on crocodilians has not yet been quantified and in the absence of more research, observers will have to assume equal sightability under varying population levels (Woodward and Moore 1993).

Pacheco (1996) showed that apart from environmental variables that affect the probability of detection on spotlight surveys, variation in density could also affect the sighting proportion, resulting in a biased estimate of the population.

6.2.3 Physical features and environmental factors of the survey area

Factors that might exacerbate the effect of visibility bias could include, among other, the width of the river, the sinuosity and frequency of bends, (Bayliss 1986, 1987) uncontrolled weather, choppy water surface, (Bayliss 1986; Woodward and Marion 1978) clarity of water (Bayliss 1986; Marsh and Sinclair 1989) and glare and deep shade during aerial surveys (Bayliss 1987). Bayliss (1987) also found a negative correlation between structural complexity and the number of crocodiles seen, resulting in a very low probability of detecting crocodiles in well vegetated, highly sinuous side streams.

Caughley (1977) mentioned that the effect of visibility bias could be ignored if the bias is held constant by rigid standardisation, for instance using the same survey crew, constant height and speed of the aircraft. Bayliss et al. (1986) believe that this assumption might not be true for crocodiles in the Northern Territory of Australia, where the age-size distribution is unstable over time (Webb et al. 1984 cited in Bayliss et al. 1986) and the effect of age-size on wariness has been well demonstrated.

6.2.4 Observer bias

Observer bias is the variation between the number of crocodilians in an observer's line of view and the number of crocodilians counted by that observer during a survey. This kind of bias or error could be quantified through a double-counting technique (Hutton and Woolhouse 1989).

Evidence suggests that only a certain proportion of animals visible to an observer are actually seen during a wildlife survey and that even trained observers might only see 60 – 70% of the animals in their field of view (Seber 1977). Bayliss et al. (1986) found that in river habitats with large exposed mudbanks, aerial observers missed between 20 - 33% of sightable crocodiles in their field of view, and this increased to 33% - 75% in side creeks lined with mangroves. Their results furthermore suggested that the probability of observing a crocodile from a helicopter varied between observers and between different habitats, but that the proportion of crocodiles missed by a specific observer was constant, regardless of the total number of crocodiles seen. The skill of the observer thus affects the probability of detection, but for a well-trained observer this relationship is constant over time. Conversely, for an inexperienced observer the correlation between the number of sightable crocodiles and number of crocodiles seen will improve up to a point where the training intervention stabilises the effect of the bias.

It seems that the speed of the observer travelling through the survey area, correlates negatively with the ability to detect crocodiles. Hutton (unpublished data cited in Hutton and Woolhouse 1989) found a negative correlation between survey speed and observer bias during spotlight counts at night from a boat. Norton-Griffiths (1978) found that a low counting rate, which is the number of animals counted per unit time, results in high accuracy and *vice versa*. He also showed that counting error (undercounting of crocodiles as a result of observer bias) increases with counting rate.

However, at high density, slow survey speed can lead to overcounting as the same crocodile within the surveyor's field of view' moves underwater and is counted twice. In the extreme example, stationary counts (sometimes done, for example, sweeping a large pond with a spotlight from a station on the bank) need to be conducted with careful procedures with regard to time and scanning pattern to avoid double counts.

Observer bias could also influence the size estimation of crocodilians, which is an important component of many surveys and monitoring programmes, especially when estimates are required for sustainable yield harvesting (Woodward and Moore 1993). Variation of an observer competence in judging size estimates and variation between observers over time could influence size distribution recorded during surveys. This could be compounded by the wariness effect on size-age in crocodilians (as discussed earlier) distorting accurate size estimates for larger crocodilians during spotlight surveys (Woodward and Moore 1993). At least some of this bias can be addressed through training programmes where observers are given the opportunity to make size estimates of a range of measured crocodiles in order to calibrate their estimates for survey programmes.

As a result of the positive effect of training on observer bias, Parker and Watson (1970) spent three days prior to the actual aerial survey flying the survey area customising the pilot and observers in searching for crocodiles. Ramos, de Buffrenil and Ross (1994) conducted two aerial reconnaissance overflights prior to quantitative aerial surveys of the southeastern portion of the Zapata Swamp in Cuba, to gain familiarity with the terrain and to train observers.

It has been proved that the ability to detect crocodiles during surveys improves rapidly to a point of stability, emphasising the importance of observer training programmes (Woodward and Moore 1993).

6.2.4.1 Quantifying observer bias

In crocodilian surveys, and especially as part of a monitoring programme, it is imperative to quantify the effect of observer bias in order to have some measure of the precision of the survey. That would allow for comparisons between independent surveys, which is one of the main objectives of any monitoring programme.

Observer bias is quantified through a simultaneous double count in an effort to estimate the proportion of crocodiles that each observer missed in their common field of view (Magnusson, Caughley and Grigg. 1978). These proportions are then used to derive correction factors when different observers are used, in an attempt to standardise the effect of observer bias on surveys (Bayliss et al. 1986) but also to calculate the precision of the survey. Aerial surveys are the preferred method for the double count technique.

Two observers are necessary for this technique by which each observer records the position of every crocodile seen during the aerial survey, on his map (e.g. at a 1:50 000 scale). Sightings are then recorded as S_1 (crocodiles seen ONLY by observer 1), S_2 (seen ONLY by observer 2) and B (seen by BOTH observers). The total number of crocodiles is then calculated from:

$$N = \left[\frac{(S_1 + B + 1)(S_2 + B + 1)}{(B + 1)} \right] - 1$$

and the variance with:

$$V = \frac{(S_1)(S_2)(S + B + 1)(S_2 B + 1)}{(B + 1)^2 (B + 2)}$$

The coefficient of Variation (CV) is used to measure the precision of counts. Counts with a CV of less than 15% are necessary in order to decide whether two estimates, or a series of estimates, are truly different and may be used in a monitoring programme (Games 1992). The CV is calculated as:

$$CV = [\sqrt{V} / N] \times 100$$

6.2.5 Environmental variables biasing survey estimates

6.2.5.1 Season

An important prerequisite for standardising crocodilian surveys and increasing precision of the estimated population is to conduct annual surveys during the same time of year (Chabreck 1966). He found variations in the level of crocodile activity between seasons, which influences the probability of detection and subsequently the results of the survey. Messel, Vorlicek, Wells and Green (1981) came to similar conclusions during a crocodile-monitoring programme in the tidal rivers of the Northern Territories of Australia, where it was found that only certain times of the year were suitable for crocodile surveys.

Woodward and Moore (1993) noted that as a result of seasonal influences on movements, crocodilians might migrate in or out of a survey area, or change their behaviour, thus changing their availability and probability of detection. To limit the variation in density, crocodilian surveys should thus be conducted either within the same season or during the same season every year. In order to collect data on seasonal differences, ample surveys should be made during other seasons as well. Although this might have cost implications, it should be considered if the focus of the survey is to investigate seasonal movements. King, Hutton, Manolis, Miller, Jelden, McNamara, Rodriguez, Ross, Saalfeld, Velasco, Webb and Woodward (1994 cited in Ross 2003) found that in Nicaragua the best time to survey was during the dry season. During the rainy months crocodilian populations might be highly dispersed and inaccessible as a result of flooded rivers and lowlands, inundated with water due to rising rivers. It was also found that torrential rains obscured the spotlight beam, making visibility difficult.

Games (1994) mentions the importance of the time of year for aerial surveys. It is best to conduct the aerial survey when water bodies are low, as crocodiles should be more concentrated and bank vegetation may have a smaller influence on visibility bias.

Pooley (1969) conducted one of the most comprehensive studies on the seasonal variation of Nile crocodile movement between 1962 to 1968 when he surveyed Inyamiti Pan, at Ndumu Game Reserve, South Africa. All surveys were conducted during the day with a vehicle. His winter and summer surveys for 1962 showed that only 20.13% of crocodiles seen during the winter months of 1962 were counted during the subsequent summer season. The proportion for 1967 was 16.78%. This emphasises the importance of standardising the time of year between annual surveys at the same location.

6.2.5.2 Water level

Woodward and Marion (1978) found that water levels correlated negatively with the number of alligators seen during a night survey. The lake they surveyed experienced fluctuation in water levels, and even marginal increases resulted in the inundation of a large swamp area, which was subsequently utilised by alligators. As a result of visibility bias alligators were more difficult to detect in these wooded swamps and consequently counts decreased with rising water levels and *vice versa*.

Hutton and Woolhouse (1989) found at Lake Ngezi in Zimbabwe, that the water level in the dam accounted for 61% of the variation in crocodiles seen during spotlight surveys. Stirrat et al. (2001) came to similar conclusions in a study in the Northern Territories of Australia, where they showed that water level significantly influences the probability of detecting crocodiles.

In Florida it was decided that as a result of the overwhelming effect of water level fluctuations on crocodilian indices obtained during spotlight surveys, the same survey routes would be counted annually during periods of minimal water fluctuation. If water fluctuations cannot be avoided, the effect of variation in water level on habitat availability must be quantified (Wood et al. 1985).

6.2.5.3 Water temperature

Murphree 1977 (Woodward and Marion 1978) showed that the probability of detecting crocodilians was positively correlated with water temperature in a thermally altered reservoir in South Carolina. Woodward and Marion (1978) came to similar conclusions, and found more variation in the cooler weather periods than during periods of warm weather. This could be attributed to crocodilians that rely on their immediate environment to maintain the necessary body temperatures. Smith (1975 cited in Woodward and Marion 1978) found that daily and seasonal activity patterns closely relate to body temperature. Woodward and Marion (1978) conclude that as water temperature changes, so do the levels of activity and hence the visibility of crocodilians. King et al. (1994 cited in Ross 2003) found that temperatures below 25°C resulted in reduced crocodilian activity and sightings while Stirrat et al. (2001) mentioned that in the Northern Territories of Australia, temperature significantly influenced the detection of crocodiles. Games, Zolho and Chande (1992) found that the proportion of basking crocodiles on the bank of a river will vary with water and air temperature changes.

6.2.5.4 Wind

The velocity of the wind could influence the numbers of crocodilians seen. More counts are expected on a windless night or if the speed of the wind is less than eight miles.h^{-1}/13 km.h^{-1} (Chabreck 1966). King et al. 1994 (cited in Ross 2003) found that wind in excess of about 33 km.h^{-1} reduces crocodilian activity and sightings. Pacheco (1996) found that wind speed had the greatest effect (negative) on the probability of detecting black caimans during a night survey in the Beni Biosphere Reserve in Bolivia and as mentioned above, Hutton and Woolhouse (1989) found that prevailing wind with resulting wave action had a negative influence on the probability of detecting crocodiles at Lake Ngezi, in Zimbabwe.

Mazzotti (1989 cited in Pacheco 1996) found that despite the excellent swimming ability of crocodilians, they tend to avoid strong winds with subsequent wave action. Woodward and Marion (1978) showed that during periods of cool weather wave height correlated negatively with the number of crocodilians seen. This could be caused by crocodilians spending more time under water to avoid disturbance or could be as a result of visibility bias where choppy surface conditions reduce the probability of detecting crocodilians, or both.

6.2.5.5 Exposure

Hutton and Woolhouse (1989) in a study at Lake Ngezi in Zimbabwe showed that crocodiles avoided shorelines with a westerly or northwesterly aspect, as a result of the prevailing winds and subsequent rough water.

6.2.5.6 Moonlight

The effect of moonlight/phase is unclear in the literature and different studies are contradictory. Chabreck (1966) notes that the probability of detecting crocodilians would increase if surveys were conducted in the absence of moonlight.

Woodward and Marion (1978) found that only warm weather counts were significantly affected by moonlight ($p<0.05$). Their regression coefficient revealed a positive relationship between the probability of detecting crocodilians and nocturnal light, which indicated that spotlight survey counts would increase with moonlight. Woodward and Marion (1978) also believe that during warm weather, alligators might be stimulated by the phase of the moon, which could result in increased activity. This is contrary to Chabreck's (1966) findings and popular belief that moonlight has a negative effect on counts (Pooley 2003 pers. comm.).

In the Cedral lagoon in Bolivia, Pacheco (1996) found that the detection of non-hatchling *Melanosuchus niger* (black caiman) was not influenced by the phase of the moon. But, he found a positive relationship between hatchling counts and moon phase, and suggest that they might use the moon for orientation, as Lang (1987 cited in Pacheco 1996) found for hatchling *Alligator mississippiensis* (American alligators).

Larriera, Del Barco, Imhof and Von Finck (1993 cited in Pacheco 1996) found no relationship between *Caiman latirostris* (broad-nosed caiman) and moonlight. In the absence of any clarity the prudent course would be to record moon phase and cloud cover, so that any effects can be evaluated at later analysis.

CHAPTER 7
CROCODILIAN SURVEY TECHNIQUES

7.1 DIRECT SURVEYS

Estimating the population size of crocodilians by counting observed animals during a survey, also known as direct counting, is the most common method of assessing the number of crocodilians in an area (Denny 1979). This method is usually associated with lower variability (Gibbs, Droege and Eagle 1998 cited in Stirrat et al. 2001) compared to indirect counts such as methods that involve trapping or attractants.

7.1.1 Diurnal surveys

Although still used throughout the world (Pooley 1969; Parker and Watson 1970; Thompson and Gidden 1972; Webb, Manolis and Buckworth 1983; Montague 1983; Kyle 1990; Leslie 1997; Swanepoel 1999; Thorbjarnarson, Platt and Tun Khaing (2000), diurnal surveys at ground level (foot patrol, boat or vehicle) are probably the least used method for surveying and monitoring crocodilians (Graham 1987), mainly due to the relatively small proportion of the population detected during daylight hours if searching from a horizontal perspective (Magnusson 1982).

Parker and Graham (1964 cited in Graham 1987) found that diurnal boat surveys recorded only 23% of crocodiles seen, compared to the same route surveyed by air. Parker and Watson (1970) counted only three percent of the crocodiles during a diurnal survey by boat and on foot compared to an aerial survey for the same area. In Papua New Guinea spotlight surveys detected 12.9 times more crocodiles than diurnal surveys in the same area (Montague 1983).

Chapman (1970 cited in Magnusson 1982) estimated that only 20 – 50% of the total Nile crocodile population in an area is detected on diurnal surveys by boat, vehicle or on foot, but Magnusson (1982) cautions that this proportion will vary between habitats, seasons and species. He noted that in certain areas, Nile crocodiles are exceptionally easy to count during the mating season, as all mature adults congregate in the same area.

Pooley (1969) surveyed Nile crocodiles at Inyamiti Pan, at Ndumu Game Reserve, South Africa, during the day from 1962 to 1968 in order to ascertain the total population and seasonal changes within the size structure. Inyamiti Pan was selected for the survey as it holds water throughout the winter; the mudbanks surrounding the pan are broad, which ensures good visibility and accuracy of counts, and the road that encircles the pan enables the observer to survey the mudbanks without difficulty. Pooley (1969) found that given certain conditions, e.g. knowledge of the habitat, good visibility, accessibility and a fairly intimate knowledge of the biology of the species, diurnal crocodile surveys from the ground could play an important part in crocodile surveys and monitoring programmes.

Thorbjarnarson, Platt and Tun Khaing (2000) found that diurnal surveys from a boat were superior to spotlight surveys for understanding the distribution of adult estuarine crocodiles, *Crocodylus porosus* in the Ayeyarwady River in Asia. This could be attributed to wariness of the larger crocodiles during spotlight surveys.

7.1.2 Spotlight surveys

Spotlight surveys, also referred to in the literature as night counts, nightlight counts or nocturnal surveys are used throughout the world in crocodilian survey and monitoring programmes (Hutton and Woolhouse 1989; Games and Severre 1990; O'Brien 1990; Woodward and Moore 1993; Ramos, de Buffrenil and Ross (1994); Campos, Mourao, Couthino and Abercrombie (1995); Woodward, Rice and Linda 1996; Leslie 1997; Games and Severre 1999; Platt and Thorbjarnarson 2000; Thorbjarnarson, Platt and Tun Khaing (2000); Stirrat et al. (2001).

This technique allows observers to count crocodiles at night in the beam of a spotlight, usually from a boat moving parallel to the shore following a survey transect. Other methods of transport used during spotlight counts at night include airboats (Chabreck 1966), wooden or aluminium canoes (Montague 1983; Pacheco 1996; Platt and Thorbjarnarson 2000), skiffs (Platt and Thorbjarnarson 2000), inflatable white-water boats with steerage oars (Montague 1983), inflatables with outboard motors (Montague 1983) on foot (Parker and Watson 1970; Webb, Manolis and Buckworth 1983), helicopter (Parker and Watson 1970) or from a moving vehicle (Campos et al. 1995; Moler 1991).

Spotlight surveys from a boat are ideally suited for an open water habitat. The accuracy of the survey will decrease in densely vegetated areas where crocodilians might be difficult to detect as a result of visibility bias (Chabreck 1966). Wide rivers and lacustrine habitats could also be surveyed by this method, as crocodiles are found in shallow water and at the land-water interface (Hutton and Woolhouse 1989). Parker and Watson (1970) and O'Brien and Doerr (1986) both found that crocodilians are species of the water's edge, inhabiting shorelines rather than open, deep water, legitimising this method in estimating crocodilian abundance for rivers, estuaries or lakes.

Crocodilians have a vertical slit-like pupil that dilates laterally in darkness (Grenard 1991 cited in Leslie 1997) and a reflective layer in the eye of the crocodilian, called the tapetum lucidum, reflects any bright light that is shone at them (Leslie 1997). This is observed as a red to orange glow, which can be seen up to 150 m or more, depending on the brightness of the light, environmental conditions and the relative position of the crocodilian (Messel et al. 1981; Montague 1983; Hutton and Woolhouse 1989; Moler 1991; Ross 2003).

This technique was initiated more than 25 years ago by Messel (Messel 1977; Messel et al. 1981; Stirrat et al. 2001) and colleagues in Australia (Stirrat et al. 2001; Ross 1993) and has been through rigorous statistical analysis during a 12-year period in northern Australia (Ross 2003). King et al. 1994 cited in Ross (2003) mention that the technique has been used in crocodilian surveys in numerous countries involving different species. The validity has been proved through other studies, which used repetitive sampling and population estimation, and by techniques such as mark-recapture studies (Bayliss et al. 1986; Hutton and Woolhouse 1989).

7.1.2.1 Method

The technique involves a small team including a driver, a navigator/recorder and an observer or spotter, operating the spotlight. Any boat with an outboard motor (15 – 40hp) could be used (Ross 2003), but in shallow areas with scattered ponds an airboat would be more suitable (Chabreck 1966). It is preferable to investigate the survey route during the day for possible hazards and salient features and return in the reverse direction at night (Messel et al. 1981; Thorbjarnarson, Platt and Tun Khaing 2000; Ross 2003). Survey routes are marked on a map, if at all possible a 1:10 000 scale and reflective markers could be placed on the shore to indicate the start and finish of each route (Messel et al. 1981). The coordinates of the start and finish of each survey and the distance travelled could be recorded with a (GPS) Global Positioning System (Thorbjarnarson, Platt and Tun Khaing 2000; Platt and Thorbjarnarson 2000), which uses satellite navigation and could facilitate navigating on complex waterways (Ross 2003).

It has been found that environmental variables affect crocodilian sightings (Ross 2003; Hutton and Woolhouse 1989; Woodward and Marion 1978; Pacheco 1996; Stirrat et al. 2001), and in order to analyse the effect of environmental variables on crocodilians and hence on their presence or absence during a survey, the following variables could be recorded:

- Water temperature at the start of the survey, measured with an appropriate instrument, such as the Model Bat-12 thermocouple meter (Leslie 1997) at a depth of 10 – 20 cm below surface level (Messel et al. 1981). An instrument like the old fashioned mercury or alcohol in glass thermometer must not be underestimated. Its great utility, low cost and absolute reliability (no batteries) makes it a very valuable instrument to have in the field (Ross 2004 pers. comm.).
- Air temperatures at the start of the survey (Woodward and Marion 1978), measured with an appropriate instrument, e.g. a copper-constantan thermocouple (Leslie 1997).
- The difference between water and air temperatures recorded at the start (Hutton and Woolhouse 1989)
- Wind speed (Messel et al. 1981), measured with an appropriate measurement. In the absence of such instruments, the researcher or field worker can estimate the wind speed into a few subjective categories, like 'calm', 'slight breeze', 'windy' or 'force nine gale' etc. (Ross 2004 pers. comm.).
- Percentage cloud cover (Woodward and Marion 1978)
- Presence or absence of moonlight (Woodward and Marion 1978)
- Presence or absence and height of waves (Woodward and Marion 1978)

The survey should start at the same standardised time (Woodward and Marion 1978), for instance, 30 minutes after sunset. The boat should also cruise at a standardised distance from the shore, for instance, 50m at a constant speed of between 8 – 25 km/h, depending on the specific survey area (Woodward and Marion 1978; Hutton and Woolhouse 1989) measured with a GPS (Thorbjarnarson 2000).

Crocodilians are located with a spotlight (100 000 – 500 000 candlepower) connected to a 12-volt wet-cell battery (Platt and Thorbjarnarson, 2000), portable generator (Montague 1983) or 6-volt headlamp (Montague 1983). In some surveys, powerful spotlights of up to one million candlepower are used Ramos, de Buffrenil and Ross (1994), but Blake (2003 pers. comm.) found during spotlight surveys on Lake Kariba that using a too powerful spotlight lights up the whole area and could startle other crocodiles in the vicinity. Conversely, Woodward and Marion (1978) found in a comparative tests between spotlights of different ranges that the light with the greater range exhibited significantly ($p<0.02$) higher counts. They also concluded that a greater intensity of light increased the sampled area and that alligators which would normally not have been observed, or which would have been submerged before entering the range of the less powerful light were counted with the more powerful light. Botha (2003 pers. comm.) found that a more powerful spotlight resulted in higher counts on the Flag Boshielo dam in South Africa, but it has been suggested that very bright lights do not reflect well from hatchlings (Blake 2003 pers. comm.; Ross 1994 pers. comm.). The most important aspect of light intensity is to standardise the intensity of the spotlight between counts and over annual surveys (Wood et al. 1985).

As the boat moves through the survey area, the observer/spotter makes rhythmic sweeps with the spotlight over the water surface in a 180° arc (Leslie 1997) and a pair of reflecting eyes will be counted as one crocodile. The boat then approaches the crocodile, and although some surveyors make use of a small tape recorder to dictate the various parametres that will be recorded (Montague 1983) it is possible to do all recordings accurately in the field (Ross 2004 pers. com.). An important parameter to record is the estimated distance of approachability to the relative position of the crocodilian (Messel 1977). That is the distance between the boat and the crocodilian at the moment the crocodilian submerges. The approachability proportion is the proportion of crocodilians successfully approached within an adequate distance to make a size estimate (Woodward and Marion 1978). Chabreck (1966) found that in order to judge the total length of an alligator, experienced observers had to come within 30 feet (10 m) of the alligator; binoculars could help in making the estimate, especially if the alligators were very wary.

Hutton and Woolhouse (1989) found that it was easier to approach crocodiles of all sizes if the engine was running. Ross (2004 pers. comm.) mentioned that they experimented with this concept and came to the conclusion that the reason for alligators to be alarmed and dive is abrupt changes in sound levels or visual clues, so keeping things constant (engine level, boat and people profile against the skylight) helps to reduce the distance of approachability.

Some crocodilians would not allow the boat to approach close enough for a fair estimate of their size. These animals should be recorded as "Eyes Only" (Messel et al. 1981; Montague 1983; Thorbjarnarson, Platt and Tun Khaing 2000; Platt and Thorbjarnarson 2000) and this proportion could give an overall indication of the wariness of a crocodile population (Messel et al. 1981; Bayliss et al. 1986), which could be related to previous disturbance by hunters or surveyors (Ross 2003). All crocodiles, apart from the "Eyes Only" category, should then be allocated into a size-class, based on total length (Messel et al. 1981; Thorbjarnarson, Platt and Tun Khaing 2000; Platt and Thorbjarnarson 2000). Size estimates should be made by the same observer on all surveys (Platt and Thorbjarnarson 2000) in order to keep observer bias constant, and the same applies to the person with the spotlight.

The recorder should mark the position of each crocodile sighted on a map (Messel et al. 1981), preferably a 1:10 000 map or aerial photo. The distance from the crocodile to the bank could be estimated and the stratum or shore characteristics recorded (Ross 2003). The habitat location of the initial observation could be classed according to a system described in Messel et al. 1981 and modified slightly by Montague (1983):

- Midstream – crocodiles encountered well out from shore in deeper water so that their limbs are not in contact with the substrate. Most "eyes only" classifications are found in this position (Messel et al. 1981)
- Shallow water at edge – crocodiles encountered at the edge of sandbanks close to the shore. Usually the water is shallow so that parts of the crocodile are in contact with the substrate. This is usually the most common position in which crocodiles are encountered (Messel et al. 1981).

- On bank – crocodiles encountered out of the water, but between the land-water interface and the line of vegetation
- In vegetation on shore
- In emergent vegetation in the water

Any behavioural characteristics displayed by the crocodilian (Messel et al. 1981) will be noted. The boat then cruises to the exact spot where the crocodile was seen and a GPS recording taken. All observations should be recorded directly onto waterproof field data sheets and then duplicated onto notebooks after the survey or the following day. Sophisticated computer technology, e.g. laptop computers and portable printers, save time as all recordings can be entered directly into an analysable format in the field so that rapid data analysis is possible (King et al. 1994 cited in Ross 2003).
Ross (2003) mentions that spotlight surveys are designed to cover long distances rapidly. An average spotlight survey might cover up to 30 km of open water, although this will depend on the type of obstruction and level of difficulty. He also notes the importance of defining the exact route and distance of the survey so that in an effort to monitor the population subsequent surveys could be carried out using the same route.

7.1.2.2 Advantages

The accuracy of spotlight surveys varies in space and time, and despite the influence of visibility bias, Hutton (1992) suggests that of all the available methods, spotlight surveys have the least bias. Spotlight surveys could also produce a more accurate assessment of the size-age structure of the population (Bayliss et al. 1986).

Ross (2004 pers. comm.) mentions other important practical advantages such as low cost compared to, e.g. a mark recapture programme or even aerial surveys, relative simple technical capacity (boat, spotlight and a notebook), the possibility of training field staff with relative ease in conducting surveys and analysing the results. These advantages are especially true for field staff in areas with limited logistics and capacity.

7.1.2.3 Limitations

Spotlight surveys can provide indices of abundance, but they are inherently inaccurate as a result of visibility bias (Bayliss et al. 1986) and if uncorrected the estimate for total abundance is usually overestimated (Hutton and Woolhouse 1989). They could also be time-consuming, restricted to habitats that are accessible only by boat and often dangerous. This is especially so in areas where crocodiles and hippopotami are found together, as in most rivers and lakes in East and Southern Africa. Extreme caution should be taken, as hippopotami are known to be dangerous, especially when approached closely at night during a crocodile survey (Jacobsen 1991; Leslie 1997; pers. obs.).

Another weakness of spotlight surveys is the bias with regards to size and wariness (Webb and Smith 1987; Jacobsen 1984) resulting in a proportion of the larger crocodilians not being accurately sized.

Woodward and Marion (1978) found that alligator hatchlings were highly mobile, which led to considerable fluctuations (could potentially increase error) in counts; consequently they excluded alligators less than 0.6 m from the analysis. In producing indices of crocodile abundance in the Northern Territory of Australia, Stirrat et al. (2001) omitted crocodiles less than 0.6 m from their analysis due to their variation as a result of breeding success the previous year. So in order to increase the accuracy of the survey, it is suggested that smaller crocodilians (i.e. hatchlings) are still counted, but ignored in the analysis, if they do not add to the information.

7.1.3 Aerial surveys

Aerial surveys are an important technique of wildlife management (Caughley 1977) and are frequently used for counting animals; the main advantage being that a larger area could be covered within a shorter time and that animals can be located and counted in areas where it would be difficult to gain access from the ground (Norton-Griffiths 1978). It is generally accepted as the most cost-effective method for surveying crocodilians, if the survey requires extensive areas of crocodile habitat to be searched. (Games 1994). However, Games (1994) cautions that in the absence of careful planning, the data obtained may be meaningless. Aerial surveys are especially useful for improving the precision of the index of relative abundance by replication, at a reasonable cost.

Hutton (1992) advises that although aerial surveys may be quick, cost-effective and simple, they are inherently subjected to large biases, such as observer competency (observer bias), density of vegetation (visibility bias), water visibility (concealment bias) and time of year (Games et al. 1992). In some areas or situations, they can be extremely expensive and can only be justified when the efficiency over large areas or difficult access is overwhelming (Ross 2004 pers. comm.).

The rationale for crocodilian aerial surveys seems to be based on three assumptions: Firstly, that crocodilians emerge to bask in the warm rays of the sun during the day (Games et al. 1992); secondly, that they are much easier to observe from the air than at water level; and thirdly, that the larger animals are less wary of aircraft compared to boats and thus are less apt to dive (Graham 1987; Stirrat et al. 2001).

Although it has been shown that smaller size crocodilians are difficult to detect from the air (Parker and Watson 1970; Bayliss et al. 1986; Bayliss 1987), a failure to do so should not necessarily be a major disadvantage if the objective of the survey is monitoring the rate of increase in a crocodile population. Recruitment to the population could be assessed by analysing long-term trends in the larger crocodile size-classes and surveys for nesting effort (Bayliss 1987).

Aerial surveys of crocodilian populations have been used in a number of studies in Australia, the United States (Bayliss 1987; Bayliss et al. 1986; Stirrat et al. 2001; O' Brien 1990), Cuba Ramos, de Buffrenil and Ross (1994) as well as in Africa as early as 1968 (Parker and Watson 1970; Pooley 1982; Jacobsen 1984, 1991; Ward 1985, 1986a; Pullen 1988; Games and Severre 1990; Games 1992; Games, Zolho and Chande 1992; Games 1994; Games and Severre 1999; Leslie 1997).

7.1.3.1 Method

This technique normally involves a pilot, a scribe/recorder and one or more observers flying a standardised route or transect at a standardised height and speed. The aircraft should keep a standardised distance inside the shoreline in order to optimise visibility of the land-water interface as well as the section of water from underneath the aircraft extending to the shoreline and beyond to cover a reasonable section of the adjacent terrestrial component as well. Care must be taken to minimise the effect of the sun's reflection on the surface of the water. Finding a suitable height for the purpose of standardisation is very important, as flying at very low altitudes reduces the area visibility, while flying at too high altitudes causes juveniles to be missed, particularly when they are in vegetation or among rocks (Jacobsen 1991). Height and speed should be monitored at constant intervals to assure consistency (O'Brien 1990) and topwing aircraft configuration or helicopter is preferred for optimal downward visibility.

In order to optimise flying and observer conditions, aerial surveys usually take place early in the morning (07:00 – 11:00) on days with maximum sun exposure and minimum or no wind or cloud cover (Games 1994; Leslie 1997). Crocodilians are known to utilise the warm early morning sun on suitable basking sites, which results in them being exposed and therefore more visible for enumeration. Normally observers are seated on both sides of the plane (Jacobsen 1991), but this depends on the specification of the aircraft used. If the aircraft flies down the middle of a river, care must be taken not to miss centrally placed sandbanks under the aircraft, or the river might become so wide that spotting one or both banks might become difficult (Games 1994). GPS recordings and time of day (O'Brien 1990) should be recorded for the start and finished of each survey (Games and Severre 1999) and in monitoring programmes this should be standardised (Games 1994) for the purpose of trend analysis. Crocodiles observed are counted, their sizes estimated and their position recorded both on a topographical map (1:50 000) and with a GPS. Usually size estimates are made by comparing the crocodile to surrounding objects like rocks, shrubs and trees (Jacobsen 1991) although it takes a very skilled observer with adequate experience to make accurate size estimates. If the specifications of the aircraft prohibit a scribe/recorder, the data could be captured on tape recorders and transcribed later, as this would allow the observer to monitor the survey area continuously without having to look away to record. In this case the observer should make use of only GPS data to record the position of the crocodilian.

If the survey continues over consecutive days, the same observers should be used in order to keep observer bias constant (Leslie 1997). A wide range of aircrafts could be employed in crocodilian aerial surveys (Games 1994) and they could be divided into three groups, fixed-wing aircraft, helicopters and microlight aircraft.

7.1.3.2 Fixed-wing aircraft

In the RSA, fixed-wing aircraft have been used in numerous Nile crocodile surveys and is still used by Ezemvelo KwaZulu Natal Wildlife for their annual crocodile survey of Lake St Lucia. Lake St Lucia is host to the largest single crocodile population in a waterbody in the country.

Graham (1987) notes that for aerial surveys, a single engine high-wing machine capable of steep, tight turns at speeds of 95- 130km/h is necessary and Cessna models ranging from C150 – 210 have all been effectively used in crocodilian surveys. He furthermore believes that the 180 series models are suitable for most situations. Fixed-wing aircraft's main disadvantage in crocodilian surveys is the relatively high speed and height that needs to be maintained for safety, and the lack of manoeuvrability.

Games and Severre (1990) believe that this lack of manoeuvrability possibly leads to an underestimation of crocodile numbers, which they attempted to correct by estimating the percentage covered of the total available habitat. Although this is a subjective estimate, it at least allows for some correction between intensely sinuous channels that were very difficult to follow, and those which were broad and easy to follow.

Pooley (1982) found that surveying rivers with a fixed-wing aircraft proved to be impractical as it was unable to follow the many sharp bends in the river. Games and Severre (1999) mention that during their 1996 survey, the fixed–wing aircraft was filled to capacity (400 litres of fuel), which resulted in the aircraft being more "sedate" which in turn affected counts negatively. The lack of manoeuvrability increases the percentage of the survey route not covered in the survey, which is exacerbated for rivers or lakes with irregular shorelines that require sharp turns Graham (1987). Parker and Watson (1970) also found that a major disadvantage of fixed-wing aircraft is their inherent high speed, which reduces the time available for observation and may result in a significant number of animals being missed during the survey, even by experienced observers.

By comparing Cessna 185 and helicopter counts on the Nile for a 40 km stretch between Lake Albert and the Murchison Falls, Parker and Watson (1970) encountered 15.2 crocodiles/km with the Cessna 185 compared to 14.7 crocodiles/km with a helicopter, indicating that under certain conditions a fixed-wing aircraft could produce comparable results to a helicopter.

7.1.3.3 Helicopters

Despite their relative high cost, helicopters are still used throughout the world to survey crocodilian populations (Parker and Watson 1970; Pooley 1982; Ward 1985, 1986a; Bayliss et al. 1986; Bayliss 1987; Jacobsen 1991; Woodward, Rice and Linda 1996; Stirrat et al. 2001, Ramos, De Buffrenil and Ross 1994).

Pooley (1982) found the Bell 47 G4A helicopter ideal for surveying the Usutu and Pongola rivers in the Ndumu Game Reserve during the early seventies, an area with one of the largest crocodile populations in South Africa. He noted that the visibility was superior to that of a fixed-wing aircraft and believed that a higher accuracy for the survey was possible by hovering or flying at a very slow forward speed above the river and over concentrations of crocodiles. Pooley (1982) furthermore believes that a helicopter is preferable to a fixed-wing aircraft as it reduces problems when observing animals less than one metre in length; observing animals in discoloured water and observing animals in aquatic vegetation

The disproportionately high cost of helicopters (between 3 - 5 times) compared to fixed-wing aircraft is the main reason why they are seldom used in crocodile surveys in Africa (Graham 1987). Theoretically, they may be the best possible aircraft for surveying crocodilians, due to their ability to operate safely at low speeds, to hover above individuals or groups to estimate total length or to take photographs if accurate size estimates is an important objective of the survey (Graham 1987).

In the Northern Territory of Australia, Bayliss (1987) found that in remote areas the cost of a helicopter survey is approximately 7$/km of habitat surveyed, which includes the hire of the helicopter and pilot, travel expenses (three people), travel time and wages. Conversely, the cost of a night count survey in remote areas is approximately 28$/km of habitat surveyed. Spotlight surveys require high investments in capital equipment and maintenance costs, relatively higher wage costs (more people and time) administrative costs such as insurance, and other hidden costs. A further advantage of helicopter surveys is their ability to improve precision of a population index rapidly by replication, at a reasonable cost (Bayliss 1987). This advantage might also hold true for microlight aircraft.

In Africa, helicopters will have limited use for crocodile surveys in the foreseeable future because of their high flying and maintenance cost, especially in the light of new cheaper alternatives, such as microlight aircraft.

7.1.3.4 Microlight aircraft

The use of microlight aircraft is a relatively novel idea in crocodilian surveys but Graham (1987) believed that they would almost certainly play an important role in future survey programmes as a result of their low capital and operating costs. During recent years, microlight aircraft have been used, albeit on limited scale, to fly on conservation missions in the RSA, Namibia, Moçambique, Botswana (Ross 2003b) and Brazil (Ross 2004 pers. comm.). Advantages are slow flying speeds at low altitudes within acceptable safety parameters. Their reasonably low flying and maintenance cost makes them especially attractive in areas where aerial surveys have been discontinued as a result of escalating costs. Their manoeuvrability allows for tight turns (pers. obs.) and in the case of a discrepancy over the size or number of crocodiles between the pilot and observer, the aircraft could turn 360° with relative ease for a repeated observation.

Fulton (2003 pers. comm.) believes that a microlight is preferable to a fixed-winged aircraft due the lower flying speed, manoeuvrability and the sound it produces. The sound-effect helps to dissipate crocodiles so that the observers can take notice of the movement. The advantage of this "disturbance effect" has also been documented by Parker and Watson (1970), although not in a microlight, in a Cessna 185. They found that alarmed and moving crocodiles are more easily seen than crocodiles lying still in riverside vegetation. Microlight aircraft have very limited sight restrictions to the observer, but maps should be fastened to a clipboard and photographic or other equipment securely anchored to the aircraft (pers. obs). Microlight aircraft could take off or land on a straight dirt road, which render them extremely useful for field conditions in remote areas.

7.1.4 Basking survey

The reason for a basking survey is based on the assumption that the characteristics and movements of the relevant species should ensure its suitability for a survey based on territoriality (Thompson and Gidden 1972). Mcllhenny 1935 and Chabreck 1985 (cited in Thompson and Gidden 1972) showed that *A. mississippiensis's*, territorial behaviour would qualify the species for such a survey, based on the supposition that alligators frequent specific favourite basking sites during the first warm front in the spring.

7.1.4.1 Method

Alligator populations were estimated by using the Peterson mark-recapture estimate (cited in Thompson and Gidden 1972) by surveying the area and marking basking alligators according to territory. The survey was conducted during the first sustained warm front in spring to ensure maximum opportunity for observing alligators. During the survey, each alligator seen on its territorial basking site was sequentially numbered and "marked" by recording the position of the site, an estimate of the total size or total length (TL) and any other unique characteristics. In the second survey, alligators that were seen (marked) during the first one were recorded ("recaptured"/resight) together with the unmarked alligators seen for the first time during the second survey. Multiple mark-recapture/resight analysis are possible as long as the unmarked alligators seen in the second and subsequent surveys are marked along with the previously marked alligators, in the same way as during the first survey.

7.1.4.2 Control

As a measure of control, Thompson and Gidden (1972) painted some alligators using a CO_2 pistol in order to document the stability of the basking territorial counts. They found that estimates of total population size for painted alligators were comparable to estimates based on basking territorial counts. Movements of painted alligators were cautiously observed and it was found to be not great enough to significantly influence the technique. They found that larger alligators sometimes move more than 3 m from their basking site, but because their size was an important component of their "mark", the possibility of confusion with another alligator was minimal.

Thompson and Gidden (1972) showed that marked alligators have a high visual recovery rate when the population is highly territorial. They believe that when 30 or more individuals are counted in the area, the level of precision will be within 20% of the sample mean (95% confidence level). It is also possible to determine the standard error through the simple Peterson ratio.

7.1.4.3 Limitations

There are several problems with the use of this technique to estimate population abundance, the first being an inability to detect all the alligators in the survey area, which is a function of both visibility and observer bias. Visibility bias is a constant, but observer bias increases as observer knowledge of alligator habits or the survey area decreases. Ross (2004 pers. comm.) cautions against the expectation of finding (what appears to be) the same crocodile during a survey in a given area on repetitive surveys, to the degree that it becomes a bias. Less serious, is ensuring that at least 30 alligators (for statistical analysis) are observed during the survey.

7.1.4.4 Application with regards to the Nile crocodile

As part of a wider movement and home range study at Lake Ngezi in Zimbabwe, Hutton and Woolhouse (1989) followed the diurnal movement of 12 Nile crocodiles ranging from 1.6 – 3.3 m, by fitting them with radio tags and recording their movements over a period of between 3 to 23 sample days for the respective individual crocodiles. He found that on average, the crocodiles moved 20 m or more only on 3.4 days during the experiment. The diurnal movements for crocodiles less than 2.5 m were infrequent, they were more common with the larger crocodiles, but most moved on less than 40% of the days.

Leslie (1997) found capturing and tagging, recapturing and resighting of adult crocodiles a useful method to study short-term distribution patterns for specific individual crocodiles in the southern parts of Lake St Lucia, in the RSA. She recaptured 11 crocodiles at the site of initial capture. Although it is a very small proportion (approximately 6.9 – 8.5 %) of the adult population of the lake system, it does indicate to some extent that behaviour is related to territoriality.

More research on the possible application of a basking survey for Nile crocodiles is suggested and this should take into account aspects like seasonal (e.g. mating) and specific movements that can influence such a survey.

7.2 INDIRECT SURVEYS

Indirect crocodilian surveys, or surveys based on the evidence of crocodilians in an area, have been in use since crocodilians became subject to survey and monitoring programmes. Prior to 1971, no empirical data was available to support the apparent downward trend (Woodward and Marion 1978) of *A. mississippiensis* and all knowledge was based on indirect indicators of population status such as rate of habitat loss, nuisance alligator complaints and hide sale volumes (Hines 1979 cited in Wood et al. 1985). Probably the most used indirect survey technique is nesting surveys, but other techniques have also been developed to augment estimates of population abundance. For instance, in Florida *A. mississippiensis* have been surveyed by observing the bellowing of territorial males during courtship (Chabreck 1966).

7.2.1 Nest surveys

7.2.1.1 Types of nests

At the start of any discussion regarding crocodilian nest surveys, Ross (2004 pers. comm.) emphasises the importance of the different types of nests and how this will influence survey methods and subsequent results. Crocodilians construct two kinds of nests, vegetation mounds (alligators, caimans, most crocodiles including *C. porosus*, *Crocodylus novaguineae* and *Tomistoma schlegelii*) and holes in the ground (*C. niloticus*, *Crocodylus acutus*, *Crocodylus intermedius*, *Crocodylus johnsoni*, *Crocodylus palustris* and *Gavialis gangeticus*).

The kind of nest influence the surveyor's ability for detection during the survey, for instance, even a trained and experienced observer might miss an inconspicuous Nile crocodile nest or the clue (e.g. path from the water leading to the nest) indicating a proximate active nest (pers. obs.). Conversely, hole nesters (e.g. *C. niloticus*) are often social/colonial with many nests aggregated together at one site, making it easier to observe, while mound nesters are invariably solitary with widely spaced nests that present unique difficulties during a survey.

7.2.1.2 Rationale

The key to understanding many of the biological aspects of crocodilians lies in the study of their reproduction (Webb 1977) and in order to better appreciate population dynamics, it makes sense to monitor the density and distribution of crocodilian nesting sites over time. Furthermore, the difficulty of direct enumeration techniques in certain inaccessible habitats, e.g. reed swamps, has led to the use of other methods of assessing the population status (Graham 1987). The state of Louisiana in the United States uses population estimates extrapolated from nest counts to estimate alligator harvest quotas (Taylor and Niel 1984). In marshy areas, a nest survey is the best known method of determining the breeding population of alligators. The number of nests counted is indicative of the minimum number of nesting females in the marsh, but it must be noted that nesting surveys focus on only one segment of the population (Chabreck 1966).

Patterson and Graham (1976 cited in Graham 1987) developed a monitoring method for the crocodile population in the Okavango River in Botswana, based on an estimate of the number of nests made each year from aerial surveys. Graham (1987) notes that a nesting survey is based on the assumption that the majority of active nesting sites in the survey area will be visible because they are exposed to the sun. He believes that the variance between the number of nests observed and the actual number of nests in the population is almost entirely a function of observer bias from overlooked and misinterpreted sites, with only a small component caused by visibility bias (hidden nests as a result of vegetation).

The effect of visibility bias as a result of densely vegetated habitat could result in some nests not being counted, which would bias the results if nests were used to estimate the size of the crocodilian population. This has been the situation in Florida, U.S., where Rice and Linda (1996) found that in the wooded habitats nests surveys were not suitable for estimating crocodilian populations. Dense riparian vegetation made nesting surveys difficult in the Ayeyarwady Delta in Asia, and although only four nests were found, the presence of hatchlings at several localities in the Meinmahla Kyun Wildlife Sanctuary suggest more nesting sites that were not found as a result of visibility bias (Thorbjarnarson, Platt and Tun Khaing 2000).

The prevalence of "hidden" nesting sites in an area could be a reflection of direct or indirect anthropogenic disturbances. In such areas, females could become very wary/secretive with regards to nesting behaviour and crocodile paths leading from the water to nesting sites might easily be missed so that the nests would not be located, especially in the absence of an aerial survey (pers. obs.). It thus seems as if there is a positive relationship between increased disturbance in the nesting area and the effect of visibility bias, which is a combination of vegetation (concealment bias) and the wariness of the crocodilian. The design of the survey should take this into account.

7.2.1.3. Survey design

Two factors influence the design of a nesting site survey; firstly, the objective of the survey and secondly, whether it will be a sample survey or a survey of the entire potential nesting area of the population. In the case of, for instance, an exploited population where accurate numbers of nests are required, the focus will probably be on the accuracy of the estimate, even if some of the precision is sacrificed in the process, and the observers will endeavour to find each and every nesting site in the population's geographical boundary, or at least in all potential nesting areas (Ward 1990).

If the objective is monitoring with high levels of precision, the focus will be on searching the survey area uniformly in a standardised way with the same intensity (Leslie 1997), thus keeping the effort constant over time. The assumption is that even if some nests are not found, it would not have an significant influence on the nest index, as the search effort was kept constant between years (Graham 1987). Manolis (1995) states that the prime objective of nest monitoring should be to determine whether the breeding population (nesting effort) is stable, increasing or decreasing. Standardised data forms should be used so that information could be recorded easily, accurately and systematically. These techniques of standardisation between surveys will ensure higher precision in the comparison of estimates between years (Graham 1987).

Chabreck (1966) suggests that if the nesting area that needs to be surveyed exceeds 10 000 acres, a sampling technique may be required. The proportion of sample area to total area will depend on the accuracy required, which is a function of the survey objectives. Graham (1987) notes that a combination of aerial and ground surveys is likely to be most effective. He suggests an extensive aerial survey of all possible nesting sites followed by an intensive ground survey of sampled nesting areas that are accessible on foot.

7.2.1.4 Aerial survey

During a nesting survey in the Okavango River, existing aerial photos of the area were enlarged to a scale of 1:12 000 and all nesting sites seen from the air were recorded on the map (Graham 1987). The proportion of both visibility bias and observer bias of the aerial survey could be calculated by doing a thorough ground survey. The visibility bias for the aerial survey is the number of nesting sites not visible from the air but found during the ground search, divided by the total number of nests seen from the air. Conversely, the observer bias for the aerial survey is the number of nesting sites found in the ground survey and were visible from the air, but overlooked as a proportion of the total number of nests seen from the air.

Graham (1987) uses visibility bias to calculate a correction factor to estimate the nesting population. The correction factor is based on the assumption that visibility bias consists mainly of observer bias, and that the influence of visibility bias (number of nests concealed from the view of the observer) is insignificant. This assumption might not hold true for disturbed populations, as females in disturbed areas have been found to be very secretive with regards to their nesting behaviour (pers. obs.). In such disturbed environments the proportion of visibility bias compared to observer bias will increase.

It is important during the aerial survey to view each possible site from a near-vertical position, as the surrounding vegetation could increase the visibility bias by blocking the view. Chabreck (1966) found that shadows produced by early morning and late afternoon flights could make it difficult to observe nests. The main disadvantage of any crocodilian nesting site survey is the failure to bring all possible sites under observation. It may take a few seasons to locate and accurately map all possible nesting habitats (Graham 1987).

7.2.1.5 Ground survey

The alternative method to aerial surveys is ground surveys for nests (Graham 1987; Hartley 1990; Kofron 1989). Given sufficient funding, aerial surveys should always precede ground surveys. The advantage of using both survey techniques is that exact comparisons can be made and corrections factors for aerial surveys calculated (Graham 1987). He also notes that in the case of a sample survey, the sample areas chosen must be thoroughly searched and their boundaries carefully mapped.

During ground surveys, possible nesting habitats are surveyed on foot, exact positions of nests documented and nest site characteristics recorded. Typically, the observers slowly walk close to the water's edge and search for paths, especially those made by hippopotami (Pooley 1969), leading from the water's edge to possible crocodile nesting sites (Kofron 1989; Swanepoel, Ferguson and Perrin 2000). Chabreck (1966) found that with alligators a clearly marked trail, generally made and maintained by the female as part of her nest attendance behaviour throughout incubation often reveals the location of the nest. The Nile crocodile's nest will be noticeable as an open sandy area with perhaps a slight depression. The depression is usually denuded of any vegetation and normally the imprint of the female's belly markings will be visible on the nest (Pooley 1969; pers. obs.).

Hartley (1990) suggests that the best time for nest surveys in the Hluhluwe-Imfolozi Game Reserve in KwaZulu Natal, RSA is between mid December and the end of January. "This period covers the middle of the nesting cycle when all the crocodiles in the system that were going to lay eggs would have done so" (Graham 1987; Hartley 1990). Leslie (1997) carried out nesting surveys by boat and on foot in the St Lucia system, including the inland pans in all potential nesting areas.

Pooley (1969) noted that at Lake St Lucia the distance from the water's edge to the nest varies from 10 to 50 m. Fawcett (1987) recorded a total mean distance of 24.1 m from the nest to the water at Lake St Lucia, but the "inland" sample (n=5) mean distance was 100.3 m.

7.2.1.6 Data collection

Care must be taken to establish the exact number of nests or clutches of eggs present at the breeding site, as Graham, Patterson and Graham (1976 cited in Graham 1987) found that a single female could attend to more than one nest simultaneously.

If a nest without a female is located, a search should be made for the female in order to estimate her size. The position of the nest should preferably be marked with a GPS (Manolis 1995) and recorded on a 1:10 000 map. A suite of nesting site characteristics could be recorded for each nest, such as:

- Gradient (sloping or level) (Swanepoel, Ferguson and Perrin 2000)
- Estimated exposure to sun per day in hours (Fawcett 1987; Leslie 1997; Swanepoel, Ferguson and Perrin 2000)
- Distance from water (Pooley 1969; Fawcett 1987; Hartley 1990; Leslie 1997; Swanepoel, Ferguson and Perrin 2000)
- Height above water (Fawcett 1987; Hartley 1990; Leslie 1997; Swanepoel, Ferguson and Perrin 2000)
- Signs of predation by other animals (Pooley 1969; Fawcett 1987; Graham 1987)
- Belly imprint visible (Pooley 1969)
- Nearest shade (Pooley 1969)
- Presence of other nesting sites nearby (Fawcett 1987; Swanepoel, Ferguson and Perrin 2000)
- Suitable habitat for a hatchery nearby

Manolis (1995) in a study on *C. porosus*, in Papua New Guinea, classified each nesting site into sub-habitats and found that most nests represented at least one sub-habitat, while some contained two or three.

7.2.1.7 Data analysis

The data obtained from the nesting survey will give two important measures of abundance. Firstly, the number of active nesting sites is an absolute value that is indicative of the abundance of the minimum number of breeding females in the population and thus an index of breeding success that could be monitored over time. Secondly, the data could be used indirectly (but not completely as it is only related to births and not to mortality) as a rate of population increase (Bayliss, 1987).

Fawcett (1987) found that if it is assumed that the number of nests at a given location is not limited by the number of potentially suitable nest sites, the number of active nests should serve as an indication of either the desirability of the location for nesting or the density of adult crocodiles in the area, or both.

7.2.1.8 Estimating crocodilian abundance from nesting data

Chabreck (1966) developed a model to estimate total population size based on the assumption that the number of crocodilian nests are equal to the number of nesting females. So in order to calculate the estimated population size, the fraction of nesting females in the total population and the number of nests in the area is required.

P = Estimate of total abundance for the area

N = Total number of crocodilians nests in the area

A = Percentage of mature crocodilians for the area - number of mature crocodilians observed during a sample survey / total number counted during the sample survey

F = Adult sex ratio - number of mature females / number of mature crocodilians (obtained either through past research for the specific species in the study area, or by a capturing experiment)

E = Percentage of adult females nesting (obtained through past research for an area, this fraction could be subjected to variation as a result of changing yearly rainfall patterns)
Nesting data for the specific area could be collected through a combination of aerial and ground surveys. Chabreck (1966) suggested that the information required for A, F and E should be a combination from various sources. The size composition could be determined

by either an aerial or a night survey in a sample section. That would result in the required fraction of mature animals to sub-adults and juveniles (A).

In order to determine the fraction of nesting females (F), information is required on the sex ratio of sexually active (mature) crocodilians. Chabreck (1966) suggests that not all females nest, but that under normal conditions the adult sex ratio and the fraction of nesting females will remain fairly constant from year to year. So the estimated population could be calculated with the following equation (taken from Chabreck 1966):

$$\hat{P} = \frac{N}{A \times F \times E}$$

7.2.1.9 Calculating nesting effort if population abundance is known

Leslie (1997) adapted the model developed by Chabreck (1966) in order to determine nest effort for the population, if the population abundance is known.

$$N = \frac{X}{A \times F \times E}$$

Where:

N = population size

X = number of nests

E = nest effort (proportion of mature females nesting)

A = fraction of mature animals in the population (number of mature crocodiles / total number of crocodiles observed in the survey)

F = fraction of females in the mature population (number of mature females / number of mature crocodiles observed in the survey)

She determined N and X from an aerial survey and nesting site survey, F from captured data and the aerial survey, and A was set to 1.0 because she included only the adult size class. The equation was then solved to obtain a value for E (nest effort).

7.2.2 Call surveys

According to Chabreck (1966) call counts of male alligators could be used to index the breeding population in a specific area. Some species, notably *Alligator mississippiensis,* call during the breeding season and when the animals are not seen the call could be regarded as an indication of their presence (Magnusson 1982). Ross (2004 pers. comm.) cautions that in the light of too many variables, this method can be use to establish presence or absence and perhaps concentrations of breeding animals, but not population trends.

CHAPTER 8
COMPARING AERIAL AND SPOTLIGHT SURVEYS

8.1 INTRODUCTION

Under certain circumstances, aerial surveys could be less expensive and less time-consuming than spotlight surveys, and yet provide a population index comparable to spotlight surveys (Bayliss et al. 1986).

Bayliss (1987) in a study done in the sinuous tidal side creeks of the Adelaide river in Northern Australia, found that despite the variation in the numbers of crocodiles sighted with habitat, tide and observer, after correcting for observer bias, the helicopter counts in the mainstream at low tides were consistently related to spotlight counts. They found that during low neap tide in the mainstream, helicopter counts were 37% lower than spotlight counts at low spring tide, but 45% higher in the side creeks. In two densely vegetated billabongs, only 18% and 29% of crocodiles were seen from the helicopter compared to a spotlight survey (Bayliss et al. 1986). They believe that after correcting for observer bias, helicopter counts in tidal river systems can provide indices comparable to spotlight indices of crocodile abundance, and a sudden change in the technique from spotlight surveys to helicopter surveys would still allow for comparisons of past and future survey data.

Leslie (1997) conducted diurnal and one spotlight survey in the tidal channel known as the "Narrows" on Lake St Lucia from 1994 to 1996. The encounter rate for the spotlight survey was measured as 4.7 crocodiles/km. She repeated the area surveyed exactly one year later by means of a diurnal aerial survey and the encounter rate dropped to 2.7 crocodiles/km. Although these two counts cannot be directly compared due to the difference in time, it still indicates a marked difference in the probability of detection between the two survey techniques, as the population is relatively stable over time and between similar seasons (Leslie 1997).

Stirrat et al. (2001) compared data from helicopter surveys and spotlight surveys over a 10 year period in the Northern Territories of Australia and found that helicopter surveys were not as sensitive as spotlight surveys, resulting in an inability to detect significant changes in populations of *C. porosus*, within the time constraints of management. Survey by helicopter is still a useful method to employ in conjunction with spotlight surveys as it might reveal the nature of changes detected by spotlight surveys while it seems to be a better method than spotlight surveys for detecting changes in the size distribution of larger crocodiles as larger crocodiles tend to be more wary and therefore less approachable by a boat at night (Stirrat et al. 2001).

8.2 CORRECTION FACTOR

Spotlight surveys are very useful as they provide a less biased reflection of the total population and they could also be used to calculate correction factors to adjust an aerial survey (Taylor 1988 cited in Games, Zolho and Chande 1992) as long as the same route was surveyed in close replication. For instance, a spotlight survey revealed 442 crocodiles in the lower Rufiji River in Tanzania, while an aerial survey along the same stretch of river found 89 crocodiles. This gives a correction factor for the aerial factor of 4.9 (Games and Severre 1999). If the survey is repeated the subsequent year as part of a monitoring programme, using only an aerial count would suffice, as long as the data is multiplied with the correction factor for a final corrected estimate.

8.3 ESTIMATING THE POPULATION

As discussed earlier, an index of relative abundance could be determined for a crocodilian population through aerial, spotlight or nesting surveys. It is furthermore possible, and in most cases advisable, to use a combination of methods to decrease the effect of bias on the estimate. Magnusson, Caughley and Grigg (1978) developed such a technique, using two independent counts to estimate the population size. This technique is a generalisation of the double-survey or tandem-count method, where the counts of two observers are used to quantify observer bias. The logic follows that when it is possible to map the position of a crocodile, it is possible to determine how many were seen during both the spotlight survey at night and the aerial survey (B), how many were counted during the spotlight survey, but not during the aerial survey (S_1) and how many were observed from the air, but not in the spotlight survey (S_2). If M is the unknown number missed by both surveys and N is the total number of crocodiles in the population, also unknown, then:

$$N \quad = B \ + \ S_1 \quad + \quad S_2 \quad + \quad M$$

$$1 \quad = P_1 P_2 + P_1(1\text{-}P_2) + P_2(1\text{-}P_1) + (1\text{-}P_1)(1\text{-}P_2)$$

P_1 being the probability of a crocodile being seen during the spotlight survey and P_2 the probability of a crocodile being seen during the aerial survey. Hence the unknown parameters can be estimated from the known frequencies B, S_1 and S_2 by:

$$\hat{P}_1 = B / (B + S_2)$$
$$\hat{P}_2 = B / (B + S_1)$$
$$\hat{M} = (S_1)(S_2) / B$$
$$\hat{N} = (B + S_1)(B + S2) / B$$

Magnusson, Caughley and Grigg (1978) believed that this model is logically equivalent to the Peterson estimate and they are confident that the same mathematics could easily be adapted to this model. During the spotlight survey crocodiles are mapped ("marked"); when comparing the maps after the aerial survey it will become evident that some of the mapped ("marked") crocodiles had been "recaptured", while other crocodiles recorded in the aerial survey were unmapped. The correction factor (Chapman 1951 cited in Magnusson, Caughley and Grigg 1978) for the Peterson estimate is applied to the first equation to become:

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

To calculate the variance, a translation of Seber's formula (1973 cited in Magnusson, Caughley and Grigg 1978) is used:

$$\mathrm{Var}(\hat{N}) = \frac{(S_1)(S_2)(S_1 + B + 1)(S_2 + B + 1)}{(B + 1)^2 (B + 2)}$$

If the respective spotlight and aerial survey maps with their recorded crocodile positions were compared, and for example, 58 crocodiles were seen during both surveys (B), 20 crocodiles were counted during the spotlight night survey that were not seen during the aerial survey (S_1), and 6 crocodiles were seen only from the air (S_2), then the probability of seeing a crocodile during the spotlight survey is estimated as $P_1 = 58 / (58 + 6) = 0.906$; during the aerial survey $P_2 = 58 / (58 + 20) = 0.744$ and the number of crocodiles missed by both surveys is estimated as $M = 20 \times 6 / 58 = 2.069$ and the total number, both counted and uncounted is estimated as:

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

$$= \frac{(20 + 58 + 1)(6 + 58 + 1)}{58 + 1}$$

$$= 86.034 \text{ crocodiles}$$

Its approximate variance is:

$$\mathrm{Var}(\hat{N}) = \frac{(S_1)(S_2)(S_1 + B + 1)(S_2 + B + 1)}{(B + 1)^2 (B + 2)}$$

$$= \frac{(20)(6)(20 + 58 + 1)(6 + 58 + 1)}{(58 + 1)^2 (58 + 2)}$$

$= 2.950$, and the standard error is $\sqrt{2.95} = 1.718$

The two important assumptions for using this method are, firstly, that the counts of the spotlight and aerial surveys are independent of each other and secondly, that there is a constant probability of detecting a crocodile by a given survey method. The first assumption is critical: the observer doing the aerial survey must either be a different one with no prior knowledge of the crocodile positions in the previous survey or has an unmarked map and should consciously search the whole area with absolutely equal effort.

Magnusson, Caughley and Grigg (1978) do not believe the second assumption to be critical, as they have conducted experiments which showed that similar estimates were produced during control situations in which probabilities were set at the means of the beta distributions.

CHAPTER 9
GLOBAL CROCODILIAN SURVEYS

9.1 INTRODUCTION

Just over 30 years ago, the entire 23 species of the world's extant crocodilians were endangered, depleted or declining in numbers due to excessive exploitation, the lack of regulated harvesting and an illegal international trade in crocodilian products. It was not surprising that one of the first priorities of the IUCN CSG (World Conservation Union, Crocodile Specialist Group) was to assess the status and distribution of global crocodilian populations. The rationale for these surveys was to have quantitative data available where necessary and to facilitate the development of sustainable yield programmes (Thorbjarnarson 1992) in order to stop the exploitation rate and to boost natural populations. Such a programme in Tanzania led to perhaps the first survey of the Nile crocodile in 1964 in the Rufiji River (Graham 1987). In Australia, stringent measures stopped the decline of crocodiles and the recovery rate of *C. porosus* has been monitored since 1971 (Bayliss 1987; Messel et al. 1981). Conservation measures implemented were so successful that currently the Northern Territories have a secure population, possibly close to the carrying capacity (Webb et al. 2000 cited in Stirrat et al. 2001).

In the United States, the Florida Alligator Recovery Team has monitored *A. mississippiensis* population trends since 1971, following severe depletion (Chabreck 1966; Wood et al. 1985; Woodward and Marion 1978). Due to stringent protection measures, surveys on wetland areas indicated an average population increase of 41% between 1974 and 1992 (Woodward and Moore 1995).

Crocodilian surveys have also been initiated in other parts of the world. For instance, in Brazil, the yacare caiman, *Caiman Crocodylus yacare* populations have been monitored by Campos et al. (1995) and in Bolivia the black caiman, *Melanosuchus niger,* by Pacheco (1996). In the Ayeyarwady Delta in Asia, Thorbjarnarson, Platt and Tun Khaing (2000) surveyed *C. porosus,* while Platt and Thorbjarnarson (2000) conducted a status survey of the American crocodile, *Crocodylus acutus,* in Belize, and Montague (1983) the Fly River Drainage in Papua New Guinea.

Despite an increase in crocodilian conservation programmes worldwide, good or adequate quantitative population survey information is available for only 10 of the 23 species and in order to ascertain the global status, an urgent need for surveys is required. Two species, *Crocodylus cataphractus* and *Osteolaemus tetraspis* are listed as extremely poor with regards to survey data, while eleven are listed as poor, among others the Nile crocodile (Thorbjarnarson 1992; Ross 1998). The listing of the Nile crocodile is as a result of inadequate survey data for most of the distribution range of the species, despite some survey information on its status in eastern and southern Africa.

9.2 AFRICA, EXCLUDING THE RSA

Nile crocodile surveys have been carried out in Tanzania (Graham 1987; Games and Severre 1990, Games 1994; Games and Severre 1999), Ethiopia, Kenya, Malawi, Moçambique, Uganda (Parker and Watson 1970), Zambia and Zimbabwe (Loveridge 1980; Hutton and Woolhouse 1989; Games 1994). Nesting surveys have been conducted in the Okavango river in Botswana (Graham, Simbotwe and Hutton 1992; Games 1994), in Central Africa (Cott 1961 cited in Kofron 1989), Lake Turkana in Kenya (Modha 1967), and Zimbabwe (Hutton 1987 cited in Kofron 1989) and Kofron (1989).

9.3 REPUBLIC OF SOUTH AFRICA

Although no comprehensive survey of Nile crocodiles has ever been conducted in the RSA (Marais and Pooley 1991), selected populations have been surveyed since the early 1970's. Although these surveys were regarded as an important component of the management of the species (Jacobsen 1991), it seems as though many of these surveys were *ad hoc* in nature and took place when funds were available or as part of hippopotami surveys (Swanepoel 1993 pers. comm.). It is estimated that in the RSA less than 8 500 Nile crocodiles survive in the wild (Marias and Pooley 1991). This population can be separated into three broad geographical groups (Blake and Jacobsen 1992):

9.3.1 Kruger National Park (KNP)

The six largest rivers flowing through the KNP were surveyed from 1978 to 1991 as part of an annual hippopotami census (Swanepoel 2003 pers. comm.). Nesting surveys were conducted along the Olifants River (Swanepoel 1999; Swanepoel, Fergusson and Perrin 2000). This population is estimated at about 3 500 crocodiles (Blake and Jacobsen 1992).

9.3.2 KwaZulu-Natal Province

The province of KwaZulu Natal has the largest Nile crocodile population in the RSA and areas that have been surveyed include Ndumu Game Reserve (Pooley 1969, 1982), Mkuzi Game Reserve (Pooley 1982), Kosi Bay (Kyle 1982, 1990, 1991) Lake St Lucia (Pooley 1969, 1982; Pullen 1988; Leslie 1997) and Lake Sibaya (Bruton 1979a; Ward 1985, 1986a, 1987, 1988, 1990, 1993). Nesting surveys were conducted in Ndumu Game Reserve (Pooley 1969), Umfolozi Game Reserve (Hartley 1990), Kosi Bay (Kyle 1990, 1991) Lake St Lucia (Pooley 1969; Taylor and Blake 1986; Fawcett 1987; Leslie 1997; Leslie and Spotila 2001) and Lake Sibaya (Bruton 1979a; Ward 1986b). This population is estimated at 4 500 (Blake and Jacobsen 1992).

9.3.3 Mpumalanga, North West and Limpopo Province, excluding KNP

Jacobsen (1984, 1991) surveyed the major rivers in the former Transvaal province, (now Mpumalanga, the North West and Limpopo Provinces) outside the KNP during 1979-1981 and 1988-1989 from the air. Crocodiles were present, albeit at low densities in the following rivers: Limpopo, Blyde, Sabie, Sand, Komati, Upper and Lower Olifants, Luvuvhu, Magalakwena, Pongola, Mogol, Klaserie, Crocodile, Marico, Palala, Mutale, Blockland and Letaba rivers (Blake and Jacobsen 1992). Generally very few nesting surveys have been conducted outside of protected areas, but the middle Limpopo River and the Olifants River near Marble Hall, have been surveyed (Blake and Jacobsen 1992). This population is estimated at approximately 1 000 crocodiles (Jacobsen 1984).

9.4 SURVEY TECHNIQUES USED IN THE RSA

9.4.1 Introduction

The majority of the surveys were aerial, fixed-wing aircraft (Pullen 1988; Leslie 1997) or helicopter (Pooley 1982; Jacobsen 1984; Ward 1985, 1986a, 1987, 1988, 1990, 1993; Jacobsen 1991).

Other techniques included diurnal boat surveys (Kyle 1990; Leslie 1997), diurnal foot surveys (Pooley 1969; Kyle 1982), microlight surveys (Swanepoel 2001) and spotlight surveys by boat (Bruton 1979a; Pullen 1988; Leslie 1997; Swanepoel 2001).

9.4.2 Spotlight surveys

Although this method is one of the most widely used techniques throughout the world to survey and monitor crocodilian populations (Messel et al. 1981; Magnusson 1982; Bayliss et al. 1986; Bayliss 1987; Graham 1987; Woodward et al. 1996; Leslie 1997; Games and Severre 1999; Platt and Thorbjarnarson 2000; Thorbjarnarson, Platt and Tun Khaing 2000; Stirrat et al. 2001; Swanepoel 2001), it seems that the total numbers of spotlight surveys conducted in the RSA were low and sporadic.

Blake (2003 pers. comm.) experimented with spotlight surveys at Lake St Lucia, but due to various difficulties discontinued the use of this technique. Bruton (1978) conducted spotlight surveys at Lake Sibaya in 1970 and 1973 along the land-water interface. Kyle (2004 pers. comm.) experimented with spotlight surveys in the Siyadla channel of Kosi Bay, but found the method not significantly more accurate than diurnal surveys.

During June 1988, three spotlight surveys were carried out at Lake St Lucia as part of the annual crocodile survey (Pullen 1988). These counts took place on the same days as the aerial counts in order to compare the aerial counts of the sample areas with spotlight counts done the same evening. The results indicate that generally, more crocodiles were counted during the aerial survey compared to the night survey, except for two sectors (Pullen 1988). It must be noted that some of the areas are extremely difficult to navigate by boat at night, which could have resulted in animals being missed during the spotlight survey.

Leslie (1997) attempted spotlight surveys in various areas of the Lake St Lucia system, but found this technique logistically impractical as a result of the manpower required, the shallowness of the lake system, the effect of tidal variation and the danger of hippopotami. With the exception of one spotlight survey, all others attempted were unsuccessful.

Spotlight surveys have never been used inside the KNP to monitor crocodile populations, mainly as a result of hippopotami and shallow rivers, which render navigation impractical (Swanepoel 1999). Conducting aerial surveys of the rivers outside the KNP with known crocodile populations has always been seen as logistically easier than spotlight surveys from a boat, mainly as a result of the difficulty in obtaining permission for spotlight surveys from farm owners bordering the river (Jacobsen 2003 pers. comm.).

Recently, spotlight surveys from a boat were used to survey the crocodile population in the Flag Boshielo dam. Swanepoel was commissioned by the Department of Water Affairs and Forestry to compile a report on the possible impact of raising the dam wall might have on the crocodile population (Swanepoel 2001). The Flag Boshielo population is currently being monitored by Hannes Botha.

10. CONCLUSION

Although crocodilians are so well adapted to their aquatic environment that they have outlived periods of natural extinction, the pressure of commercial hunting and widespread eradication programmes in the first half of the previous century have brought many species to the brink of extinction. Legal protection in the early 1970's resulted in significant recovery of *C. niloticus* over some of its former range, however in the RSA viable crocodile populations are limited to three localities, amongst other the GSLWP. This Wetland Park is situated on the seaward margin of the low-lying Moçambique Coastal Plain of the province of KwaZulu-Natal and has recently been proclaimed a World Heritage Site. Although the highest concentration of crocodiles in the GSLWP is in Lake St Lucia, crocodiles are present in many of the wetlands throughout the Park, at Kosi Bay and the second largest population is found at Lake Sibaya, a Ramsar wetland, and the largest fresh water system in the GSLWP. In recent years, conservationists have expressed their concern with regards to the state of the crocodile population at Lake Sibaya as well as a lack of population and breeding information during the past decade. This information deficit, together with reports of unregulated harvesting and killing of crocodiles as well as disturbance of nesting areas prompted the need for an integrated management plan. The first step in the development of such a plan is to conduct a comprehensive population survey as well as to determine the extent of breeding and recruitment in the lake system. As a result of crocodile surveys being complex in nature and the paucity of available scientific literature on survey techniques in South Africa, it was decided to conduct a literature review on global crocodilian survey techniques in order to gain insight into factors like types of surveys, specific techniques and the effect of bias on a survey. This information was used to develop the most appropriate survey strategy for a population and nesting survey.

Historical information on nesting and aerial surveys at Lake Sibaya were collated in order to understand the population and nesting trend as well as to identify historical nesting sites. Nesting data suggest a significant decline in the population, if taken into account that 30 nests were counted during 1970 and that has decreased to four nests counted during 1991. Research from the late 1950's suggested that crocodiles were abundant at Lake Sibaya, but mainly due to human population increase in close proximity of the lake and their dependence on the lake for daily livelihoods, only 52 crocodiles were counted during an aerial survey in 1993.

Due to a diverse shoreline habitat and resulting non-random distribution of crocodiles throughout the lake system, it was decided to conduct aerial and spotlight "total surveys" covering the entire shoreline of the lake as well as peripheral wetland areas. A combination of spotlight and aerial surveys were used as each method contains specific benefits in its application at Lake Sibaya and when used in combination as two independent counts, it is possible to estimate the population. Because all historical population surveys have been aerial surveys, four aerial surveys were conducted for comparative analysis, but also because it is a better method than spotlight surveys to gain information on the larger size crocodiles in the population. Spotlight surveys were used, as they usually result in higher encounter rates (density), despite the fact that many of the larger crocodiles dive before an accurate size estimate is possible. Spotlight surveys are superior to aerial surveys in that they produce better results on the younger segment of the population. Nesting surveys were conducted for two consecutive years and in light of the importance of a sustainable use programme, potential nesting sites were identified and evaluated in terms of their relative suitability for breeding.

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PERSONAL COMMUNICATIONS

BLAKE, D. K., Past Conservation Manager of the St Lucia Crocodile Centre: Author, Nile crocodile researcher.

BOTHA, P. J., University of Pretoria, Centre for Wildlife Management: Nile crocodile researcher.

FULTON, I., Natal Parks Board: Past Regional Ecologist.

JACOBSEN, N. H. G., Author, Nile crocodile researcher. Conducted numerous aerial surveys of rivers in South Africa, outside of Kruger National Park.

KYLE, R., Ezemvelo KZN Wildlife: Regional Ecologist (Kosi Bay) Resource Use. During the past 20 years, conducted numerous crocodile surveys in Northern KwaZulu Natal, especially in the Kosi Bay system.

POOLEY, A.C., Author, Past Conservation Manager of the Ndumu & St Lucia Crocodile Centres. Nile crocodile researcher. Played a major role in crocodile conservation in South Africa during the past 50 years.

ROSS, J. P., Co-supervisor to this study. Department of Wildlife Ecology & Conservation, University of Florida. Executive Officer of the IUCN Crocodile Specialist Group & editor of the Crocodile Specialist Group newsletter. Focussed his career on international conservation biology, specialising in the application of sustainable use to conservation and management of sea turtles and crocodilians in developing countries. Authored numerous scientific papers, principally with a focus on crocodiles and turtles.

SWANEPOEL, D. G. J., Past South African National Parks. Consultant, author & Nile crocodile researcher.

APPENDIX 1

GLOBAL POSITIONING SYSTEM (GPS) POINT LOCALITIES OF HISTORICAL, CURRENT AND POTENTIAL NILE CROCODILE NESTING SITES AT LAKE SIBAYA

GPS co-ordinates		Nursery area	Elevation	Distance to water	TOTAL
27.39782	32.71110	5	5	5	5.00
27.36484	32.65033	5	5	5	5.00
27.32012	32.66116	5	4	5	4.67
27.27688	32.67947	5	5	4	4.67
27.39649	32.65807	5	5	4	4.67
27.42243	32.69620	5	5	4	4.67
27.42214	32.69626	5	5	4	4.67
27.35806	32.59237	5	4	4	4.33
27.35613	32.61137	5	4	4	4.33
27.35365	32.61771	4	4	5	4.33
27.35204	32.61746	4	5	4	4.33
27.31754	32.66061	5	4	4	4.33
27.29405	32.66287	5	4	4	4.33
27.28974	32.65155	5	4	4	4.33
27.42327	32.69672	5	5	3	4.33
27.36795	32.63057	3	5	4	4.00
27.35631	32.61887	5	3	4	4.00
27.35252	32.59514	5	4	3	4.00
27.34652	32.60228	5	3	4	4.00
27.30055	32.68871	5	5	2	4.00
27.29472	32.66000	5	3	4	4.00
27.39212	32.67234	5	4	3	4.00
27.42149	32.69738	5	4	3	4.00
27.41722	32.69673	4	3	4	3.67
27.37043	32.65777	4	4	3	3.67
27.36720	32.65699	4	4	3	3.67
27.36513	32.63378	4	4	3	3.67
27.36063	32.56756	5	4	2	3.67
27.35688	32.61222	5	2	4	3.67
27.35418	32.59764	5	3	3	3.67
27.35231	32.59955	5	3	3	3.67
27.31846	32.66337	2	5	4	3.67
27.30450	32.68281	5	4	2	3.67
27.28859	32.65254	5	2	4	3.67
27.40018	32.65329	5	4	2	3.67
27.41863	32.70665	4	3	3	3.33
27.39615	32.66253	5	3	2	3.33

GPS co-ordinates		Nursery area	Elevation	Distance to water	TOTAL
27.36778	32.63395	4	4	2	3.33
27.36152	32.58524	3	4	3	3.33
27.35477	32.61588	4	2	4	3.33
27.31797	32.66314	3	4	3	3.33
27.29262	32.65095	5	2	3	3.33
27.29246	32.65727	4	2	4	3.33
27.39765	32.68981	4	5	1	3.33
27.34802	32.71719	4	2	4	3.33
27.41046	32.69616	4	3	2	3.00
27.37317	32.62631	4	2	3	3.00
27.37057	32.62886	4	3	2	3.00
27.36013	32.58606	2	4	3	3.00
27.35682	32.59085	4	2	3	3.00
27.34882	32.59589	2	3	4	3.00
27.32389	32.62264	3	3	3	3.00
27.31976	32.62671	3	3	3	3.00
27.31080	32.66318	4	2	3	3.00
27.28643	32.64990	3	3	3	3.00
27.28236	32.66940	2	4	3	3.00
27.28174	32.67944	2	4	3	3.00
27.39380	32.70644	1	3	4	2.67
27.37420	32.62555	3	2	3	2.67
27.36683	32.66143	2	4	2	2.67
27.35956	32.56829	2	3	3	2.67
27.35722	32.58120	2	3	3	2.67
27.34985	32.59974	3	2	3	2.67

COMPONENT B

Combrink, A.S.; Korrûbel, Jan L. & Ross, Perran

Population status and future management of *Crocodylus niloticus* (Nile crocodile) at Lake Sibaya, South Africa

South African Journal of Wildlife Research

Population status and future management of *Crocodylus niloticus* (Nile crocodile) at Lake Sibaya, South Africa.

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ABSTRACT

The Greater St Lucia Wetland Park (GSLWP) World Heritage Site is one of the most important remaining protected areas for the conservation of *Crocodylus niloticus* (Nile crocodile) in the Republic of South Africa. Although crocodiles are present at low densities in some of the wetlands throughout the GSLWP, at Kosi Bay and Lake Sibaya, the majority is found at Lake St Lucia. An index of relative abundance of the crocodile population at Lake Sibaya was estimated through aerial and spotlight surveys in 2003 and nest surveys were conducted during 2003 and 2004. The highest count during the aerial surveys was 36 crocodiles, suggesting a decline of 66% during the previous 13 years in the population index, based on earlier surveys. Sixty-five crocodiles were counted during the spotlight surveys, 72% more (excluding hatchlings) than the highest aerial count, which indicates the importance of using spotlight surveys as a method of counting crocodiles. A correction factor of 1.72 was calculated for future aerial surveys, based on the spotlight surveys, and

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the population is estimated at 112 crocodiles, with a variance of 22.49 and standard error of 4.47. Three nests were found during 2003, but none during 2004. Sixty-three potential nesting areas were identified and evaluated. These sites could play an important role in increasing the population to support a sustainable use programme at Lake Sibaya. Despite legal protection and World Heritage status, the population is clearly under threat. To secure the future viability of this population, I recommend that Ezemvelo KZN Wildlife develop an integrated crocodile management plan through collaboration with the GSLWP Authority and the local communities adjacent to Lake Sibaya. This could ensure the conservation and increase of crocodiles at Lake Sibaya, which will benefit the communities that are dependent on the lake for their daily livelihoods. The likely alternative might be extirpation of this important predator from the largest freshwater ecosystem in South Africa's first World Heritage Site.

1. INTRODUCTION

The Greater St Lucia Wetland Park (GSLWP) consists of a myriad wetlands, small lakes and rivers as well as three main waterbodies; Lake St Lucia, the Kosi Bay lakes and Lake Sibaya (See Fig. 1). Lake Sibaya, the largest natural freshwater system within the GSLWP and the largest natural lake in South Africa, hosts the second largest crocodile population in the Park. Research from the late 1950's suggested that crocodiles were once abundant at Lake Sibaya (Tinley 1976), yet only 67 were counted during the first aerial survey in 1985. Subsequent aerial surveys indicated an apparent increase in the population during the following five years, with some 107 crocodiles counted in 1990. Concerns over the current population status, breeding component and future of crocodiles at Lake Sibaya (Mountain 1990; Thorbjarnarson 1992) led to aerial and spotlight counts, nesting surveys and the identification of potential breeding areas from February 2003 to February 2004.

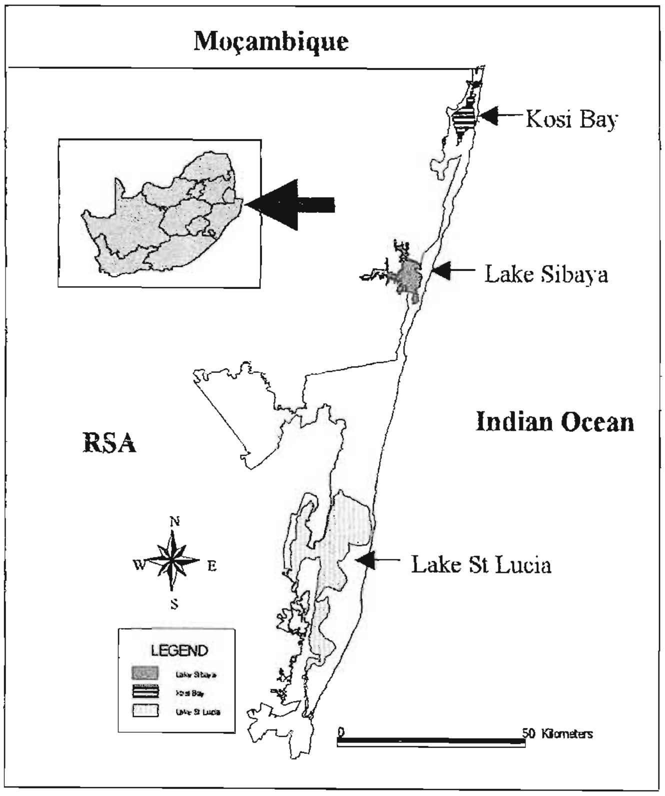

Fig. 1 The Greater St Lucia Wetland Park

2. STUDY AREA

Lake Sibaya is situated in Maputaland, the northeastern region of the KwaZulu-Natal province of the RSA on the seaward margin of the low-lying Moçambique Coastal Plain (See Fig. 1, p. 4). Maputaland is a transitional zone between tropical and sub-tropical climates, forming the southernmost limit for a number of tropical species, resulting in an area rich in biological diversity (Hearne and McKenzie 2000). The shoreline of Lake Sibaya fluctuates with wet and dry regimes, and is currently 137.3 km in length. The eastern shore of the lake lies less than a kilometre from the Indian Ocean, and is separated from the sea by a series of high forested sand dunes. The lake surface is approximately 20 m above mean sea level, and the bottom of the lake extends to nearly 20 m below sea level. With no connection to the sea, the lake level fluctuates in response to the dynamic balance between inflow and outflow (Hill 1979). The main source of inflow consists of surface and subsurface drainage together with direct rainfall, and outflow is regulated by means of evaporation and seepage to the sea (Mountain 1990). The surface area of the lake is currently approximately 7 760 ha, and it has a mean depth of 10.9 m (Kyle & Ward 1995).

The lake and its feeder streams is a unique independent ecosystem and numerous rare or threatened species are found in the lake system (Bruton 1979). Lake Sibaya was designated a Ramsar Wetland of International Importance in 1991 and although the area surrounding the lake is tribal land, the water surface was proclaimed a protected area in 1994 in terms of the KwaZulu Nature Conservation Act (Kyle & Ward 1995). In December 1999, the surface area of the lake was included in the listing of the Greater St Lucia Wetland Park Word Heritage Site.

3. METHODS

As a result of survey bias on the population estimate, a combination of aerial surveys, spotlight surveys by boat and foot were conducted.

3.1 Aerial surveys

Four aerial surveys were conducted with a microlight Trike (two-seater) aircraft, covering the entire shoreline of the lake as well as the peripheral wetlands. The first and fourth surveys (12 February and 18 April 2003) were conducted with a single microlight, while on 18 April 2003 two microlights surveyed the lake simultaneously, but in opposite directions to record data for calculating a precision value, using a method described by Magnusson, Caughley and Grigg (1978). The departure time for the surveys was standardised at approximately one hour after sunrise, and prior to departure, weather conditions and air and water temperatures of the lake were recorded. Crocodiles were counted while flying between 70–100 km/h along the lake shoreline at a height of 30–50 m above lake level. The observer sat behind the pilot and recorded the position of each crocodile on a 1:50 000 topographical map, fastened to a clipboard and secured to the plane, while the pilot recorded the position with a Garmin III GPS. Due to relatively low density of crocodiles (largest group consisted of four crocodiles), it was possible to estimate, record and allocate the size of each crocodile to one of the following classes: <1m; 1.00–1.49; 1.50–1.99; 2.00-2.49; 2.50-2.99; 3.00-3.49; 3.50-3.99; 4.00-4.49; 4.50-4.99; >5m. Each survey took approximately 2.5 hours to complete.

3.2 Spotlight boat surveys

Spotlight surveys from a boat were conducted from 8 to 26 April 2003 along the entire shoreline of the lake. The shoreline was divided into seven survey transects and a three-metre inflatable boat was used, powered by a 30hp engine. The survey team consisted of a driver/skipper and a spotter/observer who also navigated the boat and recorded the position of crocodiles seen with a Garmin GPS. In order to standardise observer bias, the same observer conducted all the spotting and size estimates. Due to the considerable distance of shoreline and observer fatigue, it was decided to limit each survey to approximately three hours.

It has been shown that environmental variables affect crocodilian sightings (Woodward and Marion 1978; Messel, Vorlicek, Wells and Green 1981; Hutton and Woolhouse 1989; Ross 2003) and in order to record possible effects on the presence or absence of crocodiles during a survey, a suite of environmental variables were recorded at the start of each survey, amongst others water and air temperature, wind speed, percentage cloud cover, presence or absence of moonlight, presence or absence of waves. The time of departure was standardised at approximately 20:00 in an effort to minimise contacts with hippopotami that were more likely to leave the water for nocturnal grazing on land. The boat cruised between 50-100 m from the shoreline, depending on the depth of the water, but always close enough that the observer was able to carefully examine the water's edge. Crocodiles were located with a 55-Watt halogen bulb spotlight connected to a 12 Volt wet-cell battery (Platt and Thorbjarnarson 2000) that was recharged during the day. The observer/spotter made slow rhythmic sweeps with the spotlight over the water surface in a 180° arc (Leslie 1997) towards the water's edge, constantly checking for crocodiles and hippopotami in front of the boat. Once the characteristic eyeshine from the reflective layer (tapetum lucidum) in the eye was sighted, the boat went closer to verify the presence of a crocodile, as the eyes of hippopotami exhibit a similar reflection. As the boat approached the crocodile, the spotter/recorder estimated and recorded the distance of approachability

(Messel et al. 1981), that is the distance between the boat and the crocodile at the moment the crocodile submerged, if it did so. Crocodiles that dived before a size estimate could be made were recorded as "Eyes Only" (Bayliss 1987; Thorbjarnarson, Platt and Tun Khaing 2000; Platt and Thorbjarnarson 2000). All other crocodiles were recorded in one of three total length size-classes, as juvenile <1.35m; sub-adult 1.35-2.4 and adult >2.4, based on Leslie's (1997) size classification for *C. niloticus* at Lake St Lucia. The position of each crocodile was recorded with a handheld Garmin 12XL GPS, and other recordings that were taken included the estimated distance from the crocodile to the bank, the shore characteristics (Ross 2003) and the habitat of the initial observation (Messel et al. 1981; Montague 1983).

3.3 Spotlight foot surveys

Spotlight foot surveys were conducted on 12 and 14 April 2003 around four wetland areas peripheral to the main water body, where crocodiles were observed during the aerial survey. The survey team consisted of an observer/spotter carrying a spotlight connected to a 12V battery in a backpack, and a recorder/scribe. The survey team walked clockwise around the wetland, while the spotter/observer made slow rhythmic sweeps with the spotlight over the water and at the water's edge on the opposite side of the pan. When the characteristic eyeshine was observed, the scribe recorded the same suite of observations as those noted during the boat surveys.

3.4 Nesting surveys

Crocodile nest surveys were conducted from 11 to 16 February 2003 and from 4 to11 February 2004. The surveys were conducted on foot, cruising close to the lakeshore with an inflatable boat and driving along the shoreline with a trail motorbike. Nesting sites identified by field rangers were also visited and maps of historical breeding sites consulted (Ward 1991), as crocodiles are known to re-use previous nesting sites. Previously unknown nesting sites were identified by the presence of egg fragments (Ward 1991). During the surveys, the shoreline zone was systematically covered, looking for crocodile paths or those made by hippopotami (Pooley 1969), leading from the water's edge to possible crocodile nest sites (Kofron 1989; Swanepoel, Ferguson and Perrin 2000). The position of every located nest was marked with a handheld Garmin X12 GPS and digitally recorded on a recent aerial photo in ArcView GIS 3.2. A suite of characteristics was recorded for each nesting site.

During the 2004 survey, it was decided to focus the bulk of the survey effort on potential and historical nesting areas, and cover the more unsuitable areas with a lower intensity. This was decided as a result of the length of the shoreline (137.3km), extensive unsuitable breeding areas (exposed shoreline with no vegetation) and severe anthropogenic and livestock disturbance in parts of the lake.

Potential breeding areas were identified when all of the following characteristics were present: sandy soil (Kofron 1989) at least $6m^2$ in size; exposure to the sun (Fawcett 1987; Kofron 1989); nearby shade for female (Fawcett 1987; Kofron 1989); height above water (elevation) (Fawcett 1987; Kofron 1989; Hartley 1990) close proximity to fresh water (Fawcett 1987; Kofron 1989; Hartley 1990) and a nursery area.

Because all potential nesting sites had to have sandy soil, adequate exposure to the sun as well as close proximity of shaded areas, each potential nesting area was evaluated in terms of the following variables; nursery area; elevation above water and distance of site from water. Each variable was allocated a score out of 5, with 0/5 being totally unsuitable and 5/5 ideal conditions for that variable. A total score for each site was calculated through summation. The position of each site was recorded with a Garmin *Etrex* GPS.

4. RESULTS

4.1 Aerial surveys

On 12 February 2003, 34 crocodiles were counted (See Table 1 and Fig. 2, p. 13) under optimal conditions (no cloud cover or wind). On 18 April 2003, two surveys were conducted simultaneously in cloudy and windy conditions and 27 and 16 crocodiles were counted respectively. The survey was repeated the next day (19 April 2003) under optimal environmental conditions and 36 crocodiles were counted (See Fig. 2, p. 13).

Table 1 Aerial surveys

Observer	No. 1	No. 1	No. 2	No. 1
Weather conditions	No clouds or wind	Overcast and windy	Overcast and windy	No clouds or wind
Date	12 April '03	18 April '03 (1)	18 April '03 (2)	19 April '03
South Eastern Basin	3	6	2	5
Main Basin	15	14	10	14
Northern Arm	9	2	0	6
Western Arm	4	2	4	7
South Western Basin	2	3	0	2
Bordering pans	1	0	0	2
Total	**34**	**27**	**16**	**36**

4.2 Spotlight surveys

Sixty crocodiles were counted during seven boat surveys and five during the foot surveys (See Table 2 and Fig. 2, p. 13).

Table 2 Spotlight surveys

		Main Basin	Western Arm	Northern Arm	SE Basin	SW Basin	Pan	TOTAL
Estimated size	Juvenile < 1.35 m	2	8		2		1	**13**
	Intermediate 1.35 - 2.4 m	5	8	6	3		2	**24**
	Adult >2.4 m	2	4	3	1			**10**
	"Eyes only"	7	6		1	2	2	**18**
Shoreline habitat	Sand	1	3	6	2			**12**
	Reeds	13	21	3	4	2	5	**48**
	Grass	2	2		1			**5**
Shoreline aspect	Steep sloping		4	1	4			**9**
	Steep vegetated bank	2	4	2			1	**9**
	Gradual sloping	14	18	6	3	2	4	**47**
Position of crocodile	In deep water	2	14	2	4		1	**23**
	In shallow water	14	12	7	3	2	4	**42**
	In vegetation in water	2	14	3	5	2	4	**30**
	On bank	1		1				**2**
Distance to shore	Mean distance	8	3	13	3	2	5	7
TOTAL		**16**	**26**	**9**	**7**	**2**	**5**	**65**

4.3 2003 nest survey

Three nesting sites were found during the 2003 breeding season (See Table 3 and Fig. 2, p. 13), two in a pre-hatching stage while the third nest was discovered as a result of nearby hatchlings observed during a spotlight survey.

Table 3 Nesting survey (2003)

	Nest 1	Nest 2	Nest 3
Substrate	Sandy	Sandy	Sandy
Exposure to sun	c.10:00-16:00	c.09:00-17:00	c.10:00 - 16:00
Elevation	c.5	c.2	c.6
Old nest nearby	2	1	1
Distance to nearest water	73	17.6	11.7
Distance to lake	594	17.6	11.7
Closest shade	4	1.5	1
Aspect	West facing	None	West facing

* Distance measured in metres

4.3.1 Nest 1

This nest (See Table 3 and Fig. 2, p. 13) was discovered incidentally during the 1986/87-breeding season when field rangers on patrol saw a female on a path between the nest and a nearby wetland. The site is situated 594 m from the main lake and 73 m to the closest wetland and nursery area. Nesting at this site was recorded in 1987, 1990 and 1991 (Ward 1991). During the breeding season, the female was never observed on the nest during the day, but changing belly imprints on the nest suggested visits to the nest during the night. A post-nesting check suggests that the nest had been excavated by the female and eight eggshells were found at the nest. A spotlight foot survey was carried out on 14 April 2003 to verify the presence of hatchlings, but the dense reed beds made it too dangerous (hippopotami and possibly the female) to try to establish the exact location of the nursery area.

4.3.2 Nest 2

This nest is situated on the eastern shoreline of Lake Sibaya (See Table 3, p. 12 and Fig. 2, p. 13), and is part of the Coastal Forest Reserve. Nesting at this site was recorded during 1986, 1988 and 1989 (Ward 1991). The nest is situated 17.57 m from the shoreline, two metres above the lake level with immediate access to deep water. The exposed roots of a large *Ficus sycomorus* (Sycamore Cluster Fig) tree on the bank of the lake provide an ideal nursery area for hatchlings (pers. obs.). The post-nesting check indicated that the nest had hatched successfully and the fragments of five eggs were present at the site, while three hatchlings were observed during a spotlight survey.

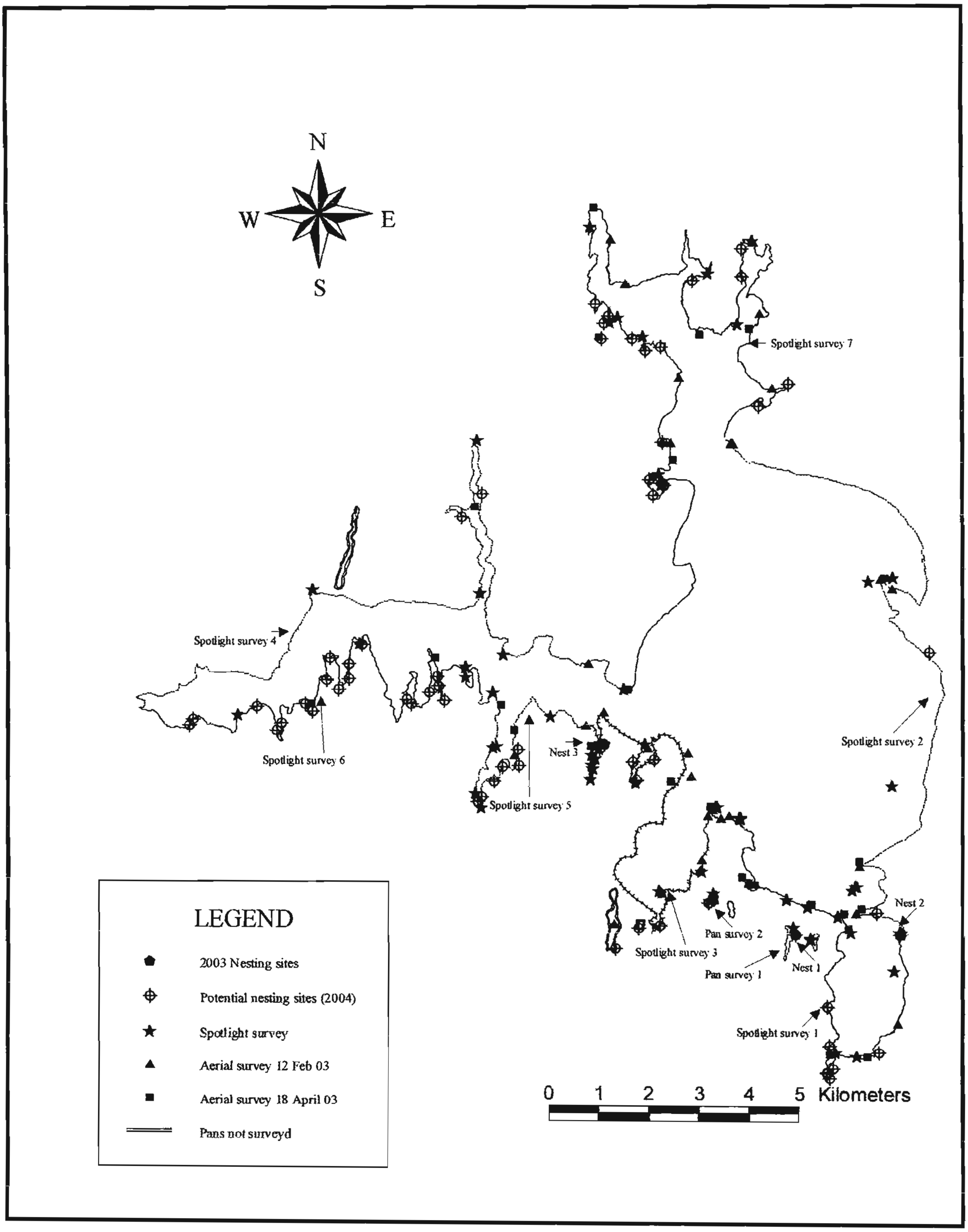

Fig. 2 Survey transects and GPS point localities of crocodiles, nests and potential nesting areas recorded.

4.3.3 Nest 3

This nest, which is situated in the Western Arm of the lake (See Table 3, p. 12 and Fig. 2, p. 13), was found approximately 100 m from the site where hatchlings were observed during a spotlight survey. Eggshells were present and two hatchlings were observed during a spotlight survey. The nest is situated 1.6 m from a footpath, used by subsistence fishermen.

4.4 2004 Nest survey and identification of potential nesting sites

No nests were found during the 2004 survey. Sixty-three potential nesting sites were identified (See Fig. 2, p. 13) and evaluated in terms of their relative suitability for nesting.

5. DISCUSSION

Aerial surveys

The combination of clear water with sparsely vegetated and exposed shorelines, favours aerial surveys for large parts of Lake Sibaya, although most of the channels have dense reed beds, making accurate counts from the air very difficult. The population appears to have declined significantly during the past decade (See Fig. 3) with 36 crocodiles being the highest number counted during the 2003 aerial surveys. Weather conditions affected the number of crocodiles counted, with 34 and 36 counted during optimal conditions, but only 27 counted during an overcast survey (18 April) with a moderate wind (See Table 1, p. 11). The same observer (observer 1) conducted the aforementioned surveys, but a second observer (observer 2) participated during a simultaneous double count on 18 April and counted 16 crocodiles, while observer A counted 27, highlighting the effect of observer bias on crocodile surveys. The results of the two highest counts (34 and 36) suggest that a high precision (repeatability) is possible, even if the count is not an accurate reflection of the true population.

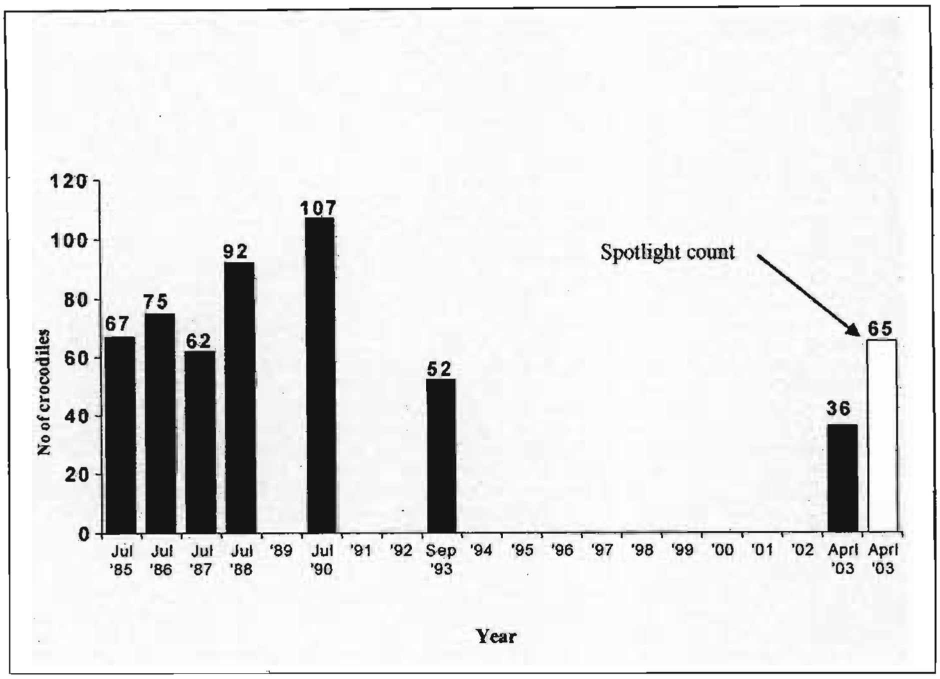

Figure 3 Aerial (1985 – 2003) and Spotlight surveys (2003) at Lake Sibaya

Spotlight surveys

Spotlight surveys seem to be a more accurate method to assess the relative abundance of the population and 65 crocodiles were counted as opposed to the highest aerial count of 36 crocodiles (See Fig. 3, p. 15). This reflects a 72% increase in density (excluding hatchlings) and highlights the importance of spotlight surveys when surveying relative low-density crocodile populations, such as at Lake Sibaya.

Approachability proportion

Woodward and Marion (1978) defined the approachability proportion as the proportion of crocodilians successfully approached (during a spotlight survey) within an adequate distance to make an accurate size estimate. An adequate distance was defined as 10 m or closer, and the approachability proportion was 63.08% during the spotlight surveys. The distance of approachability seemed to increase with an increase in total length, e.g. the mean distance of approachability for a juvenile was 2.8 m, intermediate 5.3 m and adult 16.7 m. One of the shortfalls of spotlight surveys was the relatively high proportion of large crocodiles in the "Eyes Only" category (See Fig. 4). The effect of this shortfall could be reduced by augmenting the size data with aerial surveys, where the size of crocodiles is positively correlated with the probability of detection, highlighting the importance of a combined (aerial and spotlight) survey approach.

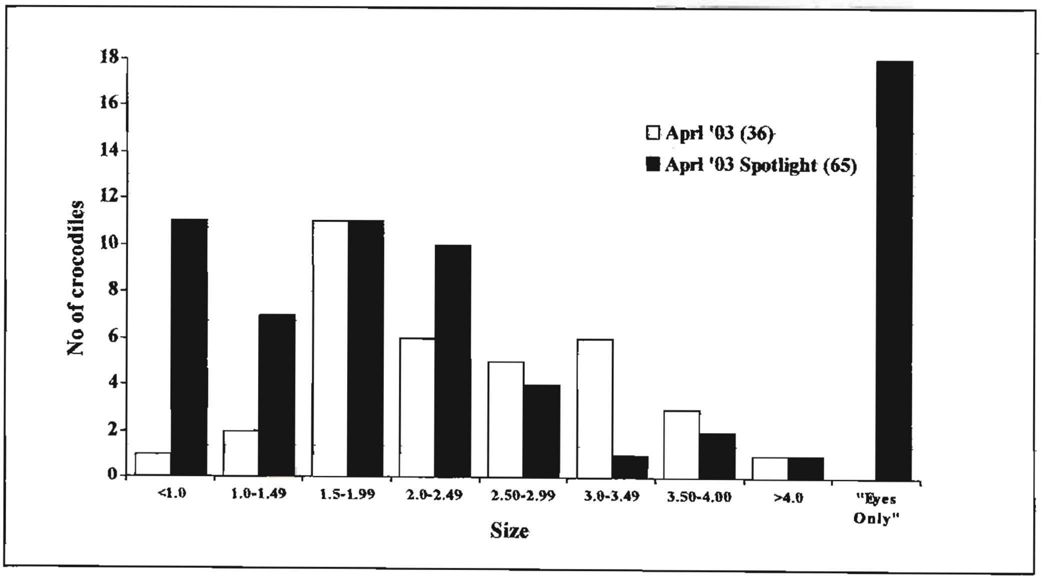

Figure 4 Approachability proportion per size class

2003 nest survey

The three nests found during the survey indicate that crocodiles are nesting at Lake Sibaya, but at very low numbers if compared to the 30 nests found during 1970 (Bruton 1979). Nesting activity has declined over the past 35 years and it seems that subsequent to the 1975 flooding, the highest number of nest recorded was six nests for the years 1986, 1988 and 1990. It seems like anthropogenic related pressures, such as the disturbance of cattle along the shoreline (pers. obs.), disturbance by local fishermen and illegal harvesting (Bruton 1979; Ward 1985; Kyle & Ward 1995) is keeping the breeding population at low density and causing females to nest in marginal areas (e.g. Nest 1). A cause for concern is the presence of cattle very close to Nest 2 (pers. obs.), an area part of the Coastal Forest Reserve that has historically benefited from a higher status of protection. Although the area is not fenced, past ranger patrols have kept cattle outside of this area and an increase in patrols between October and March should be a priority.

2004 nest survey

No crocodile nests were found during the 2004 nesting survey. In order to interpret this finding, it is necessary to consider a few aspects regarding the nesting ecology of *C. niloticus* within the context of the state of the population at Lake Sibaya. No biological research has ever been conducted on any aspect of the nesting ecology of *C. niloticus* at Lake Sibaya, and comparative aspects like the average clutch size and weight or reproductive frequency is unknown. Crocodiles rarely produce every year in the wild, but rather have an average or sometimes low reproductive efforts compared to other reptiles of similar size (Ross 1999). Kofron (1989) showed that often *C. niloticus* do not nest in consecutive years and Leslie (1997) found a reproductive frequency of between 13.0 – 29.7% at nearby Lake St Lucia. The highest aerial count suggests that 15 adult crocodiles are present in the lake, and in the absence of any biological data and an assumption of a 50% sex ratio, it is possible that seven are female. With a 30% reproductive frequency, 2.3 nests are expected and as a result the fact that not a single nest was found during the 2004 survey is not that surprising, as the likelihood of missing two nests is quite possible.

Identification of potential nesting areas

The 63 potential nesting areas identified and evaluated are important within the framework of a proposed programme for the sustainable use of crocodiles at Lake Sibaya. One of the first aims of such a programme would be to secure and protect the most important breeding areas in the system, and in order to prioritise nesting areas each one had to be evaluated. Nineteen potential nesting sites are situated within the Mabaso Community Game Reserve, which is fenced and thus limited to cattle disturbance, one of the key factors preventing successful hatching.

Estimating crocodile abundance

An index of relative abundance for the crocodile population was determined from the aerial and spotlight surveys using the technique developed by Magnusson et al. (1978) for combining two independent counts. Each crocodile mapped by GPS at a unique location represented one animal and the relatively low density and wide spacing of crocodiles seen, and close timing of aerial and spotlight surveys justify this assumption. Using GPS technology, it was possible to determine the number of crocodiles seen during both the spotlight and the aerial surveys, how many were counted during the spotlight survey, but not during the aerial survey and how many were observed from the air, but not seen during the spotlight survey.

Magnusson et al. (1978) believed that the model is logically equivalent to the Peterson estimate and they are confident that the same mathematics could easily be adapted to this model. During the spotlight survey crocodiles are mapped ("marked"), and if the maps are compared after the aerial survey it will become evident that some of the mapped ("marked") crocodiles have been "recaptured", while other crocodiles recorded in the aerial survey are unmapped.

To calculate the variance, a translation of Seber's formula (1973 cited in Magnusson et al. 1978) is used and by comparing the mapped crocodile positions of spotlight and aerial survey sightings, the probability of seeing a crocodile during the spotlight survey was estimated as 0.80. The probability of seeing a crocodile during the aerial survey was estimated as 0.539, and the number of crocodiles missed by both surveys is estimated as 10.25. Thus, the total number, both counted and uncounted is estimated as 112.04 crocodiles, with an approximate variance of 22.49 and a standard error of 4.74.
The two important assumptions for using this method are firstly, that the counts of the spotlight survey and aerial survey are independent of each other and secondly, that there is a constant probability of detecting a crocodile by a given survey method.

Calculating the Coefficient of Variation (CV)

The same method developed by Magnusson et al. (1978) was used to calculate the coefficient of variation, or precision for the total count. By comparing the mapped crocodile positions for the simultaneous aerial double count on 18 April 2003, it is evident that 20 crocodiles were seen by *both* microlight aircraft/observers, 17 crocodiles were counted *only* by microlight A which flew clockwise around the lake, and 6 crocodiles were counted *only* by microlight B, which simultaneously flew anti-clockwise around the lake.

The variance (required to calculate the CV) is 10.787 and the coefficient of variation is 2.93%. This is small enough (< 15%) for the data of this survey to be used in future monitoring (Hutton 1992).

Calculating a correction factor

By excluding the three hatchlings, a correction factor of 1.72 based on the spotlight surveys, was determined and could be used for future aerial surveys at Lake Sibaya, although continuing with further night surveys is suggested until it has been shown that this correction factor is stable.

6. CONCLUSION

The Greater St Lucia Wetland Park World Heritage Site is one of the most important remaining areas for the conservation of *C. niloticus* in the Republic of South Africa. Although waterbodies such as Lake Sibaya, within the Greater St Lucia Wetland Park, are protected by a plethora of legislation and international conventions, e.g. KwaZulu Natal Nature Conservation Management Act no. 9 of 1997, World Heritage Convention Act no. 49 of 1999, Ramsar Convention, they exist within a larger landscape of tribal land where unemployment and poverty is causing apparent unsustainable levels of natural resource use, including the illegal harvesting and killing of crocodiles as well as disturbance of crocodile nesting areas.

In the light of the present situation, an integrated crocodile management plan is required to address the apparent decline in the crocodile population as well as to deal with the fears, concerns and possible opportunities for the local communities. This plan should be developed by Ezemvelo KZN Wildlife through collaboration with The Greater St Lucia

Wetland Park Authority and the local amaThonga communities living adjacent to Lake Sibaya. Important information for such a management plan was acquired by conducting a population survey and providing information on the population structure, distribution and density and investigate factors affecting breeding for 2003 and 2004.

A combined survey approach was used consisting of four aerial surveys, seven spotlight surveys by boat and two spotlight surveys on foot and the population was estimated at 112 crocodiles with a variance of 22.49 and standard error of 4.47. The highest count during the aerial surveys was 36 crocodiles, suggesting a decline of 66% during the previous 13 years in the population index, based on earlier surveys. Sixty-five crocodiles were counted during the spotlight surveys, 72% more than the highest aerial count, which indicates the importance of spotlight surveys.

During 1970, at least 30 female crocodiles nested at Lake Sibaya, which decreased to three during 2003 and not a single nest was found in 2004. Even if the nest effort or reproductive frequency is naturally low at Lake Sibaya, a significant decrease in nesting over the past three decades is evident. Only three hatchlings were found during the spotlight surveys and this apparent scarcity suggests diminished recruitment in the lake.

It is clear that the crocodile population are under threat as a result of direct and indirect anthropogenic pressures, a product of years of antagonism and hostility, combined with illegal harvesting in crocodile parts, mainly for traditional medicine.

In the light of the reality that the communities living adjacent to Lake Sibaya will probably keep their right of access to the lake in the foreseeable future, the only viable option is to enhance the commercial value and benefits crocodiles can provide to the community, thereby increase incentives to conserve them (Webb 2003). This programme should be part of a integrative crocodile management plan.

Sixty-three potential nesting areas were identified and evaluated in terms of their relative suitability for nesting. These sites could play an important role in increasing the population to support a sustainable use programme at Lake Sibaya. The likely alternative might be extirpation of this important predator from the largest freshwater ecosystem in South Africa's first World Heritage Site.

7. RECOMMENDATIONS

7.1 Initiate a programme based on the sustainable use of crocodiles

To ensure the survival, growth and viability of the crocodile population at Lake Sibaya, I recommend the implementation of a programme based on the sustainable use (ranching/eco-tourism) of crocodiles. Sustainable use or "market driven conservation" is often controversial and there is general acceptance that it never will be a universal panacea against the loss of biodiversity (Hutton, Ross and Webb 2001). However, with proper management, it can provide the needed economic incentive for communities to maintain crocodiles and their habitat in a natural state (Ross and Godshalk 1994) thereby increase incentives to conserve them (Webb 2003). It is imperative that the local community and Ezemvelo KZN Wildlife be partners in this initiative, with a clear and realistic understanding of how this initiative could benefit the community in the long-term.

7.2 Actively protect historical, recent and potential breeding areas

I recommend the active protection of historical, present and a selected number of identified potential nesting areas. These sites must be restricted areas for cattle and subsistence fishermen during nest selection and the breeding season, from October to April at Lake Sibaya. Community members could be contracted and trained to act as custodians of these sites, so that no physical barrier needs to be constructed.

7.3 Closer co-operation with Mabaso Community Game Reserve

The Mabaso Community Game Reserve, bordering the shoreline of Lake Sibaya, can play an important role in the conservation of crocodiles at Lake Sibaya. It is currently one of the only areas, which is fenced and as a result could become an immediate sanctuary for crocodile breeding. This community game reserve could act as a catalyst for ecotourism in general and crocodile ecotourism in particular, as a much needed niche in the area.

It is also a suitable site to start a small community crocodile ranch, where a few crocodiles could be kept to augment the natural breeding in the lake. The community crocodile ranch should not divert the emphasis from the sustainable use (harvesting) programme in the lake, as ranching requires that wild crocodiles and *in situ* nests be conserved as source of stock (Ross and Godshalk 1994).

7.4 Restock Lake Sibaya with a viable breeding component

As a result of the present low numbers of potential breeding females (approximately seven) and in order to fast track the proposed sustainable use programme, restocking the lake with a viable breeding component within the ecological parameters for Lake Sibaya is recommended. Breeding stock could be obtained from Ndumu Game Reserve, with due caution of the genetics involved in such a translocation. Sexually mature females released in the lake should be fitted with transmitters in order to monitor movement for the first few months. A restocking plan could only ensure subsequent to negotiations with the Greater St Lucia Wetland Park Authority and the three local communities living adjacent to Lake Sibaya.

7.5 Link future conservation programmes with postgraduate research

The proposed sustainable use programme should be linked to a postgraduate study, in order to ensure a comprehensive literature review and knowledge of the concept. Not all conservation programmes based on "market driven conservation" have been successful (Hutton et al. 2001) and it is suggested to gain as much as possible insight into practical lessons learned prior to the startof such a programme at Lake Sibaya. The research should be applied in nature with the intention to provide guidance to the overall management of the crocodile population.

7.6 Establish a multi-sectoral crocodile partnership

The conservation of crocodiles and proposed sustainable use programme should be managed through a multi-sectoral partnership, including Ezemvelo KZN Wildlife, local communities around Lake Sibaya, the Greater St Lucia Wetland Park Authority and stakeholders of Mabaso Community Game Reserve.

7.7 Initiate a crocodile educational programme

As part of the overall conservation of crocodiles, a educational programme should be launched with the intention to inform and educate the local communities on the dangers, ecological and economical benefits of having a viable population of crocodiles in the lake.

This should be targeted at schools, adults and users (fishermen and tour guides) of Lake Sibaya.

7.8 Continue with population monitoring

Continue with aerial surveys, spotlight monitoring and nesting surveys at Lake Sibaya in order to monitor the population index as well as recruitment in the lake. Monitoring would also play a crucial part in a sustainable use programme, as the levels of harvesting will be adjusted according to the state of the population.

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