The ecology, conservation and management of Nile crocodiles *Crocodylus niloticus* in a human dominated landscape

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May 2009

A thesis submitted to Imperial College London in candidacy for the degree of Doctor of Philosophy

Author's declaration

This thesis is the result of my own research and contains no work done in collaboration. The text does not exceed 100000 words and no part has been submitted to any other university in application for a higher degree or diploma.

Patrick W. Aust

Abstract

Nile crocodiles were extensively persecuted throughout much of the 20th century. The extinction of the species was only averted by the timely intervention of conservationists and by the beginning of the 21st century most populations had recovered. Many of the conservation measures designed to curb the original extinction threats remain unchanged and are now perceived by some to be outdated. The recovery of Nile crocodile populations has been accompanied by rapid human population growth and demands for freshwater resources. This phenomenon has resulted in a converging conflict crisis between Nile crocodiles and humans. The aim of this thesis is to (a) quantify the extent of human crocodile conflict (HCC) and (b) establish the implications for conservation and development.

(a)The extent of HCC was assessed by (i) analysing losses incurred by local communities (ii) analysing the demographics of crocodiles in relation to human activities (iii) analysing the relationship between humans and crocodile prey species.

Nile crocodiles pose a substantial threat to subsistence livelihoods whilst rural communities have significant negative impacts on crocodiles (i) Estimates suggest an annual loss of between ~255 and ~6864 cattle per year and damage to an estimated 71500 fishing nets per year in North Eastern Namibia. (ii) All crocodile size classes showed a negative relationship with people at the inter- and intra-river levels. (iii) Crocodile prey species showed a significant negative spatial relationship with cattle.

(b) Conservation and management implications were assessed by estimating the spatial patterns of HCC explanatory variables on a continental scale. Protected areas are important for crocodile conservation. The use of crocodile habitat as boundaries for protected areas raises important questions relating to HCC.

Acknowledgements

The Beit Trust funded my full scholarship and provided substantial funding towards fieldwork costs in Namibia. In doing so the Beit Trust has enabled me to transform my Africa bound passion into an international career and for this I will be eternally grateful. I would especially like to thank Angus Ramsay for his personal support and encouragement over the last four years. The Namibian Nature Foundation (NNF) acted as my host institution in Namibia and provided invaluable support in the field, including the use of a vehicle and boat. In particular I would like to thank Chris Brown for his wisdom and invaluable contributions to the project. Fieldwork costs were further supplemented by the Integrated Rural Development and Nature Conservation (IRDNC) and a grant from the Nedbank Namibia Go Green Fund. The IRDNC also provided crucial logistical support in Caprivi. I would also like to thank the following lodges for their substantial contributions in the field: Lianshulu, Kings Den, Shamvura and Savannah. Funding for travel costs in the UK was generously provided by Tim Coulson.

I am grateful to the Ministry of Environment and Tourism for granting me permission to carry out research in Namibia, build a field camp in Bwabwata National Park and for their general support wherever needed. In particular I would like to thank Shadrek Siloka, Apollinaris Kannyinga and Toivo Uahengo. I would also like to thank Richard Aingura and the rest of the Susuwe team for their friendship and support around camp.

For assistance with fieldwork I would like to thank Brenna Boyle, Fiona Llewellyn, Robin Beatty, Ben van der Waal, Dave Ward, Alfred Sibongo, Dick Sharp, Mark Paxton, Ralph Meyer, Duncan Cummings, Calvin Maiba, James Maiba, Mike Chase, Kelly Landen and Thandazani Nkala. I would especially like to thank the members of the community conservancies of North Eastern Namibia for providing endless support and companionship in the field.

The IRDNC and the community conservancies of North Eastern Namibia provided the event book data, the NNF provided the aerial survey data and the UNEP – WCMC and the IUCN SSC Crocodile Specialist Group provided the crocodile survey data. I am very grateful to these organisations and the relevant people involved for allowing me to analyse their data. In particular I would like to thank Chris Brown, Jon Hutton and Daniela Lainez.

I would like to thank a number of local residents who contributed in a variety of ways towards making our stay in Namibia such a pleasure. Dick, Katy and the rest of the Sharp family, Carol Murphy, Alfred Sibongo, Duncan Cummings, Robin Lines, Benedict Libanda, Ben and Willie van der Waal, Denyse Faulkner, Ron Phillips, Robin Beatty, Kelly Landen, Mike Chase, Garth Owen-Smith, Mark and Charlie Paxton, the IRDNC Caprivi office team, NNF office team, Friedrich Alpers**,** Dorothy Wamunyima, Ralph and Sharon Meyer and the Diggle family. I would especially like to thank Dave Ward for his hospitality and willingness to share his phenomenal knowledge of the area.

In the UK many people gave me advice, encouragement, friendship and critical assistance with my thesis, including Joe Smith, Tom Ezard, Aurelio Malo, Arpat Ozgul,

Isabel Smallegange, Brenna Boyle, Kevin Wallace, Rodolphe Bernard, Luca Borger, Fanie Pelletier, Kelly Moyes and Mila Plavsic. My PhD would not have been possible without the excellent supervision and mentorship of Tim Coulson, whose difficult job essentially began many years ago when I was chasing wild dogs around Zimbabwe. I would also like to thank Jacqui and Jules Pelissier for generously providing me with a home from home in Sunningdale.

Finally, I would like to thank my family. Jan Tink and the rest of the Tink clan for sponsoring much of our camp equipment and providing us with a much needed home in Zimbabwe. I would like to thank Lady Jane and Sir Bruno Welby for their exceptional generosity and kindness over the last ten years. Nothing would have been possible without my long suffering mother and father and two sisters. They have endured and indeed encouraged my passion for creepy crawlies and their unconditional love has given me the fortitude to be bold and unafraid. I would like to make a special mention of my wife, Rene, whose name should appear in just about every paragraph above, and whose love has transcended my antisocial habits and caveman mentality. Above all else, I would like to thank God, for keeping a wandering lamb on life's green floodplains, away from the rivers edge, where there be dragons.

Contents

Title page.....1
Authors declaration.....2
Abstract.....3
Acknowledgements.....4
Contents.....6

CHAPTER 1: Introduction.....7

CHAPTER 2: Study Area.....19

CHAPTER 3*: The impact of Nile crocodiles on rural livelihoods.....27
3.1 Introduction.....27
3.2 Methods.....30
3.3 Results.....35
3.4 Discussion.....42

CHAPTER 4*: The impact of rural communities on Nile crocodiles.....46
4.1 Introduction.....46
4.2 Methods.....49
4.3 Results.....54
4.4 Discussion.....61

CHAPTER 5*: The distribution of wildlife within the wetland ecosystems of North Eastern Namibia and implications for crocodile conservation.....65
5.1 Introduction.....65
5.2 Methods.....69
5.3 Results.....74
5.4 Discussion.....76

CHAPTER 6*: A large scale spatial analysis of Nile crocodile conservation in Africa.....83
6.1 Introduction.....83
6.2 Methods.....86
6.3 Results.....100
6.4 Discussion.....108

CHAPTER 7: Discussion.....113

Appendix I.....122
Appendix II.....134
References.....138

*These chapters are to a large extent in stand alone paper form. The format has been altered for the purpose of the thesis but the content remains unchanged.

CHAPTER 1: Introduction

Populations of wild Nile crocodiles can be considered economically and ecologically valuable assets, particularly in the cash poor countries of the third world. Crocodile meat and skins command high prices on the international market (Thorbjarnarson, 1999) and wild crocodiles are a valuable component of the photographic (Llewellyne, 2007; Ryan, 1998) and hunting tourism industries (Lindsey, Roulet & Romanach, 2007b). Crocodiles are top predators and as such perform an important role in maintaining the structure and function of freshwater ecosystems (Glen *et al.*, 2007; Leslie & Spotila, 2001; Ross, 1998). As a usable resource, population numbers have increased dramatically in recent decades and they are now considered locally abundant in many areas.

Paradoxically, the survival of Nile crocodiles in the wild is increasingly uncertain due a combination of anthropogenic threats. First, the deterioration and loss of habitat is an omnipresent conservation threat facing many large animals in Africa (Hanks, 2001), including crocodiles (Ross, 1998; Shacks, 2006). In addition, growing freshwater scarcity threatens all the important Nile crocodile range states in Southern, Eastern and Sudano-Sahelian Africa (ECA, AU & AfDB, 2000; UNEP-WCMC, 2008), yet the alleviation of Africa's socioeconomic poverty crisis is heavily dependent on the increased utilisation of freshwater resources (ECA *et al.*, 2000). As a result, crocodile specific habitat is increasingly restrictive and disproportionately threatened.

Second, the vast majority of people living alongside crocodiles in Africa derive minimal benefit from them and see crocodiles only as dangerous problem animals (Graham & Beard, 1973; McGregor, 2005; Pooley, 1982; Ross, 1998; Thomas, 2006). As a listed CITES species, Nile crocodiles enjoy considerable national and international protection and in most cases the killing of wild animals is restricted and rigorously controlled (UNEP-WCMC, 2008). This traditional approach to conservation has often been blamed for increasing attacks on humans and livestock resulting in decreased local support for conservation initiatives (McGregor, 2005). Illegal persecution driven by reprisals and the defence of livestock and equipment is now a commonplace in many areas (Boyle, 2007).

Third, primary Nile crocodile habitat is inherently difficult to conserve. Crocodiles are dependent on rivers and wetlands which have proved notoriously difficult to manage due to their complexity and connectivity (ECA *et al.*, 2000; Ramutsindela, 2007). In Southern Africa, for example, perennial rivers are often used as geographical barriers demarcating the boundaries of human landscapes. Freshwater is also a valuable and highly contentious commodity within the region (Chenje, 1998) and as a result, large sections or both banks of a river are rarely governed by homogeneous conservation or land management policies. This makes the effective conservation of large aquatic species like crocodiles particularly difficult.

Considerable literature exists on Nile crocodiles. Their hide value and conservation status have been a major driving force behind extensive research into the biology, ecology and captive propagation of the species (Blake & Loveridge, 1975; Gans & Pooley, 1976; Graham *et al.*, 1973; Hocutt, Loveridge & Hutton, 1992; Hutton, 1987; Shacks, 2006; Siamudaala, Kunda & Nambota, 2004). As infamous predators of humans, work has also been done on the nature and mechanics of crocodile attacks (Boyle, 2007; Fergusson, 2004; Scott & Scott, 1994; Thomas, 2006; Vanwersch, 1998). Apart from Thomas (2006) and Boyle (2007), comparatively little work has been carried out on the broader impacts of crocodiles on rural communities, and until recently virtually no work had been carried out on the impact of rural communities on crocodiles (Shacks, 2006). Furthermore, very little work has been carried out on the sustainable management of Nile crocodiles specifically for the benefit of those who bear the costs of living alongside them.

Evidence suggests that the collective value of Nile crocodiles could offset many of the threats facing them and reduce the costs associated with conserving them provided the population is managed and exploited in an ecologically and socially sustainable manner (Adams *et al.*, 2004; Hutton & Leader-Williams, 2003; Ross, 1998). Viewed in this way, crocodiles could also be employed as a valuable tool in poverty alleviation and freshwater conservation (Adams *et al.*, 2004; Hutton *et al.*, 2003).

The first step towards achieving these goals requires a sound understanding of the relationship between people and crocodiles within the human wildlife landscape that characterises much of rural Africa.

1.1 History of crocodile exploitation in Africa

The large scale harvest of Nile crocodiles for their skins essentially began with the Industrial Revolution in Europe and the concurrent opening up of the African colonies. By the end of World War II hunting crocodilians was a lucrative enterprise throughout the tropics. The scale of the exploitation was impressive; during the mid 1950s, nearly 60 000 Nile crocodile skins were exported from East Africa each year (Ross & Garnett, 1992) and between 1956 –1977 some 40 000 skins were exported from Botswana alone (Cott & Pooley, 1971). Crocodiles also suffered from persecution as a result of their sinister reputation. Colonial governments throughout the continent categorized the crocodile as a pest and sanctioned its killing (Cott, 1961). In Uganda, 1500 to 2000 nesting females were destroyed in control programs from the 1930s to 1950 (Gans *et al.*, 1976).

By the late 1950s most populations of Nile crocodiles were severely reduced. Gans and Pooley (1976) reported population reductions of up to 90% in virtually every crocodile range state in Africa between 1940 and 1976. These catastrophic population crashes combined with the global conservation movement of the 1960s began to change the way people perceived crocodiles (McGregor, 2005). Furthermore, people began to appreciate the economic potential of crocodiles as a natural resource. By 1972 most African governments had adopted some form of conservation measure (Cott *et al.*, 1971). National laws were further backed up by international controls in the crocodilian skin trade with the 1975 listing of Nile crocodiles as a CITES appendix I species (UNEP-WCMC, 2008). This effectively halted the decline of most populations.

Crocodilians are resilient animals and have demonstrated a remarkable capacity to recover from severely depleted numbers (Webb *et al.*, 2001). The dramatic recovery of American alligator and saltwater crocodile following the cessation from uncontrolled exploitation has been well documented (Read *et al.*, 2004; Thorbjarnarson, 1999). As a

result of linked conservation and commercial interest the Nile crocodile populations have expanded dramatically over recent decades (McGregor 2005).

1.2 Ecology and Conservation of Nile crocodiles

Nile crocodiles are found in a wide variety of freshwater habitats throughout tropical and sub tropical Africa (Branch, 1990; CSG, 2009; Ross *et al.*, 1992; Sindaco & Jeremcenko, 2007; Spawls *et al.*, 2004). In southern Africa they usually breed in the hot summer months, the female laying a clutch of approximately 16-80 eggs in a hole dug close to the waters edge (Branch, 1990). Diet varies with age: small crocodiles eat mainly invertebrates whilst sub adult and adult animals feed mainly on fish. Large adult crocodiles feed on terrestrial mammals including livestock and humans (Ross *et al.*, 1992).

Crocodilians play an important role in maintaining the structure and function of freshwater ecosystems (Ross, 1998). In India, Whitaker and Whitaker (1977) found aquatic systems to have suffered and fisheries declined as a result of removal of crocodiles (Whitaker & Whitaker, 1977). As large predators crocodiles can be considered important 'umbrella' species for the conservation of freshwater ecosystems (Seddon & Leech, 2008).

Reptile species are declining on a global scale (Whitefield Gibbons *et al.*, 2000). Out of a total of 23 crocodilian species, seven are listed as either endangered or critically endangered on the IUCN red list (CSG, 2008). Habitat loss and degradation, introduced invasive species, environmental pollution, disease, unsustainable use and global climatic change have been listed as the most significant threats to reptiles (Whitefield Gibbons *et al.*, 2000). Ross (1998) lists several past and present anthropogenic threats facing crocodilians but cites habitat loss and alteration as the foremost and most significant threat.

Despite this, Nile crocodiles remain well represented throughout most of southern and east Africa and have so far proven to be resilient to human encroachment and

habitat degradation. They are considered by the IUCN to be 'lower risk, least concern' (CSG, 2008).

1.3 Management: exploitation and sustainable use of Nile crocodiles

1.3.1 The trade in Crocodilians

The trade in crocodile skins focuses around the utilization of skins for the manufacture of luxury leather goods. More recently the industry has begun to develop markets for other products including the meat and organs (Cummings pers comm)

The annual world trade of all crocodilian species is estimated at 1.3 million skins (Caldwell, 2004). Nile crocodile skins number about 160 000 (Caldwell, 2004) of which about 10 000 are of wild origin (UNEP-WCMC, 2008). Illegal trade is thought to be insignificant (Ross and Garnett 1989).

The raw material of the trade is the skins which originate from farms, ranches and wild populations. These skins are bought by middlemen who in turn sell them on to tanneries in France, Italy, Spain, the US, Japan and the Far East (Ross and Garnett 1989). From the tanneries the trade diversifies into a number of interrelated industries specializing in luxury leathers.

Affluent consumers represent the core market for crocodilian leather. Demand for skins fluctuates greatly due to trends in the high fashion industry and this, along with cheap imitations can pose a threat to the industry (Thorbjarnarson, 1999).

1.3.2 Farming and Ranching

The decline in the supply of wild skins and the simultaneous rise in skin prices provided the incentives for the development of the first crocodile farms. Crocodile farming involves the captive breeding and rearing of crocodiles whilst ranching relies on harvesting wild populations to some degree (Ross *et al.*, 1992). Most Nile crocodile ranching involves the collection of wild eggs but a small number of young crocodiles are taken legally in some countries (Fergusson pers comm).

Crocodile farming and ranching have been subject to some criticism. Traffic International argues that there is a lack of demonstrable sustainability and the absence of any significant linkage between the trade and conservation action at the habitat or species level (Jenkins & Broad, 1994). Production systems involving non-traditional animal species have however been shown to have ecological benefits. For example, iguana farming in several Central American countries stimulated nature conservation attitudes and promoted forest protection (Eilers *et al.*, 2002). There has also been scientific spin-off with countries funding research projects on crocodiles leading to increased understanding of the species (Webb, Manolis & Whitehead, 1987). Many farms and ranches have become commercial tourist attractions promoting greater awareness and tolerance towards crocodiles. The IUCNs Crocodile Specialist Group regards crocodile ranching as an economically sound practice with conservation value (CSG, 2004).

Most crocodile farming and ranching operations are intensive production systems requiring high levels of financial investment and skilled labour (Ntiamoa-Baidu, 1997). As such the vast majority of subsistence communities living alongside crocodiles seldom benefit directly from these operations (McGregor, 2005).

1.3.3 Harvesting crocodiles from the wild

Harvesting strategies of wild crocodilians may vary according to species and size class. In 2005, CITES parties issued 11571 Nile crocodile permits for animals taken from trophy hunting, problem animal control and animals harvested for their skins (UNEP-WCMC, 2008).

Large wild crocodilians are considered valuable trophy animals by the sport hunting industry. Foreign clients pay up to $3000 US to shoot a single Nile crocodile (HHKSafaris, 2008). In Namibia trophy hunting generates at least US$19.6 million in direct expenditure and represents a significant component of the Namibian economy (Humavindu & Barnes, 2003). Furthermore, some 24% of the income earned in the trophy hunting industry accrues to poor segments of society and it is seen as an important contributor to development and wildlife conservation in Namibia (Humavindu *et al.*, 2003).

Crocodiles may be harvested directly for their skins and/or crocodile eggs may be collected to provide stock for crocodile ranches. In Venezuela, the sustainable harvest of more than one million wild spectacled caimans (*Caiman crocodilus*) between 1983 and 1995 brought in foreign earnings in excess of US$115 million (Thorbjarnarson & Velasco, 1999). Large crocodiles that pose a threat to humans or livestock are sometimes harvested or removed as problem animals (Kofron, 2004). Detailed population monitoring and ecological research programs have demonstrated that harvested crocodilian populations can continue to grow (Thorbjarnarson *et al.*, 1999).

To date the management of wild Nile crocodiles has been based largely on crocodile ecology and economics with very little regard for social implications at the local level (McGregor, 2005). Wild harvests are usually carried out by a limited number of licensed individuals in the private commercial sector and local communities see very little direct benefit from these harvesting strategies. Stearman et al (1992) suggests that any attempt to develop and implement resource conservation management plans must include both biological and social research to assess fully the complexities inherent to the human exploitation of faunal resources (Stearman & Redford, 1992).

1.3.4 Non consumptive use

Ecotourism has the potential to contribute to the sustainable use and persistence of wildlife and natural resources (Milner-Gulland & Rowclife, 2007). Very little information exists on the non consumptive instrumental value of wild crocodiles. In the Northern Territory of Australia, crocodiles are considered a significant part of the tourist offering and crocodile attractions such as boat trips draw in many tourists each year (Ryan, 1998). Similar crocodile based tourism activities exist in North and Central America but no such activities are known to exist in Africa. In Namibia wildlife based ecotourism is a significant growth industry and a major contributor to rural development (NACSO, 2006b). There is significant room for expansion and diversification in the industry (NACSO, 2006b) and there is evidence to believe that crocodiles could provide a valuable addition to the standard tourist activities (Llewellyne, 2007).

1.4 Crocodiles as problem animals

The growing industrial, agricultural and domestic demands for freshwater throughout much of Africa have resulted in many freshwater ecosystems being settled by growing human populations (Chenje, 1998; ECA *et al.*, 2000). Human encroachment on alligator habitat in the United States has been show to be positively correlated with attacks and nuisance alligators (Langley, 2005) and it is likely that a similar situation is arising in Africa with Nile crocodiles.

Crocodiles are efficient colonisers of suitable habitat and they are found in many rivers and freshwater impoundments outside of protected areas (Kofron, 2004; Pooley, 1982). Their amphibious nature and cryptic behaviour enable them to move relatively freely and remain undetected even in densely populated areas (Pooley, 1982). Furthermore, whereas practical and effective methods exist to constrain the movement of large terrestrial carnivores (Wade, 1982) and sharks (Dudley, 1997), no such methods exist for crocodiles.

Nile Crocodiles are one of the most dangerous crocodilians to humans (Revol, 1995). They readily kill livestock and people, particularly if their natural prey base has been eroded. Accurate figures on crocodile related human fatalities and livestock losses are difficult to ascertain but from available reports it would appear that the problem is considerable (CSG, 2009). For example, 27 human fatalities were recorded in the first eight months of 2005 in Mozambique (Anderson & Pariela, 2005) and similar large figures have been recorded elsewhere in Africa (Fergusson, 2004; Scott *et al.*, 1994).

Crocodiles may compete with humans for food resources. Crocodiles prey on many economically important fish species (Graham *et al.*, 1973; Wallace, 2006) and are often perceived to be major competitors to fisheries (Santiapillai & de Silva, 2001). There is however evidence suggesting that crocodiles may not pose a serious threat to fisheries (Games & Moreau, 1997) and in fact may be beneficial to them by eating more significant fish predators like water birds (Santiapillai *et al.*, 2001).

Crocodiles may destroy valuable fishing equipment and interfere with fishing efforts. Fish caught in nets or on fishing lines are known to attract crocodiles which often end up destroying the fishing gear whilst attempting to feed on the ensnared fish

(Boyle, 2007; McGregor, 2005). Fishing equipment is considered a valuable asset to developing fisheries and any losses can impact heavily on livelihoods (McGregor, 2005).

Crocodile human conflicts can have secondary social and political implications. In many rural African communities crocodiles are the subject of great cultural and spiritual importance (Ross *et al.*, 1992) with the potential to disrupt the social stability in small communities (McGregor, 2005). In some cases the failure of governments to deal with problem crocodiles effectively has resulted in fractious relationships between fishing communities and local authorities (Anderson *et al.*, 2005). Historically most crocodile conservation programmes were developed without reference to local attitudes (Blake *et al.*, 1975). More recent crocodile conservation and management efforts have focused on providing benefits to local communities (Dzoma, Sejoe & Segwagwe, 2008; Revol, 1995), however in many cases these programs are believed to be inadequate (CSG, 2009).

1.5 Sustainable use with multiple stakeholders

'Sustainable use, both extractive and non-extractive, is a dynamic process toward which one strives in order to maintain biodiversity and enhance ecological and social economic services recognising that the greater the equity and degree of participation in governance the greater the likelihood of achieving these objectives for present and future generations' (IUCN, 2001). Sustainable use is an explicit component of sustainable development (IUCN/UNEP/WWF, 1980).

Bennett & Robinson (2000) identified six factors that influence the sustainability of a harvest system: (i) physical (e.g. accessibility of exploited populations), (ii) biological, (iii) cultural (e.g. taboos prohibiting hunting), (iv) social (e.g. human population density) (v) economic and (vi) institutional (e.g. legislation) (Bennett & Robinson, 2000).

The sophisticated theory of sustainable use, or at least the application of the theory, has been questioned due to frequent failure to prevent over exploitation. For

example, many fisheries have collapsed despite the timely application of sustainable use management protocols (Mullon, Freon & Cury, 2005). However there are also numerous examples of successful sustainable exploitation of species e.g. (Thorbjarnarson *et al.*, 1999)

Species resilient to overexploitation have a high rate of population growth rate. Growth rate depends on life history strategy. With respect to sustainable use, an ideal life history strategy would enable a species to mature immediately after birth, have zero mortality and produce offspring at an infinite rate (Law, 1979). Growth rates may also be affected by density-dependent and -independent processes. As populations grow they become regulated by intrinsic density –dependent processes such as conspecific competition and extrinsic density independent processes such as environmental stochasticity. Populations that exhibit a strong density dependent response at high population levels and that are not vulnerable to stochastic processes can support high levels of harvesting (Kokko, 2001).

As a species crocodiles exhibit many desirable traits for sustainable utilisation. Their life history includes high reproductive capacity and growth rates that are strongly density dependent both in terms of survival and fecundity (Webb 2001).

Crocodilian sustainable use programs have a wide variety of stakeholders ranging from subsistence farmers to the high end fashion industry. The activities and destinies of multiple stakeholders and resource users are interconnected in complex ways (MacGregor, 2002; Ross *et al.*, 1992). Although they all depend on the resource, their use patters often overlap and their interests are often in conflict (MacGregor, 2002; Thorbjarnarson, 1999). The key to sustainability is having species and population specific management plans and tightly controlled use together with local institutions with rights over management and mechanisms to enforce those rights (Brown & Jones, 1999). Sustainable use can provide the necessary economic incentives to encourage people to maintain crocodilians and their natural habitats (Arroyo-Quiroz, Perez-Gil & Leader-Williams, 2007; Ross, 1998).

1.6 Crocodiles in Namibia

In Namibia wild crocodiles are found in the four main river systems in the North of the country and these populations are contiguous with larger populations from neighbouring countries (Branch, 1990).

During the 1960s and 1970s, the hunting of wild crocodiles for their skins throughout the region resulted in a drastic decline in numbers (Gans *et al.*, 1976). This prompted the relevant National Governments to curb crocodile hunting and in 1975 the then Namibian Department of Nature Conservation listed the Nile crocodile as a protected species (Griffin, 2003). This, together with increasing international controls in the trade of crocodilian skins resulted in the gradual recovery of the wild population.

Today the provisional conservation status for this species in Namibia is "Peripheral" implying that the species is vulnerable only due to limited habitat (Griffin, 2003). A national status survey carried out in 2004 found crocodile numbers in the North East of the country to be healthy with an estimated 2208 adult individuals (Brown *et al.*, 2005). In recent years crocodiles have become a major problem (Brown pers comm). These findings have contributed to the January 2005 CITES down listing of the wild Namibian Nile crocodile population from appendix I to appendix II (UNEP-WCMC, 2008).

The current management and conservation of crocodiles in Namibia is limited. A single small crocodile farm near Windhoek operates independently from the wild population. Trophy hunting is limited to approximately 25 animals per year (CITES, 2007) and is restricted to specialised management areas. Negligible numbers of problem animals are destroyed by government personnel (probably less than 5 per annum). With support from local non government organisations (NGOs) some local communities have started to offer financial compensation for crocodile related livestock and human losses however this scheme is still very new and has yet to prove effective at mitigating crocodile conflict (Murphy, 2007b). In 2005 NGO funding allowed the erection of crocodile proof harbours in several areas. Unfortunately, by 2007 all of these harbours had fallen into a state of disrepair (personal observation). There is no crocodile ranching operation nor is there any exploitation of the wild population for their skins. No formal research on crocodiles has been carried out in Namibia.

1.7 Aim and structure of this study

The aim of this study was to investigate various ecological, economic and social aspects of the human crocodile conflict interface with the objective of augmenting crocodile conservation and management efforts. These aims were assessed by:

1.) Determining the impact of crocodiles on rural livelihoods
2.) Determining the impact of humans on crocodiles at the local and regional scale
3.) Determining the impact of humans on important crocodile prey species
4.) Determining the relationship between crocodiles and humans on the continental scale
5.) Predicting key conservation and management parameters through simple spatial modelling

CHAPTER 2: Study Area

A large part of this study took place in the Kavango and Caprivi regions of North Eastern Namibia. This area is uniquely characterized by a highly dynamic and interconnected hydrogeography and an equally complex socio-political landscape set within a patchwork mosaic of land-use types. The spatial and temporal complexities of the various crocodile habitats that transect this region have made many of the important variables affecting the human crocodile relationship difficult to isolate and demonstrate as succinctly as would otherwise be the case. This chapter is intended to present a general overview of the human and physical geography of North Eastern Namibia. A good understanding of the broader context of this study will enable the reader to better appreciate and interpret the methods and results presented in the data chapters.

2.1 Background

Namibia is a large (824,292 km^2) and sparsely populated country (2.34 people per km^2) (CBS, 2002). It is a peaceful country which has maintained nearly two decades of stability and growth since achieving independence on 21 March 1990 (Stanley, 2002). The country is economically prosperous as a result of its productive mining, fishing, tourism and agricultural industries (Brown *et al.*, 1999; Humavindu *et al.*, 2003). Namibia is situated on the west coast of Southern Africa and as such is dominated by an arid climate and desert conditions.

North Eastern Namibia incorporates two of the 13 regions of Namibia: the Caprivi and Kavango. These two regions are bounded by four countries: Botswana to the south, Angola and Zambia to the north and Zimbabwe to the east (Fig 2.1). The Caprivi region forms a narrow projection which extends Namibia's border 300 km west to touch the border of Zimbabwe. The shape of this region is the sole result of negotiations between Germany and other colonial governments at the end of the 19th Century (Mendelsohn & Roberts, 1997). It was agreed at the Berlin Conference that the Caprivi region would be added to German South West Africa to allow the German colony to gain access to the Zambezi River (Mendelsohn *et al.*, 1997). At the time borders were drawn up with little

regard for environmental or cultural boundaries and in most cases either straight lines or the midstream of rivers were used as international boundary lines (Fig 2.1).

2.2 Landscape and Climate

Topographically North Eastern Namibia is relatively flat with elevations ranging from ~1300m in western Kavango to ~ 930m in eastern Caprivi (Mendelsohn & el Obeid, 2004; Mendelsohn *et al.*, 1997). The area is dominated by thick deposits of Kalahari sands and several large rivers with their associated floodplains, channels and deposits (Mendelsohn *et al.*, 2004; Mendelsohn *et al.*, 1997). These underlying variables dictate the various land types found within the region which include floodplains, riverine woodlands, Mopane woodlands, Kalahari woodlands and Impalila woodlands (Mendelsohn *et al.*, 2004; Mendelsohn *et al.*, 1997). Thirty six different vegetation units have been identified within the region (NACSO, 2006a). Dominant tree species include *Baikiaea plurijuga, Colophospermum mopane* and *Burkea coleosperma*. Most of the wetland areas are dominated by the grass *Cynodon dactylon* which occurs as extensive lawns and provides valuable grazing to domestic livestock and wildlife (Mendelsohn *et al.*, 1997).

The Caprivi and Kavango regions enjoy the highest rainfall in Namibia, receiving 500-800 mm of rain a year, mostly during the summer months of November to March (Mendelsohn *et al.*, 1997) . Although relatively high, rainfall can be highly variable from year to year and from place to place. The region also experiences less evaporation and generally warmer winters than the rest of Namibia. Average daily maximum temperatures in the summer vary between 32° C and 35° C whilst average daily minimum temperatures in the winter vary between 20° C and 5° C (Mendelsohn *et al.*, 2004; Mendelsohn *et al.*, 1997).

2.3 Hydrology

North Eastern Namibia is home to three of the five permanently flowing rivers in Namibia – the Kavango, Kwando, and Zambezi (Fig 2.1). These rivers are not only perennial but are also considered large by continental standards. In addition, the Caprivi

region incorporates the distributaries of the Kwando River and a large tributary of the Zambezi River. These two latter water bodies are often considered rivers in their own right (the Linyanti and Chobe rivers respectively) (Fig 2.1). If waters are high enough, which usually requires several successive high rainfall years, all of these rivers can connect with one another (Schlettwein *et al.*, 1990).

Seasonal changes in the levels and volumes of these rivers reflect seasonal changes in rainfall. In Namibia these changes are effected after a lag time determined by the characteristics of the catchments and this is often a period of several months. The Kavango, Kwando and Zambezi rivers have their catchments in Angola and Zambia up to 800 km from where they reach Namibia (Mendelsohn *et al.*, 2004). The total area of Angola and Zambia drained by these rivers is approximately 750 000 km^2 (Mendelsohn *et al.*, 2004). The Kavango river flood season peaks in April at about 4m above the low water mark (NamPower 2005). The flood season of the Kwando River only reaches Namibia in June – July and peaks at around 1m-2m above the low water mark (Næsje *et al.*, 2004). The flood season of the Zambezi and Chobe rivers usually peaks in about April at about 5m above the low water level (Hay *et al.*, 2000). Within the study area annual and seasonal flow rates are highly variable both within and between rivers (Schlettwein *et al.*, 1990). In general the Zambezi has the highest annual discharge, followed by the Okavango and then the Kwando river (Mendelsohn *et al.*, 2004; Mendelsohn *et al.*, 1997; Schlettwein *et al.*, 1990). The extent of seasonal flooding in Caprivi may reach as much as 40% of the total land mass (Schlettwein *et al.*, 1990).

The confluence of the Zambezi and Chobe rivers is characterised by an extensive seasonal floodplain covering an area of approximately 1800 km^2 (Schlettwein *et al.*, 1990). The Kwando River also supports large floodplains, although in recent decades extensive flooding has been limited to above average rainfall years. The Kavango and Kwando river catchments are dominated by nutrient deficient arenosols and consequently nutrient levels in these rivers are relatively low (NACSO, 2006a). Vegetation communities along all the rivers are broadly similar consisting of varying degrees of permanent wetlands and ephemeral floodplains flanked by riverine woodland (Mendelsohn *et al.*, 1997).

2.4 People

People have inhabited North Eastern Namibia for at least tens of thousands of years. The area is home to a number of tribal groups and historically has witnessed several major cultural migration events (Malan, 1980). The area has further undergone a multitude of social and administrative changes over the last 100 years to the point where most people now living in the area are descended from recent immigrants (Mendelsohn *et al.*, 2004). The Caprivi region has been subject to three colonial governments (Germany, Britain and South Africa) and was administered through three separate countries before 1992 (Botswana, South Africa and what was then South West Africa). The most recent sources of instability have been the civil war in Angola (1976-2002), the liberation war in Namibia (1966-1989) and the civil unrest relating to the Caprivi regions cultural affiliation with western Zambia (Mendelsohn *et al.*, 2004; Mendelsohn *et al.*, 1997).

North Eastern Namibia is controlled by a combination of state and communal administration. State controlled land consists primarily of game reserves and national parks, state forest and a variety of state sponsored agricultural projects. Communal land makes up about 60% of the region and the dominant land use in these areas is subsistence farming (NACSO, 2006a). Over the last decade the Namibian Ministry of Environment and Tourism and local NGOs have been supporting the establishment of community conservancies (Brown *et al.*, 1999; NACSO, 2006b). Conservancies have enabled local communities to gain greater legal control over their natural resources which has facilitated a greater diversity of land use types, including more commercialised forms of natural resource utilisation such as tourism (Murphy, 2007a; Murphy & Mulonga, 2002; NACSO, 2006b).

Caprivi and Kavango regions have some of the highest human population densities (4.2 –5.5 people per km^2) and growth rates (1.8 – 3.7 % population increase per year) in Namibia (CBS, 2002). The population of the Caprivi is estimated at 100,000 people (CBS, 2002) and is made up of two main tribal groups, the Fwe in the west and the Subia in the east (Malan, 1980). The Fwe include several smaller communities of Yeyi, Totela and Lozi (Malan, 1980). As a result of their historical

social interaction with Zambia, Zimbabwe and Botswana, the majority of local people can speak English. North Eastern Namibia has a relatively low life expectancies compared to the rest of Namibia (<60) however it has a good network of health facilities and schools and most people have access to these resources (Mendelsohn *et al.*, 2004; Mendelsohn *et al.*, 1997). The most important health problems are malaria, HIV/AIDS, acute respiratory infections, diarrhoea, scabies, tuberculosis, malnutrition and bilharzia (Mendelsohn *et al.*, 2004).

Rural communities make up 72 % of the population (CBS, 2002). The average number of people per household in the study area is 5.6 (CBS, 2002). The great majority of rural households practise small scale farming involving dry land agriculture and livestock production. Crops grown include maize, millet, beans, sweet potatoes, groundnuts pumpkins, melons and sugar cane (Murphy *et al.*, 2002). Livestock farming makes up 8% of household income (Mendelsohn *et al.*, 2004) but cattle represent a disproportionately important cultural and social security component of many households (Murphy *et al.*, 2002). The average number of cattle per household is 10 (Ashley & LaFranchi, 1997). Disease represents the greatest threat to cattle. Lung sickness, foot-and-mouth, rindepest, anthrax and sleeping sickness are prevalent throughout the region and mass die-offs have occurred periodically throughout the last century (Mendelsohn *et al.*, 2004). Fences and vaccination programs are the main methods of disease control (Mendelsohn *et al.*, 2004).

Non agricultural resources (e.g. fuel wood, fishing) make up only 19% (Mendelsohn *et al.*, 2004) of household income but most riverside communities are heavily dependent on the waterways for fishing (Tvedten, 2002). One of the commonest possessions of households living alongside the wetlands of North Eastern Namibia is the traditional dugout canoe. Traditional canoes are relatively cheap and easy to buy (~£50), rent or borrow by Namibian standards. On the Kwando River, where suitable trees are plentiful, traditional canoes are made by local craftsmen. On the Kavango and Zambezi rivers canoes are imported in large flotillas from Angola or Zambia and sold to Namibian fisherman. Traditional canoes are used for a variety of purposes including transport, hunting and harvesting reeds and water lily bulbs but their main function is fishing (Boyle, 2007). Traditional canoes are highly visible from the

land and air and can be used as a proxy for human presence and/or fishing pressure within the wetland ecosystems.

Rural to urban migration has increased dramatically over the last decade and current urbanisation rates are approximately 6% (Mendelsohn *et al.*, 2004). The levels of regional employment have reflected these growth rates and salaries now make up over 60% of household incomes (Mendelsohn *et al.*, 2004). Despite this, the area remains one of the poorest in Namibia as a result of its unstable past and remote location (Stanley, 2002) and subsistence agriculture will likely remain an important livelihood activity for the foreseeable future.

2.5 Wildlife and Tourism

Tourism in Namibia is predominantly nature based (Shangula, 2007) and to a large extent relies on the countries diverse wildlife resources. The tourism industry has recorded consistent growth over the last several years with numbers of tourists increasing from 254878 in 1993 to 833350 in 2006 (Shangula, 2007). Tourism now accounts for about 8% of the country's GDP and totals approximately N$4.2 billion (Shangula, 2007). Broad estimates are that tourism directly employs about 30 000 people, or 7.8% of the total labour force of 360 000 (NTB, 2009). The wider tourism economy, taking into account multipliers into other sectors such as transport, retail shopping and construction, is estimated at 56 000 jobs, or about 16% of the labour force (NTB, 2009). Trophy hunting makes up about 14% of the tourism industry and contributes 18% of the economic value of the wildlife based component (Humavindu *et al.*, 2003).

Several protected areas occur in North Eastern Namibia and adjacent areas in neighbouring countries (Fig 2.1). These include National Parks and game reserves, partial reserves, forest reserves and wildlife management areas (NACSO, 2006a). The region supports a large biomass and biodiversity of large mammals and other wildlife (Stander, 2004). Numbers are concentrated in and around protected areas however in recent years populations of many species have increased and expanded their ranges considerably. There is considerable movement of wildlife along the major rivers and

the Caprivi region represents an important corridor linking the protected areas of south western Zambia and south eastern Angola with those in northern Botswana (Chase, 2007). Over the last decade there have been significant increases in numbers of wildlife both through natural immigration and through game capture and translocation (Brown *et al.*, 2005; Chase, 2007; Stander, 2004). Examples of large mammals commonly occurring within regional wetland areas include:- Elephant *Loxidonta africana*, Hippopotamus *Hippopotamus amphibius*; Sitatunga *Tragelaphus spekei*; Reedbuck *Redunca arundinun;* Buffalo *Syncerus caffer*; Puku *Kobus vardinii* and Impala *Aepyceros melanpus* (Stander, 2004).

Wildlife is responsible for considerable conflict, particularly adjacent to the protected areas and along the rivers.(Mulonga, Suich & Murphy, 2003) Most conflicts between animals and humans result from damage caused to crops and to a lesser extent livestock (Mulonga *et al.*, 2003). Damage and losses usually occur sporadically over space and time. The Namibian Ministry of Environment and Tourism and local NGOs are currently pursuing several mitigation measures including animal deterrents, compensation schemes and lethal control (IRDNC, 2003).

The wildlife together with the scenic beauty of the wetland ecosystems has made North Eastern Namibia a popular tourist destination in recent years (Murphy, 2007b). Numerous photographic tourist lodges are located along all the major waterways and safari hunting activities have been established in collaboration with several conservancies and community associations (NACSO, 2006b). Wildlife based tourism already represents a significant percentage of North Eastern Namibia's economy and it is forecast to increase significantly in the future (Murphy, 2007b).

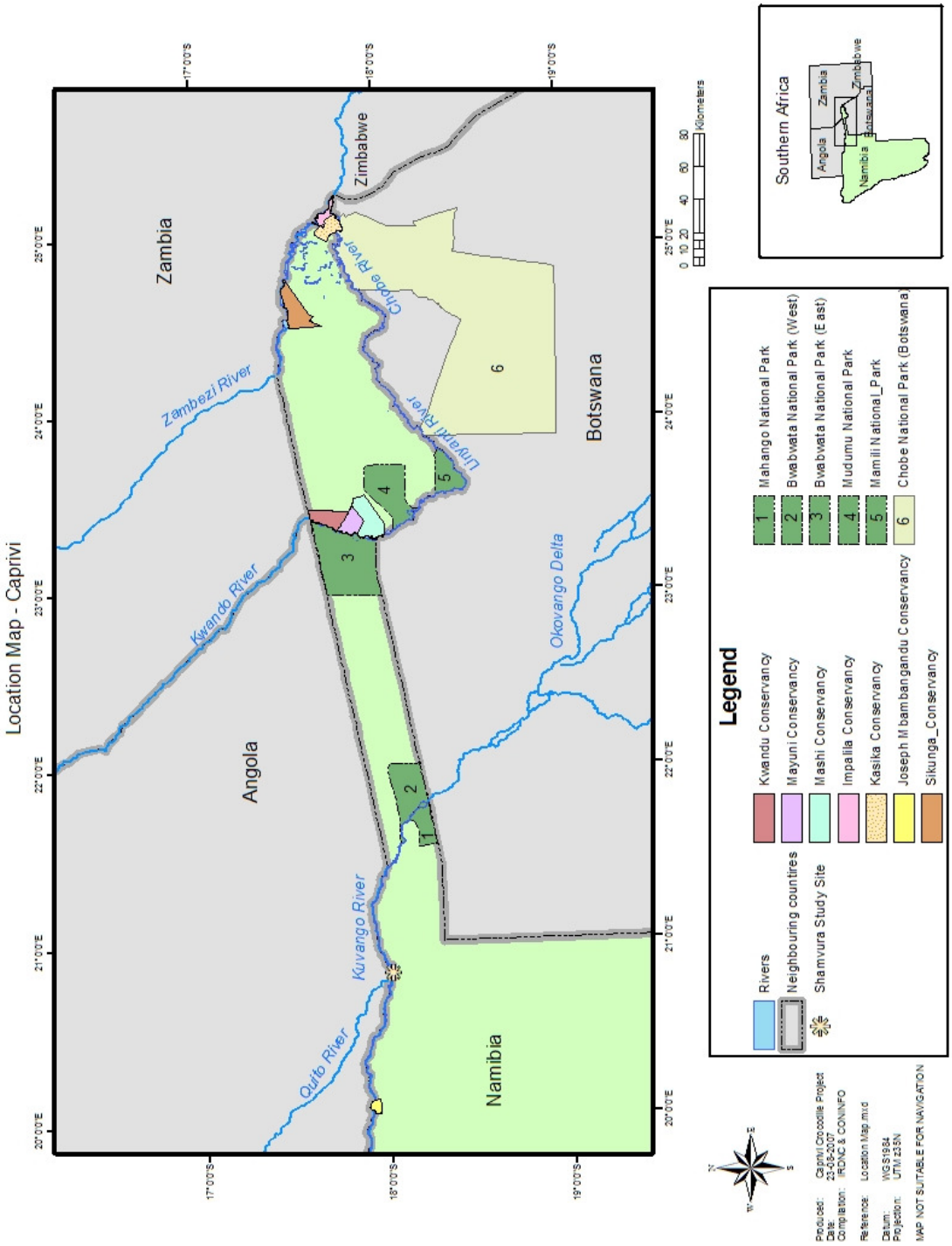


Figure 2.1. North Eastern Namibia showing the study area and main study sites.

CHAPTER 3: The impact of Nile crocodiles on rural livelihoods *

This chapter was accepted for publication by South African Journal of Wildlife Research on 18 February 2009 as the impact of Nile crocodiles (Crocodylus niloticus) *on rural communities in North Eastern Namibia.*

3.1 Introduction

In recent years, conflict between humans and wildlife has increased worldwide due to growing human populations and associated land use changes (Madden, 2004). Crocodile and alligator attacks are increasing in many parts of the world (Langley, 2005). Several scientific publications have highlighted these conflict trends in developed nations, including saltwater crocodiles (*Crocodylus porosus*) in Australia (Caldicott *et al.*, 2005) and Mississippi alligators (*Alligator mississippiensis*) in the USA (Langley, 2005). By comparison, human crocodile conflict (HCC) in Africa has been poorly documented. Available reports (Anderson *et al.*, 2005; Fergusson, 2004; McGregor, 2005; Scott *et al.*, 1994; Vanwersch, 1998) suggest HCC in Africa is not only more prevalent than elsewhere but in some cases may also represent a growing threat to rural livelihoods and development. I attempt to gain a better understanding of impact of crocodiles on humans in Namibia, with particular reference to quantifying environmental determinants, feeding biology and costs to rural communities. By understanding these dynamics, especially across differing ecosystems, we can start to make generalities about the threats crocodiles pose to subsistence communities. This will enable us to develop more effective long-term solutions to the problem of human crocodile conflict in Africa.

Nile crocodiles were extensively exploited throughout much of their range after the Second World War (Gans *et al.*, 1976; Musambachime, 1987). By the late 1960s, the high demand for crocodile skin fashion accessories coupled with the rapid development of the former colonies had severely depleted most wild populations (Gans *et al.*, 1976). By 1972, most African governments had adopted some form of conservation measure (Cott *et al.*, 1971). The decline of wild populations was further slowed by the 1973 listing of Nile crocodiles as a CITES Appendix I species.

Populations of most crocodilian species are resilient to bottlenecks in numbers and have demonstrated a remarkable capacity to recover from severely depleted numbers if habitats are intact (Webb *et al.*, 2001). The dramatic recovery of American alligator and saltwater crocodile populations following the cessation of unregulated exploitation has been well documented (Hines & Percival, 1986; Read *et al.*, 2004; Webb *et al.*, 2001). Because of conservation and commercial interests, Nile crocodile populations have also expanded dramatically in recent decades (Brown *et al.*, 2005; McGregor, 2005). Today Nile crocodiles are considered ubiquitous throughout much of their southern African range (Broadley pers comm, 2005). In Namibia, the provisional conservation status of Nile crocodiles is "Peripheral" implying vulnerability only due to limited habitat (Griffin, 2003). A national status survey carried out in 2004 found crocodile numbers to be healthy (Brown *et al.*, 2005). Following the survey the Namibian population of Nile crocodiles was down listed from CITES appendix I to CITES appendix II.

Over the last few decades, human populations in the Zambezi basin have also been increasing and expanding rapidly (Chenje, 1998). The agricultural and domestic demands for freshwater have resulted in many freshwater ecosystems being heavily settled and degraded by humans and their livestock (ECA *et al.*, 2000; Mendelsohn *et al.*, 2004; Postel, 2000). Regular access to water is essential and in rural Africa, this often means drawing water directly from natural water bodies (Mendelsohn *et al.*, 2004). Thus, every year more people are exposed to the risk of crocodile attack throughout the species range (Fergusson, 2004). Resurgent crocodilian populations coupled with expanding human populations have been cited as primary causes of HCC elsewhere (Langley, 2005).

In recent years, crocodile attacks on humans and livestock has emerged as one of the foremost concerns of rural communities in North Eastern Namibia (Brown, pers comm, 2006). Despite gaining national attention, little progress has been made towards solving the problem. In Namibia, Nile crocodiles are a protected species and may not be captured or killed without the necessary authorization from the Ministry of Environment and Tourism (MET). The only exception occurs in the case of defence of human or livestock life, in which case the incident must be reported to the MET within

10 days (MET pers comm). In most cases, only animals responsible for human fatalities are destroyed by the MET (personal observation, 2006). More recently, some local communities have been allocated limited quotas of wild crocodiles to sell to the sport hunting industry. This has met with success in terms of the removal of large crocodiles whilst generating financial benefits; but is limited because most sport or 'trophy' hunters are by definition only interested in exceptionally large individuals and are thus unwilling to pay for comparatively smaller crocodiles, even if they are confirmed problem animals (Cilliers, pers comm, 2007).

Some community conservancies have started to offer financial compensation for livestock losses through support from a local non-government organization. Although an attractive concept for most community members, at present, the scheme suffers from technicalities relating to claim assessments (e.g. proof of loss specifically to crocodile) and insufficient funds, and the long-term viability remains questionable (Kwando, Kasika and Impalila Conservancies, pers comm). In 2005 the Global Environmental Facility supplied funds for the erection of several crocodile proof wire mesh fences on the Chobe River, however fluctuating water levels coupled with hippopotamus damage and rampant vegetation growth have resulted in all of these fences falling into a state of disrepair (personal observation). Ultimately, most rural communities perceive control measures to be inadequate and the current status quo between humans and crocodiles is tenuous. If the conflict issue is to be resolved, research into the dynamics of crocodile human conflict is imperative.

3.2 Methods

3.2.1 Data collection and analysis

Data were obtained by means of two principal methods: a) records of crocodile attacks collected by local communities (mainly conservancies), and b) community surveys carried out with local people by means of questionnaires and semi structured interviews. Community surveys were designed to collect a wide variety of social data on the broader issue of HCC, including the impact of humans on crocodiles. In the context of this chapter, community surveys were primarily used to gain a better understanding of specific costs sustained by rural communities. Consequently only information directly related to quantifying the impact of crocodiles is presented here.

3.2.1.1 Collection of existing records - HCC surveys

I carried out HCC surveys on the Kavango, Kwando, and Chobe Rivers. A small section of the Zambezi River is covered by one on the survey sites (Impalila Island) but for the purpose of this study, this section is considered part of the Chobe River system. Six survey sites were identified, five of which corresponded to registered community conservancies.

Community conservancies in North Eastern Namibia consist of areas of communal land on which neighboring members have pooled resources for the purpose of conserving and using natural resources (NACSO, 2006b) Registered community conservancies are granted legal ownership of their natural resources by the Namibian government provided they meet certain management criteria. One of the compulsory management activities is monitoring human wildlife conflict. Conservancy members are required to document all records of crocodile attacks in a locally based event book (Stuart-Hill *et al.*, 2006). All conservancies have field offices in which the event book records are archived. The event book system has been operating efficiently since at least 2000 in all surveyed conservancies.

HCC surveys on community conservancies entailed retrieving original records of crocodile attacks from the event books. Conservancy field offices were visited and individual record cards were photographed with a digital camera. In all cases, a member

of the respective conservancy committee was present to assist in interpretation of records (e.g. records in local languages and the use of colloquial spelling). Records were obtained from two conservancies on the Chobe River, (Kasika and Impalia), and three conservancies on the Kwando River (Kwandu, Mayuni and Mashi). Each conservancy was considered a separate study site.

There is no event book system in operation on the Kavango River. In order to obtain some comparable crocodile attack data from this river, we employed the services of a local youth group. These data were considered comparable to the above archived records only from the point of view that they were obtained by local community members with minimal external agenda and are therefore less vulnerable to the emotive responses seen in the more typical social surveys (see below). Eight members the Makena Environmental Education Group were asked to gather information on HCC from two large villages (Makena and Katere) and surrounding settlements fronting a ~18km stretch of the Kavango River. Their instructions were to unobtrusively (casual conversation) collect all recall information regarding location, date, species attacked (names of victims if possible) and outcome of attack. Lead information was gained through local knowledge and word of mouth and this was followed up by interviews with people directly involved in the attack (e.g. eyewitnesses or next of kin). The Kavango HCC survey was carried out in August 2006 and this area is henceforth referred to as Shamvura study site (Fig 2.1).

Sporadic records on HCC within the study area exist as far back as 1993, however, data prior to 2001 is relatively incomplete. Records prior to 2001 (n=11) have been ignored unless otherwise stated. No distinction is made between fatal and non-fatal attacks in the event book record system. It is generally accepted that non-fatal attacks are not reported unless the victim succumbs to resultant injuries; accordingly, all incidents are assumed fatal unless otherwise stated. Detailed information on attack victims is not required in the event book system, however in most cases complainants voluntarily recorded details pertaining to age and/or sex.

3.2.1.1.1 Analysis

We fitted a generalized linear model (GLM) to data from the Chobe and Kwando rivers to identify which variables are responsible for most of the variation in crocodile

attacks (R version 2.4.0, R Development Core Team 2006). Because of different data collection methods, records from the Kavango River were ignored. Counts of crocodile attacks were fitted as the response variable and year, month, water level and river were fitted as categorical explanatory variables. Water level classes (high, low, rising and falling) were derived from Hay et al (2002) and Naesje et al (2004) (Table 3.1). I fitted month and year as factors and a two-way interaction between year and water level was tested. I checked data for over dispersion and a quasipoisson error structure was used. To select the minimum adequate model, a backward stepwise procedure from the full model was used (Crawley, 2003). Non-significant terms were sequentially removed after testing with analysis of variance (ANOVA).

Table 3.1.Water level classes for the Chobe and Kwando Rivers, derived from Hay et al 2002 and Naesje et al 2004

Month	*Chobe*	*Kwando*
January	rising	low
February	rising	rising
March	high	rising
April	high	rising
May	high	high
June	falling	high
July	falling	high
August	falling	falling
September	low	falling
October	low	falling
November	low	low
December	rising	low

3.2.1.2 Community Surveys

Data were collected from five study sites, three of which covered the above-mentioned HCC survey sites (Fig 3.1). Two additional study sites were established, one on the Kavango River ~100km west of the Shamvura study site, and one on the Zambezi River ~60km up stream of the Impalila study site. Roads running alongside the rivers were used as transects for locating villages. Households within villages were randomly selected to avoid biasing the sample (Milner-Gulland *et al.*, 2007). Houses were allocated numbers and then a number was drawn at random. If nobody was available to be interviewed in the selected house then the nearest house with an available respondent was chosen. Random sampling was, however, difficult to achieve

in a village setting due to the availability of respondents. Thus, the sample is not entirely random, but is non-selective.

Questions were designed to be simple and clear to elicit consistent responses. The questionnaire followed a logical progression and began with general "ice-breaker" questions, such as details about livelihood (Milner-Gulland *et al.*, 2007). Bias was avoided through neutral phrasing and a non-leading question order (Milner-Gulland *et al.*, 2007). The survey was intended to take approximately 30 minutes to complete to avoid the respondent becoming impatient. See appendix 1 for complete questionnaire.

Local guides were employed in each of the survey sites to assist with translation and introductions. The interviewer was introduced to the respondent as a student from England wishing to find out what it is like to live in the area. There was a 1.5% refusal rate to participate in interviews (two out of 148 people). Interviews were carried out with a single member of the household although there were often other people present.

3.2.3 Estimates of costs

Due to the diverse and complex ways in which crocodiles affect subsistence communities, it is very difficult to estimate the total economic cost of living with crocodiles. I estimated the number and value of cattle and nets lost to crocodiles in North Eastern Namibia in an effort to determine a basic annual cost. Two estimates for the number of cattle lost were obtained, one from existing records and one from the community survey data. Averages of cattle killed and nets destroyed per kilometre of river frontage within the study sites were calculated and extrapolated to obtain figures for the whole of North Eastern Namibia. Kilometers of river frontage per study site were calculated using an Arc View GIS v3.2 GIS software package (ESRI, Redlands, CA) and a 1:250 000 scanned satellite image. Only main river channels were measured. I ignored all data from neighbouring countries (Angola, Zambia and Botswana). Recorded attacks are limited to one bank of the river, the only exceptions being a 10km section of the Kavango River (near Divundu) and the Chisaya channel running through the Chobe floodplain. According to Curtis et al (1998), there is 1106 km of perennial rivers in North Eastern Namibia, of which 100 km lies in protected areas (Curtis *et al.*, 1998). Since 1998 however, much of the Linyanti River has dried up and no longer represents permanent crocodile habitat (Meyer-Rust, pers comm, 2006, personal

observation, 2007). Excluding the Linyanti River there is approximately 880km of perennial river frontage in North Eastern Namibia situated outside of protected wildlife areas.

For the community survey analysis, study site population densities were obtained from NACSO (2006) and Mendelsohn and Roberts (1997) (Mendelsohn *et al.*, 1997; NACSO, 2006a). An average of 72 people/km2 and 5.6 people/household (CBS, 2002) was used to calculate average household density per kilometre of river frontage (see methods above for river frontage calculation). Using these figures I estimated an average of 13 households per kilometre of river frontage, or 11440 households situated along river frontage in North Eastern Namibia.

3.3 Results

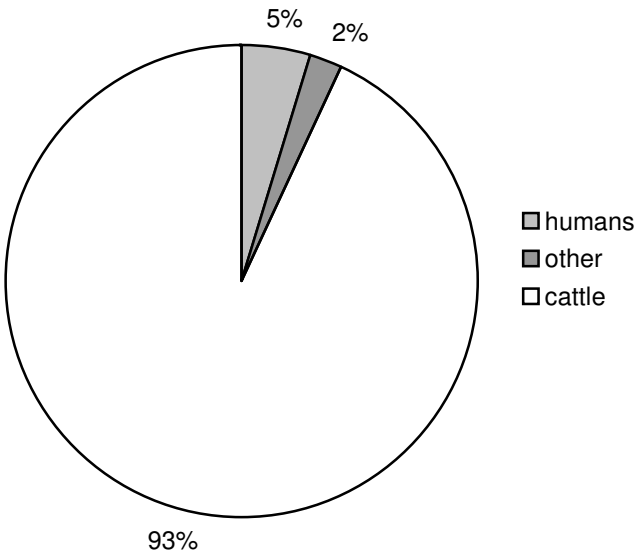
3.3.1 HCC Surveys

In total 489 cases of crocodile attack were recorded from 1993 to 2005 inclusive. Table 3.2 summarizes records of crocodile attacks by survey site. Study sites on the Chobe River (Impalila and Kasika) recorded the highest numbers of attacks as well as the highest density of attacks per kilometre of river frontage. Figure 3.1a summarizes species composition. Other species recorded included dogs, goats, a horse and a pig. Twenty three cases of human attacks were recorded. Figure 3.1b summarizes some age and sex criteria of cattle records. Adult female cattle made up nearly three quarters of cattle depredations.

Table 3.2 Summary of attack records per study site from 2001 to 2005 inclusive

Survey site (and river)	*Cattle (n)*	*Human (n)*	*Other (n)*	*Total (n)*	*% of total attacks recorded (%)*	*Km river frontage per survey site*	*Number of attacks per km river frontage*
Kasika (Chobe)	171	2	0	173	36	62	2.8
Impalila (Chobe)	201	12	1	214	45	127	1.7
Kwando (Kwando)	25	3	7	35	7	35	1
Mayuni (Kwando)	34	0	0	34	7	23	1.47
Mashi (Kwando)	7	0	0	7	1	39	0.2
Shamvura(Kavango)	7	6	2	15	3	18	0.8
Totals	445	23	10	478	99	304	

(a)



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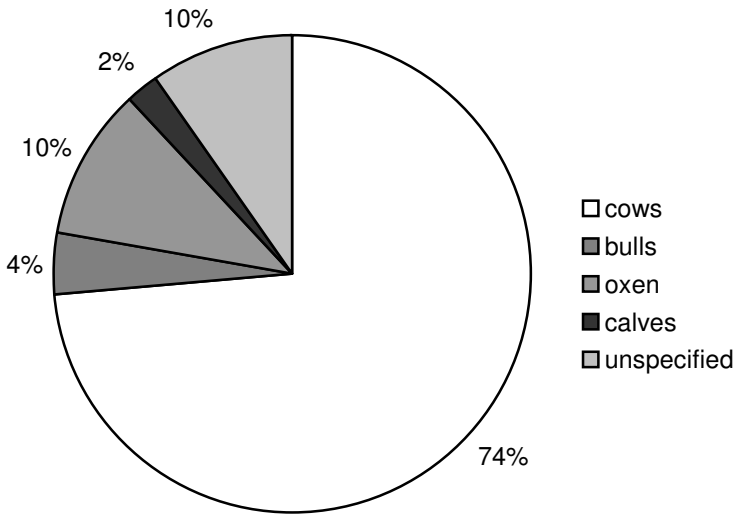


Figure 3.1. a) Species composition of crocodile attacks from 2001 to 2005 inclusive. b) Breakdown of cattle records from 2001 to 2005 inclusive

Figure 3.2 summarizes crocodile attacks recorded by month from 1993 to 2005. Close to half the attacks (43%, n=212) occurred in the hot dry season months of September, October and November. After the dry season peaks, incidents decline sharply towards December before rising again in January. Few attacks are recorded in the cool winter months of May, June and July (n=58).

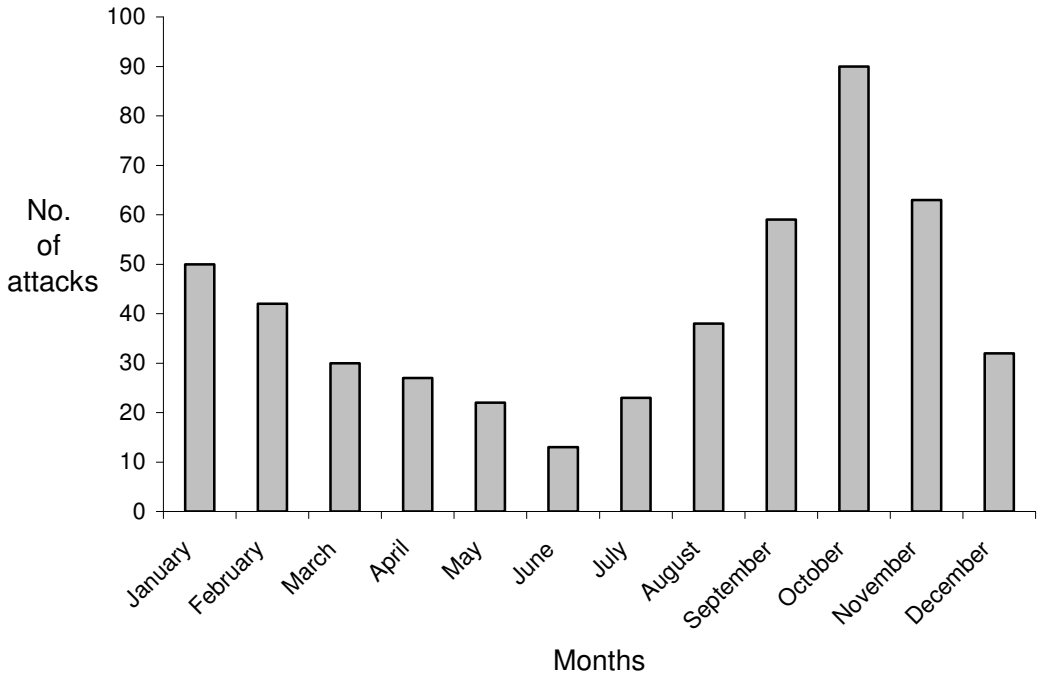


Figure 3.2 Total number of attack records by month from 1993 to 2005 inclusive.

The minimum adequate model retained river and month as significant determinants of crocodile attacks (Table 3.3). Together these two variables explained 50.25% of the deviance. Sequential elimination of water level, year, and the interaction between year and water level showed no significant difference between models. Removal of river from the model proved highly significant ($p<0.001$), as did removal of month ($p<0.001$). The model did not show any significant relationship between years and numbers of attacks (Fig. 3.3).

Table 3.3. Analysis of Deviance. "F" tests are against the minimum adequate model Total ~ month + river

Model	*Resid.Df*	*Resid. Dev*	*F*	*Pr(>F)*
Total ~month + river	70	131.565		
Total ~month	71	215.407	43.88	p<0.001
Total ~river	81	203.148	3.41	0.0008

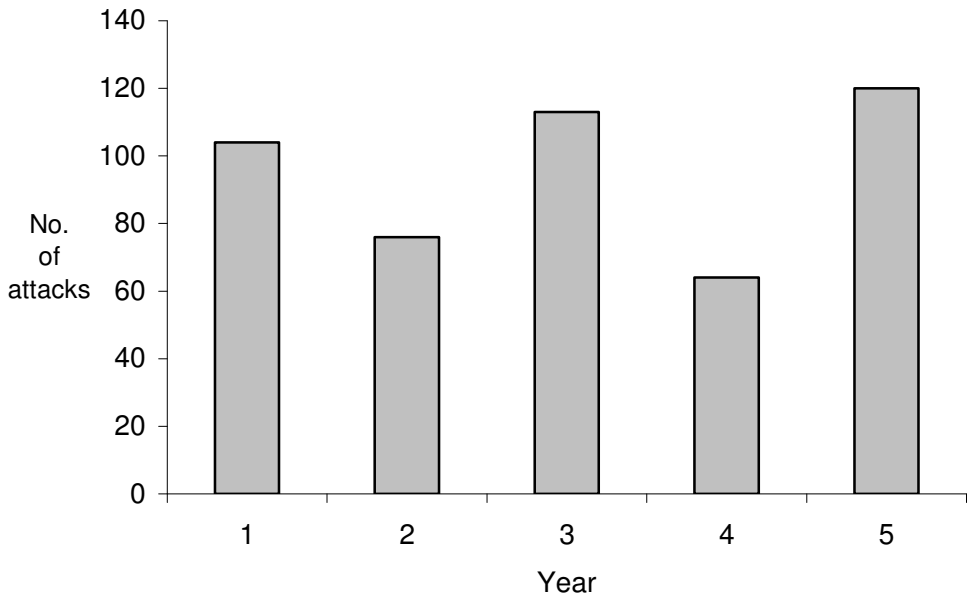


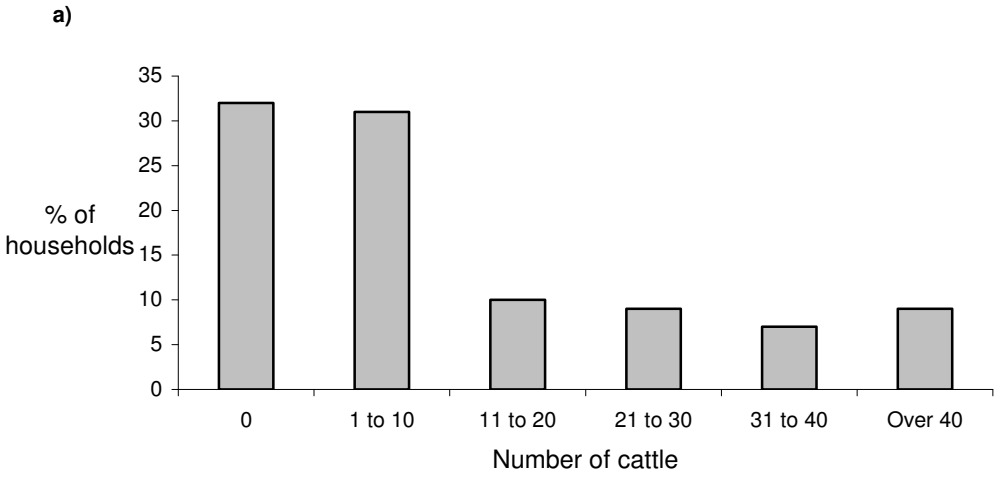
Figure 3.3. Total recorded crocodile attacks from 2001 to 2005 inclusive.

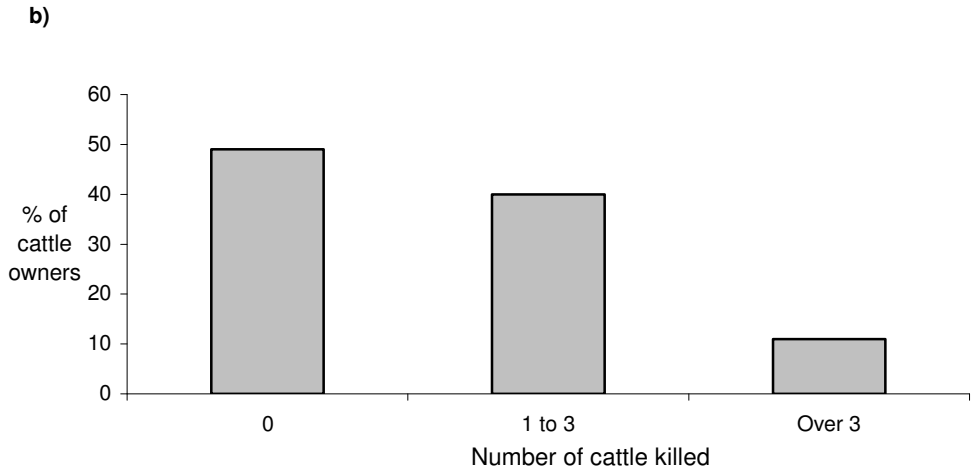
3.3.2 Community Surveys

In total 146 interviews were carried out. The number of interviews done on each river were not significantly different (χ^2 = 4.2466, df = 3, p = 0.2360). There is no association between river and age (χ^2=17.4056, df=18, p=0.4954), sex (χ^2=0.7429, df=3, p=0.863) or wealth (χ^2=14.1013, df=15, p=0.5179) of respondents. Results suggest that the sample of respondents is an accurate representation of the rural population of North Eastern Namibia and that the study sites are similar in the demography and wealth of respondents.

Figure 3.4 summarises a) cattle ownership per household, b) number of cattle attacked per owner and c) rate of attacks on cattle per river. 71% of households currently keep cattle (n=96). Almost half of the households that do own cattle have

between one and ten animals (n=44, 46%). Respondents reported a total of 176 cattle and 39 goats killed by crocodiles in the last year, and 435 cattle killed over the last five years. On average each household lost 0.6 head of cattle per year (SD+-1.57). The Chobe study site recorded much higher levels of cattle depredations (1.97 cattle per household per year) relative to the Kwando, Kavango and Zambezi study sites (0.32, 0.21 and 0.36 respectively).





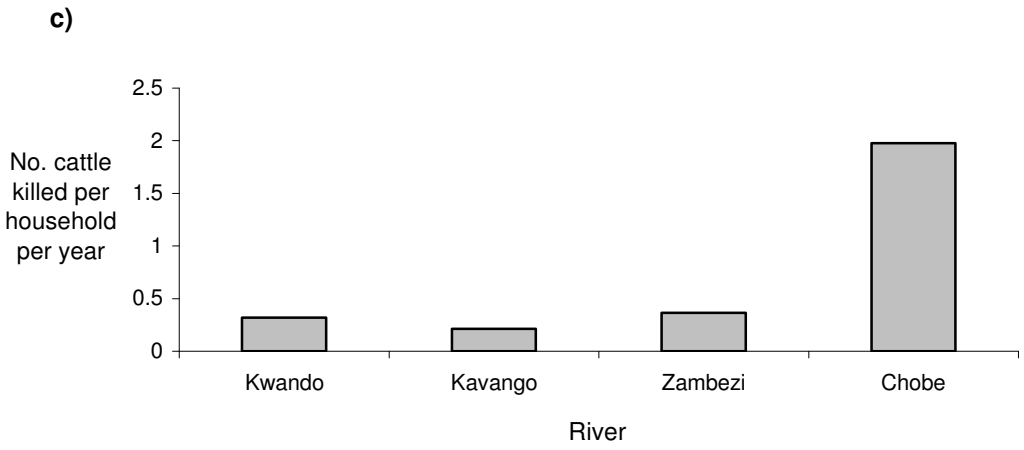


Figure 3.4 a) The numbers of cattle owned by households. b) The number of cattle killed by crocodiles in the last year. c) The number of cattle killed by crocodiles per household per year on each river (data from the past five years).

Figure 3.5 summarises net damage by crocodiles. 39% of respondents rely on nets to catch fish (n=56). 88% of net fishermen (n=49) reported damage to nets by crocodiles. Crocodiles damaged 824 fishing nets in the last year (~June 2006 to ~May 2007). On average 5.6 fishing nets are damaged per household per year (SD+-24.55). Fishermen on the Chobe reported much greater levels of relative net damage (19.4 nets per fisherman per year) compared with the other rivers (Kwando=0.7, Kavango=1.2 and Zambezi =3.7). 55% (n=27) of net fishermen reported that they did not repair nets (i.e. cheaper or necessary to buy new nets after damaged by crocodiles).

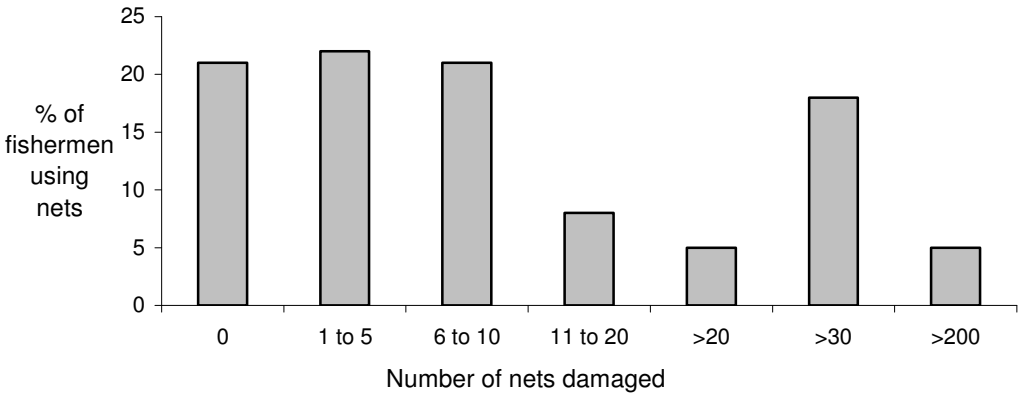


Figure 3.5 The number of nets damaged by crocodiles in one year (~June 2006 to ~June 2007).

41% of respondents reported experiencing a crocodile attack in their family (n=60). Over the last five years, 10 cases of attack occurred on the immediate family of the respondent, giving and estimate of one attack per 70 households per year (SD+-20.7). The fatality rate is approximately 51%

3.3.3 Estimate of costs

3.3.3.1 HCC cattle loss estimate

Approximately 89 cattle are killed per year within the six study sites (SD+-26.5). Extrapolation estimates approximately 255 cattle attacked per year in North Eastern Namibia, or 0.29 cattle per kilometre of river frontage in NE Namibia.

3.3.3.2.1 Community survey cattle loss estimate

Approximately 0.6 cattle are killed per household per year within the five study sites (SD+-1.57). Extrapolation estimates a figure of 6864 cattle attacked by crocodiles per year in North Eastern Namibia, with about half of these occurring on the Chobe river. For direct comparison with the HCC survey estimates, this translates to approximately 7.8 cattle per km of river frontage per year.

3.3.3.2.2 Community survey fishing equipment loss estimate.

Approximately 6.25 nets are damaged by crocodiles per household per year (SD+_24.55). Extrapolation estimates 71 500 nets damaged by crocodiles per year in North Eastern Namibia. The Chobe river accounts for more than two thirds of the incidents. Approximately 21355 nets are damaged on the Kwando, Kavango and Zambezi rivers. Approximately half (55%) of the nets damaged by crocodiles are destroyed beyond repair. The average number of nets purchased per net fisherman between ~June 2006 and ~May 2007 was 2.4 (SD+-8.9)

3.4 Discussion

The primary objective was to describe the consequences of local communities living in close proximity to Nile crocodiles. Specifically I wanted to quantify the major impacts of crocodiles on humans and describe the seasonal and spatial variation in this conflict. I did this by using records collected and stored by local communities and through the use of questionnaires and semi-structured interviews.

Before interpretation is considered, it is important to acknowledge the limitations of this research. This HCC survey relied largely on data recorded by members of rural communities, many of whom have limited appreciation for scientific rigor. In all cases community members were initially instructed in basic data recording procedures and these instructions were reinforced annually throughout the data collection period (Ward, pers comm). Despite this, it would be reasonable to assume that considerable human error persists. For example, under-recording of crocodile attacks is common in cases where conservancy members have considerable distances to travel to report incidents and often forget or fail to do so. Over reporting often occurs in cases where crocodiles are found feeding on a carcass and consequently incorrectly reported as the cause of the fatality. The data are thus vulnerable to both over and under-reporting. Nevertheless, wildlife conflict is considered one of the most accurate components of the event book system and is generally considered reliable (Ward, pers comm).

It seems likely that exaggeration of HCC incidents was a fundamental problem with social surveys. Exaggeration may have occurred accidentally or deliberately as an expression of frustration, and may have itself increased in areas with elevated levels of conflict (as may be the case in the Chobe River study site). There is also a danger that respondents may have told the team answers based on what they thought the desired response was. This was avoided as much as possible through a neutral introduction and non-leading question order. It is, however, likely that data collected through social surveys represents an upper limit to the level of HCC within the region.

In Southern Africa, Nile crocodiles occur throughout most large tropical rivers and wetlands. Crocodiles are poikilothermic, becoming most active at warmer

temperatures (Branch, 1990; Pooley, 1982). In southern Africa they usually breed in the hot summer months, the female laying a clutch of approximately 16-80 eggs (Branch, 1990). The female guards the nest and in most cases does not eat during this time. Adult Nile crocodiles feed predominantly on large vertebrates and are adept at ambushing terrestrial mammals at the waters edge. Because of this Nile crocodiles are considered one of the most dangerous of all crocodilians to humans (Revol, 1995).

Every year Nile crocodiles kill a number of livestock animals in North Eastern Namibia. Estimates ranged from 0.29 to 7.8 cattle per kilometre of river frontage per year, with community surveys recording the highest rate. Cattle are the most frequently attacked species (74%-82%) probably because of their abundance. Cattle also spend considerable time grazing on emergent floodplain vegetation and regularly expose themselves to crocodile attack. Attacks on smaller livestock (including cattle calves) may be under reported due to relative lack of value. Between 0.01 and 0.09 humans are attacked per year within the study area. The lower estimate derived from the event book data is a surprisingly low number considering that 44% of riverside communities rely solely on rivers for household water (this study). In Tanzania, Scott and Scott (1992) reported about one human death (fatal crocodile attack) a week associated with the breakdown of a town's water pump (thus forcing dependence on river water). In Australia, where virtually all humans have access to pumped water, Caldicott et al (2005) reported only 62 attacks on humans in 33 years (1971 to 2004).

Several authors have reported that crocodile attacks increase in warm summer months (Caldicott *et al.*, 2005; Fergusson, 2004). This study also recorded an overall increase in the number of attacks in the hot summer months (43% from September to November) but unlike previous studies revealed an abrupt decline in numbers of attacks in mid summer (December). Mid summer coincides with the crocodile breeding cycle during which time a proportion of the population (breeding females) do not feed. Breeding activity could explain the sharp decline in attacks during the month of December. It could be that previous studies may have failed to elucidate these trends due to comparatively small data sets (in total less than 400 records). Interestingly, crocodile attacks did not show a significant trend with seasonal water level changes, despite the fact that during the low water season crocodile, livestock and human activity is concentrated around remaining water bodies thus increasing the likelihood of

interactions. The analysis also failed to detect a significant temporal trend towards increasing or decreasing numbers of attacks between years.

Both HCC and community surveys recorded substantially more crocodile attacks on the Chobe River relative to the other rivers. The most likely explanation for this is that the Chobe River has highest density of adult crocodiles within the study area (Brown *et al.*, 2005). Furthermore, unlike the other rivers, virtually the entire south bank of the Chobe River has been a protected National Park since 1967 and thus the area supports relatively older and larger crocodiles (personal observation).

Given the substantial discrepancies that exist between HCC and community survey estimates, it is difficult to estimate a meaningful value for the total cost of crocodiles. It is likely that the two methods predict lower and upper estimates with the true figures lying somewhere in between. What is clear is that the cost of crocodile attack to local communities is substantial. Crocodiles are responsible for approximately 30% of wildlife related stock losses in Caprivi, second only to lion (60 %) (Mulonga *et al.*, 2003). Cattle are the most important sources of social and financial security in Caprivi (Murphy *et al.*, 2002). The average price for slaughter cattle in Namibia in 2001 was N$1332.00 per animal (Mulonga *et al.*, 2003), which is more than three times the monthly minimum wage of N$429 (Matongela, 2003). Even so, the pure financial value is surpassed by the multitude of basic needs values cattle represent. These include meat, milk, draught power and social and cultural activities relating to prestige, bride wealth, and social status (Ashley *et al.*, 1997). With an average of less than 15 cattle per household, it is not difficult to see how the loss of a single animal to crocodile attack can have significant impacts on individuals' future prospects.

Nile crocodiles regularly feed on fish ensnared in gill nets and consequently destroy fishing equipment and interfere with fishing efforts (McGregor, 2005; Pooley, 1982). Pooley (1982) elaborates by describing how crocodiles in Lake St. Lucia, South Africa, learned to associate net setting activities with easy meals and began to follow a motorized fishing boat in anticipation. In this study, most fishermen reported damage to multiple nets within the last year. At N$20 to N$40 per net, the cost of annual net damage per fishermen can rapidly exceed the monthly income, especially when combined with the associated loss of catch and fishing effort. It is likely that a

considerable proportion of the total HCC experienced within the Caprivi region arises from net damage alone.

Crocodiles also prey on many economically important fish species and are often perceived to be major competitors to subsistence fisheries (Graham *et al.*, 1973; McGregor, 2005). Increasingly crocodile human conflicts are having secondary social and political implications. For example, the failure of governments to deal with problem crocodiles effectively has resulted in fractious relationships between local communities and government departments in Mozambique (Anderson *et al.*, 2005). HCC may also have wider implications on development. For example, human wildlife conflict is as a major obstacle to the development of community based wildlife tourism because most local communities cannot sustain long-term conservation objectives if the short-term impacts are perceived as being too costly.

Despite the rise in HCC the international community has heralded the recovery of crocodilian populations as a conservation success story (McGregor, 2005). In the USA and Australia, where only a small percentage of the human population remain directly dependent on natural water bodies, comparatively few human fatalities are reported and the costs of resurgent crocodilian populations are perceived to be mainly leisure activity related and negligible. Conflict in these countries is meticulously documented and current management and conservation policies are considered adequate.

By comparison, in Africa, where a large percentage of the population remains dependent on natural water bodies, very little is known about modern trends in crocodile human conflict. In the absence of this information, crocodile conservation and management policies have continued to be directed by international attitudes with limited reverence for current local opinion. This study suggests that the recovery of Nile crocodile populations has resulted in substantial levels of human crocodile conflict. In particular, the effects on subsistence communities are acute and could potentially undermine development initiatives. Furthermore, growing human pressure and diminishing tolerance levels could ultimately compromise the viability of crocodile populations. If long term crocodile conservation efforts in Africa are to be successful, it is important to recognise the critical role subsistence communities play as the custodians of a significant proportion of crocodile populations.

CHAPTER 4: The impact of rural communities on Nile crocodiles

4.1 Introduction

The relationship between man and wild animals is most often antagonistic due to competition for declining resources (Weladji & Tchamba, 2003). This human-wildlife conflict has become a serious issue within the world today (Holmern, Nyahongo & Roskaft, 2007) and is now considered one of the key threats to conservation in Africa (Naughton-Treves, 1997; Tchamba *et al.*, 1994). Chenje 1998 states that "once development needs and poverty begin to compete with conservation, the latter is certain to lose"(Chenje, 1998). The threat is escalating in both frequency and severity (Nyhus *et al.*, 2005) and has therefore become a major component of many conservation programmes (Marshall, White & Anke, 2007; Rondinini & Boitani, 2007). The first step towards reducing the conservation threat involves understanding the relationships between humans and the species in question.

Namibia is an arid country with erratic rainfall and nutrient deficient soils (NACSO, 2006b). Over 60% of the population live in rural areas where subsistence agriculture and natural resource utilisation are the dominant livelihood strategies (NACSO, 2006b). Wetlands potentially represent the single most valuable resource to food security in Africa (Thompson, 1976). Not surprisingly, the highest rural population densities and growth rates in Namibia can be found along the four major perennial rivers in the North East of the country (CBS, 2002). The sustainability of the water environment is critical to development in southern Africa and the demands for freshwater continue to grow (Chenje, 1998). Despite this, very little, if any, quantitative research has been carried out on how rural communities interact with and impact on freshwater ecosystems within the Zambezi and Okavango basins.

Baseline research on even economically important wetland specific human activities in North East Namibia is limited (Næsje *et al.*, 2004). For example, Van der Waal (2007) analysed ten years of detailed biological fisheries data to reveal that over fishing is likely having costly impacts on biodiversity and local fisheries (Van der

Waal, 2007), yet virtually no corresponding social or economic fisheries data exist to verify these trends. Available literature suggests that over fishing, habitat destruction, stream bank cultivation, industrial pollution, water abstraction and water impoundment are major anthropogenic threats facing freshwater ecosystems within the region (Chenje, 1998; Hay *et al.*, 2000; Næsje *et al.*, 2004). Without a detailed understanding of what humans are doing where, little can be done to manage and conserve Namibia's limited freshwater resources.

The listing of Nile crocodiles (*Crocodylus niloticus)* as a CITES appendix I species in the 1970s has been coupled with extensive research on the species. Most of these studies have focused on general crocodile biology and ecology (Gans *et al.*, 1976; Hocutt *et al.*, 1992; Hutton, 1987; Junker *et al.*, 2006; Kofron, 1989, 1990; Pooley, 1977) and the commercial value of Nile crocodiles (Ayensu, 1983; Blake *et al.*, 1975; Crafter, 1986; Dzoma *et al.*, 2008; Morpurgo, Gvaryahu & Robinzon, 1991; Revol, 1995; Siamudaala *et al.*, 2004). Towards the end of the last century, few scientific studies had looked at the interactions between wild crocodile populations and rural livelihoods. The exception to this is the crocodile form of human-wildlife conflict - human crocodile conflict. Most HCC studies, however, have focused on only one aspect of the conflict - the impacts of Nile crocodiles on humans (Anderson *et al.*, 2005; Boyle, 2007; Fergusson, 2004; Graham *et al.*, 1973; MacGregor, 2002; Scott *et al.*, 1994; Vanwersch, 1998). More recently, the impact of humans on crocodiles has received greater attention (Fukuda, Whitehead & Boggs, 2007; Leslie *et al.*, 2001; Llewellyne, 2007; Santiapillai *et al.*, 2001; Shacks, 2006; Thorbjarnarson & Hernandez, 1992). Fires, overgrazing, invasive species, climate change, fishing activities and direct persecution have all been highlighted as significant anthropogenic threats facing crocodile populations. Shacks (2006) found 59% of remaining crocodile breeding habitat disturbed by human activities in Northern Botswana. Importantly, it would appear to be those activities that are associated with rural subsistence communities that are cause for most concern. For example, In Australia where subsistence communities are characteristically absent, Fukuda et al (2007) found no significant impact of human population density and land use in catchment areas on saltwater crocodile *(Crocodylus porosus)* populations. No studies have specifically attempted to quantify the impacts of rural livelihood activities on Nile crocodiles in the wild.

North Eastern Namibia has experienced a rapid growth in the tourism industry in recent years (Murphy, 2007a). The reasons for this are many and varied but include historic underdevelopment due to regional conflicts (Stanley, 2002), abundant wildlife resources (O'Connell-Rodwell *et al.*, 2000; Stander, 2004) and close proximity to world famous tourist attractions like Victoria Falls and the Okavango Delta (Murphy, 2007a). Today, virtually all development within the region focuses at least to some extent on the growing wildlife based tourism industry (personal observation). Wildlife is therefore one of the most important natural resources within the area, yet the management of this recently realised asset remains poorly understood, highly variable and hotly debated (Owen-Smith, pers coms).

Quantifying the relationship between crocodile biology and human activity would be seen as an important step towards developing a sustainable conservation and management plan for economically valuable populations of Nile crocodiles existing outside of protected areas, both within Namibia and throughout Africa where similar land use patterns exist.

4.2 Methods

4.2.1 Boat surveys

The initial aim of this study was to obtain density estimates of crocodile populations, and compare these with various human activity variables on four large river systems in North Eastern Namibia. Unfortunately, due to the expansive nature of the study area and limited resources, it was not possible to use more formal and robust techniques such as mark recapture to estimate densities (Mazerolle *et al.*, 2007). Instead, I used boat surveys to obtain simple count statistics uncorrected for detection probability. Count statistics were used as an index of relative density for both crocodiles and human activities. A total count was assumed in the area covering the river and immediate river banks up to ~100m on either side of the river.

Boat surveys were carried out on eight study sites covering the Kwando, Zambezi, Chobe and Kavango Rivers. Where possible, three boat surveys were carried out at each site. Due to resource limitations it was not possible to survey all sites simultaneously. This meant that some sites were surveyed at different times of the year to other sites.

Boat surveys entailed travelling up or down stream by day recording anthropogenic data followed by a return trip at night recording crocodile data. Survey routes were logged using a Garmin GPS III and waypoints were automatically recorded every kilometre. Survey lengths were thus divided into kilometre segments for the purpose of recording spatial data. Surveys were carried out by a minimum of two people – one to drive the boat whilst the other observed and recorded data. Two 750 000 candlepower spotlights powered by two 12v car batteries were used during the night surveys. A variety of small single engine river boats were used, the most common being a four meter fibreglass tri-hull powered by a 40hp Yamaha motor.

Boat surveys at night with the use of a spotlight have been widely used for researching crocodile biology and ecology in the wild. Spotlight counts indicate the minimum number of animals present but concealment and diving biases make it very difficult to estimate total population size (Bayliss *et al.*, 1986; Hutton & Woolhouse,

1989; Pacheco, 1996). Temperature, river structure, moon phase, water levels, emergent vegetation and wind have all been cited as variables which can significantly alter spotlight counts (Bayliss *et al.*, 1986; Hutton *et al.*, 1989; Pacheco, 1996). Hutton and Woolhouse (1989) used mark-recapture concurrently with spotlight counts to estimate population size. They concluded that the proportion of crocodiles observed in spotlight counts varies between 10% and 63%, depending on environmental conditions. Water level and the difference between water and air temperatures were the most important environmental conditions, accounting for 64% of the variation in numbers of crocodiles observed. Due to logistical constraints, it was not possible to standardise surveys with respect to water level and temperature during the study. For the analysis, months with an average temperature below 15°C were classified as 'Cool', and months with an average temperature above 15°C were classified as 'Hot' (Mendelsohn *et al.*, 1997). Water level estimates were derived in a similar fashion with each survey falling into one of three different categories, low, mid or high water level. Relative water levels for the individual rivers were obtained from Mendolson & Roberts 1997 and Mendolson & Obeid 2004. Although crude, these classification systems do provide biologically meaningful data necessary for the analysis.

The survey team departed from a designated start point at approximately 15:00Hrs. Where possible the team travelled along the centre of the river however in some cases it was necessary to navigate along deep water channels. The average survey speed was 21.3km/hr. The survey team counted people, traditional canoes, cattle, and tourist boats per marked kilometre. People and cattle counted included all those within ~100m of the river banks and therefore it was sometimes necessary to stand on the boat to see over emergent vegetation or high banks. People in traditional canoes were also counted but those in tourist boats were ignored. Similarly, people within the grounds of tourist facilities (e.g. hotels, lodges) were ignored. Apart from human infants, which were not counted, no distinction was made between age or sex in the people and cattle data. Traditional canoes and tourist boats included all those visible (in or out of the water) that appeared to be in working order. Estimates were made in cases of large cattle herds or groups of people. Data were recorded by a designated scribe without reducing the boat speed. In the three surveys where only two team members were present, the observer recorded the data whilst the boat pilot reduced speed and continued with observations.

After the human surveys had been completed, the team moored the boat and awaited nightfall. The survey team departed as soon as it was dark enough to use the spotlights effectively (approximately 30 minutes after sundown). Using the 'Trackback' function on the GPS, the afternoon's survey route was retraced. The average speed was 15.58km/hr. One spotlight (held by the pilot) was used predominantly to scan the route ahead and watch for hippos *(Hippopotamus amphibius)* whilst the other was used to search for the reflective eyes of crocodiles. No spotlight search was made in front of tourist facilities and government establishments (e.g. military bases). Upon sighting a crocodile, the speed of the boat was reduced and the crocodile was approached. Crocodile sightings were assigned to a marked kilometre and then recorded into one of four size classes: - 1 (hatchling – neonate form below 50cm), 2 (hatchling to 1m), 3 (1m to 2m) and 4 (greater than 2m). In cases where size could not be assessed accurately (e.g. animals submerged prior to close approach) they were recorded in an 'unknown' class (class 5).

4.2.2 Analysis

The data posed two main challenges. Firstly, because relatively few surveys were carried out, most surveys experienced unique combinations of critical environmental variables making robust comparisons and assumptions difficult. Ideally, the survey regime laid out in Table 3.1 should have included surveys for all combinations of temperature and water level classes at all survey sites. Secondly, multiple surveys were carried out on the same rivers and in the same months and therefore individual surveys were not strictly independent. Because of the limited sample size, this study necessarily treated each survey as an independent sample resulting in spatial and temporal pseudo replication.

In the preliminary analysis, average encounter rates and correlation coefficients for human activities and crocodiles were determined at three different levels of resolution. The 'survey level' included 20 spatially and temporally distinct surveys, 'survey site level' included eight spatially distinct survey sites, and the 'river level' included four large perennial rivers.

I then looked at finer scale associations between humans and crocodiles using the repeated samples of 224 kilometres of river. The open-source software R, version 2.4.1 (R_development_core_team, 2006) was used for this analysis. In an attempt to cope with the spatial and temporal pseudo replication associated with my survey regime, I followed the following set of steps:

First, I constructed a series of general linear models with two variables fitted as additive independent terms and crocodile counts as the response variable (Table 2). I did this because I did not have sufficient comparative samples at each survey site to construct a biologically meaningful full model at the outset (Table. 1). Instead, comparing pairs of terms provided a simple method for estimating the relative importance of individual variables. The explanatory variable combinations included one human activity variable and one environmental variable. Crocodile counts were divided into three different classes and each class was analysed separately. The classes were: little (hatchling and small counts combined), big (medium and large counts combined) and total (all classes combined). Year, month and river were fitted as factors. Model fit was determined by R^2 values (R^2 = 1-residual deviance/null deviance). When I fitted these models I found that models with people and time of the year (month) explained more variation than other combinations of variables.

Secondly, I fitted generalised linear mixed effects models where I examined whether month and river fitted as random intercepts improved model fit. I did this because I had repeated measures on rivers and months leading to pseudo replication. To select the most parsimonious models, alternative random error structures of the minimum adequate models were assessed by comparing the Akaike Information Criterion (AIC) values. People and canoes were strongly correlated and consequently were not fitted together as fixed effects. Percentage variance caused by the random effects was compared with the null model variance (Table 3). In practice, I found that there was little support for keeping random effects and I concluded that repeated observations in the same month or on the same river do not lead to significant amounts of pseudo replication.

Finally, I fitted temperature and water level to my original generalised linear models containing people and month as explanatory variables. I checked data for over

dispersion and a Poisson error structure was used. As in the previous linear model analysis, selection of the minimum adequate model was based on the lowest AIC value. I could not use sequential elimination of non-significant terms using ANOVA because of unequal data sets. These GLMs allowed me to examine whether the difference I found between month and river could be explained with temperature and/or river water level.

4.3 Results

4.3.1 Preliminary analysis

In total 20 surveys were carried out between July 2006 and October 2007 (Table 4. 1). The total distance surveyed was 525km. Survey lengths averaged 26.25km (range 15 -32km). Encounter rates between rivers, survey sites and surveys varied greatly (Table 4.1, Fig 4.1). Overall the Chobe River had the highest density of crocodile counts (2.84 per km) (Figure 4.2a). The Kavango had the highest density of people counts (10.94 per km) and cattle counts (4.17 per km) whilst the Zambezi had the highest density of canoe counts (2.44 per km). The Kwando River had the lowest densities of canoes, people and cattle counts (0.03, 0.2 and 0.26 per km respectively) (Figure 4.2b).

The Kwando river had relatively large numbers of hatchling and small crocodile counts (0.74 per km) compared with medium and large crocodile counts (0.16 per km) This trend was reversed on the other rivers, which in general showed greater percentages of the medium and large crocodiles (Figure 4.2a).

In general correlations increased with increasing sample size and spatial resolution. The survey site and river levels recorded the highest correlation coefficients for all variables. People, cattle and canoes produced very strong correlation coefficients at all levels (e.g. range 0.5 to 0.7 at the survey site level). Crocodiles and people showed a negative correlation at all levels (range -0.26 to -0.54) but large and medium crocodiles showed a positive correlation coefficient with canoes at all levels (range 0.18 to 0.33). Large crocodiles also showed a positive correlation with cattle at all levels (range 0.32 to 0.41).

The spatial and temporal variation associated with my survey regime made it difficult to clearly define associations at these spatial levels. I therefore concluded that although my results lacked robust statistical evidence, there was a general negative relationship between crocodiles and people at the survey, survey site and river levels.

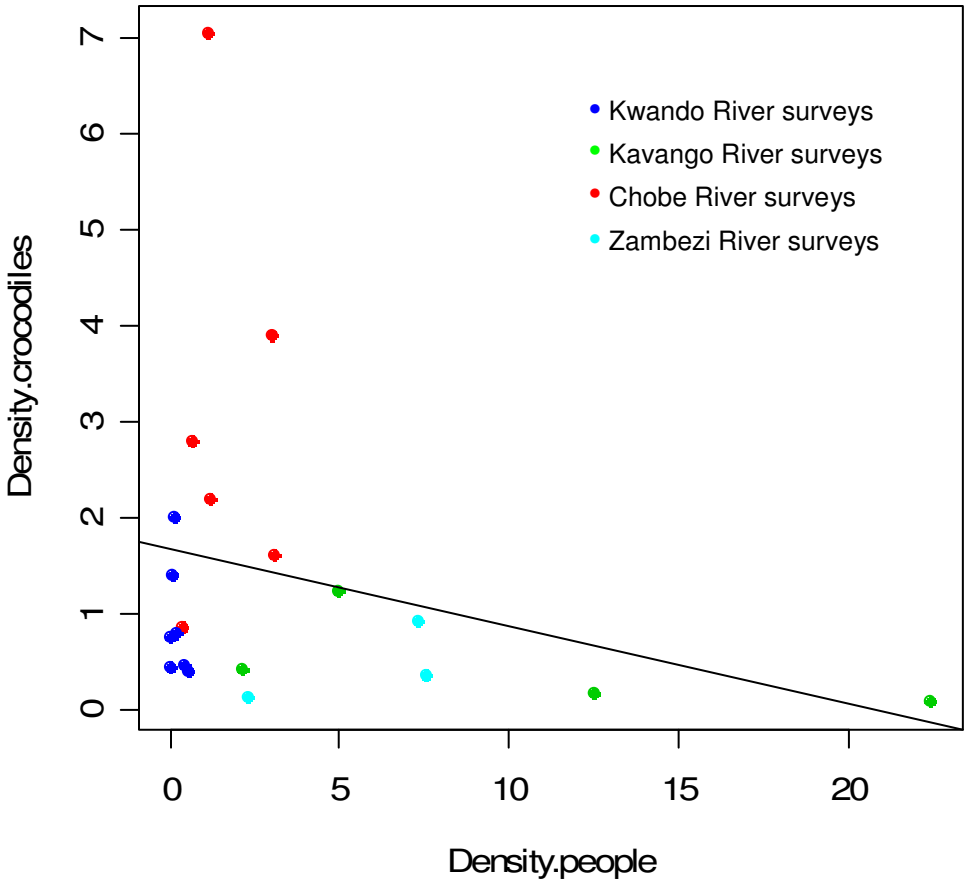


Figure 4.1. Scatterplot showing the negative relationship between people and crocodiles at the survey and river levels (crocodile counts~people counts). Similar patterns were observed for all crocodile size classes. y=-0.0795x+1.8

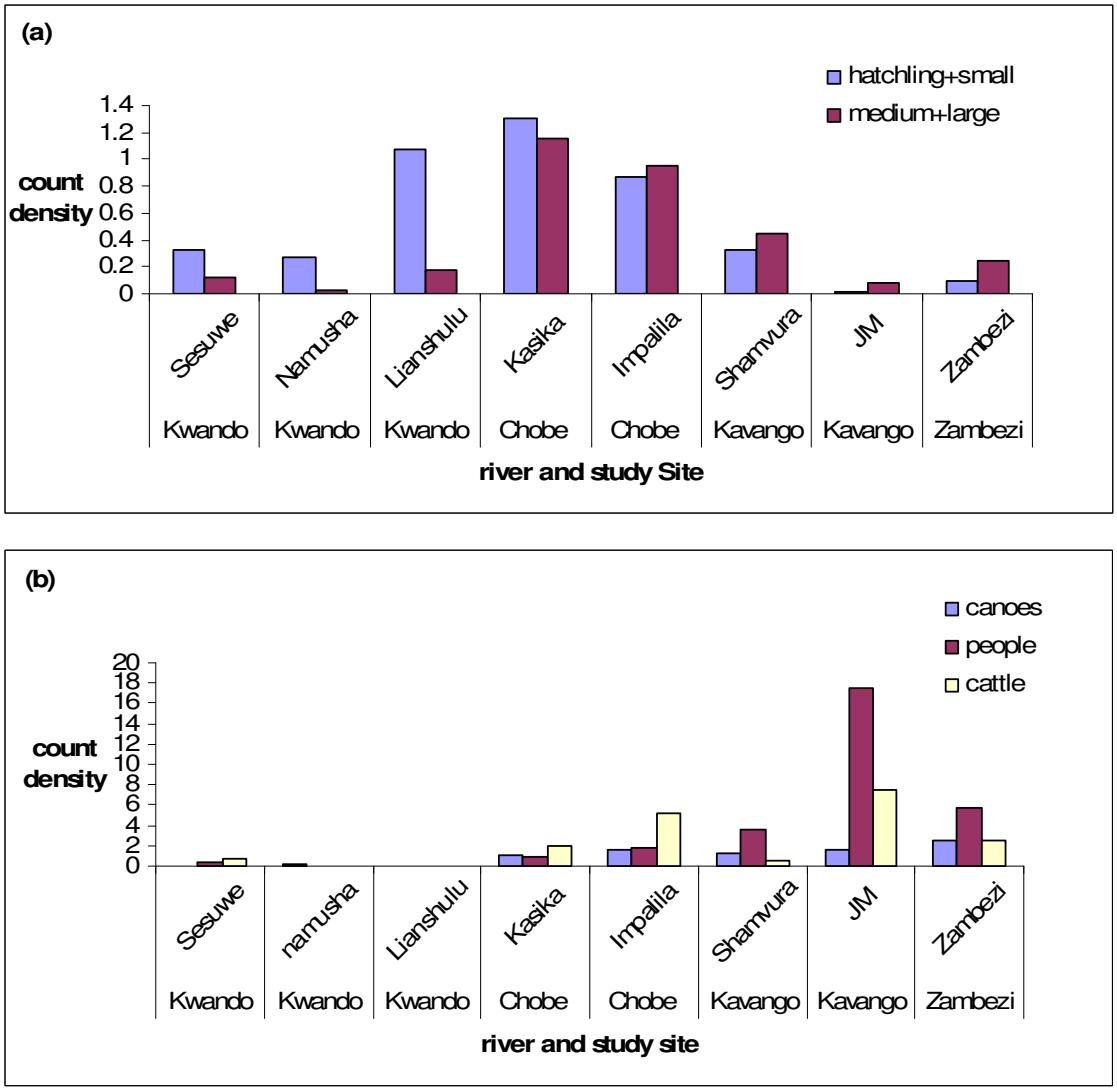


Figure 4.2a and b. Count densities of crocodile size classes and human activities recorded within survey sites and rivers.

Table 4.1 Summary of boat survey statistics including densities of people and crocodile counts per survey.

				River	**Sur.site**								
				Chobe		Kavango		Kwando			Zambezi		
Year	**Temp.**	**Wat.Level**	**Data**	Impalila	Kasika	JM	Shamvura	Lianshulu	Namusha	Susuwe	Zambezi	ave.peop.	ave.crocs
2006	cool	low	people	3.1	1.2						7.55	3.95	
			crocodiles	1.2	2.2						0.36		1.39
		mid	people			12.5	4.95	0	0	0.43		3.58	
			crocodiles			0.18	1.23	0.75	0.44	0.47			0.61
2007	cool	high	people			22.42	2.17					12.3	
			crocodiles			0.08	0.42						0.25
		low	people								7.35	7.35	
			crocodiles								0.91		0.19
		mid	people	0.4	0.7			0.06		0.57		0.43	
			crocodiles	0.85	2.8			1.4		0.4			1.36
	hot	high	people								2.35	2.35	
			crocodiles								0.13		0.13
		low	people	3.04	1.15							2.1	
			crocodiles	3.89	7.05								5.47
		mid	people					0.16		0.2		0.18	
			crocodiles					2		0.8			1.4
			ave.peop.	2.18	1.02	17.46	3.56	0.07	0	0.4	5.75		
			ave.croc.	2.11	4.02	0.13	0.83	1.38	0.44	0.56	0.47		

4.3.2 Model analysis

I then looked at associations at the kilometre level, beginning with simple generalised linear models (Table 4.2). For all three crocodile classes the generalised linear models containing the variables month and people captured the most variation (R^2_{total}=0.42, R^2_{little}= 0.27, R^2_{big}= 0.36). Of the environmental variables, month explained the most variation followed by water level and then year. A similar pattern was observed for all crocodile classes.

Because multiple measures were made on the same river and in the same months, there was a possibility of bias in these results caused by spatial and temporal pseudo replication. To check whether this was a problem, I fitted linear mixed effects models (Lmers) to the data (Table 4.3). River and month fitted as random effects accounted for less than 5% of the variance in the null models of all crocodile classes and they did little to improve the model fit (Table 4.4). The Lmers did not provide strong support for pseudo replication suggesting that the results obtained from the generalised linear models were unbiased.

Returning to the simple generalised linear models, I added temperature and water level as explanatory variables in order to examine whether the difference I found between month and river could be explained by these variables. Temperature and month could not be fitted together because month explained all of the variation in temperature. When fitted separately, the models containing temperature had higher AIC values than the models containing month (Table 4.4). Temperature was therefore not included in the minimal adequate models. Water level proved to be a highly significant determinant of crocodile counts for all classes ($p<0.001$). The additive effects of people, time of year (month) and river water level explain 47% of the variation in the overall density of crocodiles. The model fares less well with individual size classes, explaining only 38% of the variation in density of crocodiles greater than one meter and 36% of variation in density of crocodiles less than one meter in length.

Table 4.2. Model selection: Generalised Liner models with total crocodiles counts fitted as the response variable. Bold case indicates significance at the 95% level. Month and People explains the most variation. A similar pattern was observed for all crocodile size classes.

Model	Null Dev	Resid.Dev	Rsd.d.f	Proportion r^2
total~**people+river**	1110	739.62	480	0.33
total~cattle+**river**	1183.78	836.21	520	0.29
total~canoes+**river**	1183.78	835.58	520	0.29
total~**people+month**	1110	639.46	476	**0.42**
total~cattle+**month**	1183.8	754.8	516	0.36
total~canoes+**month**	1183.78	754.45	516	0.36
total~**people+year**	1110	966.58	482	0.12
total~**cattle+year**	1183.8	1125.3	522	0.04
total~**canoes+year**	1183.8	1119.3	522	0.05
total~**people+water.level**	1110	787.74	481	0.29
total~cattle+**water.level**	1183.78	923.02	521	0.22
total~**canoes+water.level**	1183.78	909.68	521	0.23
total~**people+temperature**	1110	888.17	482	0.19
total~cattle+**temperature**	1183.8	1016.4	522	0.14
total~**canoes+temperature**	1183.8	1006.2	522	0.15

Table 4.3 Model selection statistics for the comparison between linear mixed effects models and generalised linear models for all crocodile classes.

Null models	**Null deviance**.(nd)	
Total~1	1183.8	
Big~1	657.32	
Little~1	702.99	
Lmer models	**Deviance** (dl)	**Lmer R2** (nd-dl)/nd
Total~People+Month+(1|River/Month)	626.8	0.47
Big~People+Month+(1|River/Month)	394.3	0.4
Little~People+Month+(1|River)	439.8	0.37
GLM models	**Residual deviance** (rdg)	**GLM R2** (nd-rdg)/nd
Total~People+Month	639.46	0.46
Big~People+Month	394.31	0.4
Little~People+Month	466.61	0.34
Response variable	**Difference between Lmer and GLM R2 values**	
Total	0.01	
Big	0	
Little	0.03	

Table 4.4. Model selection for three different classes of crocodiles. The minimum adequate models are in bold.

Model	AIC	Resid Df	Resid Dev	R2
Total~People+Month+Water.level	1232.6	474	593.08	0.47
Total~People+Water.level+Temp.	1331.3	480	703.78	
Total~People+Month	1275	476	639.46	
Total~Month	1469.8	517	754.97	
Total~People	1679.1	483	1057.6	
Big~People+Month+Water.level	673.94	474	382.38	0.38
Big~People+Water.level+Temp.	742.14	480	462.58	
Big~People+Month	681.87	476	394.31	
Little~People+Month+Water.level	812.69	474	411.35	0.36
Little~People+Water.level+Temp.	848.15	480	458.82	
Little~People+Month	863.94	476	466.61	

4.3.3 Results summary

In both the preliminary analysis at the broader geographical scales and in the more detailed analysis at the finer geographical scale, crocodiles showed a negative relationship with people. Furthermore, all these analyses were carried out separately on different size classes of crocodiles and without exception similar trends were observed. The relationship between crocodiles and canoes and cattle is less obvious and appears to vary with size class and spatial scale.

4.4 Discussion

My primary objective was to describe the consequences of rural communities living in close proximity to Nile crocodiles. Specifically I wanted to quantify the impact of key anthropogenic activities associated with subsistence livelihoods on the abundance of various size classes of crocodiles. I did this by carrying out a series of boat surveys from which simple count statistics were obtained for anthropogenic activities and crocodiles.

4.4.1 Limitations

The most important limitations of this study were the small sample size and erratic survey schedule. The limited number of surveys carried out at random times of the year resulted in large amounts of variation in both the crocodile and the human data. A larger number of surveys and a more temporally uniform survey schedule would have eliminated much of the variation associated with the key environmental variables. A survey regime of this nature would have enabled separate analyses to be carried out for each month and each river thereby eliminating the problem of pseudo replication. In light of these limitations, the more detailed quantitative aspects of the results should be interpreted with caution. More importantly, this study provides evidence for general trends in the crocodile human relationship.

4.4.2 Analysis at broader geographical scales

On the larger spatial scales of river and survey site there is a negative impact of people on all crocodile size classes. Details of the people-crocodile relationship will be discussed below. Large and medium crocodile size classes show a positive relationship with canoes at all levels, despite strong correlation between canoes and people at all levels. Nile crocodiles display an ontonogenic shift in diet with young animals feeding primarily on invertebrates whist larger animals feed primarily on fish (Pooley, 1982; Wallace, 2006). In NE Namibia, 81% of traditional canoes are used for fishing (Boyle, 2007) with the highest densities of canoes being found in the richest fishing areas (personal observation). It is possible that crocodiles over one metre in length and canoes are indirectly correlated through the distribution and abundance of fish. Large crocodiles also show a positive correlation with cattle although co-linearity between

canoes and cattle could be the cause of this (e.g. $R^2_{survey.level}$ =0.26). Crocodiles in NE Namibia prey readily on cattle and are known to follow cattle herds grazing along the river banks (personal observation). In the absence of natural terrestrial prey species, large crocodiles may be frequenting areas where cattle congregate close to the rivers edge.

The Kwando River differed from the other three rivers in two noticeable respects. Firstly, this river recorded substantially lower levels of human activity than the other rivers and secondly, this river recorded relatively higher proportions of smaller crocodiles. This demographic trait of relatively large numbers of younger animals suggests that the population is increasing (Purves, 2003), probably as a result of the relatively lower human presence and associated direct and/or indirect persecution.

Unfortunately the large amounts of variation observed between surveys, survey sites and rivers made it difficult to extract statistically significant results at the larger spatial scales and further research is needed to verify these associations.

4.4.3 Analysis at finer geographical scale

4.4.3.1 Analysis at finer geographical scale – environmental effects

On the finer scale of associations within kilometre sections of river, people and month emerged as the most important human activity and environmental variables respectively. Despite repeated measures on rivers and months, spatial and temporal pseudo replication did not appear to be biasing results. This is probably because there is greater within river variation than between river variation, and there is substantial variation in the numbers of crocodiles counted during surveys within each month. Both human activity and crocodile densities do vary substantially along rivers and within months. For example, fishermen may travel up to 40 km to exploit seasonal abundances of fish (Van der Waal pers comm). Crocodiles may also travel considerable distances up and down rivers to feed on temporary food sources (Pooley, 1982). In 2005, at least 66 large crocodiles were observed feeding on a single hippo carcass in the Chobe River survey area (Murphy pers comm) – considerably more than the total number of adult crocodiles counted during all subsequent boat and aerial surveys of this area. The variation that does exist between rivers is probably still governed to a large extent by the underlying nutrient levels and biological productivity within these greater

ecological systems. Monthly variation in crocodile counts may also have been attributed to spotlighting conditions. Moon phase, for example, has been cited as a source of bias in crocodile spotlight counts (Graham *et al.*, 1973; Hutton *et al.*, 1989; Pooley, 1982).

The model selection statistics strongly supported a model incorporating people, month and water level as the most important variables in determining crocodile population densities. Together these three variables explained almost 50% of the variation in densities of crocodiles. Table 3.4 shows that month has a particularly strong association with crocodile density. The reasons for this are most likely related to seasonal temperatures. Crocodiles are poikilothermic, becoming most active in warmer temperatures and less active in cooler temperatures (Ross *et al.*, 1992). In South Africa, highly visible behaviour like breeding and feeding activity occur almost exclusively in the hot summer months (Pooley, 1982). Seasonal water level fluctuations can also have impacts on crocodile visibility by increasing or decreasing the amount of suitable habitat available. This is particularly so in the Zambezi and Chobe rivers where water levels fluctuate annually by as much as eight meters. In the Chobe floodplain for example, large numbers of crocodiles temporarily inhabit ephemeral floodplain pools (Macaulay, 1960), a phenomenon that likely results in considerable population fluctuations in the main river channels.

4.4.3.2 Analysis at the finer geographical scale - Anthropogenic effects

This study suggests that there is support for the notion that abundances of crocodiles are substantially influenced by variation in human intensity or the scale of the human presence. Crocodiles are despised virtually throughout their range as wanton killers of humans and livestock and many people readily persecute them (Boyle, 2007; Pooley, 1982; Shacks, 2006). Apart from representing a threat to human life, they are responsible for considerable livestock losses and damage to fishing equipment in Namibia and little has been done to curb the problem. National and international conservation policies prohibit the killing crocodiles without a permit yet despite this the illegal trapping, shooting and spearing of crocodiles is known to take place on a regular basis (Boyle, 2007). Furthermore, in some regions crocodiles and/or their eggs are eaten by humans although it is believed that few people actually harvest the animals for this purpose (Boyle, 2007). Indirect persecution of crocodiles remains poorly

understood. Crocodiles are vulnerable to being caught and drowned in fishing nets as by catch (Pooley, 1982; Santiapillai *et al.*, 2001), although given canoe distributions and densities, this study would suggest that this is not a major threat to crocodiles, at least those over one metre in length. Similarly, habitat destruction through livestock farming and overgrazing would not appear to be an important direct negative influence on crocodile abundance and reproduction. This study fortuitously recorded crocodile nest sites and it is interesting to note that virtually all the nests recorded outside protected areas were located in isolated sites generally inaccessible to livestock and/or humans (e.g. islands and inconspicuous clearings in dense reed beds), whereas crocodiles in the Chobe National Park nested in a semi-colonial fashion on exposed banks. Less well understood is the impact of the growing levels of tourism and boat traffic along rivers. Noise pollution and bank erosion from boat wakes in particular have been cited as potential threats to crocodiles (Shacks, 2006). At present motorised boats remain relatively uncommon in the rural areas of NE Namibia due to their cost of purchase and maintenance. Nevertheless, with continued growth and development it is likely that this threat will increase dramatically in the future.

4.4.4 Management and conservation implications

At present environmental variables would appear to be the most important determinants of crocodile abundance in the region. Nevertheless, with rapidly growing human populations and demands for wetland resources, it is likely that the relative importance of these variables will begin to shift. Namibia in particular poses unique threats to wetland resources. By African standards the country is large, stable, wealthy and well educated with fresh water being one of the few limitations to development potential. Recent improvements in the transport and communication sectors have, however, made the remote rivers of the north economically accessible to international commerce and many former fishing hamlets are now rapidly expanding growth points. The stage has been set for exponential increases in river usage and it seems unlikely that crocodile survey statistics will remain unchanged over the next decade. In all likelihood conservationists will be hard tasked to find any suitable refuge for a large and dangerous predator in such a fertile commercial location.

CHAPTER 5: The distribution of wildlife within the wetland ecosystems of North Eastern Namibia and implications for crocodile conservation.

5.1 Introduction

In Southern Africa Nile crocodiles feed readily on large terrestrial mammals (Branch, 1990) and are thus to some extent dependent on healthy populations of these animals. Understanding the distribution of terrestrial mammals in relation to crocodile habitat may therefore be considered an important aspect of Nile crocodile conservation biology. Furthermore, understanding the determinants of the distribution of terrestrial prey species in highly fragmented human wildlife ecosystems would provide valuable insights into human crocodile conflict (HCC).

The savannahs of south central Africa support a high diversity and abundance of large terrestrial mammals (Smithers, Skinner & Chimimba, 2005). Biologically one of the most important limiting factors to the mammalian biomass and diversity within this region is water. The area is characterised by erratic and highly seasonal rainfall patterns resulting almost no permanent surface water away from the perennial rivers (Mendelsohn *et al.*, 2004; Mendelsohn *et al.*, 1997). Instead, the region relies largely on water transported from distant catchments in Angola and Western Zambia (Mendelsohn *et al.*, 2004), and it is these large perennial rivers that partly determine the regions wildlife carrying capacity. During the dry season water dependent animals congregate in high densities along the few perennial rivers (Stander, 2004). The larger rivers and wetlands also support a number of specialist wetland species (Stander, 2004). Hippopotamus (*Hippopotamus amphibius*) , stiatunga (*Tragelaphus spekii*) , southern reedbuck (*Redunca arundinum*) and red lechwe (*Kobus leche leche)* are resident species dependent on wetland habitats (Smithers *et al.*, 2005). This considerable assemblage of large mammals concentrated close to the water has been an important evolutionary driving force behind the aggressive nature of Nile crocodile feeding behaviour (Ross *et al.*, 1992). Few other crocodilians demonstrate such a willingness to tackle large mammals at the waters edge (Ross *et al.*, 1992).

Nile crocodiles show an ontonogenic shift in diet as they mature. Hatchling and small crocodiles feed primarily on shoreline invertebrates and small vertebrates including frogs, shrimps, snails, crabs, insects and fish (Wallace, 2006; Wallace & Leslie, 2008). As they grow there is a gradual increase in the number of fish consumed (Wallace, 2006; Wallace *et al.*, 2008) and by the time they are young adults fish may constitute up to 70% of the diet (Games *et al.*, 1997; Ross *et al.*, 1992). Although fish may form the bulk of the diet, adult crocodiles can subsist on a wide variety of prey species ranging from frogs and snails to large ungulates and carrion (Ross *et al.*, 1992). Crocodiles are believed to grow throughout their lives however growth rates slow considerably once they reach sexual maturity (Webb *et al.*, 1987). With age they begin to fill out and become increasingly robust. Older mature crocodiles tend to expend less energy pursuing small agile prey and instead focus their efforts on ambushing larger terrestrial species at the waters edge (Pooley, 1982). The most frequently recorded mammalian prey taken by large Nile crocodiles in southern Africa include waterbuck (*Kobus ellipsiprymnus*), sitatunga, lechwe, wildebeest (*Connochaetes taurinus)*, zebra (*Equus quagga)*, impala (*Aepyceros melampus)* and warthog (*Phacochoerus africanus)* (Branch, 1990). It is pertinent at this point to make a distinction between mature crocodiles and large crocodiles. Nile crocodiles mature at approximately 2.4m in length but it is only once they exceed three meters that they start to feed regularly on terrestrial mammals (Ross *et al.*, 1992). For the purpose of this chapter, large crocodiles are classified as those animals over three meters in length.

In many species, the larger adult individuals are an important component of the population. Chase (2007) demonstrated how the older elephants can retain and relay information on the location of resources along historic migratory routes (Chase, 2007). In crocodiles size and age can infer a variety of desirable survival qualities. Rapid learning has been implicated in the demonstrated tendency of wild crocodilians to become increasingly wary when approached and/or captured (Webb & Messel, 1978) resulting in older, more experienced animals having potentially higher survival rates. During the course of this study (~1000 km of boat surveys) large crocodiles living in areas where fishermen were harpoon fishing at night with the aid of spotlights (and possibly fortuitously stabbing crocodiles with spears) were noticeably more wary than smaller crocodiles and large crocodiles living in less disturbed areas. Larger female

crocodiles are more fecund than younger animals. Egg viability, egg size, clutch size and egg mass are all positively correlated with female size in the Orinoco crocodile, (*Crocodylus intermedius)* (Thorbjarnarson & Hernandez, 1993). Larger female crocodiles are reported to be more successful at defending nest sites from human intervention (Spencer Creek Crocodile Farm, pers comm). In terms of ecology and conservation, large crocodiles are therefore potentially valuable components of the population, particularly in environments facing dynamic conservation challenges from growing human pressure.

In relation to the numbers of adult crocodiles present and the level of rural community interaction with crocodile habitat, attacks on humans in Namibia are relatively uncommon. A possible explanation for this phenomenon is that many adult crocodiles in Namibia have yet to reach a size class that regularly includes large mammalian prey in the diet. From casual observations, three phenomena are apparent in many human attack instances. The first is that a spate of livestock attacks often precedes a human attack. The second is that after an attack local communities often single out and identify a particular individual as the culprit, and the third is that a significant number of problem crocodiles appear to be in relatively poor condition (various, pers comm). This circumstantial evidence tentatively suggests that attacks are not random but are the result of a gradual shift in feeding behaviour (i.e. fish to mammals) of conspicuous (i.e. noticeably larger) individuals. It is therefore reasonable to assume that larger crocodiles are likely responsible for a significant proportion of attacks on humans, and are also probably responsible for proportionately more fatal attacks due to their relative size and strength.

Large Nile crocodiles are the most valuable instrumental size class in both managed and fully protected populations. Crocodiles less than three meters in length are considered essentially valueless by the trophy hunting industry whereas large animals command trophy fees of up to US$ 3000 (HHKSafaris, 2008). Similarly, photographic tourists often show considerable interest in large crocodiles (Llewellyne, 2007) but display limited interest in smaller apparently less impressive animals (personal observation). In countries where crocodile ranching is permitted and wild egg harvests are a component of the industry, large females are disproportionately valued because they lay large clutches in known localities every year thus improving search

effort to yield ratios (Spencer Creek Crocodile Farm, pers comm). Therefore, in terms of the sustainable use value of wild Nile crocodile populations, it is the large individuals that command the highest price.

The science behind the conservation of Nile crocodiles specifically within human dominated environments is in its infancy. Historically studies have tended to focused on the pure biology (Gans *et al.*, 1976; Hocutt *et al.*, 1992; Hutton, 1987; Junker *et al.*, 2006; Kofron, 1989, 1990; Pooley, 1977) and the instrumental value of the species (Ayensu, 1983; Blake *et al.*, 1975; Crafter, 1986; Dzoma *et al.*, 2008; Morpurgo *et al.*, 1991; Revol, 1995; Siamudaala *et al.*, 2004). More recent conservation orientated research has been directed towards the socio-economic aspects of crocodile conservation with particular regard to HCC (McGregor, 2005; Thomas, 2006). Specific research on the ecology of crocodiles living within human landscapes lies at the interface of these broad research fields has to some extent been over looked. Understanding the feeding ecology of crocodiles living within human landscapes would directly improve our understanding of human crocodile conflict, and consequently increase our ability to formulate successful conservation and management strategies. This study aims to understand the distribution of large mammalian prey species within an extensive wetland ecosystem utilised concurrently by humans and wildlife.

5.2 Methods

5.2.1 Study Site

The wetland ecosystems of the Caprivi Strip consist of several interconnected rivers and associated backwaters, tributaries and floodplains. A large proportion of these habitats are ephemeral with dry cycles ranging from seasonal to several decades. The analysis for this chapter only covers the perennial rivers and their immediate surroundings and ignores those areas that experience intermittent inundation. The greater Kwando river stratum consists of a meandering river with a broad well vegetated floodplain. Compared to other wetland ecosystems within the area the floodplains, channels and backwaters are morphologically stable and biologically infertile. In most years the river ends in series of distributaries forming a delta called Mamili Swamp (NACSO, 2006a). The greater Chobe stratum consists of the Zambezi and Chobe rivers and incorporates the junction of the two rivers. This stratum is dominated by an extensive floodplain ecosystem ranging from permanent swamp at the junction to seasonal grasslands at the outer extremities of the stratum area. In comparison to the Kwando River, the greater Chobe stratum is dynamic, nutrient rich and supports a greater level of biological activity. Because of the flood risk the greater Chobe and the Kwando strata are mostly devoid of permanent human settlements although semi permanent fishing camps occur sporadically over time and space (pers. obs.)

Apart from distributaries in Mamili Swamp, all the rivers in the study area represent borders between land use types. Several attempts have been made to erect fences across or along the rivers but virtually all have failed due to wild animal and/or flood water damage (pers obs, various, pers comm). As a result there are no manmade barriers inhibiting the movement of wild animals or cattle along or across the rivers. Cattle are abundant throughout the two strata. Most occur in small resident herds (Murphy *et al.*, 2002) which are penned at night in village enclosures. Herd boys are usually employed to shepherd livestock to and from the villages but generally cattle are allowed to roam freely during the day (Ashley *et al.*, 1997). Some herds, particularly on the Chobe floodplain, are partially migratory in concert with the seasonal water levels.

Cattle depend heavily on floodplain vegetation and regularly swim or wade to reach fresh grazing (pers obs).

Wildlife in North Eastern Namibia occurs mainly within the designated wildlife areas although these are all unfenced and animals are able to move freely. Where villages do occur, ribbon type settlement patterns usually present a strong deterrent preventing animals from free movement (Chase, 2007). In contrast, the rivers enable wildlife to move relatively freely throughout the Chobe and Kwando study strata.

5.2.2 Aerial Survey

Data were collected by means of two wildlife aerial surveys carried out in North Eastern Namibia. These surveys were carried out specifically to determine the status of wetland species and were thus restricted to a predefined area demarcating major rivers and associated wetlands. The first survey was conducted between 11 and 20 August 2004 and the second was carried out over 11 days between 29 August and 21 September 2007. These dates correspond to the winter dry season when there is increased visibility and wildlife is aggregated close to perennial water bodies. Similar methodology was used for both surveys. A total block-count design divided the survey area into five strata including the Kavango (56 km^2), Kwando (370 km^2), Mamili National Park (377 km^2), Chobe /Linyanti (520 km^2) and Zambezi (455 km^2) (Fig 5.1). Each stratum was subdivided into counting blocks of approximately 15 km^2 in size. Each counting block was surveyed systematically and all animals were counted.

The survey was a total count of water bodies and floodplains. Two wands were attached to each of the wing struts to delineate a 250 m interval for recording wildlife observations at an altitude of 90 m. Transects were spaced 500 m apart, providing a 100% sampling coverage. Transects were typically flown during morning hours (~0730 - ~1030 hrs); however occasionally it was necessary to fly in the afternoon (~1600 - ~1730 hrs) due to logistical constraints. Transects were flown at ~100 knots using a Cessna single engine fixed winged aircraft, and altitude was maintained at approximately 90m using a radar altimeter. Prior to flying, all transects were incorporated into a digital map of the survey area with their beginning and end point coordinates. This digital map was created using ArcView 3.2 (ESRI 2002) software

and showed observable landmarks and boundaries. GPS receivers and associated software were used to navigate along transects.

For all strata I used the standard methodology for transect sampling developed by Norton-Griffiths (1978) (Norton-Griffiths, 1978). Only wildlife observations that were observed within the interval were counted and recorded. For the Chobe River stratum the flight path was restricted to the river and adjacent floodplains and observers recorded wildlife species inside and outside the counting interval. Observers recorded herds when they were as perpendicular to the plane as possible. For each observation seen within the transect interval, the observer called out the species and number. With each observation, a data recorder entered a waypoint on the GPS. The recorder also kept a written data log for each observation including: the waypoint number and time, altitude from the radar altimeter, and number of individuals observed. A different pair of observers was used for each of the years, however all four observers had considerable prior experience in wildlife aerial surveys.

To verify herd size and the sighting of herds, cameras or video footage were employed. For the 2004 survey, freestyle video footage and/or digital photographs were taken of large herds or gatherings of animals. For the 2007 survey, two remotely operated digital cameras were mounted on either side of the plane with lenses focused on the centre of the count area. This enabled the observers to photograph animals via remote with minimal distraction.

5.2.3 Analyses

Two principal methods were used. First, in the preliminary analysis, randomization techniques (Manly, 2007; Manly, McAlevey & Stevens, 1986) were used to assess spatial patterns and relationships of wildlife species and anthropogenic observations. Second, a multivariate analysis using generalized linear models was carried out to better understand the spatial distribution of cattle. Data from the Kavango stratum were omitted from the analysis due to method inconsistencies.

5.2.3.1 Randomisations

Randomisation techniques were employed to test for significant intra-specific aggregation or avoidance behaviour within the various wildlife species and anthropogenic observations (henceforth each species, anthropogenic observation or 'observation entity' is referred to as a class or observation class) within the survey strata. Analyses were carried out on two principal areas within the total survey area, namely the greater Kwando strata (Kwando and Mamili strata) and the greater Chobe strata (most of the Chobe and Zambezi strata) (Fig 5.2). These areas were selected based on the presence of visible surface water at the time of the surveys (e. g. much of the Linyanti stratum and part of the Chobe floodplain were dry during both surveys). The spatial limits of the greater Kwando and Chobe strata were further refined according to the area covered by the marginally less expansive 2004 aerial survey. The vector data demarcating the boundaries of the two strata areas were created using GIS software (ESRI, 2006) and incorporated into the analysis using the software 'R' (R_development_core_team, 2006). All observations outside of the greater Kwando and Chobe strata were ignored. I performed randomization simulations (1000 iterations) to create 'pseudo-populations' of each observation class within each of the strata and for each year. For herd and group living animals (e.g. hippo, impala), two sets of randomization simulations were carried out, one for individuals in the population and one for herds. Thus in effect an additional class was created for each herd species whereby each herd observation was recorded both as a number of individuals and as a single entity representing the new 'species'. The test statistics of the empirical data (mean distance between individual observations within each class) were analyzed by comparing the observed values to the upper and lower tails of the simulated null distribution. Confidence limits were set at the 95% level. This was done to see whether observed mean distances between observations within each class were significantly large or small for the null distribution. The simulations and analyses were done in 'R' version 2.6.1. (R_development_core_team, 2006)

Randomization techniques were then used to test whether species were randomly distributed with respect to one another, and in particular weather species or observation classes were avoiding one another. To do this a similar randomization process to above was carried out on pairs of classes. The following pair combinations were analyzed; species to species, species to herds, anthropogenic class to anthropogenic class, anthropogenic class to herds and anthropogenic class to species. With each pairing,

pseudo populations were simultaneously created for each class using 1000 iterations. The empirical data were compared with the randomized null distribution using mean minimum distances between classes as the principle test statistic. By comparing the observed values to the upper and lower tails of the simulated null distribution it could be deduced whether observed mean minimum distances between pairs of classes were significantly (95% level) larger or smaller than the null distribution.

5.2.3.2 Multivariate analysis

To further explore the results from the second randomization analysis I used a multivariate analysis to determine the factors influencing the distribution of cattle observations within the strata. I used a generalized linear model with a quaispoisson error structure. Cattle observations were fitted as the response variable and soil texture, vegetation structure, distance to settlements, distance to river, distance to nearest neighbor and proximity to national parks were fitted as explanatory variables. Soil texture and vegetation structure were fitted as factors with six levels each. The full model contained all interaction terms and model simplification followed Crawley (2006). In a second similar model distance to settlement was fitted as a quadratic term to test for a non linear relationship between cattle and human settlements. Explanatory variable data were derived either directly from existing high resolution spatial data (NACSO, 2006a) or calculated from this data using the 'join and relates' function in ArcGIS (ESRI, 2006).

5.3 Results

Flying time for the 2004 survey amounted to 36.5 hours (including ferry time), flight altitude averaged 93m (range 84-101 m) and a total of 9,515 animals were counted. For the 2007 survey, flying time amounted to 42 hours (including ferry time), flight altitude averaged 92 m (range 85-112 m) and a total of 17,050 animals were counted. Table 5.1 summarises the species and counts per stratum for each of the surveys.

5.3.1 Randomisations

Table 5.2 presents the results from the randomisation analysis showing random (non –significant) or non random (significant) distribution patterns for each species. Cattle and traditional canoe data were not available for the 2004 survey. Hippos were included in analysis as the large regional population potentially represents an important source of carrion for crocodiles. Rare species which recorded few observations (e.g. Sitatunga) were omitted from the analyses. No single species showed a consistent random or non random spatial pattern between years and study areas although some general trends did emerge. With the single exception of impala herds, non wetland specific species including kudu, warthog and impala individuals showed non-random distribution patterns. The floodplain specialists including lechwe and reedbuck showed either random or near random (i.e. null hypothesis acceptance at the 94% level) distribution. Cattle individuals and herds showed significant non random distribution patterns in both the strata. Hippo showed a highly significant non random distribution during both surveys and within both strata.

Table 5.3a and 5.3b present matrices showing significant and non significant outcomes from the randomisation analysis testing for spatial relationships between species classes. The distribution of most wildlife species with respect to others was generally random on both the greater Chobe and Kwando strata. Only impala showed a greater than expected minimum distance from other mammalian wildlife species. All species recorded a greater than expected minimum distance from cattle. Impala and lechwe showed some avoidance patterns with traditional canoes. In general the cattle

and wildlife relationship displayed a stronger negative correlation than the traditional canoe and wildlife relationship.

5.3.2 Multivariate analysis

A generalised linear model was used to determine the distribution of cattle. The minimum adequate model retained soil texture and settlement as significant determinants of cattle distribution (table 5.3). Together these two variables explained 24% of the variation in cattle distribution. Sequential elimination of vegetation structure, proximity to protected area, distance to nearest neighbour and distance to river from the maximal model showed no significant difference between models. The additional GLM model fitted with distance to settlement as a quadratic function showed no significant change or improvement on the minimal model ($r^2_{minimal\ model}$=0.236). Removal of soil texture from the model proved highly significant ($p<0.001$), as did removal of distance to settlement ($p<0.001$).

5.4 Discussion

Understanding the feeding ecology of Nile crocodile populations living in close proximity to human communities is an important prerequisite for the resolution of HCC. The aim of this study was to describe the distribution patterns of crocodile prey species specifically within the confines of and with respect to the multiple use wetland landscape of North Eastern Namibia. I did this by determining the spatial structure of wildlife populations and exploring some of the potential anthropogenic factors influencing these distribution patterns using randomisation methods and generalised linear models.

Within the wetland ecosystems high densities of humans and wildlife converge on a limited resource where they are forced to exist in close proximity to one another. Physical segregation is mostly impossible and the nature of the landscape lends itself to continuous movement and integration of humans and wildlife. The wetland ecosystems provide a unique duel purpose corridor simultaneously linking neighbouring wildlife areas and human settlements.

Impala, kudu, lechwe and warthog are to some extent dependent on perennial wetland resources. Impala, Kudu and Warthog are only dependent on the rivers for drinking water and are essentially residents of the surrounding woodlands and grasslands (Smithers *et al.*, 2005). Impala and warthog do utilise floodplain grazing, particularly during the dry season (personal observation). In comparison Lechwe, Reedbuck and Hippo are largely dependent on wetland ecosystems and are permanently resident within these areas (Smithers *et al.*, 2005).

In Caprivi the distribution and abundance of cattle is strongly tied to the availability of reliable drinking water (Mendelsohn *et al.*, 1997). Most of the cattle counted during the surveys are dependant to some extent on perennial wetlands for both drinking water and grazing. Boreholes and artificial watering points have decreased livestock dependence on the surface water (Mendelsohn *et al.*, 1997) however wetland vegetation remains an important resource for the cattle industry in Northern Namibia, particularly during the dry winter season (Mendelsohn *et al.*, 2004).

Non wetland specific wildlife and aquatic wildlife showed an aggregated distribution pattern. The majority of non wetland specific wildlife observations were recorded on the periphery of the survey area and many animals where probably fortuitously counted either coming to water or grazing on the edge of the floodplains. Hippo prefer deep water river channels and pools as day time retreats (Olivier & Laurie, 1974) and are therefore normally absent from the more expansive flooded grasslands and shallow water areas. Similarly crocodiles seem to favour larger bodies of water and avoided heavily vegetated or isolated backwaters (personal observation). Although no consistent pattern was observed, lechwe and reedbuck showed random distributions suggesting utilisation of the entire wetland landscape. Reedbuck are thought to favour the drier, grassier areas on the periphery of wetlands whilst lechwe favour the wetter zones closer to permanent water (Smithers *et al.*, 2005; Williamson, 1990). Due to the relatively stable nature of the greater Kwando strata, many of the islands support perennial *hyperina* grassland communities creating a mosaic of preferential reedbuck habitat throughout the wetland.

All wildlife species avoided cattle to some extent. This marked pattern was not evident to the same degree in the relationship between wildlife species and traditional canoes. Furthermore, traditional canoes showed no significant auto correlation with cattle. These findings suggest cattle and wildlife have some direct negative spatial relationship. The impact of cattle on wildlife remains uncertain. Some authors suggest that wildlife does not necessarily avoid livestock farming areas (Georgiadis *et al.*, 2007) whilst others suggest that livestock and associated human activity does have a significant negative impact on the distribution of wildlife (de Leeuw *et al.*, 2001). Modern animal husbandry techniques often enable cattle numbers to be maintained above environmental carrying capacity leading to overgrazing and altered vegetation communities (Behnke & Abel, 1996). Cattle may therefore denude species niches and thereby indirectly negatively influence species abundance (Georgiadis, 1988). Most cattle in Caprivi are herded and the presence of humans may influence wildlife numbers. The lack of a significant relationship between canoes and wildlife suggests however, that humans alone are not necessarily a cause for decreased wildlife numbers. Furthermore, much of the study area is now covered by community conservancies that

derive direct benefit from wildlife and therefore in general humans actively encourage the presence of most species (NACSO, 2006b)

Lechwe and reedbuck showed a significant negative relationship with crocodiles. It is unlikely that niche differentiation between crocodiles and lechwe and reedbuck is detectable at the resolution of this study. A possible explanation would be active avoidance behaviour displayed by species that have evolved in close proximity to crocodiles. Predator avoidance behaviour has been demonstrated in a wide diversity of species ranging from frogs (Pizzatto & Shine, 2009) to large carnivores (Durant, 2000). It is therefore plausible that under suitable conditions (e.g. vacant habitat to accommodate displacement) similar avoidance behaviour could be displayed by reedbuck and lechwe towards Nile crocodiles.

The distribution of cattle within the floodplain ecosystem remains poorly understood. Settlements and soil texture were significant determinants of distribution but explained less than a quarter of the model variance. Cattle are typically selective grazers but they can tolerate a wide range of forage (Hansen, 2006). This generalist feeding behaviour enables them to survive in a variety of vegetation communities including all those covered in the analysis. More specifically, cattle probably seek out the heavier clay and clay loam soils because they support the more palatable annual grassland communities compared to the tannin rich perennial grasslands on the sandier soils (van Oudtshoorn, 1992). In any event human factors probably explain more than environmental variables. North Eastern Namibia has undergone intense episodes of human displacement and migration over the last century (Mendelsohn *et al.*, 2004). The net result is a convoluted political landscape incorporating several distinct tribal groups (Mendelsohn *et al.*, 2004). Furthermore, a complex series of tribal and legal arrangements determines rights to natural resources and these are constantly evolving (NACSO, 2006b). In light of this, the distribution of cattle within the wetland environs is possibly a complex function of past and present socioeconomic and political factors with environmental variables playing a relatively lesser role.

Large crocodiles over three meter in length are not essential for the survival of the species. Nile crocodiles breed below this size (Hutton, 1989) and the elimination of large individuals would likely reduce levels of HCC and thereby potentially improve

the species long term survival prospects. If the evolutionary integrity of the Nile crocodile is however, to be preserved, and the full economic value of the species is to be extracted for the benefit of rural communities, it is necessary that we conserve the larger individuals.

The wetland ecosystems of North Eastern Namibia currently support large populations mammalian prey species. The presence of these animals specifically within crocodile habitat remains vulnerable to human influences. This is because crocodile habitat in Caprivi is invariably used as a geographical boundary separating protected wildlife areas from human communities. In the National parks wildlife rangers operate rigorous anti poaching and anti trespassing policies but often adopt a less severe attitude towards livestock infringements on the floodplains (pers obs). In the community wildlife conservancies' conservation measures seldom include restrictions on numbers or movements of livestock. This study suggests that the presence of livestock has a negative effect on distribution and abundance of important crocodile prey species. Protected areas and conservancies may be ineffectual at conserving wetland species if livestock numbers and movement patterns are left unchecked. A decreased natural prey base would necessarily force crocodiles to seek alternative food sources and this would almost certainly have dire consequences for levels of HCC.

This study recommends additional research is carried out on the impact of cattle on the wetland ecosystems and wildlife in North Eastern Namibia. More detailed and finer scale data is needed to provide accurate quantitative and species specific information. This research would provide a robust platform from which management decisions could be made to better conserve the greater wetland ecosystem for the benefit of both humans and wildlife.

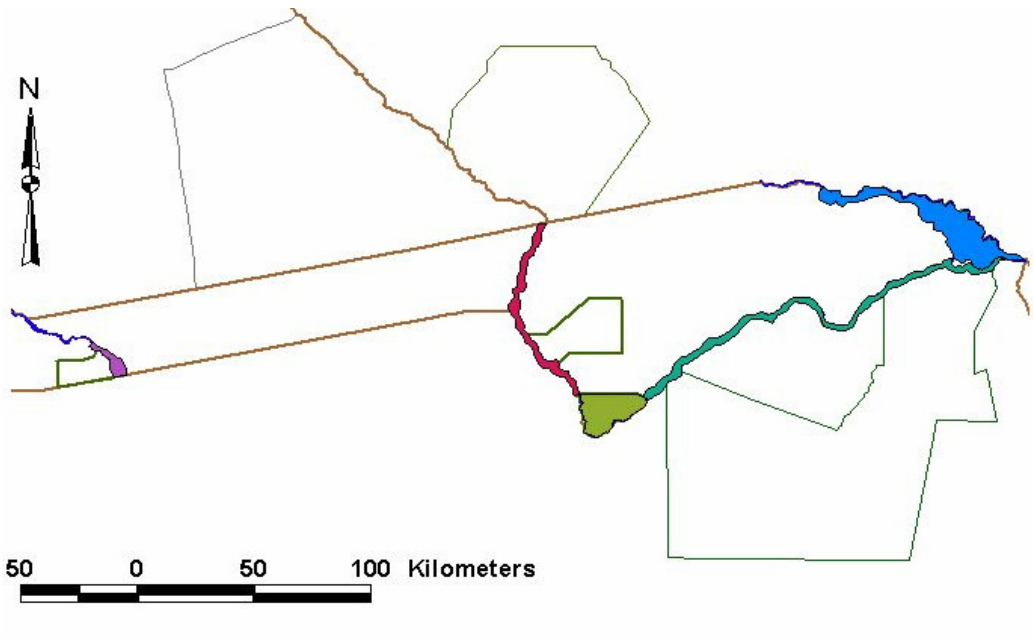


Figure 5.1 Layout of five strata for the two Caprivi river systems aerial surveys.

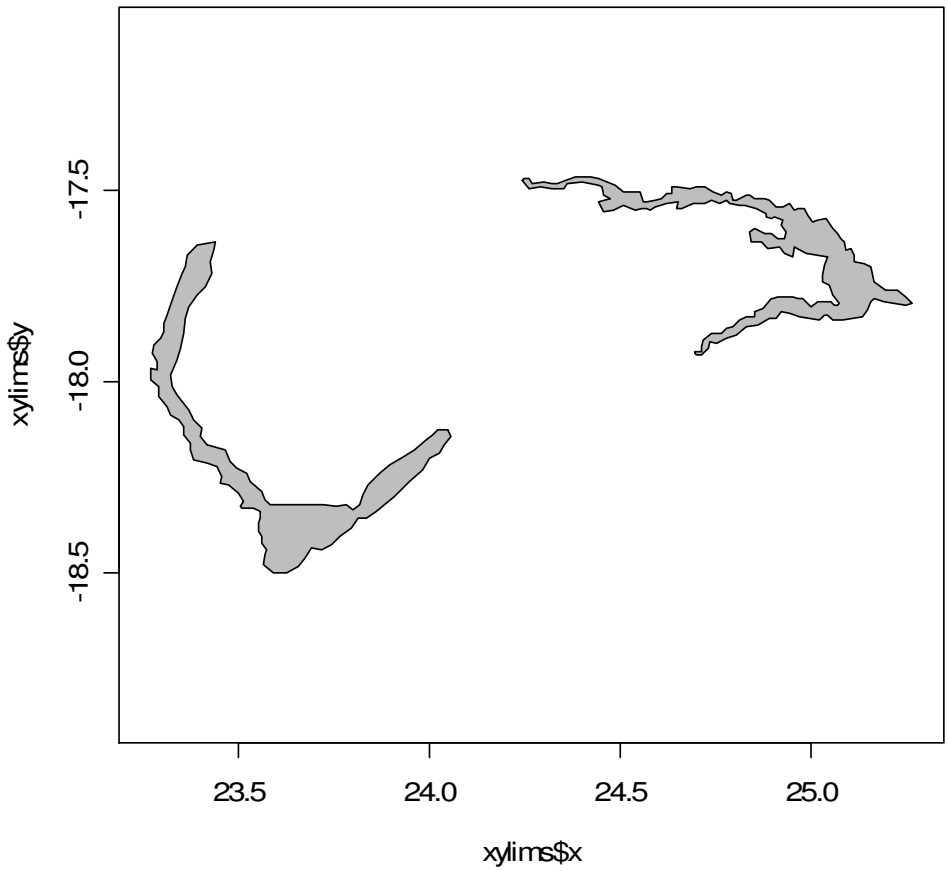


Figure 5.2 The greater Kwando and Chobe strata polygons representing the limits of the randomisation analysis.

Table 5.1 Summary of the 2004 and 2007 survey statistics.

Species	Survey Stratum and Species Counted											
	Linyanti/Chobe		Kwando		Mamili NP		Zambezi		Kavango		Total	
Year	2004	2007	2004	2007	2004	2007	2004	2007	2004	2007	2004	2007
Baboon	0	15	20	40	118	50	0	0	20	0	158	105
Buffalo	918	2043	304	1040	993	1902	232	105	815	861	3262	5951
Bushbuck	0	0	0	1	2	0	0	0	4	3	6	3
Crocodile	58	60	40	40	37	48	55	59	17	36	207	243
Elephant	73	259	267	453	473	1935	4	293	43	122	860	3062
Hippo	255	173	306	389	560	344	17	12	247	351	1387	1269
Giraffe	8	1	0	0	13	0	0	0	0	0	21	1
Impala	485	801	64	262	150	142	0	0	43	156	742	1361
Kudu	4	14	6	12	31	27	0	0	57	81	96	134
Lechwe	314	134	132	331	137	156	1	4	154	142	738	767
Lion	4	8	0	0	0	2	0	0	0	0	4	10
Pelican	498	1919	0	0	0	5	0	0	0	0	498	1924
Reedbuck	0	3	29	102	15	33	0	0	32	24	76	162
Sable	0	0	0	22	0	0	0	0	45	80	45	102
Sitatunga	0	0	2	5	0	2	0	0	0	0	2	7
Tsesseby	18		4	31	0	0	0	0	21	0	25	31
Warthog	0	8	17	30	182	123	0	0	9	15	226	176
Wattle Crane	53	0	6	0	0	13	0	0	2	11	8	24
Waterbuck	0	27	7	3	0	0	0	0	0	0	60	30
Wildebeest	0	14		21	0	0	0	0	6	0	6	35
Zebra	1047	1558	13	57	0	0	0	0	24	38	1064	1653
Total	3735	7037	1219	2839	2711	4782	309	473	1539	1919	9513	17050

Table 5.2 Results of the randomisation analysis showing non random (S) and random (NS) distribution patterns within the wetland strata.

	Kwando		Chobe	
Species	2004	2007	2004	2007
crocs	NS	S	S	NS
hippo	S	S	S	S
hippo.pods	S	S	NS	S
impala	S	S	S	S
impala.herds	NS	NS	NS	S
kudu	S	S	na	na
kudu.herds	S	S	na	na
lechwe	NS	S	S	S
lechwe herds	NS	S	S	NS
reedbuck	NS	S	na	na
reedbuck.herds	NS	S	na	na
warthog	S	S	na	na
warthog.herds	S	S	na	na
cattle	na	S	na	S
cattle herds	na	S	na	S
canoes	na	S	na	NS

Table 5.3a. Summay of randomisation analysis to test for spatial relationships between species. N=acceptance of the null hypothesis (minimum distance between species is not

significant), S= rejection of the null hypothesis (greater than expected minimum distance between species)

a)

2007 Chobe	crocs	hippo	hippo pods	impala	impala herds	lechwe	lechwe herds	canoes	cattle	cattle herds
crocs		N	N	N	N	N	N	S	N	N
hippo				N	N	N	N	N	S	N
hippo pods				N	N	N	N	N	N	N
impala						S	S	S	S	S
impala herds						S	N	N	S	S
lechwe								S	S	S
lechwe herds								S	S	N
canoes									S	N

b)

2007 Kwando	crocs	hippo pods	impala	impala herds	lechwe	lechwe herds	reedbuck	reedbuck herds	canoes	cattle	cattle herds
crocs		N	N	N	S	S	N	S	N	S	N
hippo			N	N	N	N	N	N	N	S	S
hippo pods			N	N	N	N	N	N	N	S	N
impala					S	S	S	S	S	S	S
impala herds					N	N	N	N	S	S	N
lechwe							N	N	S	S	S
lechwe herds								N	N	S	S
reedbuck									N	S	S
reedbuck herds									N	S	S
canoes										N	N

Table 5.3 Analysis of Deviance. “F” tests are against the minimum adequate model.

Model	*Resid.Df*	*Resid.Dev*	*F*	*Pr (>F)*
cattle~soil.text + dist.settlement	229	7340.3		
cattle~soil.text	230	8022.8	14.209	p<0.001
cattle~dist.settlement	232	8729.4	9.6401	p<0.001

CHAPTER 6: A large scale spatial analysis of Nile crocodile conservation in Africa.

6.1 Introduction

Of the 22 species of crocodilian occurring worldwide the Nile crocodile *Crocodylus niloticus* is one of the least threatened (Ross *et al.*, 1992; UNEP-WCMC, 2008). One of the primary reasons for this has been the relatively under developed and sparsely populated status of many of the countries found within the Nile crocodiles extensive range. As many African countries enter an era of political stability and rapid economic growth, this fortuitous conservation boon is set to change.

To understand the potential conservation threats now facing Nile crocodiles it is worthwhile exploring the fate of similar species living in other parts of the developing world which have already undergone a similar development transition.

Much of Asia is a geographically and biologically similar part of the world to Africa. It has a relatively comparable biodiversity and is home to several species of large crocodilians. Socially it has a similar recent history to Africa. Much of the area was colonised by European powers in the 19th century and newly formed countries gained independence in the 20th century (Walter, 2009). The human population has also followed similar population growth patterns driven by persistent traditional birth rates coupled with access to modern medicine (Dupaquier, 1998; Kirk, 1996). One major difference is apparent. Asia has surpassed Africa in terms of development rates (Collier & Gunning, 1999). This development disparity is largely responsible for the Asia's considerably higher population densities and greater demand on natural resources.

The population burden and associated demand for natural resources is a constant and dominant threat to Asia's wildlife (Xie & Sung, 2007). Despite this, nationally initiated and orchestrated conservation success stories are evident in many parts. Several flagship species have been brought back from the brink of extinction including the Asiatic lion (*Panthera leo persica)* (Khan, 1995), Indian rhino (*Rhinoceros unicornis)* (Bonal & Jagmohan, 2002; Singh, 1986) and Bengal tiger (*Panthera tigris*

bengalensis) (Harihar *et al.*, 2009). A major contributor to these success stories has been the advent of protected areas (Ding *et al.*, 2008; Singh, 1986). Asia has relatively small intensively managed protected areas which provide adequate protection for much of the terrestrial biodiversity (UNEP-WCMC, 2009). Species which cannot be effectively conserved in small isolated areas are those which are now facing the greatest threats. Wide ranging species like the great Indian bustard (*Ardeotis nigriceps)* or those that rely on interconnected habitats like riverine species including the baiji (*Lipotes vexillifer)* are most vulnerable (Rajput, 2008; Turvey *et al.*, 2007).

There are eight species of crocodilian in Asia (Ross *et al.*, 1992). According to the IUCN Red List of Threatened Species (IUCN Red List) three of them are listed as Critically Endangered and a further two listed as Endangered (UNEP-WCMC, 2008). The specific threats facing each of these species are many and varied but the underlying catalysts are unanimous. These species rely on rivers and wetlands; habitats which are difficult to incorporate effectively into protected areas and which represent a valuable resource to a large number of humans. The dire conservation status of Asian crocodilians has yet to be stabilised and the plight of many species remains uncertain. The most recent evidence of this saw the IUCN Red List status of Indian gharials (G*avialis gangeticus*) raised to Critically Endangered in 2007 (Gad, 2008).

The current conservation status of Nile crocodiles under the IUCN Red List is Lower Risk, Least concern. The assessment was carried out in 1996 and the justification for this status was 'May be threatened in parts of its range'(Ross, 1998). This statement refers mostly to west and central Africa where at the time few ecological surveys had been carried out and little information existed on the status of crocodiles (Ross, 1998). CITES list Nile crocodiles on either appendix I (much of west and central Africa), or appendix II (much of east and Southern Africa)(UNEP-WCMC, 2008).

Human population growth rates and development patterns in the main range states of Nile crocodiles are rapidly approaching or surpassing those of many Asian countries. Since 2005, Sub Saharan Africa has consistently recorded higher annual Gross Domestic Product growth rates (~5.65%) than Asia and Oceania combined (~4.89%) (Shane, 2008). The demands for fresh water resources are increasing accordingly and

the associated threats on crocodile habitat in Africa are steadily mounting (Postel, 2000).

This study intends to review some of the important geographical aspects of Nile crocodile conservation in Africa in an effort to pre-empt a potential large scale conservation crisis. The analysis follows an inductive approach and is divided into two sections. The first consists of a series of related questions designed to establish large scale relationships between crocodiles and humans. The second section collates the important determinants of human crocodile conflict in a series of simple spatial models. The objective of these models is to provide a management tool for population and community level conservation initiatives.

6.2 Methods

The raw data for this study consist of several geographical spatial data and the UNEP-WCMC database of Nile crocodile surveys (Lainez, 2008). These baseline data have been merged and manipulated using GIS software (ESRI, 2006) to create a series of synthesized spatial data (data layers) that form the basis of the analysis. The first part of the methodology describes the formulation procedures and manner of the primary synthesized data. The second part of the methodology describes the statistical analysis.

6.2.1. Spatial data synthesis

Spatial data synthesis was carried out in ArcGIS version 9.2 (ESRI, 2006). The projected coordinate system used was Africa Albers Equal Area Conic and the geographic coordinate system used was GCS WGS 1984.

6.2.1.1 Crocodile habitat

The total extent of Nile crocodile habitat was mapped on a continental scale. To do this, I synthesized a spatial data layer using key physical properties to define suitable crocodile habitat. These physical properties were determined by the broad habitat requirements of crocodiles such as suitable combinations of terra firma and permanent surface water and known distribution of Nile crocodiles (Branch, 1990; Ross *et al.*, 1992; Ross, 1998; Sindaco *et al.*, 2007; Spawls *et al.*, 2004). Two spatial data sources were used to create a baseline map of crocodile habitat which in turn was modified. The spatial data included:

a.) All African streams excluding stream orders one and two (USGS, 2009). Stream order is a simple hydrology algorithm used to define stream size based on a hierarchy of tributaries. Stream orders one and two were eliminated on the basis of being generally too small to support viable breeding populations of crocodiles. b.) Classes 1, 2 and 3 of inland water (Lehner & Döll, 2004). This includes rivers, lakes and reservoirs. Freshwater marshes, floodplains, swamp and flooded forests, pans, brackish and saline wetlands, bogs, fens and mires, intermitted wetlands and lakes and 50-100% wetlands were excluded. In general these latter freshwater classes do not provide suitable breeding habitat and are therefore independently unlikely to support substantial Nile crocodile populations (Shacks, 2006). The baseline spatial data were then modified

in the following way: Inland water raster data were converted to polyline vector data to facilitate compatibility with the stream data. Lake and reservoir shores were converted to the equivalent of streams and rivers (Figure 5.1). African steam data were merged with the inland water data to create a single polyline map. A two kilometre buffer was created around the polyline (2 km each side of the polyline) to represent a minimum inference habitat and to cater for geographical inaccuracies inherent in the large scale source data. Two kilometres is the estimated distance humans are likely to interact regularly with open water bodies in NE Namibia (Boyle, 2007). The resulting polygon was refined in the following ways: All sections located outside the known Nile crocodile range/distribution were deleted; all habitat over 1500m was deleted; habitat occurring in arid areas in the Southern Hemisphere was viewed on Google Earth (Google_Earth, 2009) and obvious fossil rivers or water bodies (no visible sign of surface water) were identified and deleted. Arid habitat in the northern hemisphere was treated similarly but less rigorously (only isolated dry water bodies were deleted) due to considerable hydrological fluctuations in recent times (Grove, 1995), the confirmed existence of Nile crocodiles living in caves in Mauritania (Shine *et al.*, 2001), and reports of small Nile crocodiles occurring in some of the massifs of the central Sahara (Spawls *et al.*, 2004). A measure of accuracy of this geographical definition of crocodile habitat is obtained by plotting survey coordinates from the UNEP -WCMC crocodile survey database on this map. The average distance of spotlight and aerial survey location coordinates from defined crocodile habitat is 6.54 km (N= 364, SD+-13.2km); a relatively small error given the scale.

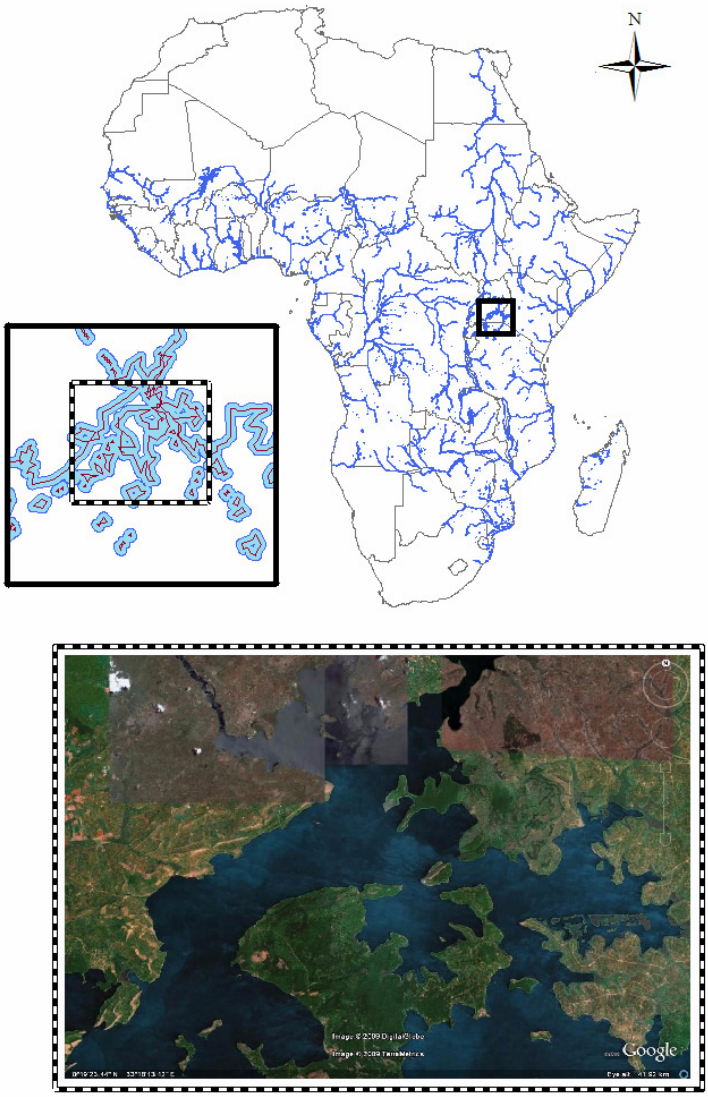


Figure 6.1. Maps and image (Lake Victoria, Uganda) showing synthesized Nile crocodile habitat and relative accuracy achieved. Red polyline represents rivers and lake shores. Blue polygon represents two kilometre buffer habitat. Aerial image eye altitude ~ 42 km. Note agricultural activity visible on far left of image (~1 hectare fields) (Google_Earth, 2009).

6.2.1.2 Crocodile surveys

Generally, crocodile counts tend to be a very imprecise estimates of crocodile population size and provide only an index of abundance (Bayliss *et al.*, 1986; Hutton *et al.*, 1989). This study uses course density estimates derived from a large number of

independent crocodile surveys carried out over a considerable area and period of time using imprecise methods. As such, these data are considered biologically meaningful only for use as an index value on the continental scale.

A total of 829 Nile crocodile surveys were carried out between 1955 – 2007 (Lainez, 2008). The database comprises several recognised survey techniques including spotlight and day boat surveys, foot surveys, aerial surveys and nest surveys. Of these, 375 surveys can be attributed to relatively standardized spotlight boat surveys (150) and aerial surveys (225). All surveys either recorded a single GPS waypoint or were assigned a Decimal Degrees reference point to define the general location. Based on the coordinates of these survey location points, eleven surveys were either conducted outside the distribution range of Nile crocodile habitat or contained abnormal information (e.g. human error in coordinate reporting) and were ignored. Spotlight and aerial surveys can provide rudimentary but broadly comparable estimates of crocodile densities (Bayliss *et al.*, 1986; Brown *et al.*, 2005). Aerial surveys can be compared to boat survey counts through the use of an aerial-to-boat correction factor (Bayliss *et al.*, 1986; Brown *et al.*, 2005). Based on the average of 25 boat and two regional aerial surveys carried out over three morphologically different river systems in North Eastern Namibia (see Chapters 2 & 3), this study used an averaged correction factor (aerial to boat) of 3.4. The total number of crocodiles seen was divided by the total area surveyed to obtain a density (number/km^2). No distinction is made between size classes and environmental variables at the time of the surveys are ignored. All records prior to 1990 and all survey points situated greater than 10 km from crocodile habitat were deleted. To avoid pseudo replication, surveys conducted at the same location (according to name and/or GPS coordinates) were averaged out and the year or decade the survey was carried out post 1990 was considered irrelevant. This left 104 survey density estimates obtained from 10 countries since 1990 (Ethiopia (1), Kenya (4) Madagascar (7), Malawi (5) Mozambique (7) Namibia (9) Tanzania (36) Uganda (6) Zambia (6) Zimbabwe (22). The average survey length for these surveys (boat and aerial) was 69.6km (SD+-59km).

6.2.1.3 Human population densities

All crocodile habitat was assigned a human population density estimate and growth rate. Density data for 1990 and 2000 was based on Gridded Population of The

World version 2 (CIESIN, 2009). The resolution of the data is total counts per ~20km2 (2.5 arc-minute grid cells) converted to people per km2. The original raster data were converted to vector data (long integer). The 1990 spatial data were merged with the 2000 spatial data using the 'joins and relates' function to create a hybrid population map. This map consisted of irregular polygons, the size and shape of which were determined by density estimates for the two years (i.e. matching identical pairs of densities). An additional data field was added to this map, the value of which was calculated by dividing the 2000 population density by the 1990 population density to give a rudimentary population growth rate for each polygon. The crocodile habitat map was overlaid on the human population map and the two maps merged using the 'joints and relates' function to produce population density and growth rate estimates for crocodile habitat (Figure 5.2).

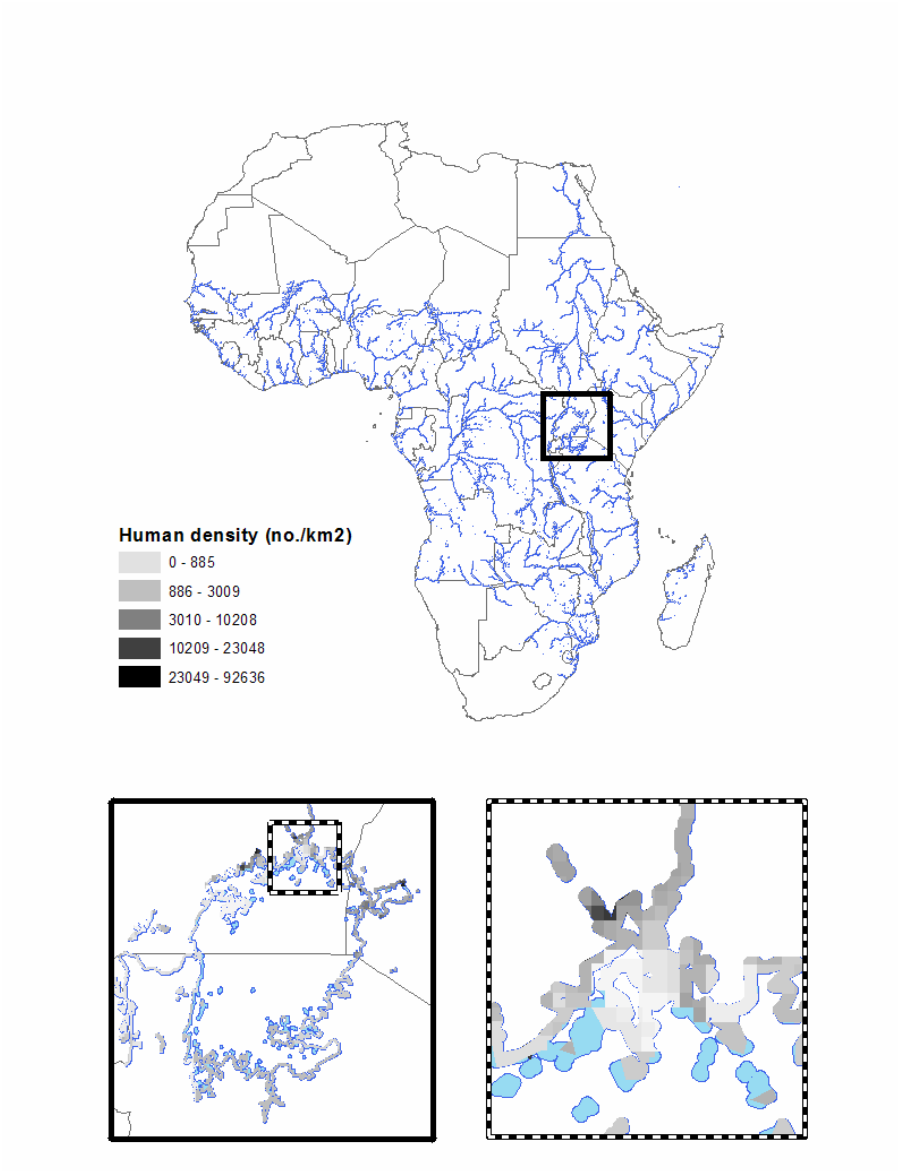


Figure 6.2. Map showing human population data merged with crocodile habitat. Each colour represents a unique combination of 1990 and 2000 population densities. Colour graduations are according to the 2000 density data. Fine scale inset is Lake Victoria, Uganda

6.2.1.4 Cattle population densities

A similar methodology to that used above was employed to produce cattle density estimates. Crocodile habitat was assigned a cattle population density estimate. The baseline cattle density data used were obtained from the International Livestock Research Institute (ILRI, 2005). The original raster data (cattle per km^2) were converted

to vector data (long integer). The crocodile habitat map was overlaid on the population map and the two maps merged to produce cattle density estimates within crocodile habitat (Figure 5.3).

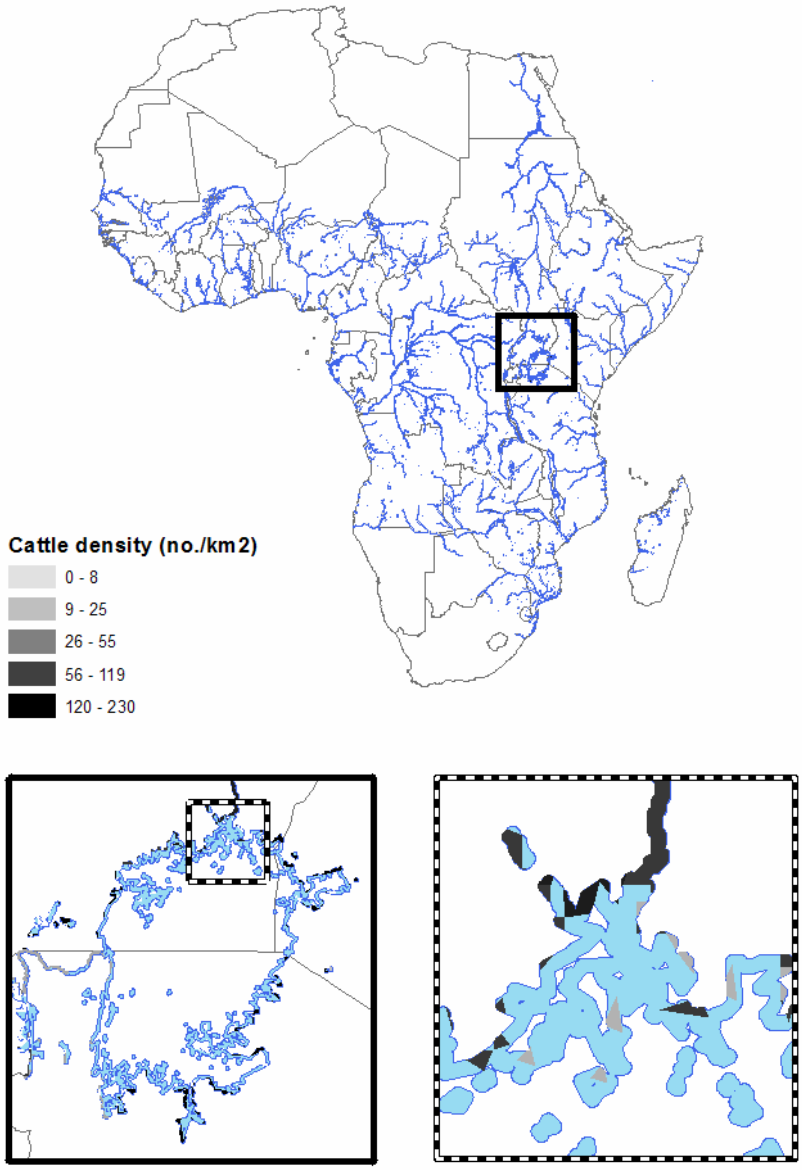


Figure 6.3. Maps showing cattle density data merged with crocodile habitat. Fine scale inset is Lake Victoria, Uganda.

6.2.1.5 Protected areas

Spatial data relating to nationally protected areas within Africa were downloaded from the World Database on Protected Areas (UNEP-WCMC, 2009). These spatial data were joined with crocodile habitat to create a synthesized map displaying those sections of protected areas covering crocodile habitat. These portions of protected areas were attributed the descriptive characteristics of the parent protected areas in addition to their new proportional surface area (Figure 6.4). For the analysis, protected area categories were divided into three combinations of factor levels (see appendix 2 for full description of UNEP – WCMC definition of protected area categories). The first included all IUCN categories (I, II, III, IV,V,VI and Unset). The second consisted of three levels (Good (I&II), Fair (III, IV, V, VI) and Bad (Unset). The last consisted of two levels (Good (I & II) and Bad (III, IV, V, VI, Unset). These factor levels were based loosely on the degree of human livelihood activity usually permitted within the various categories. For example, categories I & II usually preclude all forms of agriculture (e.g. subsistence livestock farming), and extractive resource utilisation (e.g. commercial fishing, trophy hunting)

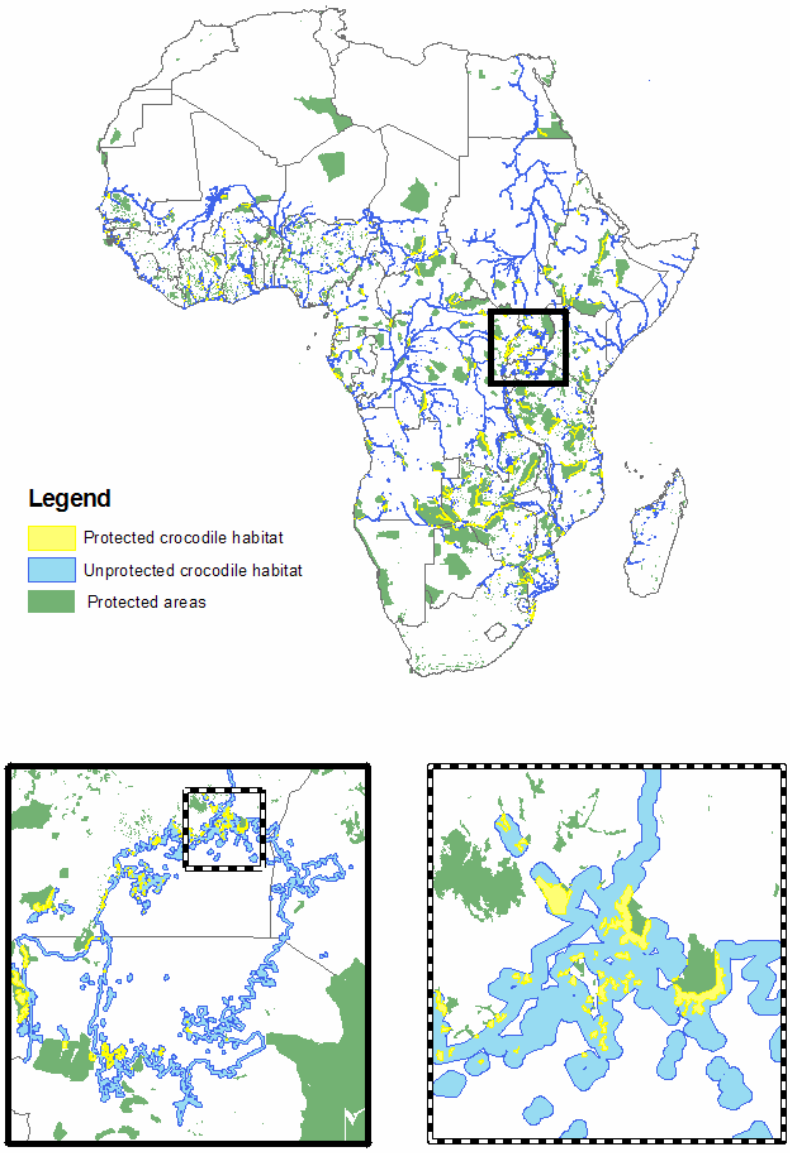


Figure 6.4. Map showing the distribution of protected areas in Africa and the proportion of protected areas falling within Nile crocodile habitat. Fine scale inset is Lake Victoria, Uganda.

6.2.1.6 Prime Crocodile habitat

In addition to the continental scale approach covered in the above methods and associated analysis, a secondary analysis was carried out on a smaller scale essentially confined to East and Southern Africa. This area was defined as prime Nile crocodile

habitat based on the following information: In 2004 it was suggested the species *Crocodylus suchus* be resurrected based on molecular evidence (Schmitz *et al.*, 2004). The distribution of *C. suchus* covers all of West Africa as far east as Lake Chad and central Africa (Schmitz *et al.*, 2004). *Crocodylus suchus* is a smaller crocodile than *N. niloticus* and less inclined to attack humans or livestock (Schmitz *et al.*, 2004; Spawls *et al.*, 2004). Forested crocodile habitat in West and Central Africa generally supports more than one species of crocodile (Ross *et al.*, 1992) and according to bush meat statistics (Inkamba, personal communication, personal observation) and available literature (Kofron, 1992), *C. suchus* does not appear to be the dominant species within forested regions. Nile crocodiles are reported to be extinct below Lake Nasser and therefore Egypt no longer represents a major range state (Sindaco *et al.*, 2007). The Demogratic Republic of the Congo (DRC) does not represent prime Nile crocodile habitat due to the total lack of crocodile sightings on an extensive tourism survey of major rivers in 2003 (duPlessis, pers comm) and country wide occurrence of *Crocodylus cataphractus* (Broadley & Cotterill, 2004; Ross *et al.*, 1992). The above points in tandem with the crocodile survey database suggests the following countries represent the most important range states for *C. niloticus*: Angola, South Africa, Zimbabwe, Mozambique, Malawi, Zambia, Botswana, Namibia, Tanzania, Kenya, Sudan, Uganda and Madagascar (Figure 6.5). Crocodile habitat occurring within these countries is referred to as prime crocodile habitat.

Figure 6.5. Countries identified by this study as the most important range states for *C. niloticus*

6.2.2 Statistical Analysis

6.2.2.1 Anthropogenic determinants of crocodile densities on the continental scale

6.2.2.1.1 Crocodile densities vs. human densities

The crocodile survey data were combined the human population data. Each crocodile survey point was assigned the value of the closest human population polygon. The result was 104 crocodile survey points with attributes including estimates of human population density in 2000 and average growth rate between 1990 and 2000.

A linear model was fitted to the data to determine the extent of the relationship between human population density and crocodile population density (R_development_core_team, 2006). Estimates of crocodile densities were fitted as the

response variable and population density 2000 and population growth rate were fitted as continuous explanatory variables. The interaction between population density 2000 and growth rate was tested. To select the minimum adequate model, a backward stepwise procedure from the full model was used (Crawley, 2003). Non-significant terms were sequentially removed after testing with analysis of variance (ANOVA).

6.2.2.1.2. Crocodile densities vs. protected areas

The crocodile survey data were joined to the protected area data. Each crocodile survey point was assigned the values of the closest protected area polygon. The distance between survey point and the closest protected area was calculated and added as a survey point attribute. Of the 104 survey points, 34 fell within the limits of protected areas and recorded a distance score of zero. The average distance between survey points and protected areas was 40.56 km (SD+-88.92). The final product was 104 survey points with attributes including the distance to the closest protected area and the proportional size and IUCN category of this area.

Linear and generalised linear models with a gamma error structure were fitted to the data to determine the extent of the relationship between crocodile population densities and protected areas (Crawley, 2003). For the generalised linear model zero values in the raw data were negated by adding one to data columns containing zero. Estimates of crocodile densities were fitted as the response variable. IUCN category was fitted as a factor and the three different categorical levels were tested. Size of protected area and distance to protected area were fitted as continuous explanatory variables. The interaction between all terms was tested in the full model. To select the minimum adequate model, a backward stepwise procedure from the full model was used (Crawley, 2003). Non-significant terms were sequentially removed after testing with analysis of variance (ANOVA).

6.2.2.2 Crocodile habitat in protected areas – summary statistics

Summary statistics for crocodile habitat in protected areas were calculated from the synthesised protected area data. All calculations were carried out using ArcGIS with spatial analyst and the associated software ETgeowizard (ESRI, 2006). The results were related to the protected area raw data to obtain comparative trends in space and time. The year used in the temporal analysis is the year or approximate year of IUCN

proclamation. These data are also compared to the growth rates of nationally designated protected areas.

6.2.3 Protected areas as refuges for Nile crocodiles

The results of part 1 of the statistical analysis prompted the following questions:

6.2.3.1 What is the relationship between protected Nile crocodile habitat and cattle?

The protected area data were joined to the cattle density data. Each protected area polygon was assigned a cattle density value. This single density value was calculated by obtaining an average for all the cattle density polygons falling within the respective protected area polygon.

A generalised linear model with a quasipoisson error structure was fitted to the data to determine the relationship between cattle densities and protected areas (R_development_core_team, 2006). Cattle densities were fitted as a continuous response variable. Country and IUCN category were fitted as categorical explanatory variables. Three different factor levels for IUCN category were tested (see above). The size of the protected area was fitted as a continuous explanatory variable. The interaction between all terms was tested. To select the minimum adequate model, a backward stepwise procedure from the full model was used (Crawley, 2003). Non-significant terms were sequentially removed after testing with analysis of variance (ANOVA). The above analysis was also carried out on the prime countries data subset.

6.2.3.2 What is the relationship between protected Nile crocodile habitat and human population densities?

The protected area data were joined to the human population data. As with the above analysis, each protected area polygon was assigned a human population density value using a similar methodology of averaging internal population density polygons to provide a single population density estimate for each protected area polygon.

An analysis of co variance (ANCOVA) was carried out on the data to determine the relationship between human population densities and protected areas (R_development_core_team, 2006). Population densities were fitted as a continuous

response variable. Country and protected area category were fitted as categorical explanatory variable and three different factor levels for protected areas were fitted in turn. The size of the protected area was fitted as a continuous explanatory variable. The interaction between all terms was tested. To select the minimum adequate model, a backward stepwise procedure from the full model was used (Crawley, 2003). Non-significant terms were sequentially removed after testing with analysis of variance (ANOVA). The above analysis was also carried out on the prime countries data subset.

6.2.4 Simple Spatial models

The results of this study can be used to define some of the spatial parameters relating to Nile crocodile conservation and management. In particular, the specific physical and social data presented are important determinants of human crocodile conflict (HCC) levels. In light of this, the findings of this research have been assimilated into three maps. This exercise makes the important assumption that unprotected crocodilian populations are invariably diminished to levels that do not necessitate significant human crocodile conflict as a result of typical rural activities and growth patterns in developing countries (Gad, 2008; Stuebing *et al.*, 2006; Thorbjarnarson *et al.*, 2002) Given the relationship that exists between crocodile densities and protected areas, and that this relationship will most likely strengthen over time proportionally to human population pressure, protected areas are used as the principal geographical reference point for the three maps. The first map is a conflict map and illustrates the distribution and intensity of human crocodile conflict. The second map is a conservation map and illustrates those protected areas where crocodile conservation initiatives will be potentially most productive. The third map is a hybrid (conservation –conflict) of the above two maps, and represents a 'least resistance' route to practical crocodile management and conservation. In addition to the above mentioned data, Ramsar site spatial data were used. Ramsar sites are areas identified and afforded special status under the internationally agreed Convention on Wetlands of International Importance (UNEP-WCMC, 2009). Continuous data values (distance, area and density) were used and categorical data converted to binary data. Simple equations were created to provide relative index of conflict, conservation and management. Index values are uncalibrated but have been designed to reflect the conditions on the ground based on the extensive scientific and popular literature reviewed for this study and personal observation over the last decade.

6.3 Results

6.3.1. Anthropogenic determinants of crocodile densities on the continental scale

6.3.1.1 Crocodile densities and human densities.

The minimum adequate linear model did not retain any of the explanatory variables (table 6.1). The model did not show any relationship between crocodile densities and human population densities or growth rate.

Table 6.1. Analysis of Deviance. "F" tests are against the minimum adequate model.

Model	*Resid.Df*	*RSS*	*F*	*Pr (>F)*
density~pop. growth rate	101	12351.5		
density~1	102	12408.2	0.46	0.49

6.3.1.2 Crocodile densities and protected areas

The minimum adequate analysis of covariance (ANCOVA) model retained area (size of protected area) and the interaction term between area and distance (distance to protected area) as the most important determinants of crocodile densities (Table 5.2). Together these two terms explained 24% of the variation in crocodile densities. Sequential elimination of protected area category and the three alternate factor levels used for this variable showed no significant difference between models. Likewise the sequential elimination of the distance and the two interaction terms between IUCN category and distance and IUCN category and area proved non significant. In the gamma model over dispersion prevented more than three terms and the interaction terms from being fitted in the maximal model. The minimal adequate model retained distance and area explaining 12.77% of the variation in densities.

Table 6.2. Analysis of Deviance. "F" tests are against the minimum adequate model.

Model type	*Model*	*Resid.Df*	*RSS/Resid.Dev*	*F*	*Pr (>F)*
anova	density~area+area:distance	100	9473.7		
anova	density~area	101	9987.2	5.42	0.02
anova	density~area:distance	101	12383.8	30.7	p<0.001
GLM (gamma)	density~area+distance	100	427.78		
GLM (gamma)	density~area	101	436.99	4.72	0.03
GLM (gamma)	density~distance	101	462.7	17.8	p<0.001

6.3.2 Crocodile habitat in protected areas – summary statistics

According to this study there are 86502.26 km^2 of Nile crocodile habitat falling within the boundaries of protected areas. This area is comprised of 1062 areas averaging 81.45 km2 in extent (SD+-204.7). In terms of overall percentage of protected habitat available within the distribution range of Nile crocodiles, protected crocodile habitat makes up approximately 24% (SD+- 33.42). In prime Nile crocodile countries this percentage drops to 14% (SD+-272). There are approximately 24227.15 km2 of crocodile habitat falling within IUCN protected area categories I & II. The average size of crocodile habitat in category I & II areas is 153.34km2 (SD+-272.26). Vertices were calculated to provide a central point for each protected area based on surface area and shape. The average distance of vertices to a protected area boundary is 1.789 km (SD+-3.95). The maximum distance is 62.4 km (Selous Game Reserve, Tanzania).

The average rate of proclamation of protected crocodile habitat (or the percentage of crocodile habitat within protected areas) is decreasing marginally but overall the cumulative growth rate of protected crocodile habitat is similar to the cumulative growth rate of protected areas (Figure 5.6 a, b and c).

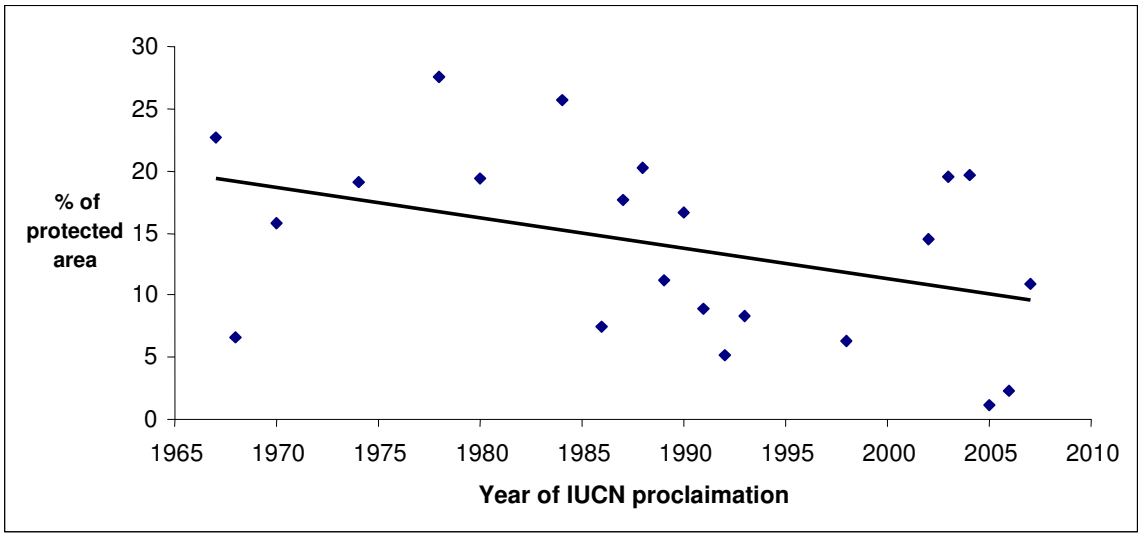


Figure 6.6a) The growth rate of protected crocodile habitat as a percentage of total protected areas (~1960 to ~2010). y=-0.245x+501.21, R^2=0.17.

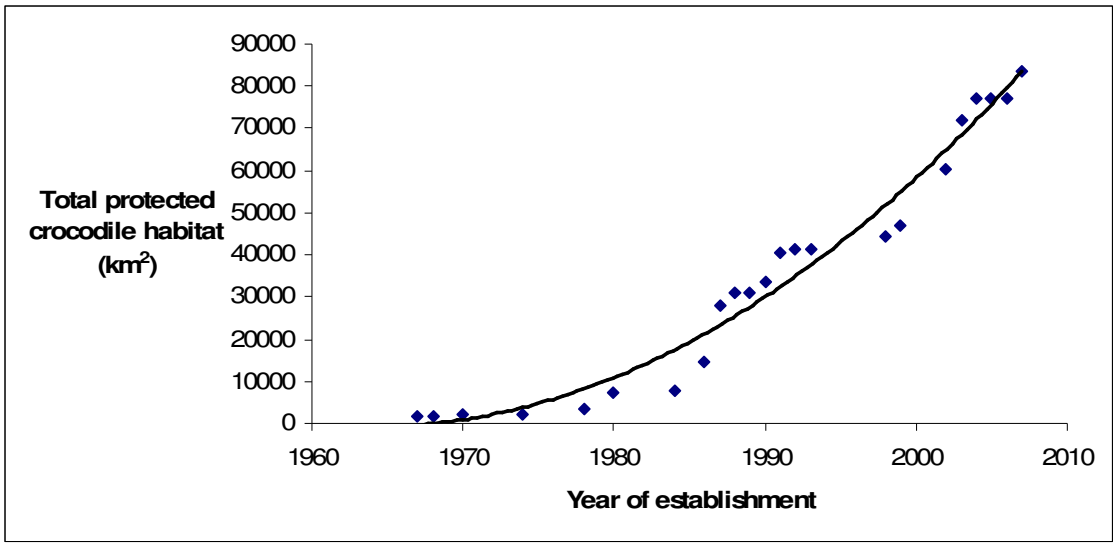


Figure 6.6b) The cumulative growth rate of protected Nile crocodile habitat (~1960 to ~2010)

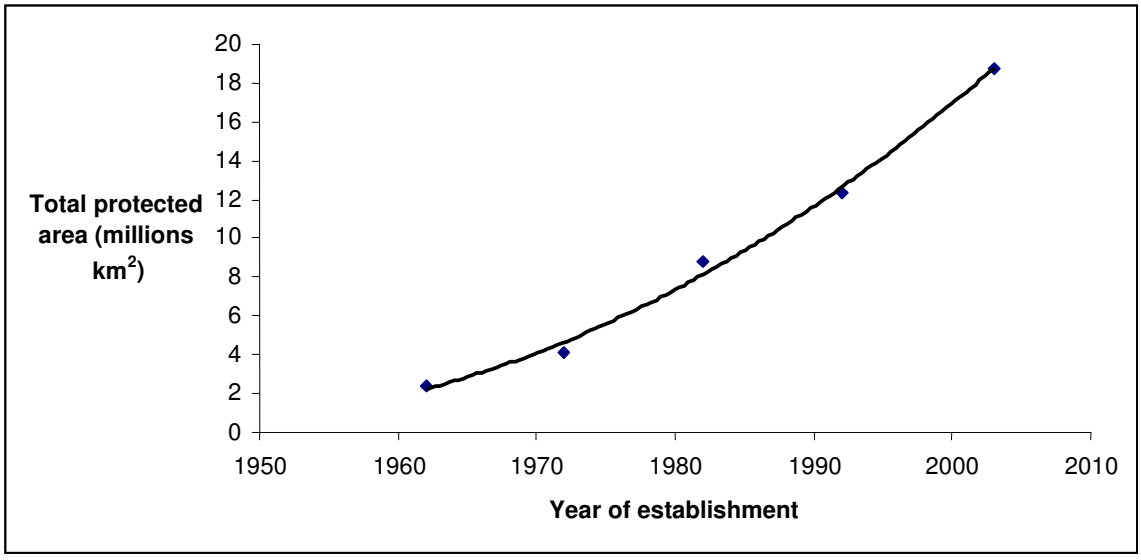


Figure 6.6c) The cumulative growth rate of Nationally Designated Protected Areas adapted from Chape et al 2005 (Chape *et al.*, 2005).

6.3.3. Protected areas as refuges for Nile crocodiles

6.3.3.1 What is the relationship between protected Nile crocodile habitat and cattle?

The minimum adequate generalised linear model retained country as the only significant determinant of cattle densities (table 6.3). Country explained 28.4% of the variation in cattle densities within protected crocodile habitat. Sequential elimination of the interaction terms, protected area category and size of the protected area showed no significant difference between models. Removal of country from the model proved

highly significant (p = 2.2e-16). Burkina Faso, Burundi, Egypt, Kenya, Nigeria, Senegal, Tanzania and Uganda show significantly higher densities of cattle in protected crocodile habitat. Similar results were obtained for the analysis of the prime country subset with country being the only significant term. The prime country model explained 15.5% of the variance in cattle density. Uganda was the only country to show a significant positive correlation between cattle and protected areas.

Table 6.3. Analysis of Deviance. "F" tests are against the minimum adequate model.

Area	*Model*	*Resid.Df*	*Resid.Dev*	*F*	*Pr (>F)*
Africa	cattle density~country	799	7637.3		
Africa	cattle density~1	836	10706.8	6.3793	p<0.001
Prime Countries	cattle density~country	539	6701.8		
Prime Countries	cattle density~1	552	7933.1	5.3711	p<0.001

6.3.3.2. What is the relationship between protected Nile crocodile habitat and human population densities?

The minimum adequate ANCOVA model retained country as the only significant determinant of human population densities (table 5.4). Country explained only 8.3% of the variation in human population densities within protected crocodile habitat. Sequential elimination of IUCN protected area category and size of the protected area showed no significant difference between models. Removal of country from the model proved highly significant (p<0.001). Nigeria, Egypt and Uganda show significantly higher densities of people in protected crocodile habitat. Similar results were obtained for the analysis of the prime country subset with country being the only significant term. The model explained 12.8% of the variance in people density. Uganda was the only country to show a significant positive correlation between people and protected areas.

Table 6.4. Analysis of Deviance. "F" tests are against the minimum adequate model.

Area	*Model*	*Resid.Df*	*RSS*	*F*	*Pr (>F)*
Africa	population density~country	1017	123247232		
Africa	population density~1	1054	134472720	2.5035	p<0.001
Prime Countries	popualtion density~country	697	32272196		
Prime Countries	population density~1	710	37730072	9.0674	p<0.001

6.3.4 Simple Spatial models

Protected areas falling within Nile crocodile habitat were attributed three index values (Figures 6.7, 6.8 and 6.9). The justification for these functions is essentially subjective and uncalibrated. The schematic end product is broadly aligned to HCC levels and the most parsimonious equations were selected to achieve this. The following equations were used to calculate the index values:

i. Conflict index = (ab)/2+1/2c-d+e
ii. Conservation index = c+d+g+f
iii. Management index (ii-i) = 1/2c+2d+g+f-(ab)/2-e

a = Log (Human population density 2000 + 1)
b = Log (Cattle density +1)
c = Log (Protected area size)
d = Log (Distance of protected crocodile habitat vertices to boundary of protected area +1)
e = Country (prime countries =1, other =0)
f = Ramsar site (yes =1, no =0)
g = IUCN protected area category (Category I&II =1, other=0)

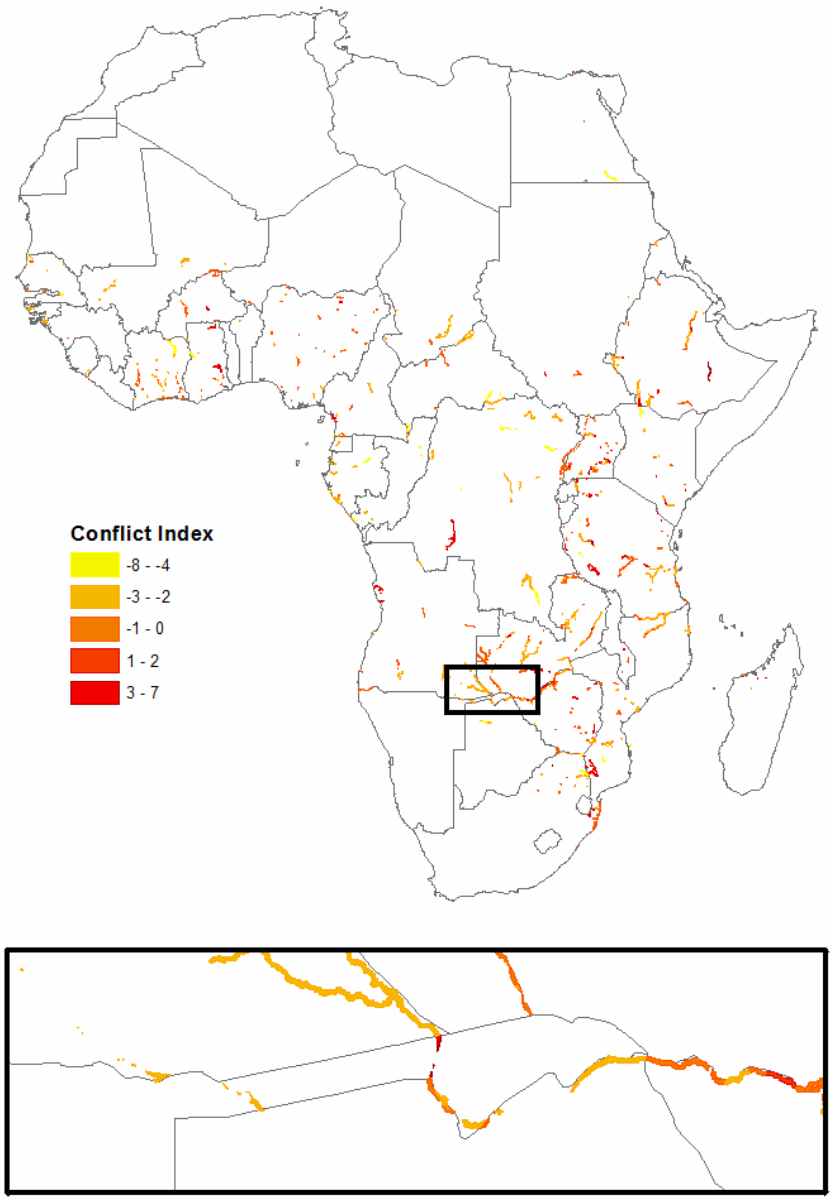


Figure 6.7. Conflict map showing protected areas and relative levels of potential human crocodile conflict based on human and physical geography. Dark red represents areas of highest conflict.

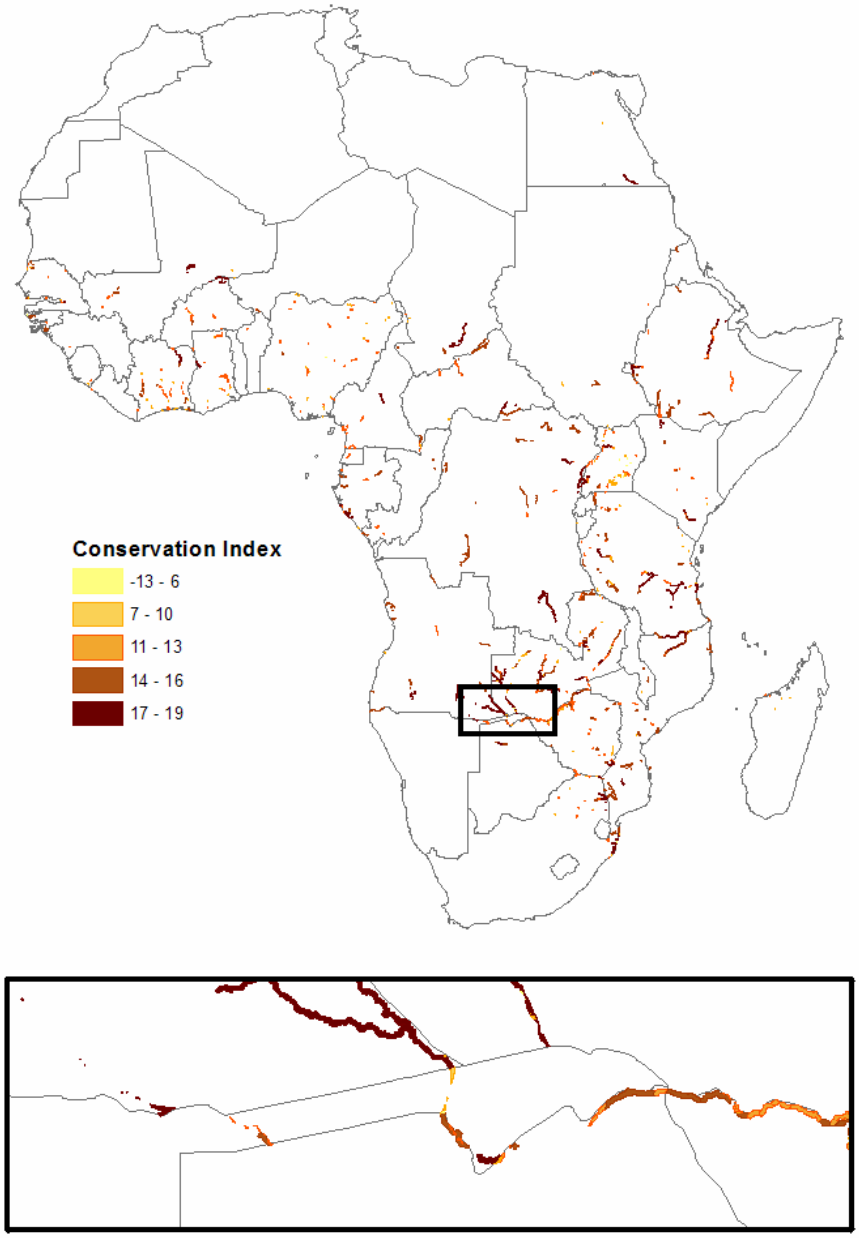


Figure 6.8. Conservation map showing protected areas with relative potential for crocodile conservation based on physical characteristics and IUCN status. Dark brown represents greatest conservation potential.

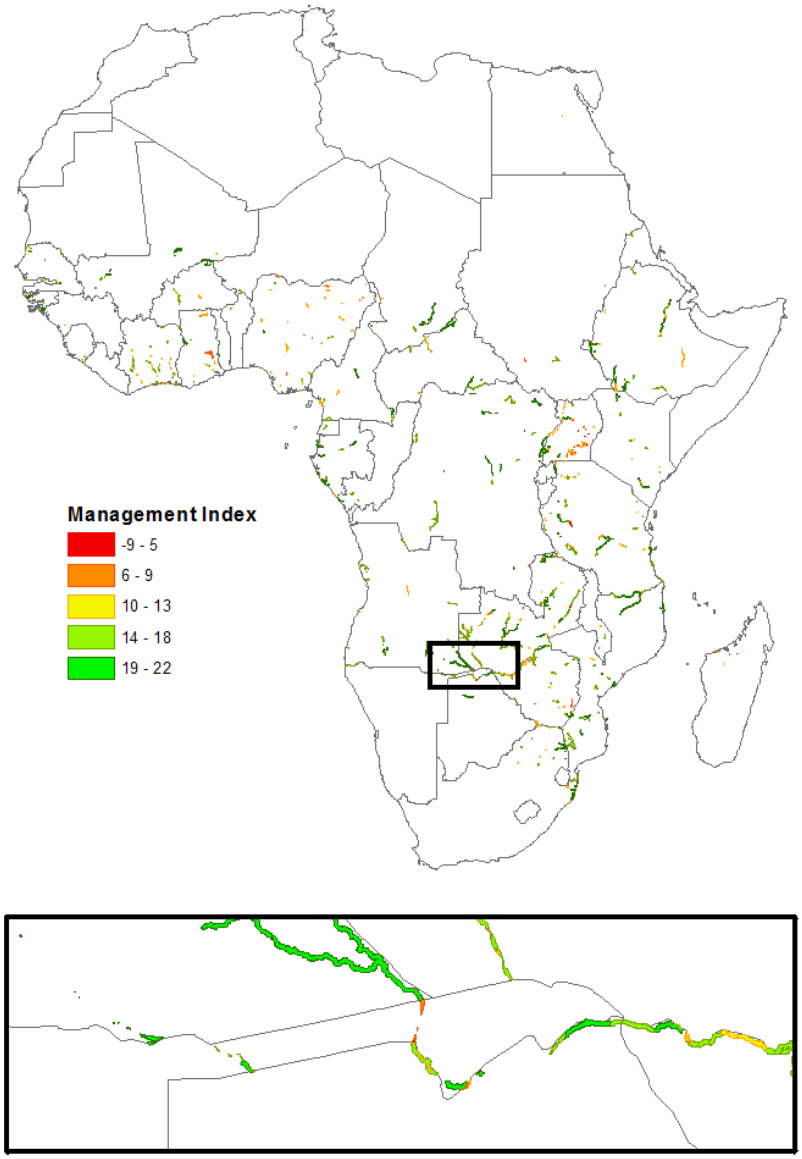


Figure 6.9. Management map showing the relative potential of protected areas for conservation after consideration for potential human crocodile conflict costs. Dark green represents most suitable protected areas.

6.4 Discussion

The aim of this study is to identify the relationships between Nile crocodiles and humans within the context of crocodile conservation on the continental scale. The motivating objective is the fundamental need to provide timely and informed decisions on a divisive species in dynamic landscapes that often lack robust baseline data. This study addresses these issues in two parts. The first determines some important large scale relationships between crocodiles and humans, and the second establishes a clear link between aim and objective by amalgamating this information into a series of simple spatial models for the conservation or management practitioner.

The specific limitations of this research are discussed in more detail as and when they apply. In general, limitations centre on the variable quality of the baseline data in relation to the accuracy required for the purpose of analysis. This is an important consideration for the reader to bear in mind throughout the interpretation process.

Nile crocodiles are currently found throughout much of Africa and in general are still relatively common wherever they do occur (Branch, 1990; Spawls *et al.*, 2004). In many range states they are considered a problem species and many believe their numbers are increasing (Anderson *et al.*, 2005). Numbers have certainly increased dramatically since the end of uncontrolled exploitation and the implementation of rigorous conservation measures in the 20th century (Ross, 1998), but studies carried out over the last few years tentatively suggest that this trend has reached an asymptote and some populations may be declining(Combrink, Korrubel & Ross, 2009; Shacks, 2006). History dictates that other large predators decline in the face of growing human populations (Woodroffe, 2000). It is probable that most Nile crocodile populations are now constrained by human processes and human crocodile conflict will catalyse an era of population decline. This downward trend will likely proximate the rural development trends that characterise the African continent over the next several years.

In this study crocodiles showed no direct relationship with human population densities or growth rates. Finer scale analysis of the relationship at the intra and inter river level showed strong negative correlations between humans and crocodiles

(chapter 2). A possible explanation for this discrepancy is the inherent lack of precision factored in when using a single point for the location and demographic description of each survey area. For example, surveys logged in close proximity to a town would create considerable bias by implying urban type human densities over the entire survey area.

Crocodiles showed a significant positive relationship with protected areas. The results suggest that the demographics of crocodile populations are determined to some extent by the size and proximity of suitable crocodile habitat protected from human interference. Although logical these findings are significant because they provide evidence of the imminent importance of protected areas as a means of conserving Nile crocodiles.

A protected area is defined as an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity and of natural and associated cultural resources, managed through legal or other effective means (UNEP-WCMC, 2009). Although subject to some debate, protected areas are generally accepted as the cornerstone of local, regional and global strategies for biodiversity conservation (Chape *et al.*, 2005; Gaston *et al.*, 2008). Fewer consensuses exist on the effectiveness of protected areas at conserving some specific aspects of biodiversity. Marine Protected Areas (MPAs), for example, are limited in their capacity to conserve due to a number of biological and socio-economic reasons centring on their lack of functional boundaries (Boersma & Parrish, 1999). In relation to terrestrial and marine environments, freshwater protected areas have received little attention and only recently have attempts been made to address this issue. From the literature that exists on the effectiveness of protected areas in freshwater ecosystems, indications are that they share similar connectivity limitations to MPAs (Abell, Allan & Lehner, 2007; Roux *et al.*, 2008; Sarkar, Pathak & Lakra, 2008). This study suggests that the relative proportion of freshwater habitat within protected areas is an important conservation requirement for a keystone apex predator and accordingly warrants further attention.

Protected Nile crocodile habitat is well represented throughout the species range. It is important to mention here again that this area calculation only provides an index of crocodile habitat – much of the actual surface area is suboptimal habitat in the form of

open water or terra firma. Crocodile habitat covers nearly a quarter of all protected areas and it is proportionately well represented in terms of the total number and surface area of individual areas. Prime Nile crocodile habitat loosely corresponds to the drier eastern and southern regions of the species range where freshwater resources are hotly contested. Despite this, protected crocodile habitat in this area remains relatively well represented at 14 percent of protected area coverage. Just over a quarter of protected Nile crocodile habitat is classified in the highest protected area categories (IUCN I&II). These categories are the most robust conservation areas subject to the least amount of human interference (appendix 1). Pristine conservation areas are potentially important for species like Nile crocodiles which are vulnerable to mismanagement due to conflict tendencies coupled with lucrative instrumental values. Probably the only concerning feature of protected Nile crocodile habitat in terms of its conservation value is its average proximity to the perimeter of protected areas. The average distance of less than two kilometres suggests a large proportion of protected crocodile habitat represents a structural boundary separating protected areas from other land use types. Rivers have historically been used as convenient administrative borders and their value as a natural resource has reaffirmed this trend over time. Edge effects and predator conflict have been positively correlated with extinction risk within protected areas (Woodroffe & Ginsberg, 1998). Crocodile populations occurring at the interface of wildlife areas and human environments are vulnerable to recurrent and/or elevated levels of HCC.

To further explore the hypothesis that protected crocodile habitat was compromised through proximity to peripheral landscapes, I looked at the relationship between protected areas and two key proxies for human activity; cattle and human density. Ideally for conservation purposes there should be some negative correlation between protected areas and human activity. This study reports the opposite. The size and category of protected areas show no relationship with human and cattle population densities whilst in some countries protected areas support significantly higher densities of cattle and/or people than others. The error introduced by the baseline data resolution (e.g. imperfect coordinate fit between different data sets) together with the manner in which crocodile habitat was defined (i.e. ‘buffer’ area straddling rivers) does limit the accuracy of these analyses. Nevertheless, these findings strongly support the hypothesis that protected Nile crocodile habitat is situated within the immediate inference zone of surrounding human dominated landscapes.

The parameters governing Nile crocodile conservation and HCC are many and varied and to cover all to the point of satisfying conservation objectives exceeds the scope of this study. These findings in conjunction with pre-existing data do however provide useful directives. Here we review important determinants before discussing the three models.

The extent of crocodile habitat falling within protected areas is positively correlated with crocodile population density and protected crocodile habitat will likely play and increasingly important conservation role in the future. The relative proximity of protected crocodile habitat to peripheral landscapes confers conservation limitations. Protected area category is not significant at the continental scale by it does have potentially important connotations centring on the regulation of human interference. Human and cattle densities are positively correlated to levels of HCC on the smaller scale. Designated Ramsar wetland sites raise international status and elevate the overall conservation capacity of wetlands thereby indirectly benefiting crocodiles (Rodriguez, 2004). Heterogeneity in crocodile biogeography implies disproportionate HCC levels in east and southern African countries compared to west and central African countries.

The conflict map incorporates those factors that directly influence the level of human crocodile conflict based on the current relationship between crocodiles and humans. This relationship is likely to vary with the level of rural development (e.g. dependence on river water). It depicts conflict levels based on the biogeography of Nile crocodiles, abundance of cattle and humans, the size of the protected crocodile habitat and the distance of the protected habitat from the boundary of the protected area. It disregards the conservation status of the area.

The conservation map incorporates those factors that directly influence the conservation capacity of an area and represents an end point rather than current conditions. Most importantly the management of protected areas needs to be harmonised with the relevant IUCN category guidelines because at present variation exists both within and between countries (Hartley *et al.*, 2007). The conservation map is based on the size of the protected habitat, distance to the boundary and overall conservation status of the area including IUCN category and Ramsar status. It

disregards the cattle and human demographic characteristics and the biogeography of HCC.

The management response to HCC will vary according to primary objectives. Short term livelihood upliftment is best addressed with the conflict map whilst long term conservation objectives are best addressed with the conservation map. The hybrid model postulates a measured response, recognising the duality in the sustainable development paradigm. This map attempts to reconcile present conflict areas with areas of greatest long term conservation potential principally to facilitate the allocation of limited resources.

These models offer a pan African overview of the Nile crocodile conflict, conservation and management. For regional level requirements, these models can be enhanced by the use of detailed local data (e.g. river flow rate/suitability) or even high resolution satellite imagery (e.g. verifying human presence/absence). Similar improvements may be used to cater for spatial and temporal variation between or within countries. More permanent improvements to the quality of the data could include direct information on HCC (no. attacks) and facilities to update the socioeconomic and environmental information on a real time basis.

Crocodilian conservation biology in the 21st century is characterised by crisis management. Limited resources and a growing list of critically endangered species ensure that minimal effort remains for preventative strategies involving least concern species over the long term. Africa and the Nile crocodile present a unique opportunity to reverse this trend. The current socio economic and ecological status of the continent and the species lend themselves to a mutually beneficial relationship centred around sustainable utilisation, provided conservation intervention precedes crisis management. Along with providing baseline knowledge and guidelines for decision makers, this study provides a platform for further applied research into the effective management and conservation of Nile crocodiles throughout Africa.

Chapter 7: Discussion

Nile crocodiles are a large aquatic predator found throughout most of tropical Africa. Where they occur they are often common and regularly found outside of protected areas (Branch, 1990; CSG, 2009; Lainez, 2008; Spawls *et al.*, 2004; Stander, 2004). Crocodile populations living outside of protected wildlife areas are subject to a dual conflict scenario. Large crocodiles prey on humans and livestock and damage fishing equipment whilst various anthropogenic factors are having a negative impact on crocodiles (Boyle, 2007; MacGregor, 2002; Shacks, 2006). Current conservation policies reflect historic extinction threats and the management of wild populations remains improvident in the face of modern threats (McGregor, 2005). Crocodiles are a highly valuable natural resource biologically well suited to sustainable utilisation (Blake *et al.*, 1975; CSG, 2004; Revol, 1995). Innovative management solutions could have multidimensional benefits for crocodiles and humans.

The aim of this study was to investigate ecological, economic and social aspects of the human crocodile conflict with the objective of augmenting crocodile conservation and management efforts. These aims were assessed by:

i. Determining the impact of crocodiles on rural livelihoods
ii. Determining the impact of humans on crocodiles
iii. Determining the impact of humans on important crocodile prey species
iv. Determining the general conservation status of crocodiles in Africa
v. Predicting important conservation and management parameters

7.1 Key findings

(i) Crocodiles pose a significant threat to humans, their property and their livestock

Nile crocodiles pose a threat to subsistence livelihoods and rural development. Estimates suggest an annual loss of between ~255 and ~6864 domestic cattle per year and damage to an estimated 71 500 fishing nets per year in North Eastern Namibia (~880km river frontage).

(ii) Humans have a negative impact on crocodiles.

All crocodile size classes showed a negative correlation with people at the inter- and intra-river spatial scales. The relationship between crocodiles and cattle and canoes varies with crocodile size class and spatial scale.

(iii) Cattle have a negative impact on the distribution of wildlife.

Important mammalian prey species showed a significant negative spatial correlation with cattle. The relationship between these prey species and canoes is less consistent suggesting wildlife avoids cattle in addition to the association of cattle with humans.

(iv) Protected areas are important for crocodile conservation.

Freshwater ecosystems occurring within protected areas are important for Nile crocodile conservation. The proximity of crocodile habitat to the perimeter of protected areas suggests that rivers are commonly used as functional boundaries. This raises important conservation and management questions.

7.2 Conservation perceptions and additional concerns

According to the literature suitable Nile crocodile habitat is widespread and relatively abundant throughout tropical Africa (CSG, 2009; Ross *et al.*, 1992). The continent is well endowed with large rivers and lakes and most regions still retain extensive wilderness areas with low population densities (Grove, 1995). For the most part this is indeed the case, and any biologist would be forgiven for thinking that Nile crocodiles have a bright future compared to other large carnivores. In reality, the situation may not be this optimistic.

Conservation biology and the socio-economics of freshwater management in Africa are often driven in part by western organisations e.g.(Chenje, 1998). Many African countries simply lack the resources to handle these complex and expensive issues (Vargas Salcedo, 1988). Often the people involved in the grant making decisions originate in temperate or boreal regions where freshwater is often an abundant resource

by African standards (The_Times, 2005). It is therefore plausible for these people to overlook the significance of perennial African rivers in favour of more iconic African conservation issues. As a consequence, the plight of African waterways may have been somewhat neglected. Circumstantial evidence for this comes from a comparative ISI Web of Knowledge literature search of the phrases 'Conservation Africa Mammals' and 'Conservation Africa Fish'. Mammals outnumber fish by about 5 to 1, or 1593 to 348 records (Thomson_Scientific, 2009), yet African fish are arguably very similar to African mammals in terms of economic and social significance.

Shifting ecological baseline syndrome is a phrase given to the problems associated with failing to accurately appreciate the original 'pre human' condition of an ecosystem. The syndrome is most often applied in a temporal sense where the baseline parameters of an ecosystem are inadvertently redefined over successive generations (Saenz-Arroyo *et al.*, 2005; Saenz-Arroyo *et al.*, 2006). Africa suffers from this syndrome because historical ecological studies and monitoring are rare in the formal literature. An example of this is elephant induced environmental degradation in North Eastern Namibia. In recent years an overpopulation of elephants has destroyed much of the riverine woodland along the Chobe river (Chase, 2007). Anecdotal reports from local residents and grey literature suggest there is evidence of the regional extinction of riverine woodland species (D. Ward and R, Sharp pers coms). Visiting biologists, with limited baseline knowledge to draw from, often fail to fully express the extent of the loss of biodiversity and this may be why elephant management remains controversial and indecisive. Shifting baseline syndrome is probably magnified with African river ecosystems which are generally more cryptic, less well understood and in many respects more dynamic than terrestrial ecosystems.

Africa is set to enter a period of rapid development in the 21st century (Openshaw, 2005). Much of this progress will occur in rural and formerly remote untapped areas where abundant natural resources can fuel agricultural and industrial growth (Openshaw, 2005). Being a comparatively arid continent, freshwater will represent a major challenge (ECA *et al.*, 2000). The growing human pressures on freshwater resources will be considerable, particularly in the more arid East and Southern African regions (Chenje, 1998; Kiwango & Wolanski, 2008). As a habitat type, permanent

bodies of freshwater may be more common but are arguably more threatened than most of the major terrestrial biomes in Africa which are well represented in protected areas.

Protecting crocodile habitat is difficult. Throughout Africa major water bodies represent natural barriers often used as functional boundaries to demarcate human landscapes and these boundaries are often further divided to enable greater resource sharing (Chenje, 1998; Niasse, 2005). Seldom do both banks of a major river lie within protected areas, and the relative size of protected sections makes many of them inadequate at supporting viable crocodile populations. Furthermore, the inherent connectivity of drainage basins and upstream human activities pose indirect threats in the form of siltation, salinisation, eutrophication, water abstraction, chemical pollution and general habitat degradation (Beeton, 2002; Chenje, 1998; Kiwango *et al.*, 2008). Human crocodile conflict is the cherry on the top. Any crocodile habitat exposed to human activity is liable to attract conflict. The subsistence nature and linear settlement patterns along African waterways compound the effects of HCC, and invariably impact negatively on crocodiles. Ultimately the vast majority of perennial rivers and wetlands, even those partially or wholly incorporated into protected areas; remain fundamentally vulnerable to outside influences and do not represent a stable refuge for Nile crocodiles.

African wild dogs (*Lycaon pictus*) solicit a large proportion of conservation resources mainly because of their threatened status and flagship value to conservation (Dalerum *et al.*, 2008; Gusset *et al.*, 2009; Woodroffe & Ginsberg, 1999). In reality, this species is well represented in numerous protected areas and in recent years population numbers have been boosted further by the creation of private game reserves and wildlife conservancies on vast tracts of agriculturally unproductive land (Lindsey, du Toit & Mills, 2004; Lindsey *et al.*, 2006; Woodroffe *et al.*, 2007). In fact, populations of these animals have increased so much in Southern Africa that they are now unofficially classified as problem animals in many parts of South Africa, Zimbabwe, Botswana and Namibia (Gusset *et al.*, 2008; Gusset *et al.*, 2009; Woodroffe *et al.*, 2005). The economics of the tourism and the wildlife industry and success of the protected area system have provided an optimal management model that promotes the long term future of many terrestrial species, including large carnivores (Lindsey *et al.*, 2007a; Lindsey *et al.*, 2007b). By comparison, Nile crocodiles are almost the quintessential opposite. They are an IUCN least concern species and draw minimal

conservation resources (CSG, 2008). Their habitat is vital for development and is fundamentally threatened (Beeton, 2002; Junk, 2002), and lastly, management strategies (McGregor, 2005) and the protected area system (Roux *et al.*, 2008) are essentially sub-optimal in terms of ensuring the status quo of the Nile crocodile.

7.3 Conservation recommendations

Crocodile conservation policies need to be restructured to accommodate the rapidly changing development patterns altering freshwater ecosystems. Once these parameters have been established, adaptive management systems should be directed towards more aggressive means of conflict resolution within the framework of sustainable utilization. Experimental procedures should be boldly pursued with the knowledge that large commercial and protected area populations provide a substantial contingency reservoir.

(i) Transboundary management

All crocodile habitat is transboundary in nature as river basins invariably incorporate a variety of land management systems. In light of this, crocodile conservation and management programs should be specifically designed to accommodate transboundary issues. A high level of coordination and collaboration between governments, government departments and other stakeholders is central to the success of transboundary projects.

(ii) Greater support for current conflict resolution measures.

An important first step towards securing the future of crocodiles would be to reduce the conflict levels between humans and crocodiles. Removing the threats faced by humans would necessarily remove many of the threats facing crocodiles. Conflict resolution measures include conflict reduction and benefit generation schemes such as: improving alternative (e.g. pumped) and/or protected (e.g. fenced harbours) water sources adjacent rivers and wetlands; more timely and effective control of confirmed problem animals and education of local communities on crocodile ecology, conflict avoidance measures and tourism potential. Crocodile specific tourism in particular could benefit from further research and development (Llewellyne, 2007). In Namibia

the benefits of trophy hunting and compensation schemes need further streamlining to offset the costs of conflict in a more effective and meaningful manner. In addition to the government and local NGOs, riverside tourist operations should be encouraged to support these initiatives either directly or through soliciting funds from clients. At the same time crocodiles should be further promoted as a flagship and umbrella species for freshwater ecosystems.

(iii) Zonation.

Zonation is the assignment of land units to specific uses. It is a useful option to mitigate conflicts and a key prescriptive tool for the administration of protected areas (Walther, 1986). The complex management considerations that surround a high value and problematic species like crocodiles may be greatly simplified through the use of zonation. For the most part IUCN protected area categories and associated national land classification systems are the only form of conservation land zonation in Africa. Because of the linear nature and function of rivers this form of terrestrial-centric zonation is largely inappropriate for crocodile habitat (Roux *et al.*, 2008). Instead, crocodile habitat should be zoned and classified according to the protected area status of river banks and shore lines. For example, areas where both banks of a river lie in protected habitat offer highest conservation value (fully protected), areas with only one bank protected offer considerable sustainable utilisation options (e.g. egg collecting, trophy hunting). Areas where no banks are protected are best suited to intensive extractive management (e.g. direct wild skin harvests*, manage population for smaller size classes). Further refinement of this classification system could include IUCN category (e.g. Both banks in IUCN category II areas would yield highest conservation value). This form of zonation would better facilitate the appropriate distribution of benefits of crocodiles according to the levels of conflict endured on an area by area basis. For example, in rivers where IUCN category II protected areas harbour healthy populations of crocodiles but border communal land on the opposite bank, the inevitable higher levels of conflict could be offset by larger egg quotas and increased levels of trophy hunting. Zonation would also enable the mutually beneficial integration of fisheries management and the two could be operated in tandem. For example, ‘net free’ zones would be a useful conservation tool for both crocodile and fish breeding activities (Van der Waal, 2007) which would ultimately result in more sustainable fish and crocodile egg harvests. Adapting the zonation approach to different types of

crocodile habitat (e.g. lakes, swamps) may require defining crocodile habitat using a similar methodology to that used in chapter 5.

* High resolution photographs were taken of the belly skins of 75 small crocodiles fortuitously caught during the spotlight surveys of this study. These photos were later graded by professional skin graders at Spencer Creek Crocodile farm, Zimbabwe. The results showed 25% A grade, 41% B grade with potential to upgrade after minor medication, 31% B grade and 2% reject. These results suggest wild populations are of sufficient quality to justify further research into wild skin harvests.

(iv) Integration of conservation and the crocodile skin industry

The commercial skin industry and conservation groups have for many years enjoyed a mutually beneficial and successful working relationship. The commercial value of crocodiles has developed into a highly profitable leather industry whilst stocks of many species of crocodilian have been able to recover as a result (Ross *et al.*, 1992). This conservation success story has been well publicised in the specialist literature but has remained largely low profile in the public domain, probably because of the controversy surrounding exotic skins and animal rights groups. Increased public awareness and understanding has now popularised the instrumental value of wild resources and this has seen a growing tolerance towards the sustainable utilisation concept (Fearnley-Whittingstall, 2003; Martin, Emery & Dyke, 2006; Mear, 2005). This, together with the success of crocodile sustainable use programs presents a unique opportunity to better illustrate and demonstrate the links between conservation and socio-economic development. Further integration should be directed towards highlighting the benefits of maintaining wild harvests. The value of skins obtained from ranches or eggs collected from the wild should carry a premium reflecting the added conservation value. This value should be transferred through to the end product and marketed in the socially and environmentally conscious genre akin to the Fair Trade concept (Gray, 2009).

7.4 Limitations of this study

This study represents a broad overview of a complex multidisciplinary subject. It attempts to incorporate a wide variety of biological and geographical topics over a large area in an effort to provide a more complete understanding of the ecology of Nile crocodiles in human dominated landscapes. This approach was specifically chosen to

reflect the state of conservation and management needs whist acknowledging the time and resource limitations of a Ph.D. As a result, detailed quantitative results (e.g. accurate population estimates) have to been sacrificed in favour of general patterns (e.g. population index values). This measure of scientific evidence is a common theme throughout the four data chapters of this thesis.

Survey techniques

Crocodile survey methods have been widely criticised and provide only a highly inaccurate estimate of population size (Bayliss *et al.*, 1986; Hutton *et al.*, 1989; Pacheco, 1996). Aerial and boat surveys are both vulnerable to bias from a range of environmental variables many of which were not accounted for in this study. In addition limited sample sizes have further jeopardised robust estimates. As a result, all estimates of crocodile numbers derived throughout this study have been restricted to comparative index values rather than population estimates.

Other factors affecting crocodile distribution

Crocodiles are exposed to other threats. Habitat loss is widespread throughout their range and has been shown to have a negative impact on crocodiles. Crocodilians have been shown to be vulnerable to water pollution and chemical poisoning, physical habitat alteration and invasive species (Gad, 2008; Leslie *et al.*, 2001; Shacks, 2006). These factors could not be evaluated in this study.

Insufficient quality of spatial data

For the continental analysis, the spatial data used in the analysis was generally incompatible with the nature of crocodile habitat. For example, in many cases the spatial data were only available at a pixel size that exceeded the limits of crocodile habitat and consequently provided an inaccurate measure of conditions specifically within the crocodile habitat.

7.5 Future work

Nile crocodiles are unequivocally linked with a dynamic and often volatile continent. Pressing socio-political and economic concerns have and will most likely continue to overshadow wildlife research for some years to come. Future research on

Nile crocodiles should therefore be succinct and well coordinated. Ideally an applied research master plan centring on sustainable development should be managed through an organisation like the IUCN -SSG Crocodile Specialist Group. There is considerable scope for future biological, social and economic research on almost all aspects of crocodile ecology in human dominated landscapes. Important knowledge gaps range from the basic mechanisms of Nile crocodile attacks on humans to understanding the complex relationships between fishermen, crocodiles and fish ecology. The science behind current and potential sustainable utilisation practices needs further attention. Economic and market research would be useful at all levels in the crocodile skin industry in order to maximise profits and profit sharing amongst stakeholders. Quantifying the ecological relationships that exist between protected and unprotected crocodile habitat both within and between Australia, Asia and Africa may provide a useful means of calibrating anthropogenic impacts and the success of management strategies. Ultimately the 'future work' list for Nile crocodiles would be best defined using a collaborative approach with various stakeholders as close to the time of research as possible to better identify priority topics.

7.6 Conclusion

Developing countries in Africa are generally receptive to new and innovative ideas, especially those involving water provision and rural poverty alleviation. Wildlife conservation is by necessity very much a secondary concern. Sustainable utilisation of crocodiles brings together these two paradigms in a mutually beneficial way that makes logical sense to all targeted stakeholders. Human crocodile conflict and competition for diminishing freshwater resources are fuelling a time bomb of conservation threats. Right now Nile crocodile populations are widespread, healthy and robust to experimental management. If long-term crocodile conservation is to be successful, it is important to recognize the critical role subsistence communities play as part custodians of crocodile habitat, and indeed crocodiles themselves. If these communities perceive the value to be real, crocodiles will once again become an integral component of Africa's waterways, and a source of enrichment for the wildlife and humans that depend on them. If not, they will end up as a mere curiosity in wildlife parks, and Africa will have lost the essence of its mighty rivers.

Appendix I

REFFERENCE:_____VILLAGE: _____ AREA:_____ WATER:_____

Nearest river: a) Kavango b) Kwando c) Zambezi d) Chobe

Distance from river: a) <100 b) 100-500m c) 500m – 1km d) 1-2 km e) 2-3km f) 4-5 km g) >5

Distance to nearest borehole: a) <50m b) 50-100m c) 100-200m d) 200-500m e) 500-1000m f) >1km

Household type: 1 2 3 4 5

Household possessions: a) electricity b) cell phone c) car d) solar panel d) other items_____

Section 1 - Personal details

1.00) Sex: a) male b) female **1.01) Year born: _____ 1.02) English speaking ability:** 0 1 2 3 4

1.03) How many people usually live in this house / courtyard?_____

1.04) Does anyone in your house / courtyard own a cell phone? a) yes b) no

Section 2 – Livelihood

Does anyone in your house / courtyard….

2.00) Do fishing	Y / N	**2.01) Ever**	Y / N
2.02) Own livestock	Y / N	**2.03) Ever**	Y / N
2.04) Grow crops	Y / N		
2.05) Make crafts	Y / N		
2.06) Receive money	Y / N		

from the Government			
2.07) Have a paid job	Y / N	**2.08) Ever**	Y / N
2.09) Do anything else for to make an income?			

2.10) Do you fish with nets, lines or traditional fishing baskets? a) nets b) lines c) traditional baskets

2.11) Which is your preferred fishing method? a) nets b) lines c) traditional baskets

2.12) Why do you prefer that method?_____

2.13) Do you make your own fishing nets or buy them? a) make b) buy c) both

2.14) Where do you buy the fishing nets from? _____

2.15) What size nets do you use?_____

2.16) Do you put your nets out in the river or the floodplain? a) river b) floodplain

2.17) Do you own a canoe? a) yes b) no

2.18) Do you use a canoe for fishing? a) yes b) no

How much livestock does your household own?

Numbers	**Cattle**	**Goats**
Currently	**2.19)**	**2.22)**
How long ago used to own livestock	**2.20)**	**2.23)**

How many had	2.21)	2.24)

2.25) Does your family have more, less or the same numbers of livestock as you had 10 years ago?
a) more b) less c) the same number

2.26) Are your livestock herded or do they walk alone? a) herd boy b) alone

2.27) Do your livestock drink from the river or borehole? a) river b) borehole

2.28) How often do your livestock drink from the river? a) less than once a day b) once a day c) several times a day

2.29) Do they drink at certain times? a) morning b) midday c) afternoon d) evening e) throughout the day

2.30) Do they always drink from the same place? a) yes b) no

2.31) Describe the place _____

Section 3 - River usage

3.00) Do you use the river or a borehole for drinking water? a) river b) bore hole

3.01) Do you use the river or a borehole for washing clothes? a) river b) bore hole

3.02) Do you use the river or a borehole for washing your self? a) river b) bore hole

3.03) Do you ever swim in the river? a) yes b) no

3.04) When you swim are you afraid of the crocodiles in the river? a) yes b) no

3.05) Do you swim in one place or in different places in the river? a) one place b) different places

3.06) Is the one place a safe place? a) yes b) no

3.07) Why don't you swim in the river? _____

Section 4 – Attitudes towards wildlife

4.00) What is your attitude towards wildlife overall? a) Like strongly b) Like c) neutral d) dislike e) strongly dislike f) don't know

4.01) Why like?_____

4.02) Why dislike?_____

4.03) What are your favourite wild animals?	**4.04) Why?**
4.05) What are your least favourite wild animals?	**4.06) why?**

4.07) Do you think wildlife is a problem or a benefit for people trying to make money in the area? a) problem b) benefit c) both d) don't know

Give top problems and benefits

4.08) Problems	**4.09) Benefits**

4.10) Which 3 wild animals kill the most cattle?_____

4.11) Which animals eat the most fish from the river? _____

Section 5 - Attitudes towards crocodiles

5.00) What is your attitude towards crocodiles? a) Like strongly b) like c) neutral d) dislike e) strongly dislike f) don't know

Give three reasons why crocodiles are good and three reasons why they are bad:

5.01) Good	**5.02) Bad**

5.03) Do you think crocodiles are a threat to human life? a) yes b) no c) neutral d) don't know

5.04) Are you allowed to kill crocodiles? a) yes b) no c) don't know

5.05) Would you like all the crocs in the area to be removed? a) yes b) no

5.06) Why not?_____
_____

5.07) Do you think there are more, less or the same numbers of crocodiles in this area today than there were 10 years ago? a) more b) less or c) the same d) don't know

5.08) What do you think are the reasons for there being more crocodiles today?_____

5.09) What do you think are the reasons for there being less crocodiles today?_____

Sectiosn6 and 7 - Living with wildlife

Section 6 - Livestock

6.00) Have your household ever had any of your livestock killed by crocodiles? a) Yes b) No

6.01) When was the last time you had livestock killed by crocodiles?_____

How many cattle have you lost to crocodiles in the last…

6.02) year?		**6.03) 5 years?**	

How many goats have you lost to crocodiles in the last…

6.04) year?		**6.05) 5 years?**	

6.06) Did you report the attack to the conservancy or the government? a) yes b) no

6.07) Was any action taken by the conservancy or the government? a) yes b) no

6.08) Why was the loss not reported?_____

6.09) Why do think it was a crocodile? _____

6.10) Have you lost livestock to other predators? a) yes b) no

6.11) Which predators?_____

6.12) When did this last happen? _____

Section 7 - Fishing

7.00) Have you had any fishing nets damaged by crocodiles? a) yes b) no

7.01) When was the last time you had a net damaged? _____

How many times did you have a net damaged in the last…

7.02) year?		**7.03) 5 years?**	

7.04) Were the nets mostly repairable or not? a) yes b) no

How many new nets have you bought in the last..

7.05) year?		**7.06) 5 years?**	

7.07) Have you ever had a crocodile caught in one of your fishing nets? a) yes b) no

7.08) When was the last time you had a crocodile caught in a net? _____

7.09) What happened to this crocodile? a) released b) killed c) already dead

7.10) Do you do anything to protect your nets from crocodiles?_____

Section 8 - Avoiding wildlife problems

8.00) Are there particular times of the day when crocodile attacks occur ?_____

8.01) Are certain areas of the rivers more dangerous than others? _____

8.02) Are certain months of the year more dangerous than others?_____

8.03) Do you do anything to protect your cattle from crocodiles?_____

8.04) Do you do anything to protect yourselves?_____

8.05) Have you received any education about how to avoid incidents with crocodiles? a) yes b) no

8.06) What form was the education in? a) talk b) leaflets c) other? _____

8.07) Who provided the education? a) government b) conservation body c) other _____

8.08) Did you find this helpful in planning how to avoid losses to crocodiles? a) yes b) no c) don't know

Section 9 - Possible solutions and tourism

9.00) What solutions do you believe there are to the difficulties of living with crocodiles? _____

9.01) Do you think it would be helpful to have more boreholes and crocodile fences here? _____

9.02) Who do you think should be responsible for carrying out these suggestions? a) government b) conservation bodies c) local people d) conservancy staff e) other _____

9.03) What is your view of tourists coming to your area? a) Like strongly b) Like c) neutral d) dislike e) strongly dislike f) don't know

9.04)
Why_____
_____

9.05) Has your family made any money from tourism? a) yes b) no

9.06) How?

9.07) Would you like there to be more tourists coming to this area? a) yes b) no c) don't know

9.08) Would you like there to be more lodges and campsites in this area? _____

9.09) What are the top 3 wild animals tourist most like to see? _____

9.10) If there was a way to make money from crocodiles through tourism would you then like the crocodiles to remain in this area? a) yes b) no

9.11) If the community could make more money from having more crocodiles here would you then like there to be more crocodiles? a) yes b) no

Section 10 - Human actions towards crocodiles

10.00) Have you ever eaten crocodile eggs?		**10.03) Have you ever eaten crocodile meat?**	
10.01) When was the last time?		**10.04) When was the last time?**	
10.02) How did you get them?		**10.05) How did you get it?**	

10.06) Why haven't you eaten these things?_____

10.07) Do you know of anyone in this area eating crocodile eggs?		**10.10) Do you know of anyone in this area eating crocodile meat?**	
10.08) When was the last time?		**10.11) When was the last time?**	
10.09) How did they get them?		**10.12) How did they get them?**	

10.13) Why don't other people eat these things?_____

10.14) Do you know of anyone killing a crocodile in the area? a) yes b) no

10.15) Who was this? _____

10.16) When was this?_____
_

10.17) Why did they kill the crocodile?_____

10.18) How did they kill the crocodile? _____

10.19) What stops people from killing crocodiles? _____

10.20) Do you think more crocodiles would be killed if they weren't protected? a) yes b) no

Section 11 - Human incidents

11.00) Has anyone in your family been attacked by a crocodile? a) yes b) no

11.01) What relation to you was the person who got attacked? _____

11.02) How long ago did the attack occur?

11.03) Were they injured or killed? a) injured b) killed

11.04) How old was the person who was attacked? _____

11.05) what sex was the person who was attacked? a) male b) female

11.06) What were they doing when the attack occurred? _____

11.07) Was the attack reported to the conservancy or the government? a) yes b) no

11.08) Did the conservancy or government take any action?_____

11.09) Why was the attack not reported?_____

Appendix II

Extract from the IUCN–World Commission on Protected Areas website.

http://www.unep-wcmc.org/protected_areas/categories/index.html

Defining Protected Area Management Categories

Defining Protected Areas

The definition of a protected area adopted by IUCN is:

An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means

Although all protected areas meet the general purposes contained in this definition, in practice the precise purposes for which protected areas are managed differ greatly.

Protected Area Management Categories

IUCN has defined a series of six protected area management categories, based on primary management objective. In summary, these are:

CATEGORY Ia:	Strict Nature Reserve: protected area managed mainly for science
Definition	Area of land and/or sea possessing some outstanding or representative ecosystems, geological or physiological features and/or species, available primarily for scientific research and/or environmental monitoring.

CATEGORY Ib	Wilderness Area: protected area managed mainly for wilderness protection

Definition Large area of unmodified or slightly modified land, and/or sea, retaining its natural character and influence, without permanent or significant habitation, which is protected and managed so as to preserve its natural condition.

CATEGORY II National Park: protected area managed mainly for ecosystem protection and recreation

Definition Natural area of land and/or sea, designated to (a) protect the ecological integrity of one or more ecosystems for present and future generations, (b) exclude exploitation or occupation inimical to the purposes of designation of the area and (c) provide a foundation for spiritual, scientific, educational, recreational and visitor opportunities, all of which must be environmentally and culturally compatible.

CATEGORY III Natural Monument: protected area managed mainly for conservation of specific natural features

Definition Area containing one, or more, specific natural or natural/cultural feature which is of outstanding or unique value because of its inherent rarity, representative or aesthetic qualities or cultural significance.

CATEGORY IV Habitat/Species Management Area: protected area managed mainly for conservation through management intervention

Definition Area of land and/or sea subject to active intervention for management purposes so as to ensure the

maintenance of habitats and/or to meet the requirements of specific species.

CATEGORY V	Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation and recreation
Definition	Area of land, with coast and sea as appropriate, where the interaction of people and nature over time has produced an area of distinct character with significant aesthetic, ecological and/or cultural value, and often with high biological diversity. Safeguarding the integrity of this traditional interaction is vital to the protection, maintenance and evolution of such an area.

CATEGORY VI	Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems
Definition	Area containing predominantly unmodified natural systems, managed to ensure long term protection and maintenance of biological diversity, while providing at the same time a sustainable flow of natural products and services to meet community needs.

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