Habitat vulnerability for the Nile crocodile (*Crocodylus niloticus*) in the Okavango Delta, Botswana.

By Vincent Shacks

Thesis presented in partial fulfilment of the requirements for the degree of Master of Arts at the University of Stellenbosch.

Supervisor: Prof JH van der Merwe (Department of Geography and Environmental Studies)
Co-supervisor: Dr AJ Leslie (Department of Conservation Ecology)

December 2006

Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature: ………………………………

Date: ………………………………

Abstract

The Okavango river along the panhandle of the Delta, in Botswana, is home to many wildlife species as well as to many large village communities. Local communities rely on the riverine system and its resources for subsistence and commerce. Activities associated with the utilization of these resources are governed by the fluctuating water levels of the river, which inhibit access during high water levels and allow access during low water levels. The high intensity of activities, such as reed harvesting, fishing and increased tourism, during low water periods coincides with the breeding season of many wildlife species in the system, including the Nile crocodile (*Crocodylus niloticus*). Over 90% of crocodile breeding areas in the Delta are found only in the panhandle region. The association between the intensity of human activities in the floodplains and crocodile nesting activity means that much of the habitat required for nesting is vulnerable to human disturbance and this could have severe negative impacts on the future of the Okavango crocodile population.

The study evaluated habitat vulnerability by mapping and spatially comparing habitat suitability, based on optimum environmental requirements for crocodile nesting, and human disturbance factors. A detailed crocodile nesting survey was carried out to locate and test all nesting sites according to criteria selected by species experts. The results from the survey were used to locate suitable nesting habitat in the study area by analysis in a Geographic Information System (GIS). Disturbance factors were visually identified and their locations in the study area spatially mapped. Their spatial influences on crocodile nesting were used as factors in a Multi-Criteria Evaluation (MCE) that evaluated the combined effect of the disturbances on the area defined as suitable crocodile habitat. The results indicate the extent of habitat vulnerable to human disturbances.

The results from the study show that 59% of once suitable crocodile habitat is currently disturbed by human activities. Most of the remaining 41% of undisturbed habitat is located along the Moremi/Phillipa side channel, which represents a core area for protection measures to be instated. The study recommends the declaration of a crocodile nesting sanctuary in this side channel to ensure the breeding success of this keystone species.

Opsomming.

Die Okavango-rivier, langs die pansteel van sy Delta, in Botswana, huisves talle wildspesies, sowel as menslike nedersettings. Plaaslike gemeenskappe is aangewese op die riviersisteem en sy hulpbronne vir hul daaglikse bestaan en kommersiële opbrengste. Aktiwiteite vir die ontginning van hierdie hulpbronne word gerig deur die wisselende watervlakke van die river, wat gedurende hoogstande beperk en tydens lae vlakke toegelaat word. Die hoër-intensiteit aktiwiteite tydens laer watervlakke val saam met die broeiseisoen van talle wildspesies in die sisteem, waaronder die Nylkrokodil (*Crocodylus niloticus*). Die broeiarea van krokodille is beperk tot die pansteel van die Okavango Delta. Die saamval van hoë-intensiteit menslike aktiwiteit in die vloedvlakte en krokodil-nesmakery beteken dat veel geskikte habitat daarvoor kwesbaar is vir menslike ontwrigting, waardeur die toekomstige Okavango krokodilbevolking ernstig bedreig word.

Hierdie studie het ten doel gehad om habitat-kwesbaarheid te bepaal deur die kartering en ruimtelike vergelyking van habitat-geskiktheid, soos gemeet aan omgewingsvereistes vir krokodil-nesmakery, en menslike versteuringsfaktore. ‘n Deeglike ruimtelike en evaluerings-opname van krokodil-neste, volgens die kriteria neergelê deur spesiekenners op die gebied, is uitgevoer. Opname-resultate is gebruik om geskikte habitat vir nesmaak in die studiegebied met behulp van analise in ‘n Geografiese Inligtingstelsel (GIS) af te baken. Ook is tekens van menslike steurnis gedefinieer en die voorkoms daarvan ruimtelik gekarteer. Die ruimtelike invloed daarvan op krokodil-nesmakery is as faktore in ‘n muliti-kriteria evaluering (MKE) ingevoer om die gekombineerde effek van stoornisse op krokodil-habitat te bepaal. Die resultate dui dus die omvang van habitat aan wat kwesbaar is vir menslike versteuring.

Die studie-resultate toon dat 59% van alle geskikte krokodil-habitat tans versteur word deur menslike aktiwiteite. Die meeste van die oorblywende 41% kom langs die Moremi/Phillipa sykanaal van die rivier voor, wat die kerngebied vorm waar beskermingsmaatreëls ingestel kan word. Die studie beveel aan dat ‘n bewaringsgebied vir krokodil-nesmakery langs hierdie sykanaal geproklameer moet word, ten einde die suksesvolle voortplanting van hierdie sleutelspesie te verseker.

Acknowledgements.

I would like to thank the Lord for opening up opportunities for me in my life. My parents for supporting me in everything I choose to do and have ever done.

To Dr Alison Leslie, for giving me the opportunity to join the team in the Delta and allowing me to carry out a project which truly interested me, thank you!

To Erich & Lore Maciejewski (Cape Town), Horst & Val Maciejewski (Richards Bay) who supported me through my research in providing "boarding and lodging." To our family away from home, Phill and Kay Potter from Sepopa Swamp Stop, thank you for all the support! To Thoralf Meyer from the Harry Oppenheimer Okavango Research Center in Maun, thank you for the assistance with the GIS and data. Thank you to Lin Cassidy who allowed the use of her data on resource use areas along the panhandle.

Finally to the Earthwatch Institute and all its volunteers who assisted during the year and the Okavango Crocodile Research Team – Audrey Detoeuf-Boulade, Kevin "Wally" Wallace, Kristi Maciejewski and Sven Bourquin for being part of an unbelievable year, Kea Lebogha!

CONTENTS

Page

1. INTRODUCTION **1**

1.1 Man and crocodile: The battle for space **1**

1.2 Human disturbance on crocodile habitat **2**

1.3 Ecological and economic importance of crocodiles **4**

1.4 Research problem: Habitat vulnerability **5**

1.5 Aims and objectives **6**

1.6 The Okavango Delta **6**

1.6.1 Delta physiography 7

1.6.2 Crocodiles of the Okavango 10

1.6.3 The human footprint 11

1.7 Methodology and data **13**

1.7.1 Literature survey 13

1.7.2 The nesting survey methods and schedule 14

1.7.3 Habitat suitability mapping 15

1.7.4 Research design 16

1.8 Report framework **18**

2. CROCODILE NESTING HABITAT **20**

2.1 Survey planning and methods **20**

2.2 Selecting nesting criteria **25**

2.3 Recording crocodile nesting preferences **26**

2.3.1 Distance to water 26

2.3.2 Vegetation characteristics 27

2.4 Nesting patterns over time: 2002, 2003, 2004 **29**

2.5 Mapping habitat suitability **31**

2.5.1 Processing methodology 31

2.5.2 Preliminary maps for habitat suitability 32

2.6 Habitat suitability patterns **34**

2.7 Map verification **37**

3. HUMAN DISTURBANCE 39

3.1 Human settlements as the focus for disturbances 39

3.2 Vegetation harvesting 40

3.3 Cattle grazing 40

3.4 Fire occurrence 42

3.4.1 Fire use and fire regimes 43

3.4.2 Fire disturbance in the Panhandle 44

3.5 Boating activity 46

3.6 Combined human disturbance 48

4. MULTI-CRITERIA EVALUATION (MCE) FOR CROCODILE HABITAT DISTURBANCE 49

4.1 The procedure sequence 49

4.2 The objective for MCE application 51

4.3 Selecting criteria 51

4.4 Mapping and rasterizing factors and constraints 52

4.5 Transformation and standardization of factors 52

4.5.1 Translating distance values into disturbance intensity 53

4.5.2 Fuzzy standardization 55

4.6 Weighting the factors 57

4.7 Performing Multi-Criteria Evaluation 59

4.8 Determining habitat vulnerability 61

4.9 Nesting sanctuary: Conserving undisturbed nesting habitat 62

5. MEETING THE OBJECTIVES 66

5.1 Nesting characteristics and habitat suitability 66

5.2 Human disturbance potential 67

5.3 Habitat vulnerability 68

5.4. Technical evaluation of the research 68

5.5. Value of the results 69

5.6. Recommendations for habitat protection 69

5.7. Future research 70

REFERENCES **72**

PERSONAL COMMUNICATIONS **76**

TABLES

Page

Table 1.1: Population figures for seven of the villages in the study area 11

Table 2.1: Results of the distance from water factor calculation 27

Table 2.2: Nest numbers and positions from previous nesting seasons used for habitat suitability map verification 37

Table 4.1 Critical distance values for each of the six disturbance factors 55

Table 4.2 Values for the monotonically decreasing, sigmoidal curve 56

Table 4.3: Pairwise comparison matrix for the MCE factors of the habitat disturbance map 58

Table 4.4: Weights of each disturbance factor and the consistency ratio as calculated in the WEIGHT module of Idrisi 59

FIGURES

Figure 1.1 The relative intensity of annual activities occurring in the panhandle of the Delta 3

Figure 1.2 The study area in the northern reaches of the Okavango Delta, Botswana 7

Figure 1.3 The drainage pattern and basin elevation of the Okavango Delta 8

Figure 1.4: Perceived scarcity of natural resources as indicated by a household survey of 22 villages in the Okavango Delta (X-axis represents the type of natural resource and the Y-axis represents the grouped villages response per category) 12

Figure 1.5 The research design 17

Figure 2.1: Location of the surveyed nest sites in the three survey sections within the Panhandle region of the Okavango Delta 21

Figure 2.2 A crocodile slide 22

Figure 2.3 A belly imprint of a female crocodile 23

Figure 2.4 Nest site characteristics 23

Figure 2.5 Fishermen in traditional mokoro boats 24

Figure 2.6 Isolated water bodies on aerial photography 24

Figure 2.7 Nesting site characteristics 28

Figure 2.8 Nest cover vegetation preference 28

Figure 2.9 River cover vegetation preference 29

Figure 2.10 Nesting positions in the 2002, 2003 and 2004 nesting seasons in the Panhandle region of the Okavango Delta, Botswana. 30

Figure 2.11 Vegetation preference factor for habitat suitability 33

Figure 2.12 The distance from water factor for habitat suitability 34
Figure 2.13 Crocodile habitat suitability 35
Figure 2.14 Nest locations along the Okavango and its' major side channels 36
Figure 3.1 Grazed grasslands along the Okavango river 41
Figure 3.2 Utilization zones 42
Figure 3.3 Burnt areas as recorded from the field 44
Figure 3.4 Evidence of fire disturbance 45
Figure 3.5 Occurrence of burnt areas recorded in the field 45
Figure 3.6 Traffic intensity and boat launching sites along the Okavango river 47
Figure 3.7 Combined human disturbance areas 48
Figure 4.1 The six steps of MCE, with Idrisi modules 50
Figure 4.2 The disturbance effect of fire 54
Figure 4.3 A monotonically decreasing, sigmoidal curve used in the FUZZY module 55
Figure 4.4 Standardized disturbance distance decay for "very intense traffic" 57
Figure 4.5 The 9-point continuous scale used in setting weights 58
Figure 4.6 Disturbance potential map 60
Figure 4.7 Habitat vulnerability 62
Figure 4.8 Crocodile nesting sanctuary 64

CHAPTER 1: INTRODUCTION

The conflict between man and crocodile over living space can only be understood once each of the species' living requirements is investigated. The village communities along the Okavango river require resources from the river system and in acquiring these resources the community members create disturbances to crocodile nesting activities. In order to identify the different areas of human disturbance and their respective intensities, the activities and the timing of these activities in relation to crocodile nesting need to be assessed.

1.1 Man and crocodile: The battle for space

Throughout history man has shown the tendency to occupy areas which provide nearby resources and open spaces. This occupancy is usually to the detriment of some natural resource, as human populations continue to increase and living space becomes less and less. The incapability of man to utilize resources without depleting stocks or disturbing natural processes is a concern for our natural world and the species that inhabit it. The crocodile of the Okavango is just one such species suffering at the hands of human disturbances. The "Panhandle" region of the Okavango Delta in Botswana, is certainly the unsung hero of the Delta ecosystem. This unique river not only provides a continuous water supply to the Delta but also supports many local communities as well as a huge diversity of fauna and flora. Fishing, reed cutting and plant collection are just some of the more common activities associated with the surrounding villages of the river. The resources of this system are shared with the surrounding wildlife, and the Nile crocodile (*Crocodylus niloticus*) is one such species forced into sharing its resources.

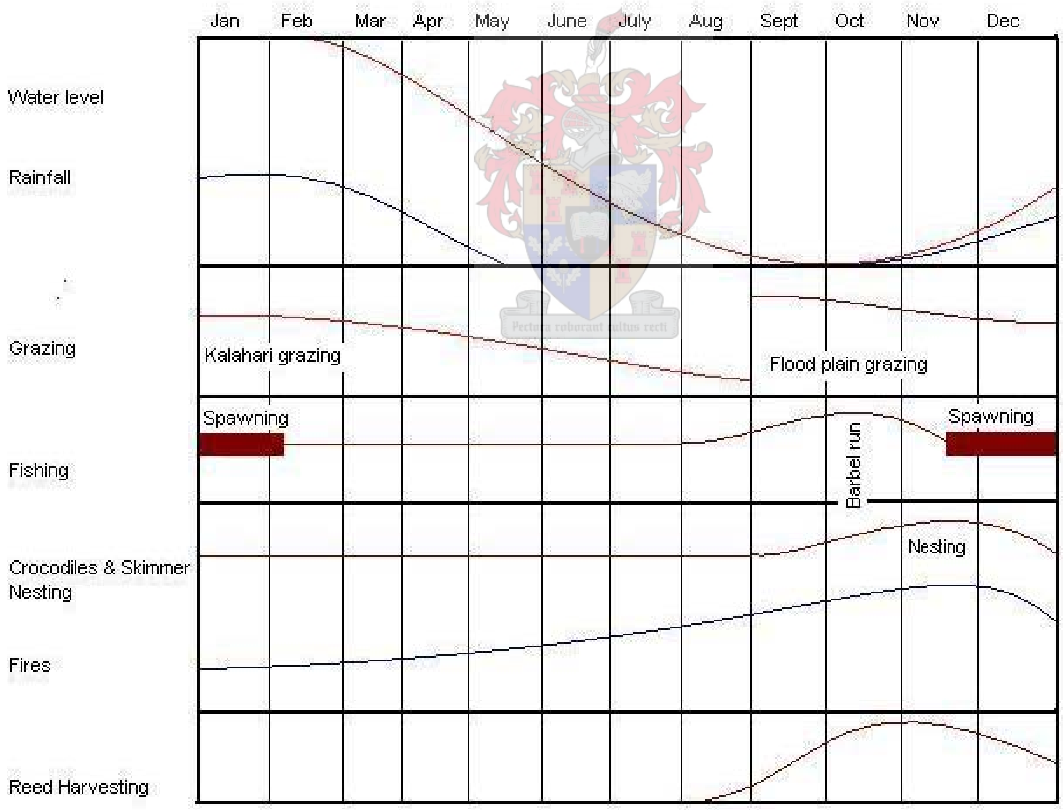
The activities centered around the human settlements are having a severe influence on the nesting success of crocodiles. Illegal burning practices each year lead to huge tracts of destroyed natural habitat. Boat traffic on the river creates a disturbance for nesting female crocodiles (Mbaiwa, 2002) and local fisherman and reed cutters readily destroy crocodile eggs and nesting sites (Leslie, 2003). Humans and crocodiles naturally come into conflict when certain resources are shared (Cassidy, 2003) but the outright destruction of this keystone species will however have very severe implications for the system and thus the people relying on it for its resources. The extent of human impacts on crocodile habitat thus needs to be evaluated, both for the sake of the species and the system which relies on it as its top predator.

1.2 Human disturbance on crocodile habitat

Crocodiles, as with many species, are severely affected by human disturbances. These disturbances come in many forms for the crocodiles of the Okavango river system. Crocodile nest site selection and egg deposition takes place from mid-September to early November. This period is marked by various other significant occurrences in the system. The water level of the river reaches its lowest point during this time period, and hatching coincides with a rising water level in the month of January, the peak of the wet season. The activities of humans in the system are also linked to low water levels as it creates easy access to various resources in the wetlands. Human activity in and around natural wildlife habitats has been shown to have negative consequences for various species. Animal species often deliberately select breeding or resting places away from human areas because of the associated disturbances (Gill-Sanchez, *et al.*, 2003; Petram, Knower & Kaczensky 2003). This behaviour usually results in species dispersing to areas which are largely inaccessible to humans (Sergio *et al.*, 2002). Certain bird species are known to show negative physiological responses to stress at nest sites leading to low hatchling rates (Fowler, 1999) as well as influences on fledgling weight and juvenile survival (McClung, *et al*., *In Press*).

Tourism related impacts are one of the growing disturbances to nesting crocodiles in the Okavango system. Mbaiwa (2002) studied environmental impacts of tourism development on the Okavango Delta and found that a major impact on wildlife in the Delta was through increased boat traffic on the river. Wake disturbances were said to influence bird, hippopotamus and crocodile populations in the river. This finding is supported by data in the Okavango River Panhandle Management Plan (NRP, 2001). The impacts they list as arising from boat operations include: noise impacts and disturbance, bank erosion due to wakes and/or propeller wash, pollution due to emissions from boat engines and/or general boat operations, and the introduction of aquatic weeds. Raadsman & Loveridge (1988) stated that due to land-use conflicts associated with the Panhandle of the Delta, previous assumptions that this area will remain a prime crocodile breeding area, are unrealistic. They also mention that the biggest threat to the crocodile population is the possibility that prime breeding habitat in the Panhandle is lost. Hutton & Games (1992) state that cattle encroachment and burning of reeds and Papyrus is incompatible with crocodile nesting.

Resource utilization in the panhandle is another major influential group of activities that occur. Cassidy (2003) shows that in September the water level in the panhandle drops rapidly. This drop in water level gives local inhabitants access into the floodplains where they begin collecting reeds and thatching grass for building and papyrus for the making of mats. During this time of low water, cattle gain access to the floodplains for grazing; and fishing is at its prime. November shows the first signs of the floods arriving in the northern reaches of the river. During this time papyrus is still being collected for mats and grazing continues in the floodplains. Fishing continues throughout the nesting period of crocodiles and is not as influenced by water levels as the other activities. By December the water in the main channels begin to rise and spill into the floodplains. At this stage the activities in the area are restricted to grazing and fishing. January brings the second pulse of the floods and only fishing occurs during this period. Figure 1.1 shows the relative intensity of activities in the panhandle throughout the year.



Source: NRP, 2001

Figure 1.1 The relative intensity of annual activities occurring in the panhandle of the Delta

The three major human related activities noted in Figure 1.1 are floodplain grazing, fires and reed harvesting. All three of these activities occur during the crocodile nesting period. The reason for the high intensity of activity around this time of the year can be directly attributed to the low water level of the river, as humans benefit from improved access into floodplains.

Every year, the panhandle of the Delta experiences intense fires, some of which are natural, but the majority of which are started by local inhabitants. According to Cassidy (2003), the locals believe that fires will improve the resource base, namely fish stocks and grazing land, on which they are so dependant. The timing of the fires is primarily reliant on the water level and the intensity of the fire depends on the wind conditions. Burning in the Delta is illegal, which means that fires can occur at any time during the dry season due to the secretiveness associated with the setting of these fires. Unfortunately this time period is also linked to the breeding period of many birds, insects, crocodiles and other species. This pattern shows that both crocodiles and humans take advantage of the low water periods and this obviously leads to conflict between the two species.

1.3 Ecological and economic importance of crocodiles

Crocodiles in the Okavango river system are a keystone species. Species diversity of a system is said to drop once a keystone species is removed. The idiosyncratic effects of individual species can be accounted for by focusing on the relationship between keystone species and ecosystem functioning (Bengtsson, 1997). The state or resilience of an ecological-economic system is directly linked to the well-being of the keystone species (Amitrajeet, 2003). McClanahan (1999) shows that exploited top predators in natural systems require long time periods to recover. He also states that these top predators "are of special concern to conservation because they can influence the ecological state, process and diversity of their ecosystem." As top predators of the food chain, crocodiles provide vital functions to the system.

The crocodiles of the Okavango are the top aquatic predators and are thus responsible for controlling fish numbers in the system. The diets of larger crocodiles (125cm-325cm in length) indicate that their main food source is fish, namely barbel (*Clarius sp*) (Blomberg, 1976). This particular species has a low commercial value due to religious and cultural taboos on eating this particular fish. These beliefs have thus created a low demand for the species when compared to the more popular bream (*Tilapia sp*), which is the most valuable fish on the market (Mosepele, 2002). Cott (1961) shows that there is a common correlation between the decline of freshwater fisheries with the removal of crocodilian populations. By controlling the numbers of predatory barbel, which are not as commercially exploited as the bream species, crocodiles are essentially keeping bream numbers in check and ensuring stable numbers for the surrounding communities and their markets. The system thus also benefits, as bream play a vital role as herbivorous feeders in the system.

Unstable crocodile numbers are significant for other parties too. Botswana currently has three commercial crocodile farms which rely on the system for re-stocking. These farms are vital for the generation of foreign exchange through the sale of crocodile products, as well as providing employment to local citizens. In order to keep their practices sustainable, these farms are also required to return up to 5% of their total collected stock from the system, back to the wild (Craig *et al.*,1992). The crocodile also makes up one of the many desired species to be viewed by tourists visiting the Delta. The lack of crocodile sightings in the wild will impact on the viewpoints of visiting tourists, who contribute significantly to the Botswana economy. Ross (1998), states that a loss of any crocodilian species would represent a significant loss of biodiversity, ecosystem stability and economic potential.

The Nile crocodile was given official international protection by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), when in 1975 habitat destruction lead to a dramatic decrease in crocodile numbers. The animal was placed on the convention’s Appendix II list in 1998 (Ross, 1998).

1.4 Research problem: Habitat vulnerability

The future of the population of crocodiles in the Okavango system is uncertain and the shortage of breeding length adults is well understood (Graham *et al.*, 1992)**.** The Okavango Crocodile Research project operating out of Ikoga in the panhandle, has also noticed a severe reduction in the number of nests found in the panhandle over the past 3 years compared to numbers found in previous years (Leslie, 2003). The Crocodile Research Team at the start of the study was made up of two Masters students Kevin Wallace and Audrey Detouf-Boulade who had been on the project for two years and Sven Bourquin (PhD student) who had been on the project for two and a half years. The project is headed by Dr Alison Leslie who has worked with crocodiles for over 12 years. Low numbers of breeding length adults and a decrease in nest numbers, combined with the associated human activities occurring in the floodplains, has lead to the question of what impacts humans are having on crocodile numbers due to the disturbance associated with their activities in the Okavango system. This study will attempt to identify habitat vulnerability by showing the difference between suitable habitat and available habitat for the crocodile, that is, habitat free of any disturbances.

1.5 Aims and objectives

The aim of the study is to indicate **crocodile nesting habitat vulnerability** due to **human disturbances** in order to have the remaining **suitable habitat** protected in the form of a proposed **sanctuary.**

The objectives of the study are to:

- Record all **nesting preferences** of crocodiles in the panhandle by carrying out a thorough nesting survey.
- Create a **habitat suitability map** based purely on nesting requirements and ecological criteria obtained from the nesting survey. Factors such as distance from water, vegetation structures and location on the river are included.
- Create a **habitat disturbance potential** map through Multi-Criteria Evaluation (MCE) based on disturbance factors including fire occurrence, boat traffic, human disturbance and cattle grazing.
- Establish **habitat vulnerability** by determining the difference between the habitat suitability map and the habitat disturbance map, which will indicate the extent of non-disturbed or available habitat remaining in the system.
- Demarcate the remaining suitable habitat (vulnerable) for protection designation in the form of a proposed **sanctuary.**

1.6 The Okavango Delta

The Okavango Delta is a unique natural system found in the North-eastern corner of landlocked Botswana (Figure 1.2) The delta supports both natural and human populations and the diversity of species and natural resources in the system can only be fully understood once the original nature of this river system is described. The extreme seasonal changes control the activities of both the human and crocodile populations and in this lies the essence of the inter-species conflict.

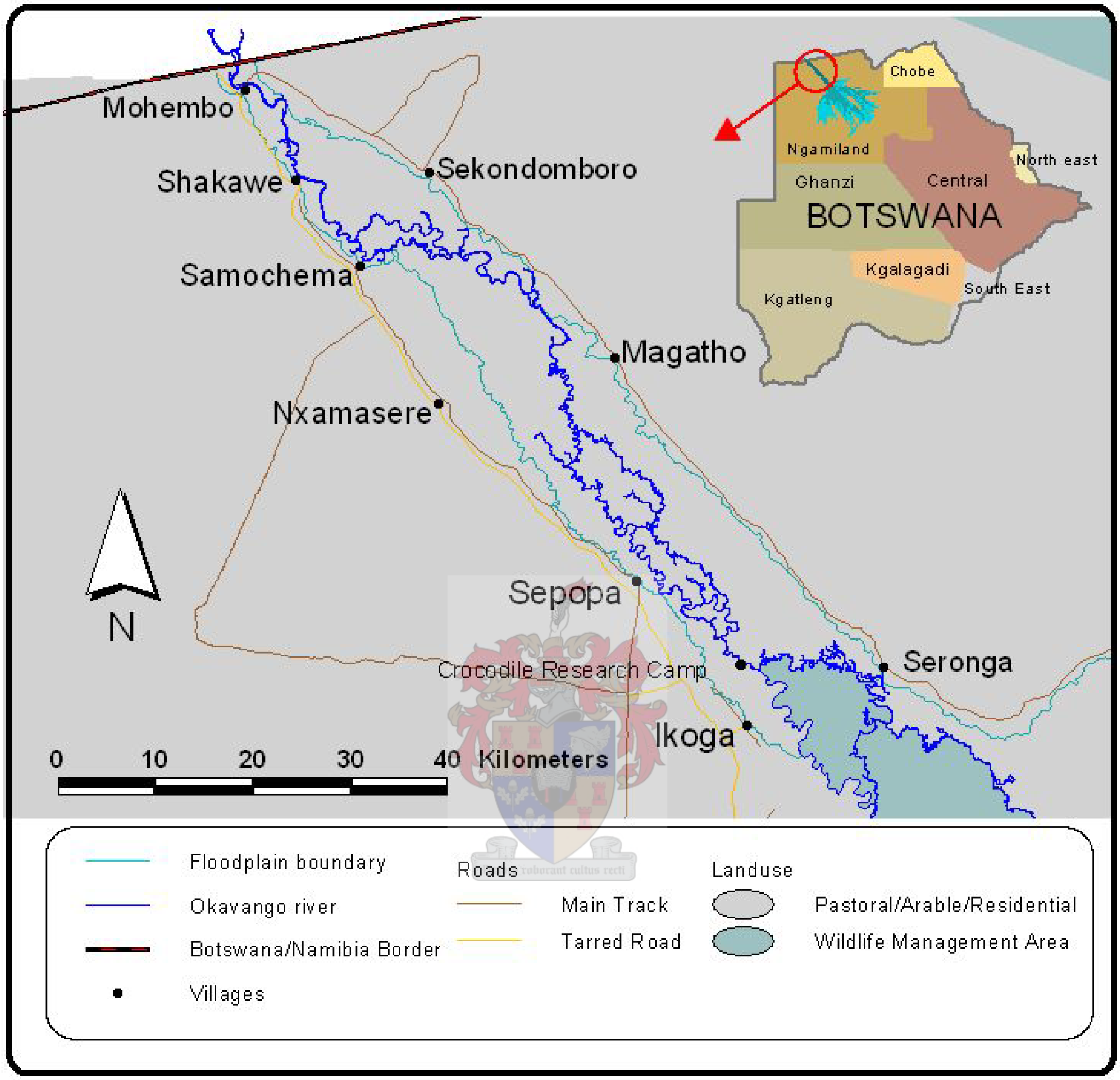


Figure 1.2 The study area in the northern reaches of the Okavango Delta, Botswana.

1.6.1 Delta physiography

The Okavango Delta is located in Botswana's Kalahari Desert at a height of between 800m and 1000m above sea-level (Figure 1.3). Its waters arise from the highlands of Angola from where it travels toward Botswana as the Cuito and Cubango rivers. These two rivers eventually converge, approximately 100km before Botswana along the Namibian border, to form the Okavango River. The river then flows approximately 85km (as the crow flies) before it fans out into the classical bird's footprint of the Delta. The upper reaches of the Okavango River and its adjacent floodplains fall between two parallel fault lines, which form a slight depression about 10-15km in width. Base flow in the Okavango river sustains about 3000km^2 of permanent swamp in the panhandle and around the apex of the alluvial fan, but the area of inundation may seasonally expand and can exceed 12 000km^2 (Gumbricht *et al*, 2003). The catchment area of the system receives rain between December and March and the runoff accumulates in the Okavango river. The water level peaks at the border between Namibia and Botswana (at Mohembo) in April and the peak at Maun occurs in August (Mendelsohn & Obeid, 2004).

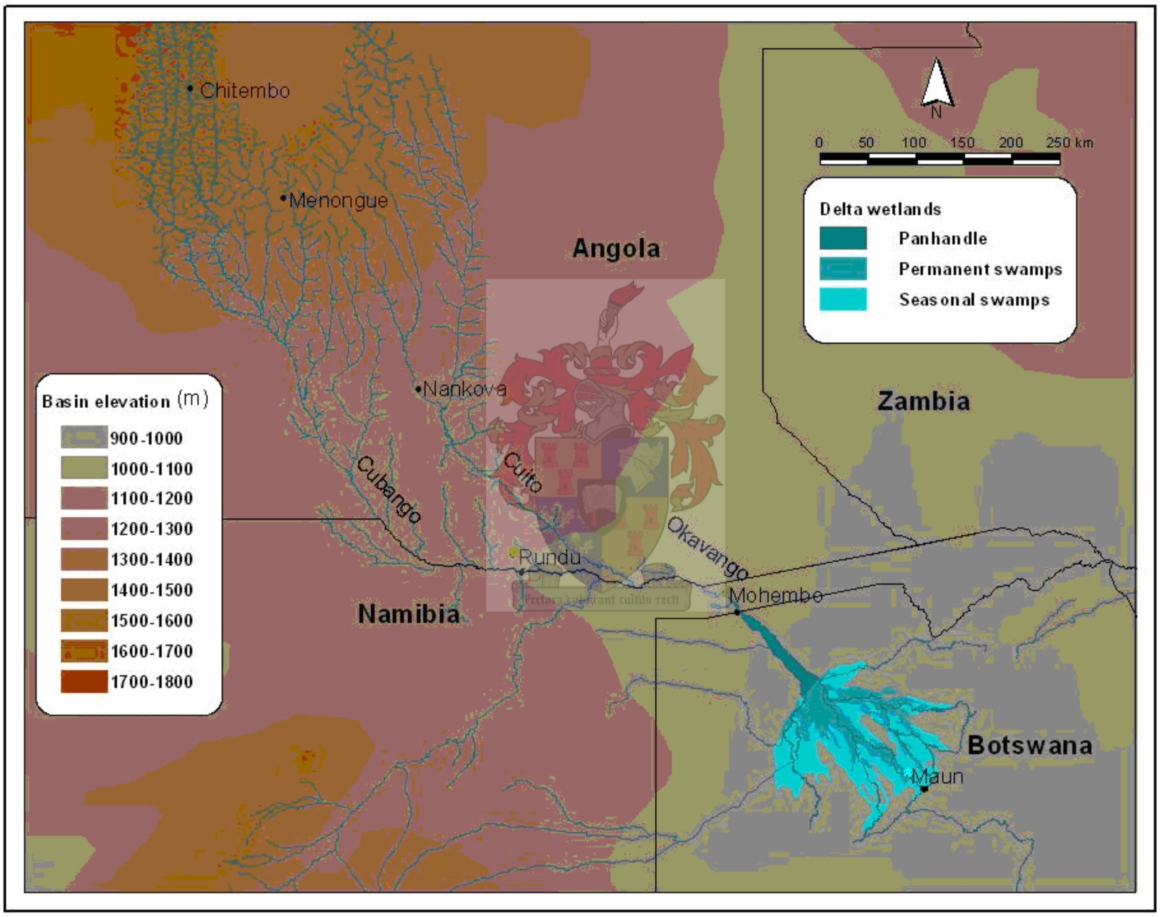


Figure 1.3 The drainage pattern and basin elevation of the Okavango Delta

The Okavango Delta is made up of the Panhandle, permanent swamps and seasonal swamps. The permanent swamps include the three main channels that distribute water from the panhandle and across the fan. The seasonal swamp receives water that filters from the permanent swamp and the extent of this flooding varies each year between 4000 and 8000km^2. The average annual flow as measured at the Botswana/ Namibia border at Mohembo between 1933 and 2001 is 9.384km^3.

The water quality in the delta is very good as there are very few sources of pollution and contamination. The soils in the catchment area and along its river banks are not prone to erosion and thus keep the water clear during the rainy seasons. The water is also free of salts as they are absorbed by plants of the many scattered islands found along the river. The salts are filtered out of the water by the plants and collected on these islands through a process of transpiration (Mendelsohn & Obeid, 2004).

The average annual rainfall in the Shakawe region is approximately 600mm. Rainfall is seasonal with 90% falling over a five month period from November to March (Murray-Hudson, 1997). Surface flooding may occur with extensive rainfall toward the end of summer and this type of flooding differs from the seasonal flood as it is more widespread (Gumbricht *et al.*, 2003).

The study area is characterized by a perennial stream dominated mainly by papyrus (*Cyperus papyrus*) and the slightly more elevated phragmites reeds (*Phragmites australis*) and thatching grass (*Miscanthus junceus*). These species are all permeable and thus facilitate the distribution of water and regulate the distribution of sediment in the system. The vegetation regulates the system and prevents stagnation in a river that would otherwise be saline and sandy (McCarthy, 1992).

The river occasionally runs along islands that form long and scattered ridges all around the floodplains of the system and are characterized by woody tree species such as *Acacia, Ficus, Diospyros* and palms (*Arecaceae sp.*). The Okavango River begins as a single broad, shallow channel which is a result of deposition on point bars and erosion on the outer channels. This single channel runs past the village of Shakawe from where it splits into the main channel and the Kgaolo Thaoga subsidiary channel, which was historically probably the main channel of this river (McCarthy, 1992). The channel divides in two again after Nxamasere, where the entrance to the Eastern Channel (Moremi/Phillipa) splits away from the main channel. This channel, unlike the upper panhandle, is not characterized by broad sweeping meanders, which indicates that most of the deposition in the river takes place in the upper reaches of the panhandle (McCarthy, 1992). The Eastern channel travels parallel to the main channel firstly as the Moremi and then the Phillipa channel. It then meets up with the main stream again about 20 km downstream of Sepopa. The main stream runs down to Seronga, where it finally splits up into the channels which form the base of the alluvial fan.

1.6.2 Crocodiles of the Okavango

The Okavango population of crocodiles has already undergone three periods of commercial exploitation in this system. Hide hunters were invited by the Department of Wildlife and National Parks (DWNP) to shoot an annual quota of 2000 crocodiles per concessionaire, between the years 1957 and 1969. This period's harvest is said to have totaled about 12 000 animals. A further 940 crocodiles were shot for skins in 1974 and 1975 (Graham *et al*, 1992). Murray-Hudson (1997), in a report of the fauna of the Okavango river basin, states that after the commercial hunting period between 1957 and 1974, the crocodile population recovered under a decade of protection stipulated by the Botswana government. He states that from 1983 to 1988, 1053 live crocodiles were caught from the wild and 14000 eggs were collected by crocodile farmers. This harvest resulted in a 50% decline in breeding females.

The population in 1987 was estimated at approximately 5000 crocodiles in the panhandle region and throughout many of the wetland habitats found in the system. These include permanent swamps, rivers, lagoons and seasonal swamps (Simbotwe, 1988). Graham et al., (1992) showed that 99% of nesting sites were found in the panhandle above the delta between Shakawe and Seronga. They also state that crocodile distribution, habitat preference and reproduction are closely linked to flood regimes and water levels as they affect food supplies, nest site selection and availability, cover requirements and hatchling survival rates. Crocodiles were also heavily persecuted in the Namibian section of the Okavango River and currently the breeding area is restricted almost entirely to Mahango Game Reserve, in the Caprivi strip of Namibia bordering Botswana (NRP, 2001).

Graham, *et al.*, (1992) described the nesting habitat of crocodiles in the Okavango River. They state that nests did not appear to be distributed randomly but that they are associated with "deep active channels". Certain channels or scroll areas are apparently discarded as suitable nesting areas as the channels themselves are too shallow, have silted up or are choked with reeds. They analyzed the distribution of nests as the number of nests per kilometer of deep-water floodplain, and concluded that nest densities declined with distance downstream. For the protected years of 1974-1979 this pattern of nest density decline with distance downstream was found to be consistent. The decrease in nest density with distance downstream could not totally be explained, but the implications for management due to this phenomenon were emphasized as being very significant for the future. The authors conclude that the 482 km² of deep-water swamp on the floodplain are crucial to the population and must form the nub of any conservation program for crocodiles.

1.6.3 The human footprint

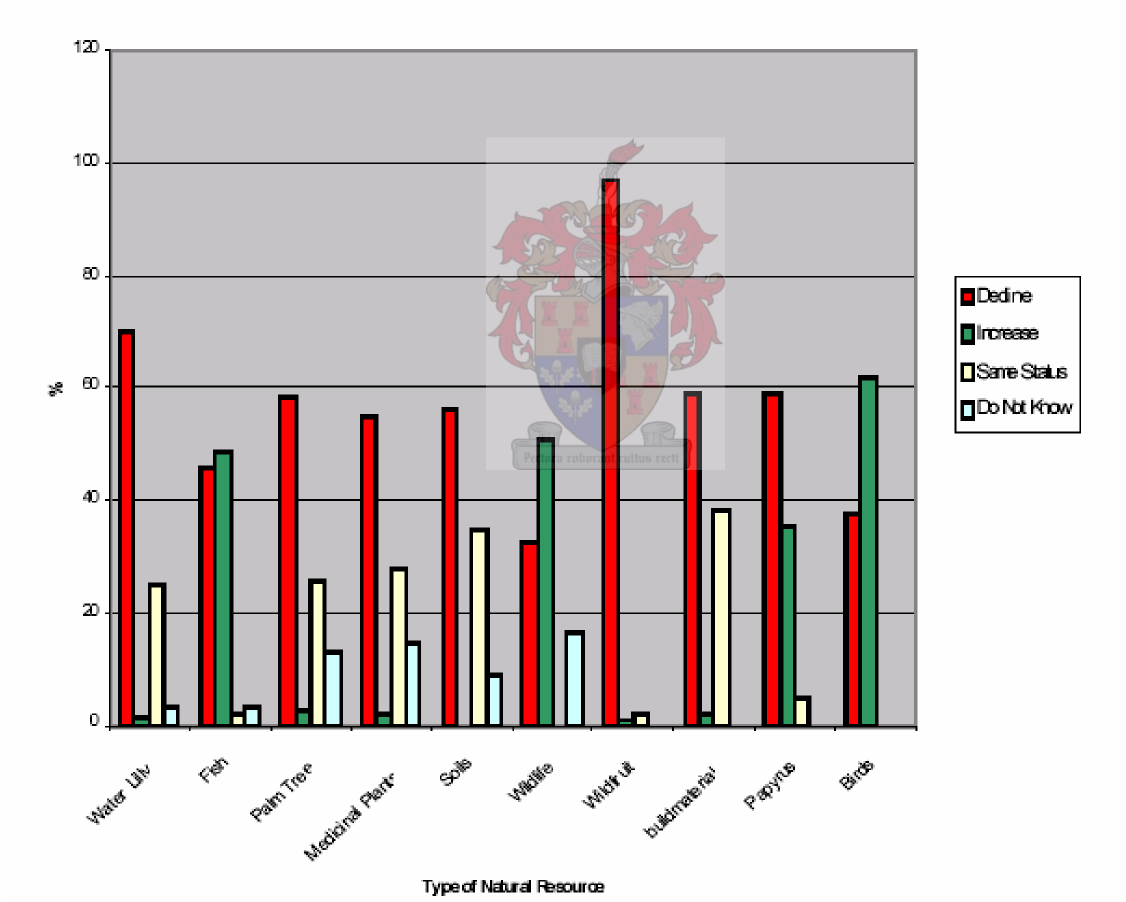
The villages surrounding the floodplains rely on the Okavango river for its resources and the crocodile population is restricted to this permanent water area for nesting. Rapidly increasing populations and expanding tourism are leading to pressures on and scarcity of natural resources. This is primarily due to an increase in the privatization of the Delta's natural resources which generally restricts access for the communities to certain areas and thus leads to intense pressure being placed on the unrestricted areas (Kgathi, *et al.*, 2003). Population figures for the main villages situated in the panhandle (Table 1.1) suggest that village community sizes in Seronga, Shakawe, Nxamasere and Sepopa are increasing (NRP, 2001). There is no clear explanation for this except that it can be assumed that persons from smaller villages are moving into larger ones to gain access to improved facilities and living conditions.

Table 1.1 Population figures for seven of the villages in the study area

Village	1981	1991	1995	2000	Trend
Sekondomboro	169	158	166	161	Stable/declining
Mogotho	400	216	227	220	Declining
Seronga	681	576	740	823	Increasing
Shakawe	1755	2198	2389	2664	Increasing
Samochima	454	533	559	543	Stable
Nxamasere	505	497	540	600	Increase
Sepopa	466	806	893	1019	Increase
Total	**4430**	**4984**	**5524**	**6030**	**Increase**

Kgathi *et. al.*, (2003) reveal in a case study of key resources, that basket-weaving resources, land for flood recession arable agriculture and river reeds are increasingly becoming scarce. This scarcity is due to changes in the flooding regime of the river and increased demand for the resources. These results were drawn from non-data intensive indicators, which generally make use of market trends, labour time and perceived scarcity. They continue by saying that the reason resources will tend to be over-utilized is because access is not restricted and there are no management principles in place. This has implications for the crocodile population as not only do they require some of the same resources, such as reeds for protection and fish as a food source, but an increase in demand means that more people are utilizing the floodplains for collection, adding to the disturbance factor. It is also common knowledge that crocodile nests are readily destroyed if found (Amose, pers. comm. 2004/5). The reason for this is due to the danger that crocodiles pose when collecting resources in the system.

A socio-ecological survey undertaken in 22 villages in the Okavango Delta indicated the perceived scarcity of natural resources (Figure 1.4).



Source: A. D. R. C. (2001)

Figure 1.4 Perceived scarcity of 10 natural resources pooled for 22 villages in the Okavango Delta (X-axis represents the type of natural resource and the Y-axis represents the grouped villages response per category)

The resources of concern to crocodiles are fish, soil, trees, building material (reeds) and papyrus. Apart from fish, every other resource material that is of direct concern to nesting crocodiles is seen as declining in the system. This emphasizes that not only are the resources at stake but that the crocodiles are also directly competing with humans for these specific resources, which means that more contact between the two species is inevitable. Increasing village populations intensifies this problem.

1.7 Methodology and data

The study was divided into three general steps which began with a thorough investigation of all existing literature on the relevant topics. The next step was to carry out a survey of all the nest sites and the relevant human disturbances affecting crocodile nesting. Finally, Geographic Information Systems (GIS) were used to establish crocodile habitat suitability and the spatial influence of human disturbance on it. These three steps are put together in the research design which accurately defines all the steps of the research process.

1.7.1 Literature survey

This study begins with the identification of a real world problem, which is the extent and effects of human disturbance on crocodile nesting habitat. Problems with breeding and recruitment of young into the system will have dire consequences for the entire population of crocodiles as the future breeding stock is put at risk. A literature survey gives an idea as to which factors need to be further studied in order to reach the objectives of the study. The factors identified for this study were the issues of habitat suitability, human disturbance on habitat, crocodile nesting habitat characteristics and finally the use of Multi-Criteria Evaluation for spatial analyses of the problem.

A habitat is a definable place in which an organism lives. The particular species concerned is reliant on its habitat for numerous aspects including food, shelter, water and protection. By defining a particular species' habitat we gain a better understanding as to how the animal lives and what it relies on from its immediate surroundings. Habitat destruction is common throughout the world and it is necessary for scientists to define different species' habitats if any protection is sought. Habitat suitability models have been used extensively on a variety of species (Gibson *et al.*, 2003; Ben-Wu & Smeins, 2000; Nevo & Garcia, 1995). The use of GIS in habitat suitability modeling has become more significant (Rubino & Hess, 2003; Yamada *et al*., 2003; Gurnell *et al*., 2001; Store & Kangas, 2001) as it provides a good spatial representation of the results and allows for more efficient land-use management.

Human disturbance on wildlife populations is an issue which will continue with ever increasing human populations and their expansion of living ranges. The effects of human disturbance on wildlife populations are varied and include negative physiological responses (Fowler, 1999), poor breeding success (Gill-Sanchez *et al.*, 2003) and loss of living habitat (Petram *et al*., 2003; Sergio, Pedrini & Morchesi, 2002). Disturbance on any species generally has a negative effect for the entire ecosystem but these negative effects are more pronounced when keystone species are involved as they are good indicators of the natural system's health (Amitrajeet, 2003; McClanahan, 1999; Leslie, 1997).

Nile crocodile nesting characteristics have been described for the species in general (Cott, 1961; Craig, Gibson & Hutton, 1992; Leslie, 1997; Ross, 1998) and more specifically for the Okavango (Blomberg, 1976; Graham, Simbotwe & Hutton, 1992; Leslie, 2003; Murray-Hudson, 1997; Simbotwe, 1988; Taylor, 1973). No crocodile research or monitoring has taken place in the area since 1992 and the literature is thus limited to this time period.

The use of a Multi-Criteria Evaluation procedure allows a number of criteria to be weighed up against each other. This means that not only can disturbances be spatially plotted but they can also hold weights according to their actual effect on crocodile nesting. The MCE makes use of factors, which enhance or detract from the potential for a given objective, and constraints, which remove areas for that objective. This process allows involved role players to give input into a particular allocation decision as they can be involved in the selection of criteria to be measured as well as setting of the particular weights. MCE is thus an efficient tool for land-use management where a range of criteria and role players influence allocation (Aras, Erdogmus & Koç, 2004; Breytenbach 2006; Ceballos-Silva & López-Blanco, 2003a; Ceballos-Silva & López-Blanco, 2003b; Dai, Lee & Zhang, 2001; Mapedza, Wright & Fawcett, 2003; Van der Merwe 1997; Van der Merwe & Lohrentz 2001; Van der Merwe & Steyl 2005).

1.7.2 The nesting survey methods and schedule

The nesting survey included patrolling the entire length of river and its major tributaries by boat and on foot. A database of nest locations (coordinates) has been created by the Okavango

Crocodile Research Project by combining independent nesting surveys carried out by the project staff and records of nesting sites recorded by local crocodile farmers. This database was used in the survey as well as investigations of all potential nesting sites identified during the survey. Monochrome aerial photographs of the panhandle, taken by the Botswana government in 2002, were provided by the Harry Oppenheimer Okavango Research Center (HOORC) of the University of Botswana. These images were digitally stored and georeferenced. Small channels could be located using the aerial photographs. The photographs were also used to digitize the main river channel and its major tributaries.

The survey included patrolling the banks of the river and looking for signs of crocodile nest sites, which include well-used “slides” created from the waters surface up on to the bank. These “slides” begin to appear on the banks of the river at the beginning of the nesting season. Other signs such as the occurrence of palm trees on elevated river banks are good signs of potential nesting sites. Once a nest was located, its position was recorded on a Global Positioning System (GPS) and the selected habitat factors were measured at each site. During the nesting survey disturbance activities were also noted and spatially recorded using GPS. These points were later entered into Geographic Information System database where points could be more accurately assessed by overlaying them onto aerial photographs of the study area.

The schedule for the nesting survey was as follows:-

- August 2004: Dividing the river into three sections and assigning dates to each section for carrying out of the nesting survey.
- September 2004-January 2005: Carrying out nesting survey in all three sections and recording disturbance activities.

1.7.3 Habitat suitability mapping

Habitat suitability can only be evaluated once habitat requirements for crocodiles are identified and this was done during the nesting survey. During this survey, specific site characteristics as decided by expert opinion and a literature review, were measured at each nest site in order to identify the specific habitat requirements of nesting crocodiles. These factors were then used to create a habitat suitability map based on the specific spatial habitat requirements of the species. The map identifies all areas within the study area, which meet the environmental variables required for crocodile nesting.

Disturbance factors were identified by means of available literature and consultation with experts. The various disturbances were surveyed during the nesting period. These disturbances were spatially captured by using a Magellan 320 Global Positioning System to plot the extent of these activities in the system. Multi-Criteria Evaluation was used to compare the disturbance factors against one another and to assign certain weights to each factor in line with their relative effect on nesting. The evaluation thus identifies the combined effect of all of the disturbances on crocodile nesting. By identifying the difference between the habitat suitability map and the disturbance map, all areas free of any disturbances can be identified for protection.

1.7.4 Research design

As shown in the flow diagram in Figure 1.5, the research starts with identification of the real world problem: threatened crocodile nesting habitat. A literature survey allows specific factors influencing crocodile nesting to be identified for further investigation. This study identified habitat suitability and anthropogenic disturbance as specific research factors. Each factor was measured and evaluated through field survey of which results were then used in mapping the specific factors. Each mapping process was suited to the factors being assessed i.e.: habitat suitability was mapped using a simple Boolean overlay of specific factors while disturbance mapping makes use of a Multi-Criteria Evaluation.

The Boolean overlay made use of a vegetation map to select the preferred vegetation communities used for nesting. The second map produced was a distance from water map, where the average distance from water that the crocodiles were nesting at was used to create a buffer around the river. The images were then overlayed to depict the habitat suitability for crocodile nesting.

The MCE made use of a six step process adapted from the "seven steps of an MCE" in Van der Merwe (1997). The first step was to define the objective of the MCE, and this was to show the spatial influence of multiple disturbance factors. Once the objective has been defined a panel of experts were brought together to decide which disturbance criteria to record and use for the evaluation. With the disturbance criteria identified it was possible to record the disturbance factors in the field and this could be done with the use of a GPS unit. Once the disturbance factors were recorded in the field they were transferred to GIS using ArcView 3.2 and the disturbance factors were represented as separate images. These images formed the factors to be considered in the MCE. Step three of the MCE process was to rasterize the images from vector shape files. This process is necessary for the MCE in the Idrisi GIS package and was carried out using its POLYRAS and LINERAS functions.

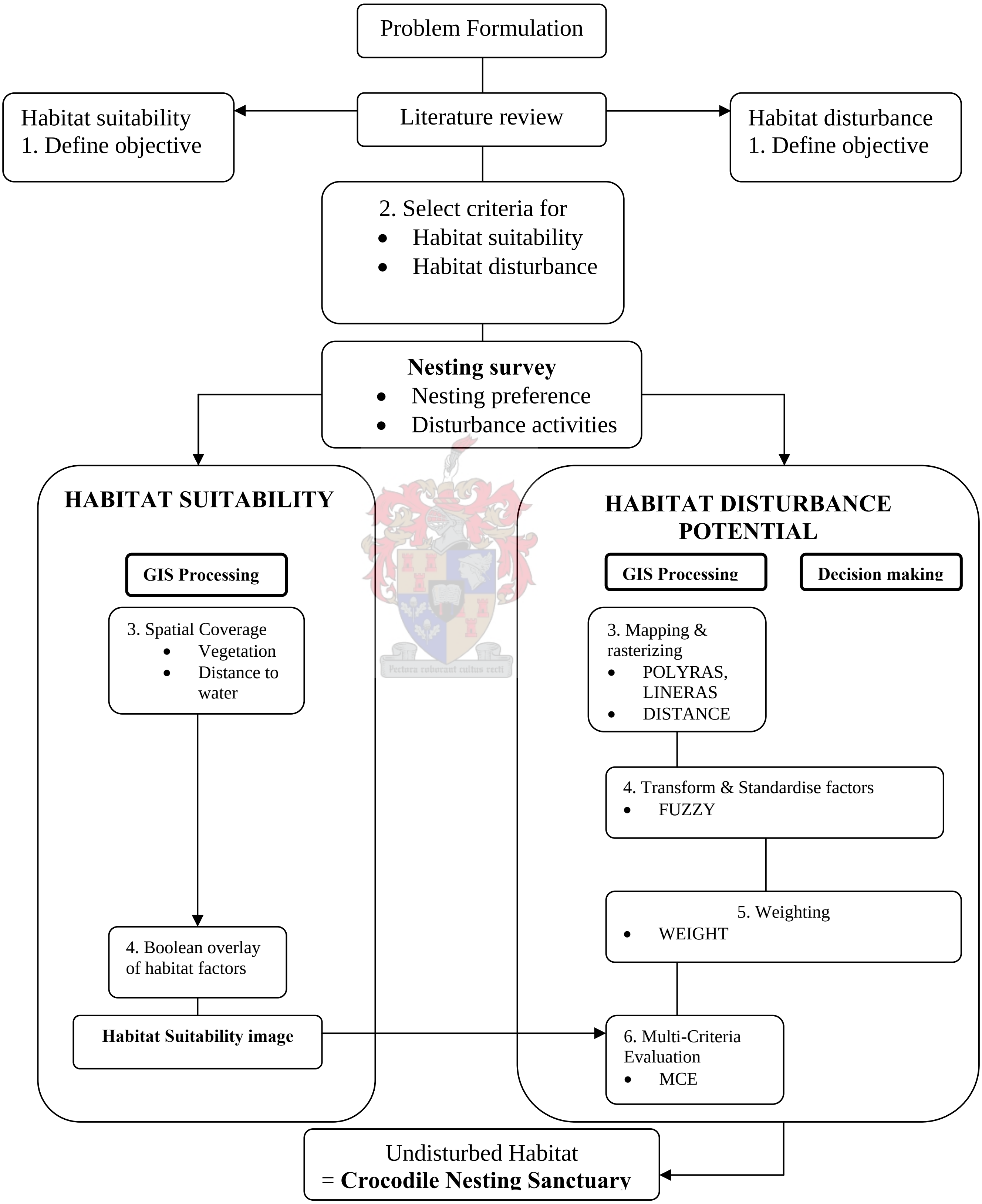


Figure 1.5 The research design

The DISTANCE module was then run on each of the disturbance images to use in setting the effect of disturbances later on in the process.

In step four all of the images are transformed and standardized in order to compare them against one another on a common scale. This is performed with the Fuzzy module in Idrisi which defines each image's disturbance effect even further by transforming the images using expert opinion. The module also allows image values to be standardized to a 0-255 (byte binary) range. This module allows the effect of disturbance to be displayed by specifically set distances and also indicates the distance decay of disturbance away from specified human activities.

Each disturbance factor has a unique effect on crocodile nesting and this effect can be accounted for in the MCE by assigning specified weights to each factor. Weight assignment was performed as step five in a process that allowed the participation of crocodile experts in deciding on specific weights. Once the weights were decided upon, the WEIGHT module in Idrisi could be used to assign each factor with its' respective weight. Step six could then be performed using the MCE module in Idrisi. This process generated the result of all the disturbances combined on crocodile nesting habitat by considering the spatial position and weight of each disturbance factor.

1.8 Report framework

The research report describes the findings in five chapters. The research aims are to assess habitat vulnerability by showing the difference in habitat suitability based on environmental factors and habitat suitability based on human disturbance factors. The two main concepts are thus habitat and human disturbances.

Chapter One introduces the problem statement, the study aims and research objectives. The study area is described in detail and spatially located. Chapter Two covers the habitat aspects of the study and describes the techniques used to gather data from the field and to process it using Geographic Information Systems. The field data combined with the GIS techniques is used to project habitat suitability based purely on the environmental requirements of female crocodiles.

Chapter Three covers the disturbance aspect of the study and describes how disturbances are selected and what the effect on crocodile nesting may be. The chapter describes the techniques used to gather the data from the field and process it for use in GIS. The chapter also describes the techniques used to create the preliminary maps to be used in the Multi-Criteria Evaluation.

Multi-Criteria Evaluation used to assess the disturbance on habitat is described in Chapter Four. The results from this process indicate the extent of disturbances on habitat. A comparison of the habitat suitability map, based on the environmental factors required for nesting, and the disturbance map will indicate habitat vulnerability by showing the extent of suitable nesting habitat that is being discarded because of human disturbances. Conservation proposals are explored in this chapter once the results have been described. Chapter Five provides a synthesis of the results and evaluates the findings of the research.

CHAPTER 2: CROCODILE NESTING HABITAT

The nesting survey began in late September when the water level of the river had started dropping significantly and crocodiles began looking for suitable nesting areas. Survey results were used to identify the habitat requirements of nesting crocodiles in the system. These results were then used, along with Geographic Information Systems, to identify all the areas of suitable nesting habitat for crocodiles in the system. The survey also allowed various nesting characteristics of the system to be explored and explained, in order to gain a better understanding as to how crocodiles have adapted to this environment.

2.1 Survey planning and methods

The river system of an area demarcated by the Botswana/Namibia (Mohembo) border, (GPS: 18° 15' 17"; 21° 46' 59") in the north to the area around the town of Seronga, (GPS: 18° 49' 43"; 22° 24' 22") in the south, was used as the study area for the nesting survey and has long been identified as the primary nesting area for crocodiles in the system (Graham *et al.*, 1992). The river was divided into three sections, which were each assigned their own dates for survey throughout the nesting season from September to January. During the survey all active nest sites for the 2004 nesting season were recorded as well as the sites from the 2003 nesting season. The reason for including the 2003 nest sites was to have a larger database from which to record sites and thus better understand nesting characteristics. The recording was limited to just these two nesting seasons as conditions recorded at these sites are still generally intact and represent the true conditions at nest sites. Nest sites from the 2002 nesting season have the risk of representing false conditions due to rapid changes in the landscape over the following years.

The process of egg deposition begins in early September and hatchlings emerge from mid January to late February. This means that nests and potential nesting sites could be located and characterized from September through February. Figure 2.1 shows the three river sections that were allocated and their relative survey dates.

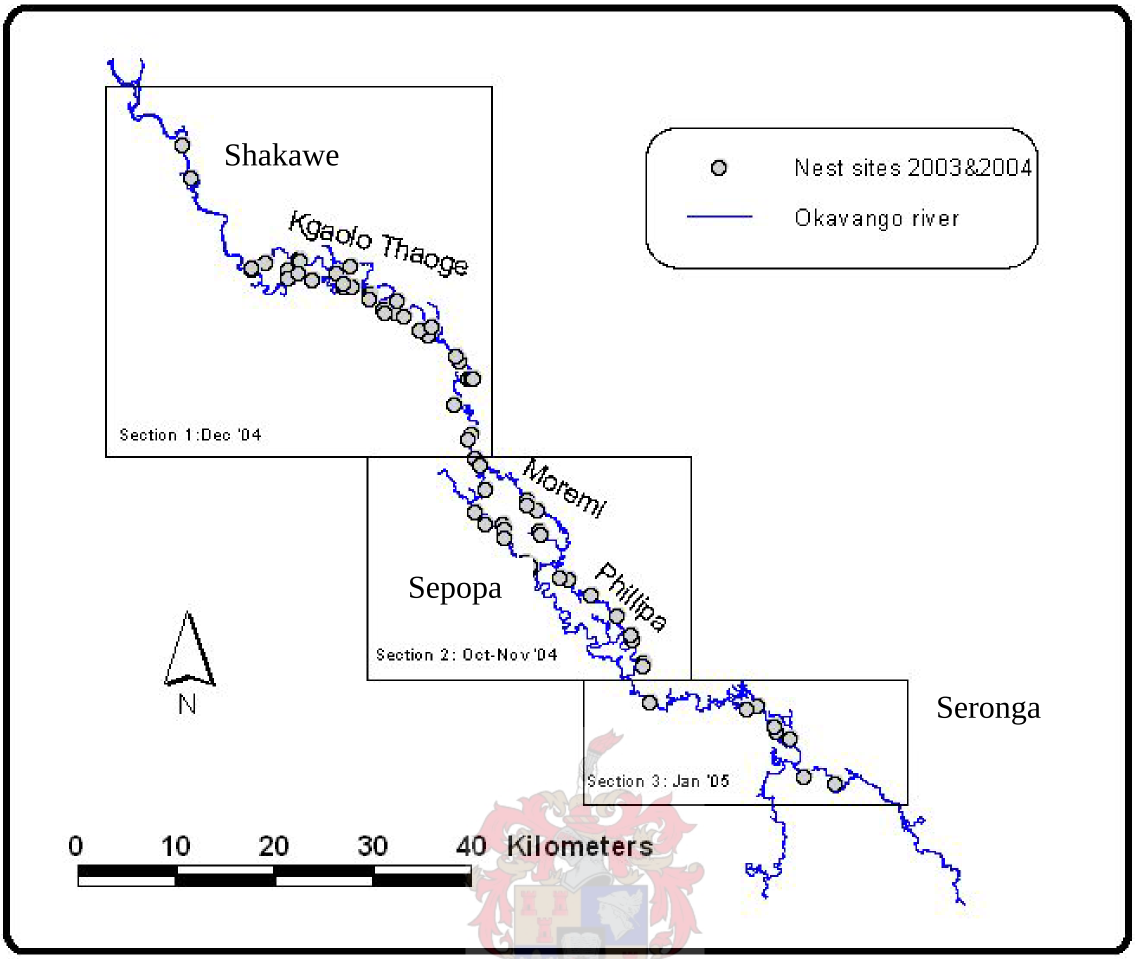


Figure 2.1 Location of the surveyed nest sites in the three survey sections within the Panhandle region of the Okavango Delta

Section 2, which is predominantly the Moremi/Phillipa channels, was surveyed first for logistical reasons only. The reason for this section taking up two months of surveying (October to November) is due to the high density of nests that were found in this area during the past three years of surveying. Section 1, which is the area from the Mohembo border in the north to the Moremi channel entrance further south, was surveyed during the month of December. This area includes the Kgaolo Thaoge channel. Figure 2.1 indicates the nest sites and potential nest sites, which were characterized during the nesting survey. The nest sites are generally well distributed along the entire length of the river, which means that the survey results would be a good indicator of the conditions found throughout the system.

No formal methodology exists for finding crocodile nest sites in the wild as nest site requirements are adapted to the specific species and its environment. A report by Hutton &

Games (1992) for the Cites Nile Crocodile Project describes populations of crocodiles in various countries throughout Africa and how these populations are able to nest successfully in different environments. These environments range from marshy swamps in Malawi, lakes in Kenya and Mozambique, to strong flowing rivers in Zambia. However, the basic nesting requirements for crocodiles are access to water, elevated land to avoid flooding of nests and suitable vegetation cover around the nesting area.

For the nesting survey along the Okavango River and its major side channels, a motorized boat was used to locate any visible crocodile "slides" from the bank. With time, crocodiles create narrow paths from the water to the nest site as they move between land and water to thermoregulate, and these "slides" are quite visible from the water (Figure 2.2).

Figure 2.2 A crocodile slide

The presence of trees also gives an indication that a nest may be present. Nests were also located by making use of the skills of a local resident who was previously employed by crocodile farms in the area to locate crocodile nests. This individual has 10 years experience in crocodile egg collection and knows the location of close to 300 potential sites used throughout his years of collecting. In recalling the routes used to reach each site, he proved invaluable in carrying out a thorough nesting survey.

As nesting females often return to the same area to nest, the guide was able to point out previously utilized nesting sites. An active site is characterized by body imprints left on the sandy surface of the site by the female crocodiles (Figure 2.3).

Figure 2.3 A belly imprint of a female crocodile

Once the imprints are located a thin metal rod is used to probe the ground and feel for the presence of eggs underneath the surface (Figure 2.4). The probing needs to be fairly firm to penetrate through the top layer of compacted soil, but once this layer is penetrated a more gentle action is required to feel the egg surface without cracking it. The feel of the rod touching the egg surface becomes easily recognized with experience and one can normally also hear a hollow sound when gently tapping the egg.

Figure 2.4 Nest site characteristics

Nests that were inaccessible by foot or motorized boat were reached by “mokoro”, which is a traditional canoe created from a hollowed out tree stump and is designed to negotiate narrow and shallow channels by “polling” through them (Figure 2.5)

Figure 2.5 Fishermen in traditional mokoro boats

All nests from the 2003 nesting season were visited and recorded along with any new active sites for 2004. Sites from the 2003 nesting season were often found to be active once again. This might mean that the female returned to the same site the following year or it could be a new female at the site. A female crocodile will move on and off her nest many times during the day, either due to disturbance or to regulate her body temperature. Crocodiles thermoregulate by moving in and out of the water throughout the day, or seeking shade under vegetation (Blake, 1993). The fate of each active nest was recorded, which required monitoring the nests until the chamber had been opened, either through hatching or predation. This meant that predictions of egg presence at a potential site could be verified in time.

Nesting crocodiles require a permanent source of water close to the nest site and these water sources are restricted during the nesting period, as this period coincides with low river levels. Aerial photographs (2002) taken during the low water season allowed most water sources to be identified and investigated, access permitted (Figure 2.6).

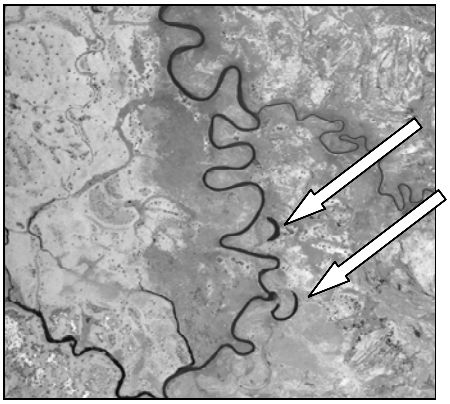


Figure 2.6 Isolated water bodies on aerial photography

Small channels located deep in the floodplains were reached by firstly, getting the boat as close to the area as possible and then covering the rest of the area on foot. Walking in the floodplains is possible by walking along elevated ridges (islands) until close to the site. Papyrus stands are rooted to one another below the water surface by an intense rhizome root system. This means that papyrus is usually associated with deep water but these thick stands of vegetation can be crossed on foot by folding the thick stalks down onto each other and creating a floating path. This technique was often used to reach sites or investigate certain areas located on the aerial photographs.

2.2 Selecting nesting criteria

Decision making through the use of GIS systems requires the input of the various experts, role players and stake holders in the field (Ceballos-Silva & Lopez-Blanco, 2003a; Ceballos-Silva & Lopez-Blanco, 2003b; Dai *et al*, 2001; Store & Kangas, 2001; Van der Merwe, 1997). The opinions of experts ensure that the correct criteria are being selected and tested and that the final decision making process is based on the input of people concerned with the issue. In deciding what factors to record at each nest site during the nesting survey, the relevant literature and species experts were consulted. Work from Graham *et al* (1992) on the Okavango crocodile population identified the variable factors for selection of suitable crocodile nesting sites. They found a close association of nests with deepwater channels. The mean height above water was 1.32m and *Phragmites* reeds, grasses and sedges were said to be the common form of vegetation surrounding the site. They also found that 40% of the sites had shrubs or trees present.

Consultation also took place with team members of the Okavango Crocodile Research Project. This team is comprised of Dr Alison Leslie, Sven Bourquin (PhD student), Kevin Wallace and Audrey Detouf-Boulade (both MSc students). The team, which has carried out nesting surveys in the Okavango system for the past three years, has recorded the characteristics of crocodile nest sites. The group was collectively interviewed to establish the factors that required surveying at nest sites in order to understand what environmental variables crocodiles consider when choosing a nest site. During this process, it is important to remember that only those aspects of crocodile nesting that can be mapped, i.e., spatial aspects, can be used in the analyses. The study is thus reliant on the availability of specific spatial data for each of the selected nesting characteristics.

After much discussion, the resulting factors to be recorded at each active and potential nest site were determined. These factors were: (i) distance from the edge of the water, (ii) vegetation cover along the river and (iii) vegetation cover around the nest. Despite previous investigations into soil type (Blomberg, 1976) this factor was not seen as a clear and specific determinant of preference. From soil type observations in the field, it was noted that soil type varied, which indicated that perhaps nesting crocodiles are able to use a variety of soil types, as long as it is dry. Nevertheless, mapping the soil moisture of the system is recommended for future suitability analyses.

2.3 Recording crocodile nesting preferences

Crocodile nesting preference in the delta is well understood and can be spatially analysed once the exact preferences are spatially recorded using GPS. The data is then transferred to a GIS for further analyses. By using the database of previous nesting sites in the study area it is possible to visit the sites again, as well as new sites, in order to measure these specific parameters.

2.3.1 Distance to water

Distance from water was measured as the distance from the nest chamber to the closest flowing stream used by the crocodile. Each nest position was recorded in the field using GPS. The points were then plotted onto the digitally stored georeferenced monochrome aerial photos. The distance from water measurement was made in meters with the use of the distance measurement tool in ArcView 3.2. This tool allows one to calculate the exact distance between the water and the nest chamber in meters. The tool was used because direct measurement in the field is often not possible as floating vegetation could not always be crossed on foot. Crocodiles often make use of small access channels, which lead to stronger flowing streams. Past studies (Leslie 1997; Graham *et al*., 1992) have used the distance from the egg chamber to the smaller access channels as the distance from water factor. This study, however, made use of the distance to the predominant stream that the smaller access channels lead too and not the closer access channels themselves.

The measurement was altered for this study as the small access channels are too small to be viewed by aerial photography and are primarily covered with over-arching vegetation (Figure 2.2), making aerial identification impossible. The more predominant streams were easier to identify from the spatial data and these streams were thus considered for this analysis. It must be emphasized that the recording of factors at nest sites was carried out in order to map habitat suitability, which is an objective of this study. The factors are not being recorded solely to describe the nesting characteristics of crocodiles in the Okavango, but this is merely a secondary use of the data collected. A distinction needs to be made between nests and nest sites. Nests are seen as the number of individual chambers for each year and nest sites are the greater areas around the chamber used by the females. Nest sites may thus be re-used over a number of years. The distance from water factor was thus calculated for each of the nest *sites* and used in the spatial analysis. The results of the distance from water measurements are summarized in Table 2.1. The distance from water for each of the nest sites from the 2003 and 2004 season were measured.

Table 2.1 Results of the distance from water factor calculation

Number of nest sites	81
Maximum Distance	919m
Average Distance	137m
Distance Factor	1000m

The total nest counts for 2003 and 2004 were 55 and 50 respectively, giving a total of 105 nests (chambers) for both years. Of these 105 nests however, 24 of the sites were commonly used in both 2003 and 2004. This means that 105 nests were found in a total of 81 sites over the nesting years of 2003 and 2004. The furthest nest measured from the water was 919m. This furthest distance of 919m was then rounded off to 1000m to represent the distance from water factor, which is the distance within which all nests would probably be found.

2.3.2 Vegetation characteristics

Vegetation cover along the river was an analysis of the vegetation type which screened the nest site directly from the water only and which grows parallel to the stream (Figure 2.7). Vegetation cover around the nest was analyzed as the vegetation which occurred around the nest site (Figure 2.7). The vegetation cover surrounds the nest site and does not cover the actual nest chamber as that needs to be exposed to the sun for egg incubation. Vegetation characteristics were recorded in order to be able to select the preferred vegetation types from a general vegetation map of the river area. The vegetation character along the banks of the river, are fairly uniform and are not composed of a large diversity of plants. In recording the vegetation character of the nesting area, the dominant vegetation type was selected to represent the vegetation class. The reason for dividing vegetation measurements into two distinct classes is because the vegetation adjacent to the water's edge (river cover) is usually either *Papyrus* or *Phragmites* reeds, no other major vegetation type is apparent on the banks. Behind

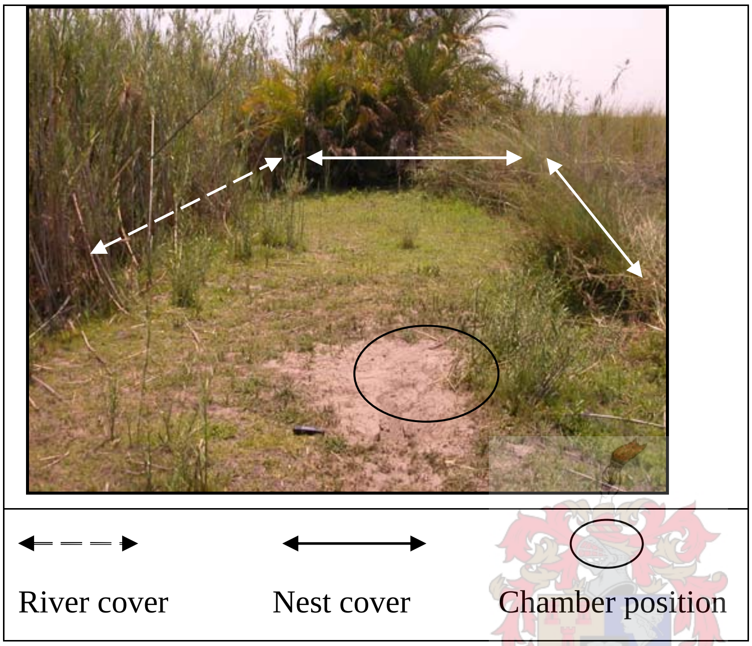


Figure 2.7 Nesting site characteristics

this primary belt of "reeds" the vegetation character varies substantially and was thus measured separately as "nest cover". Nest cover, which is all the vegetation surrounding the nesting area, apart from that screening it from the river, was made up predominantly of *Phragmites* (47%) and a *Phragmites*/Tree combination (12%) as indicated in Figure 2.8.

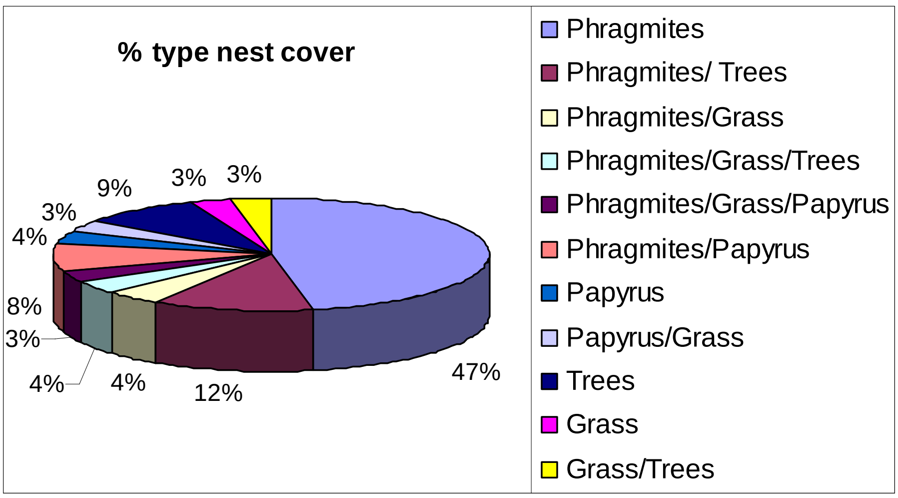


Figure 2.8 Nest cover vegetation preference

Combined, these two vegetation structures make up 59% of the total vegetation type recorded. The remaining 41% of nest cover consisted of vegetation types such as trees, *Papyrus*/*Phragmites* combination and grass.

River cover, which is the vegetation screening the nest area directly from the river, was made up predominantly of *Phragmites* reeds (64%) and a *Phragmites/Papyrus* combination (19%) as indicated in Figure 2.9.

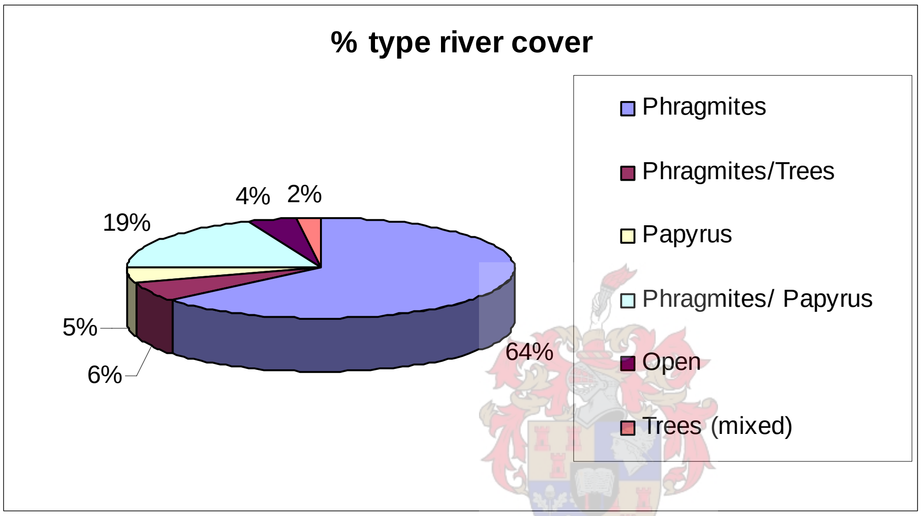


Figure 2.9 River cover vegetation preference

These two factors representing vegetation cover around the nesting site, thus show a clear preference to *Phragmites* reeds, and a *Phragmites/Papyrus* combination to a lesser extent. Together these two classes contributed to 83% of the total recorded vegetation.

2.4 Nesting patterns over time: 2002, 2003, 2004

The 2004/2005 nesting season showed results of nesting locations along the river which are very similar to those of the previous two seasons. New potential sites were explored as well as previous nesting sites. Nests were often found in the same general vicinity as the previous years, but very rarely actually in the exact same location. Assuming that crocodiles breed on an annual basis, this might indicate that the female returns to the vicinity of previous nesting years (nest site fidelity) and then explores conditions in the immediate area for locating her new nest site. This behaviour was confirmed by the presence of “test” holes being dug in the vicinity of most nest sites. The active nest locations for the 2004 breeding season indicate a tendency to nest away from the main stream (Figure 2.10) and rather along the major tributaries which are generally less accessible to people. The nest locations show a few changes over the three year period, but are generally quite consistent.

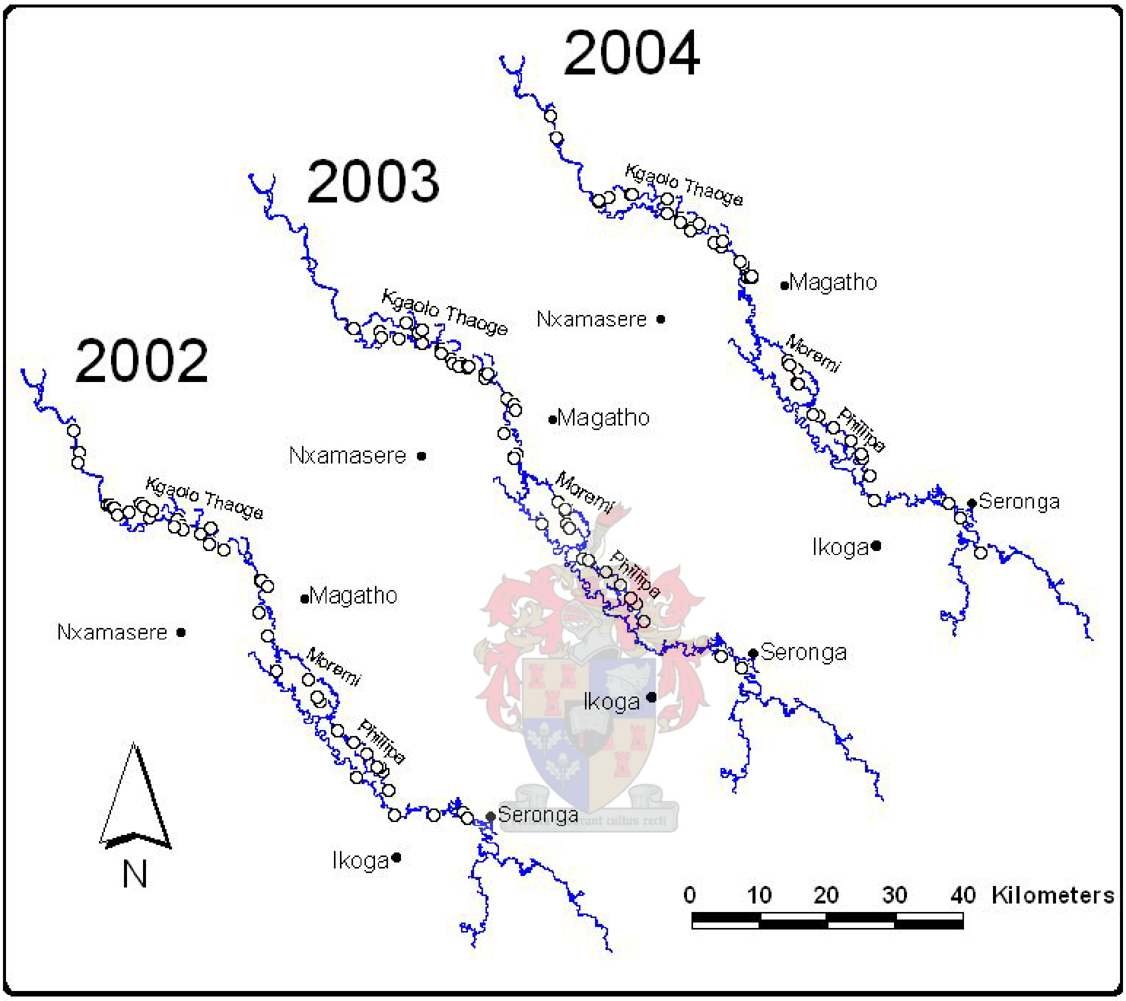


Figure 2.10 Nesting positions in the 2002, 2003 and 2004 nesting seasons in the Panhandle region of the Okavango Delta, Botswana.

Nest sites have generally moved away from the main stream and into the major tributaries running parallel to the main stream, the Khgala Taoge channel in the north and the Moremi/Phillipa channel in the south of the study site. No other major tributaries occur in the panhandle and these above mentioned channels are strong flowing with only minor blockages occurring throughout the year. This means that the channels are always available for nesting and allow female crocodiles to establish themselves in this area and to return periodically.

Figure 2.10 shows the establishment of a distinct gap, over the three years, in the center of the panhandle in the Nxamasere area. The density of nests in this area is very low with a total absence of nests in 2004. A very large gap exists between the river sections from the Magatho area all the way south to the Ikoga area along the main stream, where the presence of a single nest breaks the pattern (2003 season). Taylor (1973) first showed this gap in crocodile density in a report for the Botswana Game Industries during the hunting years of the 1970's. Graham *et al*. (1992) showed a corresponding low density of nest sites along this stretch of river. They were however, unable to explain either the nest or crocodile density gradients down the axis of the floodplain and delta. The area further south from the mentioned single nest to the Seronga area shows a low nest density, which is generally maintained throughout the three year study period. Nest numbers have not varied much over the three years with 51 nests being located in 2002, 55 in 2003 and 50 in 2004.

As the results of the nest location surveys are reliant on the practice of nesting surveys, any inconsistencies in the data could be attributed to human error in locating sites and maintaining consistent survey techniques. The data for all three years were collected by staff of the Okavango Crocodile Research Project using the same techniques and data bases for all three years. The data from 2004 was also as thorough as possible as the results in nest number and locations were compared to those of a local crocodile farm in the area, which also performed its own nesting survey for this year. The team is confident that a high level of accuracy had been maintained throughout.

2.5 Mapping habitat suitability

The images required for determining habitat suitability were created using the field data collected during the nesting survey. The images were overlayed using simple Boolean logic which used the two factors, distance from water and vegetation preference, to identify common overlapping areas. These overlapping areas would represent the habitat suitable for crocodile nesting.

2.5.1 Processing methodology

With the nesting survey complete and the criteria recorded, the nesting characteristics could then be mapped. Base maps required were river course and vegetation distribution map. These two maps would allow creation of the distance from water and vegetation factor maps to be used for determining habitat suitability. The first step in processing the images is to obtain the base maps required to carry out the production of preliminary maps for the analyses. The monochrome aerial photographs of the panhandle were used to create a river map of the Okavango River and its major channels. The river was digitized as a line theme in ArcView 3.2. Both banks of the river were digitized, as opposed to one single line, in order to keep the distance from water measurement as accurate as possible. All major channels that could be seen in the image were included to provide an accurate representation of the river system. Only the lagoons directly associated with a flowing channel were included, since crocodile nests in the Okavango are associated with deep, active channels (Graham *et al.*, 1992).

A vegetation map of the panhandle region was provided by the Harry Oppenheimer Okavango Research Centre (University of Botswana). This particular image included the whole Okavango Delta area. The map was divided into 46 different vegetation classes from which 20 were selected to represent the vegetation classes found in the panhandle area. The 20 class image was then transferred to Idrisi GIS software for further analysis (Eastman, 2001a).

2.5.2 Preliminary maps for habitat suitability

Habitat suitability is determined by using the Boolean approach in GIS. During this process two layers are selected to represent the factors necessary to display suitable crocodile habitat. These factors only represent suitable habitat in the areas where they overlap with one another, the factor on its own is not sufficient to represent suitable habitat. The Boolean approach thus divides each image into values of zero and ones. The areas representing the two specific factors i.e. preferred vegetation and distance from water, are given a value of one while all remaining areas on the images are given a value of zero.

The Boolean overlay for habitat suitability made use of the logical AND operation in Idrisi. This operation commands a multiplication of the first and second image where corresponding pixels from the two images are multiplied. The result is an image represented by zero and one values, where one represents the common area where suitable criteria (one values) met and zero represents areas where either two zero values met or a one value met a zero value. The result thus represents only those areas where both preferred vegetation and distance from water factors overlap.

The data collected from the nesting surveys on vegetation cover (nest cover and river cover) was used to identify the predominant vegetation cover for nesting. Unfortunately the vegetation classes were usually ordered in groups as opposed to specific species classes, which meant that *Phragmites* reeds, as the most preferred vegetation type for nesting, could not be mapped on its own. Two vegetation classes from the vegetation map were selected as best describing the preferred vegetation type. Firstly, tall channel fringing emergents and mats of reeds and sedges and secondly, permanent back-swamp areas with reeds and sedges. These vegetation classes were then isolated from the vegetation map using the RECLASS function in Idrisi GIS software. The result is an image displaying only those vegetation classes that were selected (Figure 2.11).

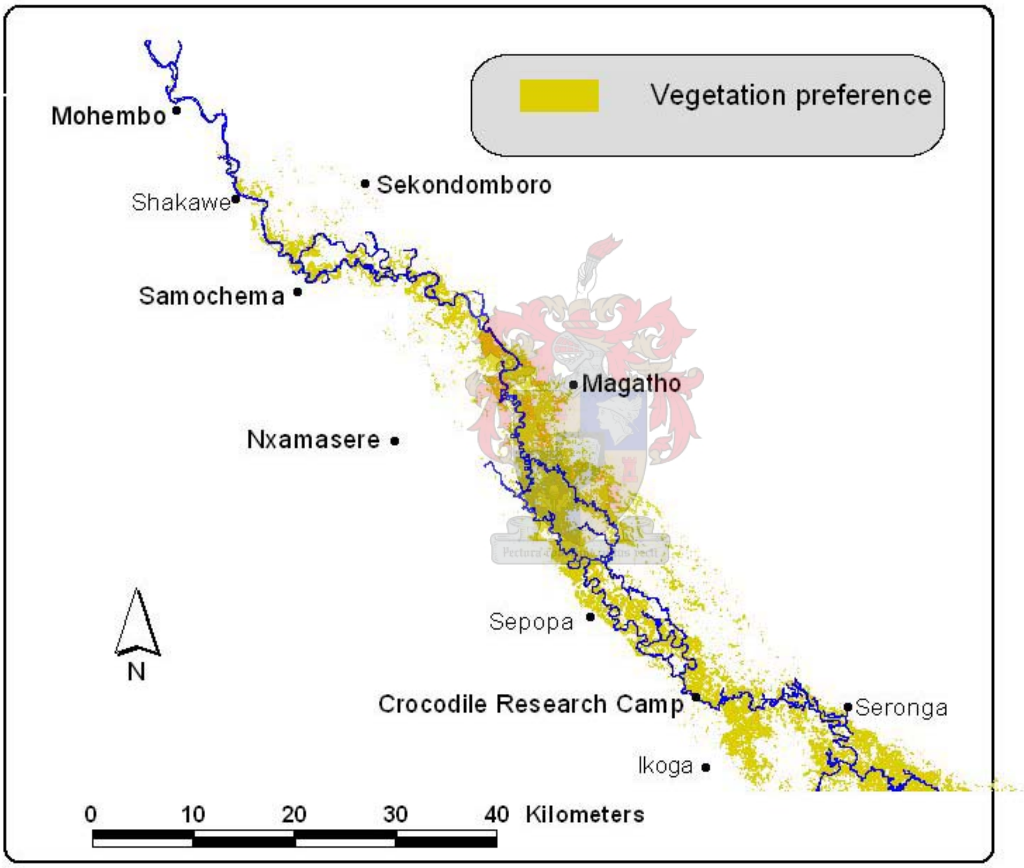


Figure 2.11 Vegetation preference factor for habitat suitability

The second factor map to be used in the evaluation was the distance from water factor. The BUFFER module in Idrisi was used to calculate the buffer zone of the river course map. The distance of the buffer was set at 1000m as calculated from the nesting survey results. The result was an image of the river with a 1000m “buffer” around it representing the distance from water factor (Figure 2.12).

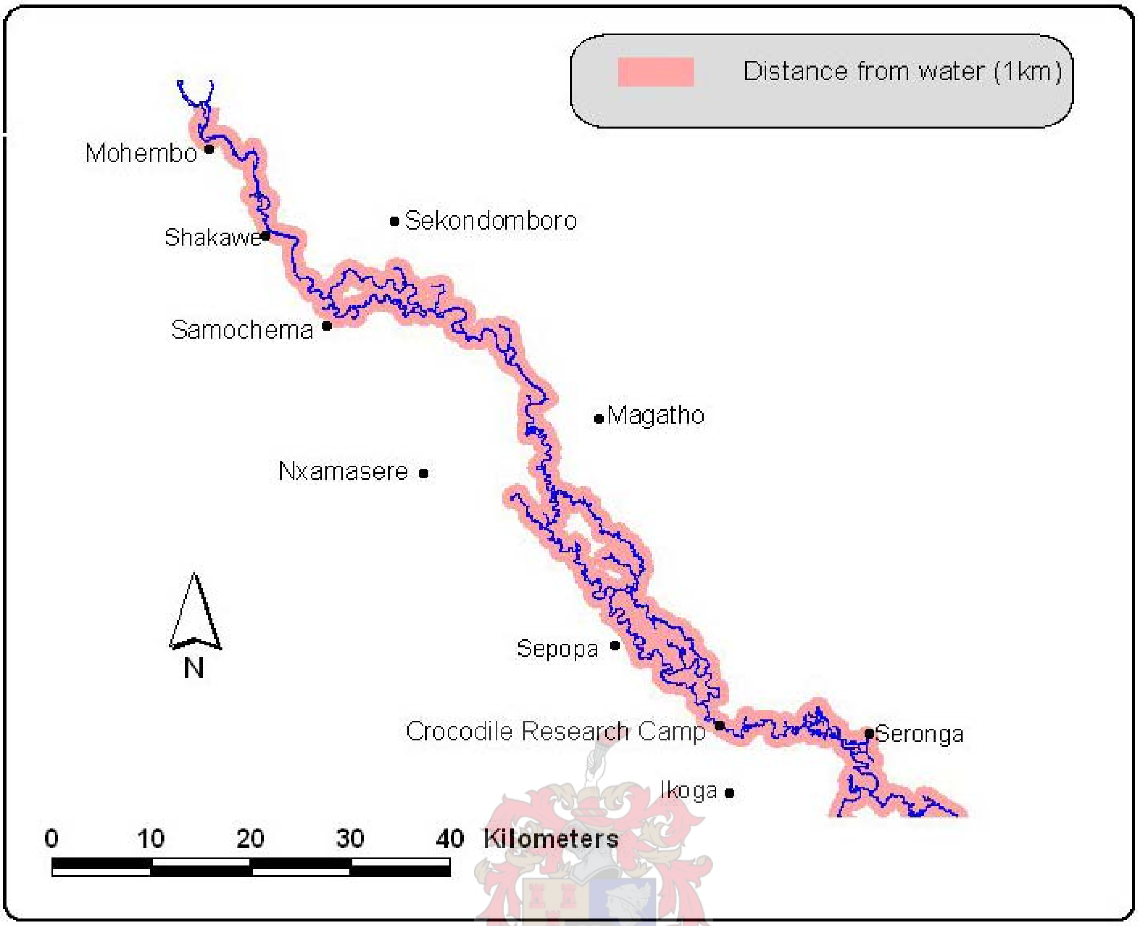


Figure 2.12 The distance from water factor for habitat suitability

Boolean overlay requires "hard' decisions to be made about suitability, which means that suitability criteria need to be strictly defined (Eastman, 2001a). The possibility of an area being partially suitable is ruled out as the boundaries of suitability are "crisp" ensuring that the image is strictly defined into suitable (1 values) and not suitable (0 values).

2.6 Habitat suitability patterns

The habitat suitability map indicates the largest possible area suitable for crocodile nesting. This habitat is suitable for nesting, but not necessarily available for nesting. The availability of suitable habitat is evaluated during the Multi-Criteria Analyses of human disturbances. The habitat suitability map (Figure 2.13) allows the area of concern, which is suitable crocodile habitat, to be delineated. This map thus becomes the base from which human disturbances will be evaluated.

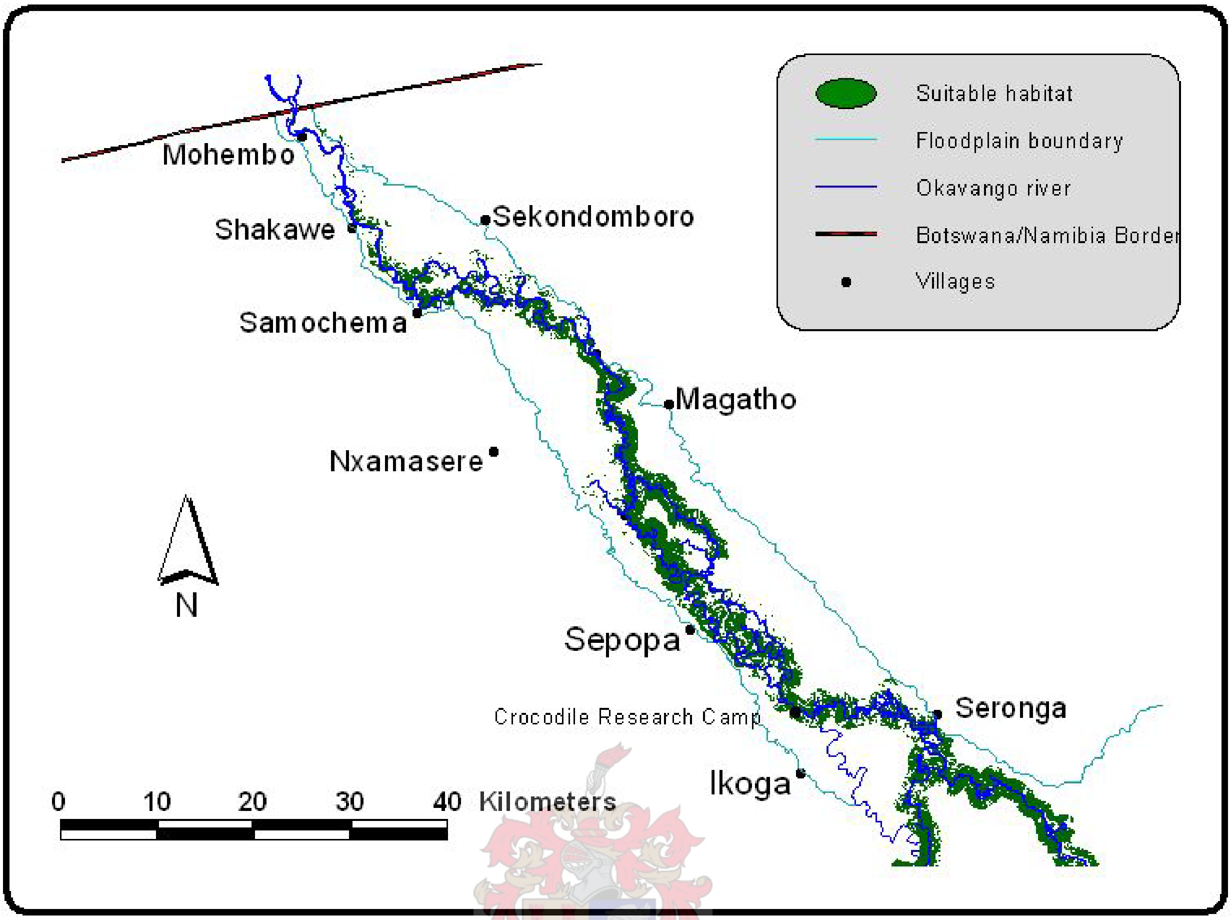


Figure 2.13 Crocodile habitat suitability

Figure 2.13 indicates that a substantial portion of the panhandle is suitable for crocodile nesting. Of the 482 km² of perennial swamp in the Panhandle, 329km² is displayed as suitable nesting habitat. The suitable areas thus account for 68% of the total study area of the Panhandle. The habitat is minimal in the northern reaches around the Mohembo region as this area is characterized predominantly by dry bushveld along the river banks with only light patches of *Phragmites* and *Papyrus.* The vegetation in this area is thus less suitable for crocodile nesting. As one moves further downstream it becomes apparent that the Kgala Thaogo channel (Figure 2.14), which runs parallel to the mainstream and had a fairly high density of nests, actually only has a few patches of suitable habitat which are scattered along the banks of the channel.

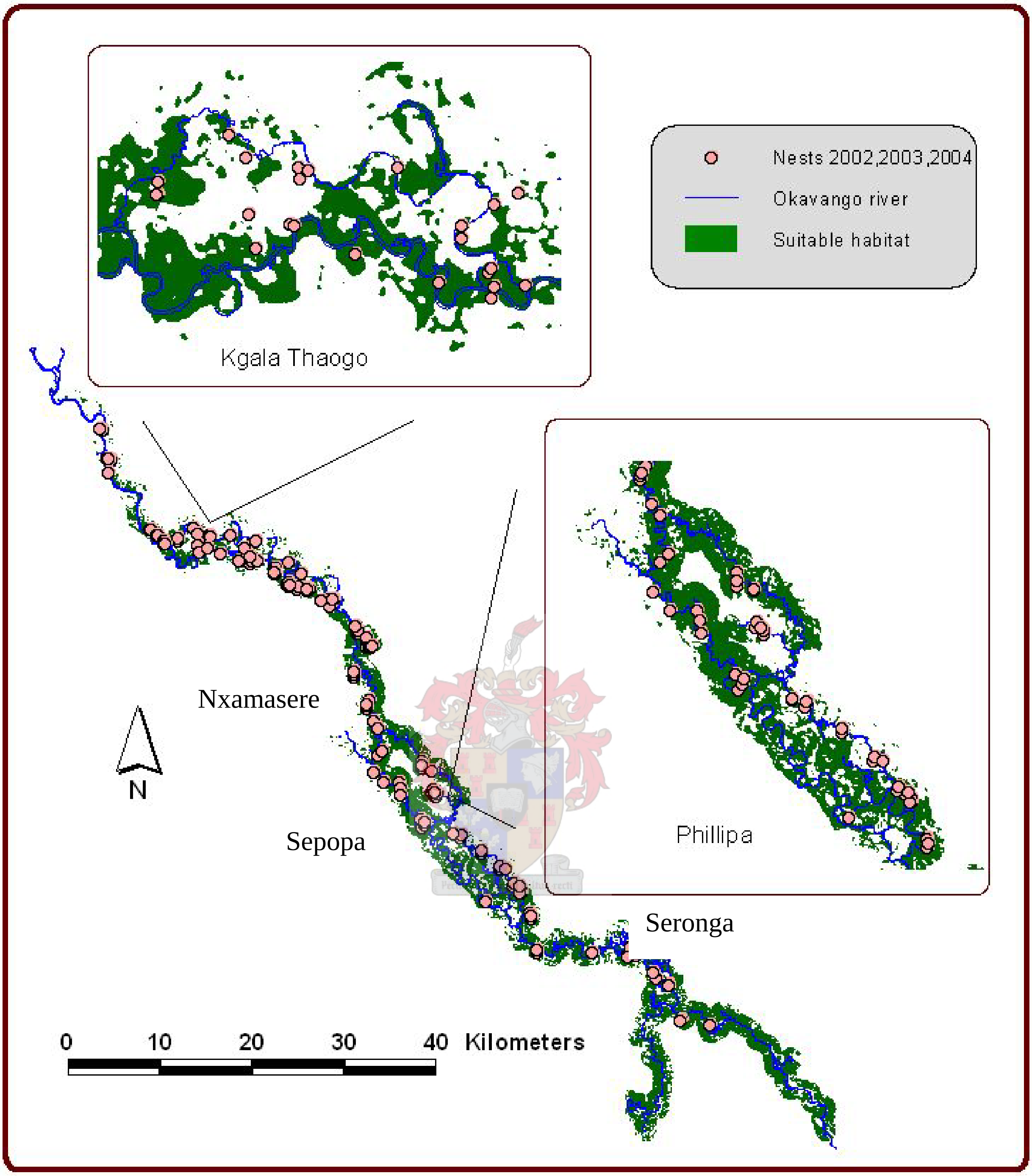


Figure 2.14 Nest locations along the Okavango and its major side channels

Moving downstream the main channel has a high density of suitable habitat, even though the middle section has a very low nesting density. This low density cannot be explained but has been apparent in the system for a number of survey years (Graham *et al*, 1992). The entrance to the next major side channel, the Moremi channel, has a high density of suitable habitat once again, but this density decreases as the channel moves into the upper and lower Phillipa sections shown in Figure 2.14.

The habitat suitability map shows that crocodile nesting habitat is plentiful in the panhandle. This fact is supported by the location of nests from the northern reaches of the study area down to the far southern reaches. The environmental factors for crocodiles nesting are thus in good order along the panhandle, but the availability of the habitat can only be evaluated once human disturbances are factored in. Human disturbance in and around suitable habitat, changes the status of the habitat into disturbed habitat and thus unavailable habitat. The habitat suitability map created in this chapter will thus be used in the Multi-Criteria Evaluation for human disturbance potential.

2.7 Map verification

The habitat suitability map indicates the area of interest for the study in that it delineates the suitable habitat and narrows down the area in which to evaluate human disturbances. It is thus necessary to verify the results of the habitat map with results from the field. Coordinates of crocodile nesting sites were recorded during the nesting survey using a GPS handheld unit. This spatial data was also recorded for the previous two nesting seasons. These recordings are thus true reflections of patterns collected from the field. The nesting points for all three years were combined in one layer and overlaid with the Boolean habitat map (Figure 2.14). This combination indicates if the areas determined as suitable for crocodile nesting correspond to the areas actually chosen by crocodiles for nesting.

As indicated in Table 2.2, for the nesting seasons of 2002, 2003 and 2004 a total of 156 nest sites were recorded. Each site was closely examined to see whether it fell within the area selected as

Table 2.2 Nest numbers and positions from previous nesting seasons used for habitat suitability map verification.

Season	**Nests**	**Nests located in habitat area**	**Percentage nests located in habitat area**
2002	51	41	80%
2003	55	52	95%
2004	50	44	88%
Total	**156**	**137**	**88%**

suitable habitat by the Boolean intersection earlier in this study. A total of 137 fell within the selected suitable habitat, which means that 88% of the nest sites found over the last three nesting seasons were found within the suitable nesting habitat created from the Boolean evaluation. This high correspondence rate indicates that the area described as suitable nesting habitat is sufficiently accurate when compared to real conditions in the field.

Having established the extent and occurrence of suitable habitat for crocodile nesting, the remaining determining factor for regional protection demarcation, namely the occurrence of major human disturbance factors, could be targeted next.

CHAPTER 3: HUMAN DISTURBANCE

The Panhandle of the Okavango Delta is not a protected area. The Panhandle falls under the arable/pastoral/residential landuse zone. The human activities have a significant impact on the wildlife and resources of the panhandle (Cassidy, 2003; Kgathi *et al*., 2003; Mbaiwa 2002; NRP, 2001). The disturbances on crocodile breeding are divided into three distinct groups. Firstly resource utilization, which was broken up into vegetation harvesting and cattle grazing. Secondly, fire occurrence, which occurs every year in the Okavango Delta and lastly, boat traffic which occurs along the entire length of the river throughout the year. All of the disturbances are human related and it is thus necessary to begin an evaluation of human disturbance by focusing on settlement areas and the nature of disturbances originating from these areas.

3.1 Human settlements as the focus for disturbances

In identifying disturbance areas around a natural resource area one would obviously have to begin at human inhabited areas. Many villages rely on the resources of the Okavango River and its floodplains. The first step in locating the disturbance zones was to identify all major villages that surround the study area and utilize its resources. The villages that were identified as influential in resource utilization of the system were, as shown in Figure 1.2, in sequence from the north: Shakawe, Sekondomboro, Samochema, Nxamasere, Magatho, Sepopa, Ikoga and Seronga. These villages were selected as they were seen as being directly associated with the floodplain and thus reliant on its resources. Discussion with local villagers in the field allowed the specific villages to be identified as major role players in human activities in the Panhandle. The villages themselves are not located within the floodplain itself but on the higher ground along the edge of the floodplain. The villages serve as nodes from which the various disturbance activities originate and because none of them are located directly in the wetlands, they themselves are not influential disturbance factors.

Informal interviews by Cassidy (2003) indicated that locals view crocodiles as a serious threat during resource collection and also as a seriously destructive menace to fisherman as they tear holes in fishing nets and eat fish from the nets. According to Cassidy, locals delay their entrance into the floodplain during the dropping of the water levels due to the risk of crocodile attacks. Crocodiles are thus viewed as a serious threat which leads locals to destroy any nests they come across while collecting resources in the floodplains. Discussions with our guide during the nesting survey revealed that crocodile nests were abundant during the 1990s between Mohembo and Shakawe. Due to the destruction of nests by humans, nests are currently absent from the area. Even when nests are not deliberately destroyed during collection activities, the associated noise and human activity in the immediate surroundings cause significant stress for female crocodiles, who might abandon nests as a consequence.

Cassidy (2003) identified four villages (Sekondomboro, Samochema, Magatho and Nxamasere) which were reliant on the resources of the system and utilized them accordingly. She was able to plot the spatial range of utilization for each of the villages, including activities such as resource collection (including reed harvesting) and cattle grazing. The spatial data for these four villages was used for this evaluation of disturbance. The data for the remaining villages (Shakawe, Sepopa, Ikoga and Seronga) were collected as part of this research.

3.2 Vegetation harvesting

Reed harvesting and plant collection areas were located by surveying the banks of the river by boat and on foot. All areas where resource collection was seen to occur were marked with the GPS as well as all reed loading points on the river banks. Informal interviews with locals from each area were also used to locate these areas. The GPS points of the resource collection areas and reed loading points, as well as the informal interviews, were combined to plot the maximum extent of the collection area and digitized over the digitally stored aerial photographs using ArcView. This analysis resulted in a preliminary map of the range within which people collected resources in the form of polygon shape files. The vegetation harvesting areas corresponded with the cattle grazing areas as both areas need to be within close proximity to villages. For this reason the vegetation harvesting and cattle grazing factors were combined and represented as utilization zones.

3.3 Cattle grazing

Grazing is viewed as a disturbance to nesting crocodiles. Cattle owners in the peripheral parts of the Delta graze their cattle in the sandveld of the Kalahari during the wet season and move the cattle into the floodplains during the dry season (Murray-Hudson & Parry, 1997). Large herds move together throughout a certain range of land to graze. Customary law in Botswana allows all tribesmen in communal areas open access to grazing and natural surface water for stock (Bendson, 2002). Cattle numbers have not been very high in the panhandle since the government slaughter of all cattle in 1996/7 to counter an outbreak of bovine pleuro-pneumonia (CBPP). During this slaughter an estimated 307 000 head of cattle were destroyed (Murray-Hudson & Parry, 1997). These numbers have, however, started increasing once again, but at a very slow rate.

Grazing becomes an issue for nesting crocodiles when performed close to potential crocodile nesting sites. Nests are often trampled by cattle, either causing complete destruction of the eggs or forcing the female to abandon her nest. Cattle that move into nesting areas also run the risk of being attacked by crocodiles which would thus cause direct persecution of the crocodile by the herder or lead to destruction of the nest in retaliation.

Firstly, the cattle grazing areas were located by surveying the river banks north and south of each village by boat and on foot and plotting the grazing areas by GPS. These areas were identified by the presence of cattle and grazed land. The grazed areas along the river are easy to identify as they are characterized by short grasses (maintained by burning) and cattle paths. The grazed areas are distinct as they normally occur between the common wetland vegetation of reeds and sedges. Figure 3.1 shows

Figure 3.1 Grazed grasslands along the Okavango river

open grazed areas that were located along the river. These images indicate how the landscape is changed from wetland vegetation to grassland due to the practice of grazing.

The areas were visited a number of times over an eight month period which provided enough time for cattle to actually be seen at all sites plotted. The grazing areas, as marked with GPS, were marked more accurately once the GPS points were plotted onto the aerial photographs and the actual extent of the open grazed grassland could be digitized as polygon shape files in ArcView. These vector images were then combined with the vegetation harvesting spatial data to represent the utilization zones depicted in Figure 3.2.

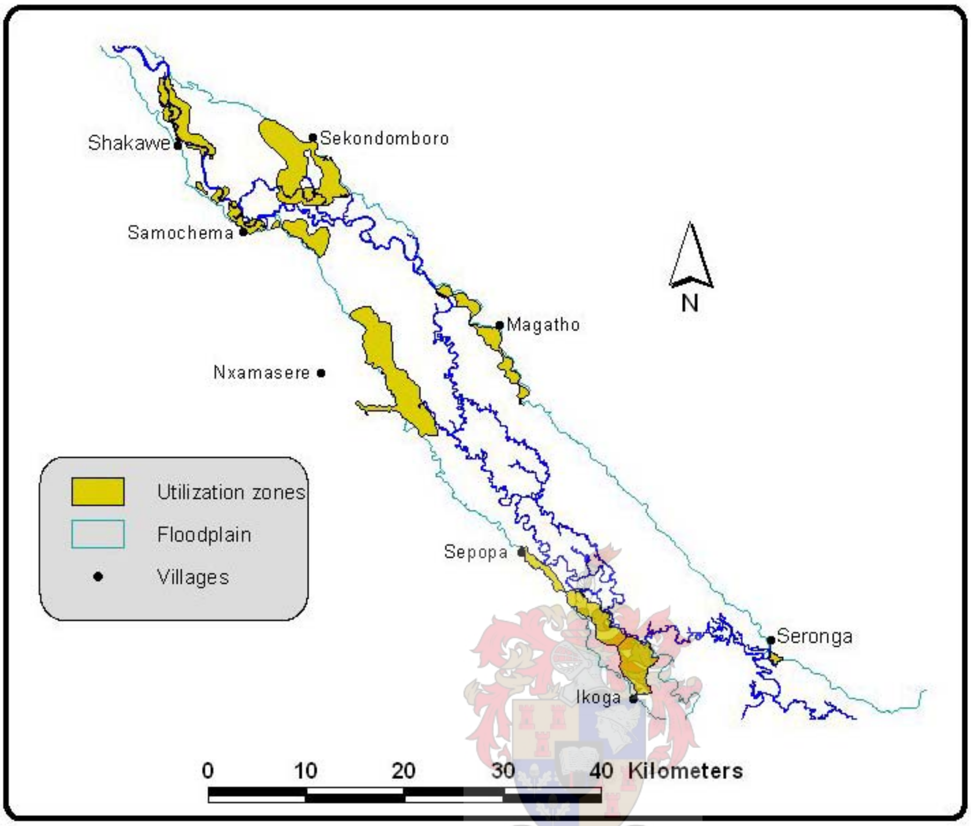


Figure 3.2 Utilization zones

The utilization zones clearly show the association of a village with each zone indicating how the villages are used as starting points for resource utilization. The zones all fall within the floodplain boundary as the desired vegetation for resource collection and grazing fall within this boundary.

3.4 Fire occurrence

Fire provides very intense disturbance to natural habitats. Fires have historically been used by rural people throughout sub-Saharan Africa since time immemorial (Bucini & Lambin 2002; Cassidy 2003; Kepe 2005). In Botswana's Okavango Delta, nesting adult crocodiles are killed, eggs are destroyed, vegetation cover is burnt and nutrient levels in soil and water are affected by fire. Fire is not only a physical destructive force but also provides disturbances wider than its actual borders. The intense heat, smoke and noise surrounding a fire causes living creatures to move away from the area. Fire is a force in the Okavango's natural history and has always occurred naturally in the area (Cassidy, 2003). With increasing populations and greater demand for resources, fire occurrences have been controlled by humans. Humans are thought to create fires for different reasons but mainly serve to improve the vegetation resource base for grazing, for material collection and to improve access into the wetlands. Other reasons for burning include poaching of wild animals; opening up areas of vegetation for grazing and some locals believe that fires improve fish numbers in the river.

3.4.1 Fire use and fire regimes

After independence, the Herbage Preservation Act in 1978, prohibited the lighting of bush fires. Fires were thus illegally lit ("arson") as local chiefs had lost their power to a centralized government (Cassidy, 2003). This same study on the anthropogenic burning practices of the Okavango panhandle, outlined the extent and distribution of fires in certain resource areas of the panhandle. The study investigated how fire affects the resources of the panhandle, how much households rely on these resources and if there are any conflicts among people over burning. The study focused on four villages of the panhandle, two in close proximity to the main channel and two closer to the shallower floodplains. The study identified the main role players in burning practices as fishermen, livestock owners and plant collectors who collect reeds, papyrus, grasses and water-lily bulbs. Fires were said to occur every year but at different intensities, based on the extent of the floods the previous year.

During the study season in 2001, 3690 hectares (4.1%) of the panhandle were burnt by October. The intensity of the fires that season were said to be low due to the intense fires experienced in the previous year (2000). The majority of all resource users believed that fire improved access to, and conditions of, the natural resources. These resources include grazing land, thatching grass, reeds, water-lily bulbs, papyrus and fish.

The only conflict over burning practices that did exist was over the timing of burning, which differed according to the resource of interest. Livestock owners and fishermen were said to start fires earlier (September) than other resource users who preferred burning to take place in October/November. The reason for preference to later burning was in order to ensure that everybody had finished their reed and plant collecting and fires would occur just before the rains which would generate renewed plant growth. The timing of fires (i.e. after October) is thus a serious factor in disturbance and destruction of crocodile nests in the panhandle. As shown in Figure 3.3, where a large patch of *Phragmites* reeds has

Figure 3.3 A burnt patch of *Phragmites* reeds

been burnt, fires destroy vegetation cover completely and in that process also all existing as well as potential future nesting sites. As such it represents one of the most serious disturbances to crocodile survival in the area.

3.4.2 Fire disturbance in the Panhandle

Fire sighting recordings were made from the beginning of the nesting season (end of September) to the end of February (the end of the hatching period). This would ensure that all the fires within the nesting period had been recorded. Fires were recorded along the entire length of the study area during nesting surveys and during all other regular observation trips made along the river. The location and extent of all burns were recorded from a boat, as only the banks of the main channel and its major side channels were of concern and not the entire floodplain. Figure 3.4 (a and b) shows examples of such features recorded.

Burn scars were marked with the GPS by plotting points around the perimeter of the burnt area on foot. Areas that could not be marked on foot, such as floating burnt papyrus, were marked from the boat on the main channel and the distance out into the floodplain was estimated.

The GPS recordings of burnt areas were transferred to ArcView 3.2, where the recorded polygons could be converted to shape files for mapping. The resultant fire patterns shown in Figure 3.5 are not sufficiently extensive to show up well on the small-scale image, necessitating the zoomed area in the figure. Nevertheless, it should be recognised that burn scars extend for the full range of nesting habitat away from the river banks.

a. Fire scar along the main channel

b. Fire scar along side channel

Figure 3.4 Evidence of fire disturbance

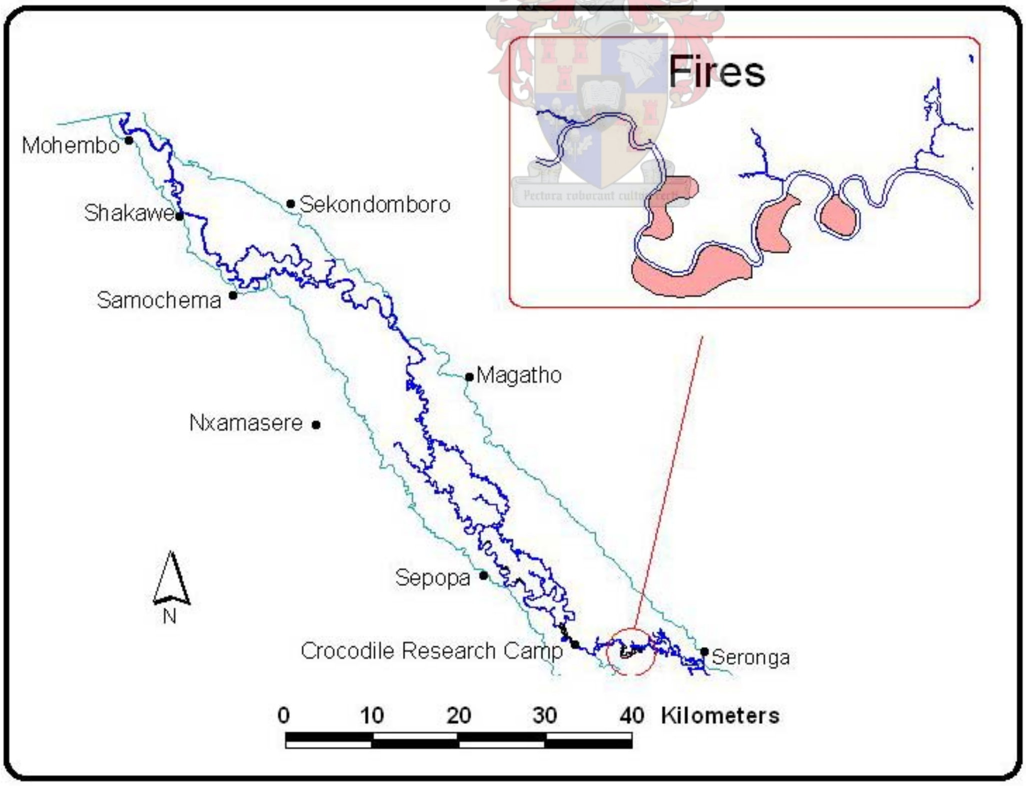


Figure 3.5 Occurrence of burnt areas recorded in the field

.

3.5 Boating activity

The detrimental effects of boat traffic on the river are mentioned in the Okavango River Panhandle Management Plan (NRP, 2001). The study divides boat operations into five categories of impacts, namely: a) noise impacts and disturbance, b) possible bank erosion due to boat wakes, c) disturbance of wildlife and vegetation due to noise, boat wakes and /or propeller wash, d) pollution due to emissions from boat engines and/ or general boat operations, and e) the introduction of aquatic weeds which are carried into the system from boats which have been on other water bodies.

Noise impacts and disturbance would be a contributing factor for nesting crocodiles as boats passing nesting areas create significant noise and disturbance to female crocodiles. Crocodiles are visibly disturbed by passing boats as they quickly enter the water once a boat is heard or seen. Tourism related activities associated with boat use also provide disturbances. Fishermen often spend long periods of time in one area and their associated noise is a major disturbance for nesting crocodiles. Boat wakes erode river banks which could be used for nesting by crocodiles. Crocodiles often nest as close as 1.0m away from main streams and continued wake action would certainly affect the condition of the nest on the bank.

Boat traffic disturbance is related to motorized boats and their associated noise and speed. Due to the high costs of purchase and maintenance of such equipment, most villagers do not have access to these boats. The traffic on the river is mostly associated with tourism activities such as boat cruises, fishing and transport to and from certain tourist destinations. The source of intense traffic can therefore be attributed to various tourism operators (including lodges) and ferry services in the panhandle area. Some of the villages also have boat launching points along the river where private boats can be launched. In total the Panhandle offers eight boat launching sites from Mohembo to Seronga as shown in Figure 3.6.

The preliminary boat traffic map was constructed by making use of information obtained from informal interviews with various boat owners/users on the river. This included interviews with various lodge managers and ferry services along the river. The questions asked were mostly spatial in nature and allowed the plotting of the most frequented routes taken by the river users and to gain a better understanding of seasonal intensity. Coordinates for the various landmarks mentioned by river users were plotted onto a map and the river was divided into sections or routes.

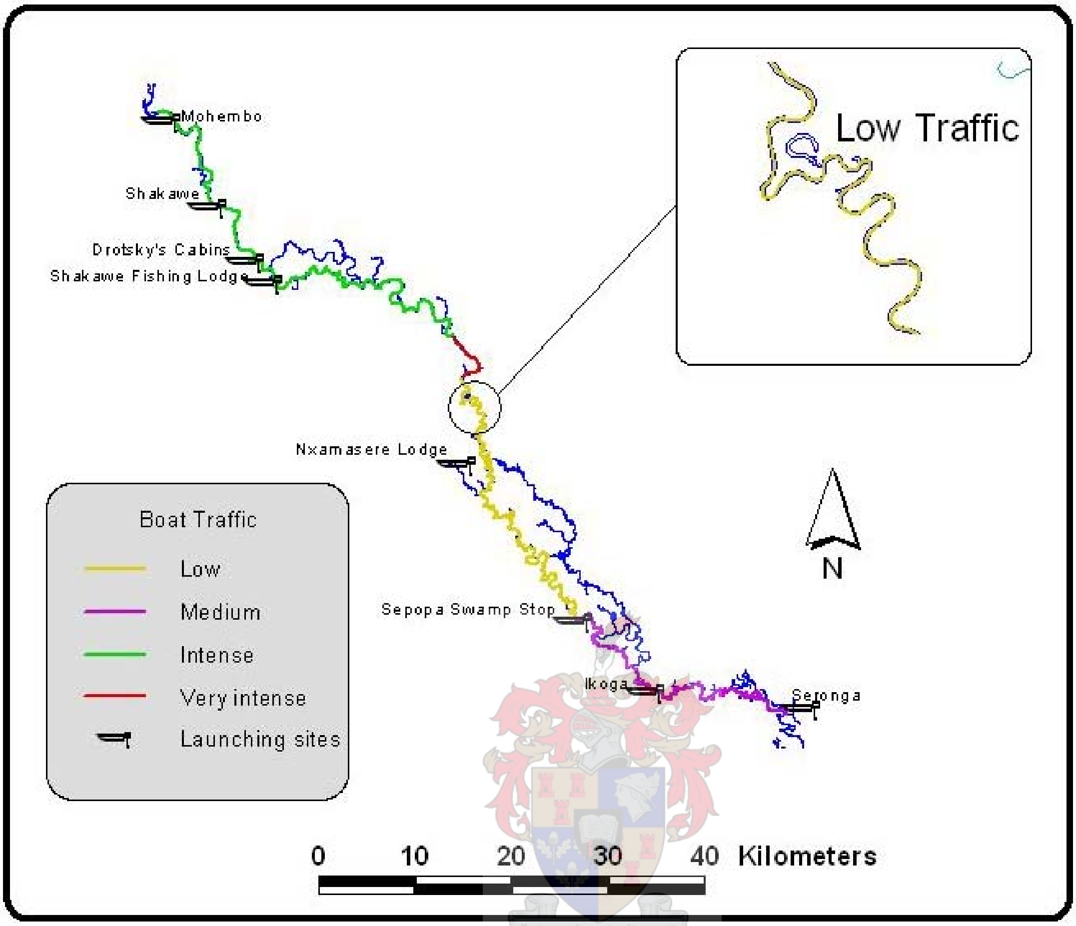


Figure 3.6 Traffic intensity and boat launching sites along the Okavango River

The river course map created earlier in the study was digitized from digitally stored aerial photographs.The right and left banks were digitized as two separate lines thus displaying the actual river width. This allowed the respective traffic routes to be digitized directly onto the river section of the map i.e. between the two river banks.

Traffic intensity classes were assigned according to the intensity of traffic on each route. The traffic was classified according to the number of passes per day for each specific route. The intensity classes distinguished were: 1-3 passes per day (ppd) (Low intensity), 3-6 ppd (Medium intensity), 6-9 ppd (Intense) and >9 ppd (Very intense) traffic. The spatial pattern of the traffic route classification in Figure 3.6 indicates that traffic intensity and launch site density is highest in the upper part of the river course.

3.6 Combined human disturbance

Vegetation harvesting, cattle grazing, fire occurrence and boating were all combined to represent combined human disturbance. The polygon and line themes used to represent the different disturbance areas were combined to form a single image representing the combined disturbance zones.

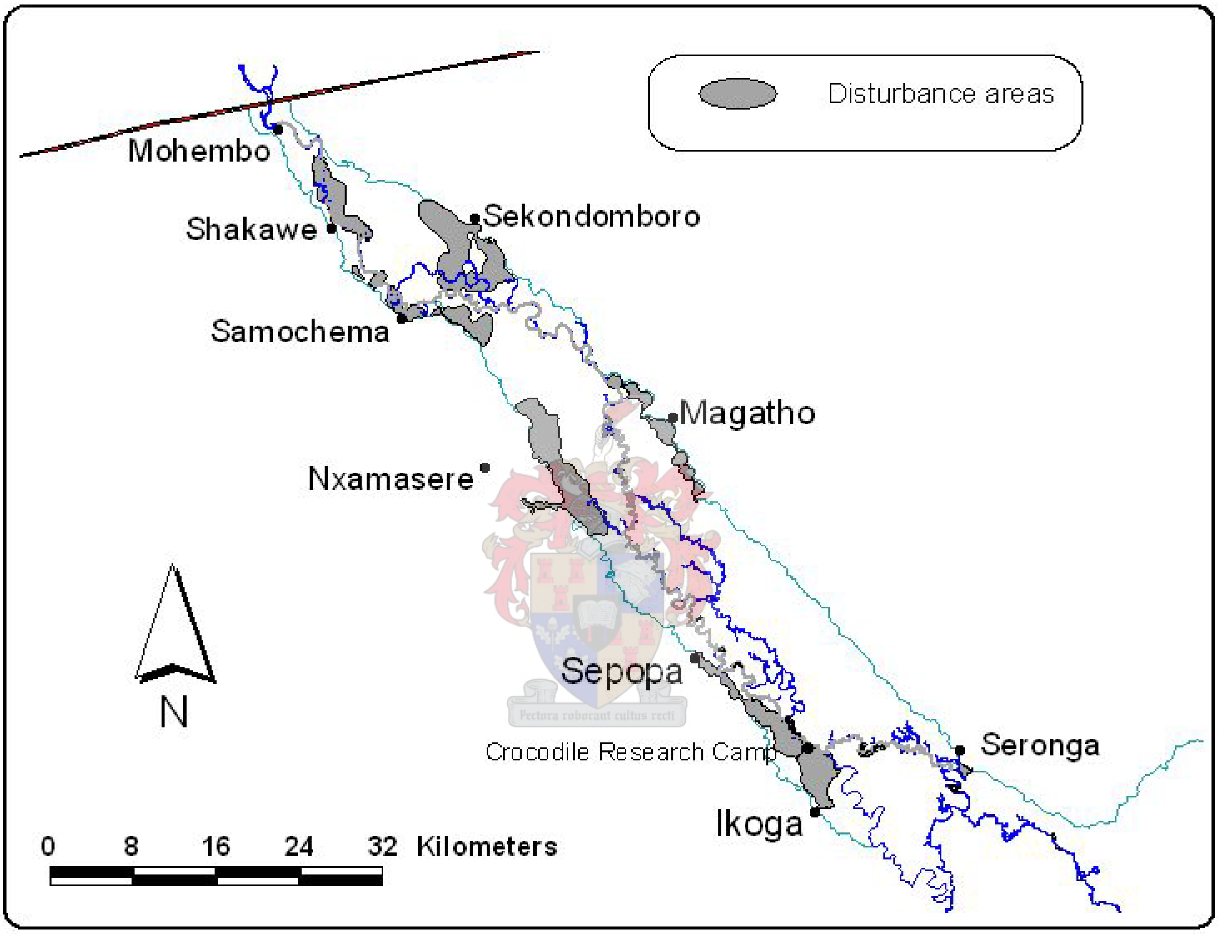


Figure 3.7 Combined human disturbance areas

Figure 3.7 indicates the spatial extent of all the disturbances in the study area. The image was created by combining the four disturbance themes displayed in Figures 3.2, 3.5 and 3.6 on a single layer and representing all the disturbance factors as a common “disturbance areas” category. This image indicates the clustering of combined disturbance activities in three separate northern, central and southern zones and a distinctly unaffected region around the Phillipa/ Moremi side channels. The next sections gauge the spatial disturbance effect that spreads outwards from these ‘soft’ borders.

CHAPTER 4: MULTI-CRITERIA EVALUATION (MCE) FOR CROCODILE HABITAT DISTURBANCE

In order to evaluate human disturbance on suitable crocodile habitat it is necessary to firstly identify the disturbances and each ones specific effect on nesting habitat. Each disturbance will have a different effect on crocodile nesting and some disturbances will impact more than others. This information will allow an accurate evaluation of the combined effect of human disturbances on suitable crocodile nesting habitat. This entire process can be carried out with the use of GIS and the Multi-Criteria Evaluation module in Idrisi. GIS are well suited to handling evaluation of spatial problems with multiple criteria to consider (Ceballos-Silva & López-Blanco, 2003a; Dai *et al.*, 2001; Store & Kangas 2001; Van der Merwe, 1997). The MCE module will translate the conditions in the field into spatial format by spatially analyzing the combined effect of human disturbances on crocodile habitat. The MCE performs this process in six steps adapted from Van der Merwe (1997).

4.1 The procedure sequence

The six step process was used to order the sequence of the MCE and follows the order required for the MCE module in Idrisi. The six steps are divided into two processes, firstly, GIS processes which involve all of the GIS processing steps that need to be carried out by the GIS operator and secondly, the decision making process which involves the input of various experts and role players. The six steps are shown in Figure 4.1, which elaborates on the research design of this study in Figure 1.5.

Steps one and two both make use of the decision making process which involves expert opinion in the case of crocodile research. This application is in line with the workshop process utilised by Van der Merwe & Lohrentz (2001). The third step entails data collection from the field in GIS format and further processing in that platform. Step four standardizes the factors via GIS functions that require no input from experts. Transforming the data and assigning weights (Step five) involves knowledge about the disturbance effects on crocodile nesting and thus requires input from expert opinion, captured through GIS processing. The final step is purely a GIS function and requires running the MCE module in Idrisi in order to evaluate the final results of the evaluation – a refined combined disturbance image. The execution of these steps for this study is now described separately in the following sections.

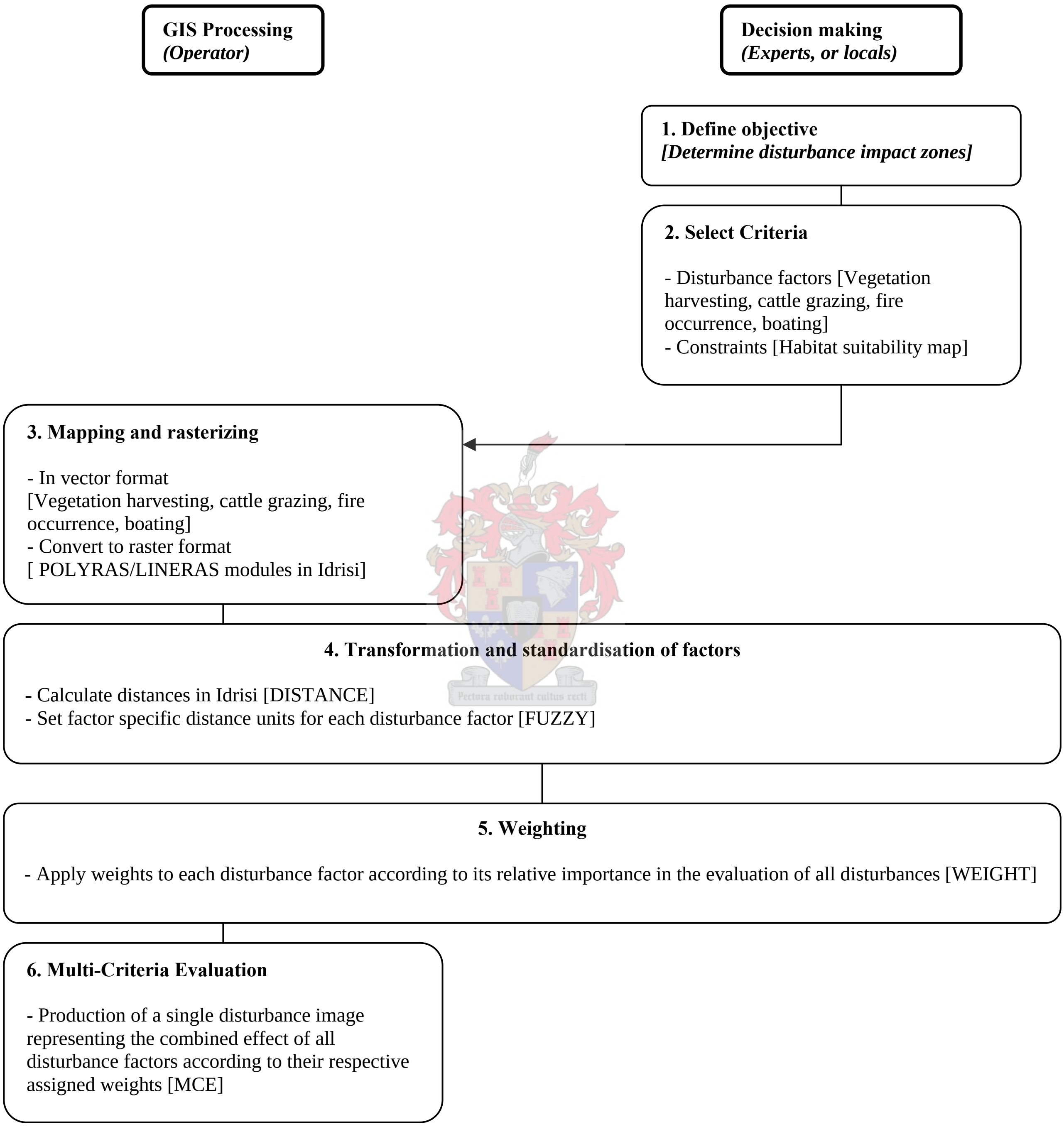


Figure 4.1 The six steps of MCE, with Idrisi modules.

Most of the technical guidance for performing this analysis, and hence much of the procedural description that follow, were taken from a range of technical sources (Eastman, 2001a, 2001b;

Idrisi 2000) and application examples (Breytenbach 2006; Van der Merwe, 1997; Van der Merwe & Lohrentz 2001).

4.2 The objective for MCE application

Crocodiles of the Okavango face the problem of human disturbance at nest sites and the objective of the MCE is to determine the combined spatial extent of the various disturbances on crocodile nesting. The MCE thus aims to display human disturbance potential on suitable crocodile nesting habitat. The objective was set against the real world problem of human disturbance identified in the previous chapter.

4.3 Selecting criteria

Decision making criteria can be divided into factors and constraints (Eastman, 2001). A factor is a variable that measures/rates the potential suitability of a characteristic of an area for a given purpose on some standardized scale, while constraints are those variables which, where present, flatly prohibit the use of that location. While establishing the relevant criteria for human disturbance potential, it is essential to consider the availability of data and the ability of the criteria to be spatially represented in map form.

The MCE thus aims to evaluate the disturbance potential on nesting habitat by combining certain human disturbance factors. The factors, as selected by the Okavango Crocodile research team, were:

1) Fire occurrence;

2) Resource utilization, which is made up of vegetation harvesting and cattle grazing;

3) Boat traffic intensity, divided into four classes, namely, low, medium, intense and very intense.

Fire occurrence and resource utilization each represent a factor, while each boat traffic class is factored separately. Each boat traffic intensity class is represented as a separate factor because each intensity has its own specific effect on nesting and thus requires its own transformation (step five) and weight allocation (step six). The study thus has six disturbance factors to incorporate.

A single constraint was used in the evaluation. The constraint allows certain areas to be discarded in the evaluation process. The habitat suitability image (Figure 2.13) created by Boolean overlay was used as the constraint as it allows all areas that do not fall under suitable crocodile habitat to be discarded from the evaluation.

4.4 Mapping and rasterizing factors and constraints

Each disturbance factor is represented in vector format in ArcView 3.2 as displayed in Figures 3.2, 3.5 and 3.6. In order to be evaluated in the MCE module in Idrisi it was required to have these images in raster format. The fire and utilization zones maps were converted to raster format by using the POLYRAS function in Idrisi, which converts polygon shape files from vector to raster format. The four traffic intensities were converted using the LINERAS function in Idrisi which converts line shape files from vector to raster format. The image resolution selected for the raster format in Idrisi was a 30x30 meter grid cell size – sufficiently coarse to accommodate data fuzziness, yet fine enough to capture the accuracy and spatial reality of the fine-scale mapping performed.

The DISTANCE function was then run on the disturbance factor images. The DISTANCE function calculates the Euclidean distance/proximity of each pixel to the nearest of a set of target pixels (Eastman, 2001). The DISTANCE function used the disturbance factors as the target and calculated the distance away from the specific targets in meter units. The Autoscale option in the Display Launcher of Idrisi automatically calculates a relationship between input values of the image (meters) and colour palette indices (from 0-255). The result was that the lowest value (0 meters) is given the lowest palette index and the highest value (maximum distance away from the target on the image eg. 7000 meters) is given the highest palette index of 255. All other values are given a palette index in direct proportion to their position within this range, meaning that the distance variables were automatically standardized.

4.5 Transformation and standardization of factors

To evaluate the combined effect of disturbance in GIS, it is necessary to represent the effect of disturbance in a spatial format. Transformation of the disturbance factors allows experts to be involved with the process of representing disturbance effects in a map format. These disturbance effects are then translated into GIS format with the use of the FUZZY module in Idrisi (Eastman, 2001a; Eastman 2001b). The module also allows all factors to be standardized to a common scale.

4.5.1 Translating distance values into disturbance intensity

The effect of different disturbances to nesting crocodiles can be assessed by the distances that crocodiles are willing to nest from that specific disturbance. The effect of the disturbance is thus evaluated in spatial terms. This means that disturbance potential correlates with distance units (meters) in that the effect of disturbance decreases with distance, from the locations of the particular disturbance factor. Each disturbance factor, however, has its own unique effect on nesting crocodiles. That is, certain disturbance effects might stay consistent for a specific distance before it actually starts decreasing. One can thus presume that the more intense the disturbance, the further a crocodile would have to move before the disturbance effect starts decreasing.

The decision making processes at this point require the input of crocodile experts. This study made use of the opinions of the Okavango Crocodile Research team. The team was made up of four staff members, namely Dr Alison Leslie, principle investigator of the Okavango Crocodile Research Project (OCRP) who has over 10 years experience with crocodiles; Mr Sven Bourquin, PhD student and member of the OCRP for two and a half years; Mr Kevin Wallace, MSc student and member of the OCRP for two years and Miss Audrey Detouf Boulade, MSc student and also a member of the team for two years. By using the opinion of these crocodile experts as well as testing conditions in the field, specific distance parameters for each disturbance factor could be set. For the effect of fires on nesting female crocodiles, the team of experts decided that a distance of 1000 meters from a fire was the critical distance that females would not nest within i.e. disturbance potential would remain consistently high for 1000 meters. From 1000 meters and onward, the disturbance potential would decrease with distance away from the disturbance. This distance decay function is represented by graph in Figure 4.2 with reference to fire as a disturbance factor.

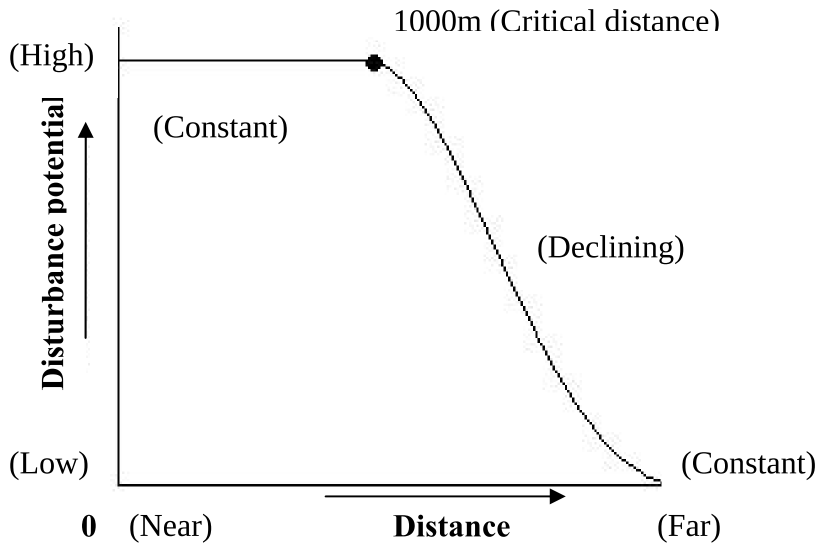


Figure 4.2 The disturbance effect of fire

The consensus expert opinion was that the critical distance for disturbance effect of the utilization zones, which includes vegetation harvesting by people and cattle grazing, was 500m. It is thus thought that the female crocodiles will not nest within 500m of a utilization zone because of the associated noise disturbance and destruction of nests by both people and cattle.

The disturbance effect of boat traffic was a lot more difficult to assess. No research has been carried out on the effect of boat traffic disturbance on nesting crocodiles. It was thus decided to use the nesting positions of the last three nesting seasons to assess the likely/potential effect of boat traffic on nest position. The traffic classes were mapped onto the river and the nest sites for the years 2002, 2003 and 2004 were overlaid. For each class of traffic intensity the distance was measured to the crocodile nests associated with that part of the river. An average was then calculated for the distance of crocodile nests from each traffic intensity route, for all three breeding seasons. These averages gave an indication of the distances that crocodiles are willing to nest from each type of traffic intensity based on the last three nesting seasons. The distances set by the experts indicate the “buffer” distance around each factor in which the crocodiles will not nest. All of the distances as decided by the expert panel and the nesting positional data, are displayed in Table 4.1. These are the critical distances up to where disturbance remains consistently high before decreasing with distance. The distances are based purely on the conditions experienced in the Okavango system by the Crocodile Research Team over the past three years.

Table 4.1 Critical distance values for each of the six disturbance factors

Factor	**Critical distance (meters)**
Fires	1000
Utilization zones	500
Very intense traffic	190
Intense traffic	240
Medium traffic	60
Low traffic	40

4.5.2 Fuzzy standardization

The FUZZY module in Idrisi allows the specific distance parameters, determined by the crocodile experts, to be assigned to each factor. The module thus allows the distance decay values to be calculated and represented graphically in map format. This is the final step in getting disturbance represented spatially for further analysis in the MCE. FUZZY is used because the effect of disturbance on nesting crocodiles is not clear and cannot be defined by a set of clear distance parameters. The effect of disturbance is thus "fuzzy". The distance values have been set by the experts, but these distances only partly define the effect of disturbances. FUZZY evaluates the fuzzy set membership values (possibilities) of data cells on any of three membership functions: sigmoidal, j-shaped and linear. These variants can be either monotonically increasing, decreasing or asymmetric (Idrisi32, 2000; Eastman, 2001b). The membership between disturbance potential and distance can be described as a monotonically decreasing (disturbance decreases with distance), sigmoidal curve. Figure 4.3 shows a monotonically decreasing, sigmoidal curve that was used in the FUZZY module for this study.

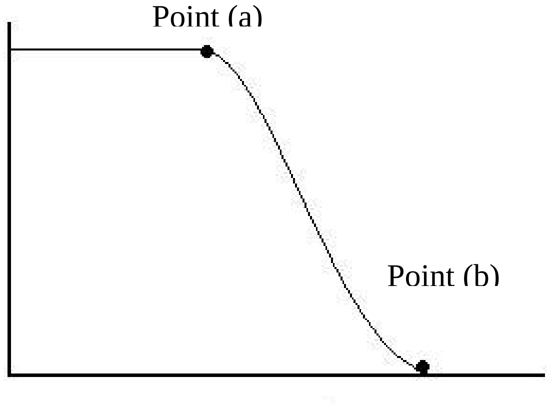


Figure 4.3 A monotonically decreasing, sigmoidal curve used in the FUZZY module

FUZZY requires the user to select a curve and membership function for a specific image and then to input values for point (a) and (b) in the curve, as shown in Figure 4.3 (Eastman, 2001b). Point (a) is the point at which membership begins to drop below the maximum and point (b) is where membership becomes zero. Fuzzy thus allows the user to decide at which point the membership begins to drop and where it ends. The distance units decided by the experts can now be assigned to this graph provided by the FUZZY module. The values for points (a) and (b) in the FUZZY module are shown in Table 4.2,

Table 4.2 Values for the monotonically decreasing, sigmoidal curve.

Factor	**Point (a)**	**Point (b)**
Fires	1000m	2000m
Utilization zones	500m	1000m
Very intense traffic	190m	1000m
Intense traffic	240m	1000m
Medium traffic	60m	1000m
Low traffic	40m	1000m

The spatial depiction of the transformation is shown in Figure 4.4 for "very intense traffic" as an example. It shows how disturbance distance decay appears in standardized image format. For fires, point (b) was set at 2000m as the experts felt the effect of fires would not be felt further than 2000m from the fire. The maximum disturbance distance for the utilization zones was set at 1000m. For the traffic factors, which were line themes, point (b) was set to 1000m. The effect of boat traffic was thought not to be influential to nesting crocodiles further than 1000m away. The FUZZY module allows the output image to be displayed in a byte binary format ranging from 0 to 255 and this standardization format was used for each of the disturbance factor maps.

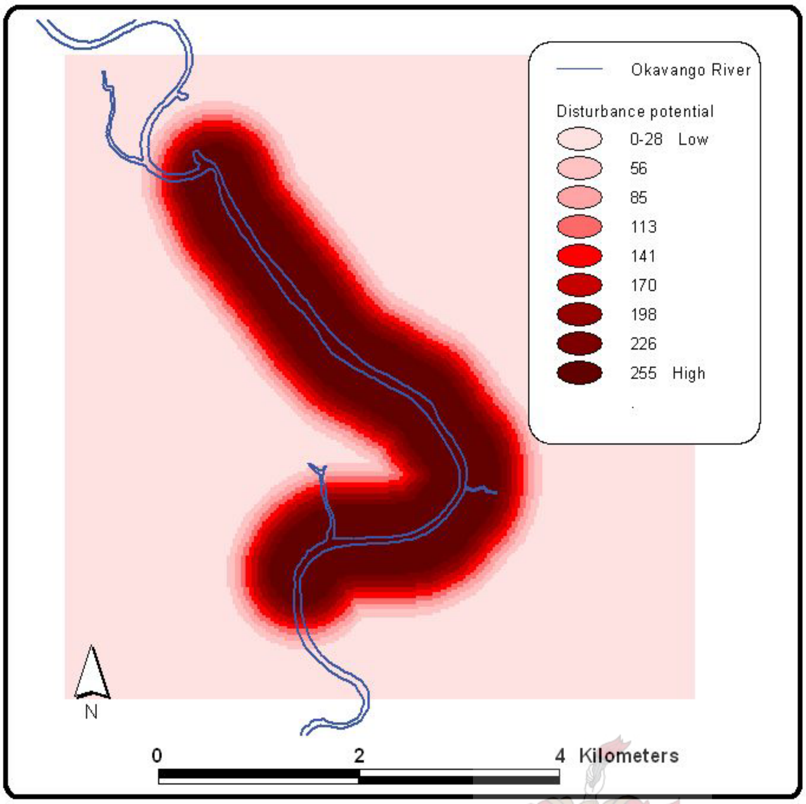


Figure 4.4 Standardized disturbance distance decay for “very intense traffic”

4.6 Weighting the factors

Because MCE combines the affect of factors, weight calculation has to allow a “relative importance” to be assigned to each individual factor. A number of techniques exist for assigning weights but one of the most popular techniques is the pairwise comparison matrix developed by Saaty (1980). The decision making process used is known as the Analytical Hierarchy Process (AHP). This process allows for a number of decision makers and role players to all play a part in the final decision making process of assigning weights, reached by consensus, to the factors.

The procedure utilized by the MCE module is a Weighted Linear Combination (WLC) that allows the weights assigned to factors to exactly sum to 1.0. Saaty’s technique allows weights to be derived by taking the principle eigenvector of a square reciprocal matrix of pairwise comparisons between the criteria. The two criteria compared are weighted according to their relative importance in determining suitability (Eastman, 2001a). A 9 point continuous scale is used to make the ratings as Figure 4.5 indicates.

1/9	1/7	1/5	1/3	1	3	5	7	9
extremely	very strongly	strongly	moderately	equally	moderately	strongly	very strongly	extremely

Less Important | **More Important**

Figure 4.5 The 9-point continuous scale used in setting weights

In weight setting for disturbance to crocodile nesting, the opinions of the members of the Okavango Crocodile Research Team were called upon. Weights were assigned according to observations in the field as little literature on the topic was available. Old nest site recordings were also used to gauge an idea of any changes in nest site patterns with time. Nest locations for 2002, 2003 and 2004 were used. The Pairwise comparison matrix was used to compare each of the factors relative to every other one. On a 9-point continuous scale the weights were developed as indicated in Table 4.3.

Table 4.3 Pairwise comparison matrix for the MCE factors of the habitat disturbance map.

Rating of the Row Factor Relative to the Column Factor

	Very Intense Traffic	Intense Traffic	Medium Traffic	Low Traffic	Fire occurence	Utilization zones
Very Intense Traffic	1					
Intense Traffic	1/3	1				
Medium Traffic	1/4	1/4	1			
Low Traffic	1/5	1/4	1/3	1		
Fire occurence	5	6	7	9	1	
Utilization zones	3	4	5	6	1/5	1

Firstly, a value of 1 is entered along the diagonal of the matrix as each factor cannot be rated differently relative to itself. The rest of the lower half of the matrix is then filled in by rating the row factor relative to the column factor (for example, Low traffic was seen as being moderately less important than medium traffic and it thus received a value of 1/3). Table 4.4 indicates the weights calculated from the

Table 4.4 Weights of each disturbance factor and the consistency ratio as calculated in the WEIGHT module of Idrisi

Factors	**Weights**
Very intense traffic	0.1311
Intense traffic	0.0834
Medium traffic	0.0445
Low traffic	0.0273
Fire occurence	0.4976
Utilization zones	0.2160
Consistency ratio 0.10	

pairwise comparison matrix in the WEIGHT module and the consistency ratio that was obtained. A maximum consistency ratio of 0.1 is required, otherwise weights have to be reconsidered.

The weights given by the results of the comparison matrix indicate the relative importance of fire (0.4976) followed by the resource zones, very intense, intense, medium and low traffic, respectively. These weights give a good indication of which factors are more significant in the final comparison evaluation and the consistency ratio of 0.10 indicates that the matrix ratings were consistently generated.

4.7 Performing Multi-Criteria Evaluation

The criteria maps produced (factors and constraints) are used in an evaluation which combines the information from these factors and constraints for each cell in the raster image. The WLC method simply multiplies each cell factor value by its weight and then sums the results according to the following formula (Eastman, 2001a):

$$\mathbf{S = \Sigma\, W_{\mathit{i}}X_{\mathit{i}}}$$

Where S is the disturbance value, W_i the weight of factor *i*, and X_i is the potential rating of factor *i* in the cell. In multiplication of the factor maps each raster cell within each map is multiplied. The resulting potential disturbance map will have the same range of values as in the factor maps used in the evaluation, since the weights all sum to one. The constraint map in Boolean format (0 and 1), is then multiplied by the result of the factor combination. This would thus leave a zero value to all areas which are not considered in the evaluation. This procedure is performed by the MCE module in Idrisi. The result is a disturbance image with cell values ranging from 255 to 0, where 255 represents maximum disturbance potential and 0 no disturbance potential. Idrisi provides a display palette of 255 colours, which allows the range of suitability to be depicted in Figure 4.6 according to the traffic light principle – red representing a no-go (high disturbance) scenario and green a go-ahead (low disturbance).

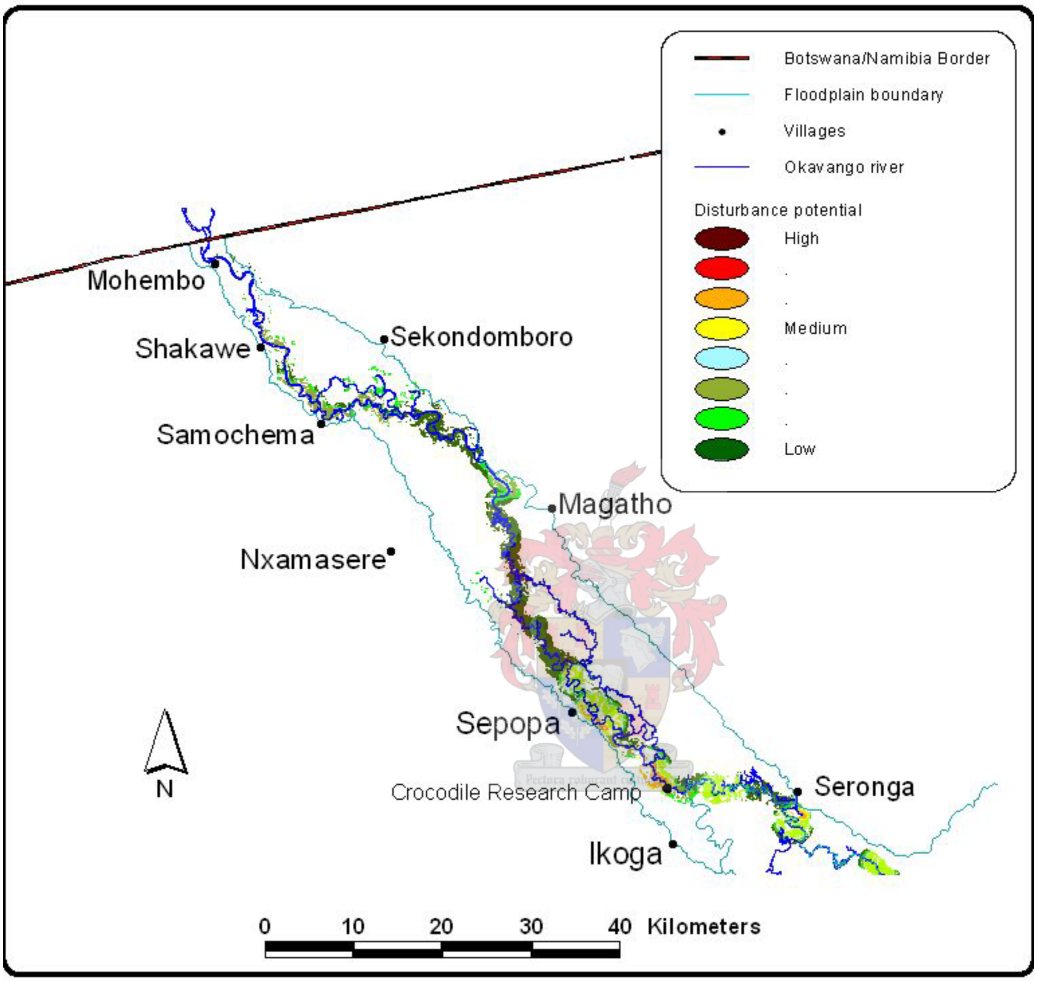


Figure 4.6 Disturbance potential map

The disturbance potential map indicates all intensities of disturbance on suitable crocodile habitat. The section of the river below Sepopa has high intensity disturbance patches. This can be attributed mainly to the fires which occured in that area over the 2004/2005 nesting season. The disturbance potential map is an evaluation of disturbance only for the 2004/2005 nesting season as the disturbance criteria was measured for this season only. Vegetation harvesting, cattle grazing and boating are activities which remain consistent in intensity and range of usage. Fire is the only disturbance which is erratic and changes from one season to the next. Spatial data for fire occurrence over 2002 and 2003 was not available at the time of the study and thus allowed only an evaluation of the 2004/2005 season. Fire occurrence during the 2004/2005 season was particularly low and isolated. Typical fire occurrence patterns are spread along the entire length of the river and thus its disturbance potential would be more evenly distributed along the river. The disturbance potential map is a useful tool in assessing the general disturbance impact of humans on crocodile nesting. This procedure can be effectively used to monitor the human disturbance potential in the area on an annual basis by adding new disturbance data as it becomes available.

4.8 Determining habitat vulnerability

When evaluating habitat availability due to human disturbances on crocodile nesting sites, the assumption is made that crocodiles are actually willing to use areas that are partially disturbed by humans. As the influence of human disturbances on crocodile nesting habitat has not been researched, it is difficult to state what levels of disturbance will actually completely deter a crocodile from a nesting site. The only issue that can be evaluated in terms of crocodile habitat vulnerability is the range of influence that humans have on crocodile habitat in terms of the disturbance activities that they perform. This particular issue can be spatially represented by indicating only those sections of suitable crocodile habitat that are totally devoid of human disturbances. The suitable habitat map (Figure 2.13) created earlier was used as the base image to represent suitable and undisturbed habitat. The disturbance potential map was converted to a Boolean image where all values >0 were converted to the value 1 and the rest remaining 0. All levels of disturbance are thus represented as a single value shown in colour on the image. This Boolean "disturbed habitat" image is then overlayed on the suitable habitat base map to show the difference between the two images and thus the extent of disturbance on suitable habitat as indicated in Figure 4.7.

The sections of suitable habitat that are still visible are those which are not disturbed and these areas of undisturbed habitat can be described as vulnerable. This comparison indicates the true spatial influence of humans on crocodile nesting habitat and clearly shows how much suitable habitat is actually jeopardized due to human disturbance. This undisturbed area is fortunately clustered in four recognizable areas of varying extent in the North, centre and South.

It is clear that a large amount of habitat is made less suitable to totally unsuitable for crocodile nesting. Using the AREA function in Idrisi, the exact area of both images could be calculated to indicate the actual percentage of suitable habitat that is disturbed by human activities. The area of the suitable habitat was 329km² and the area of disturbed habitat was 193km². This shows that 59% of the projected suitable habitat is disturbed by humans leaving the remaining 41% (136km²) of the habitat as vulnerable. It is this remaining 41% of suitable habitat that should form the basis of any protection measures in the panhandle.

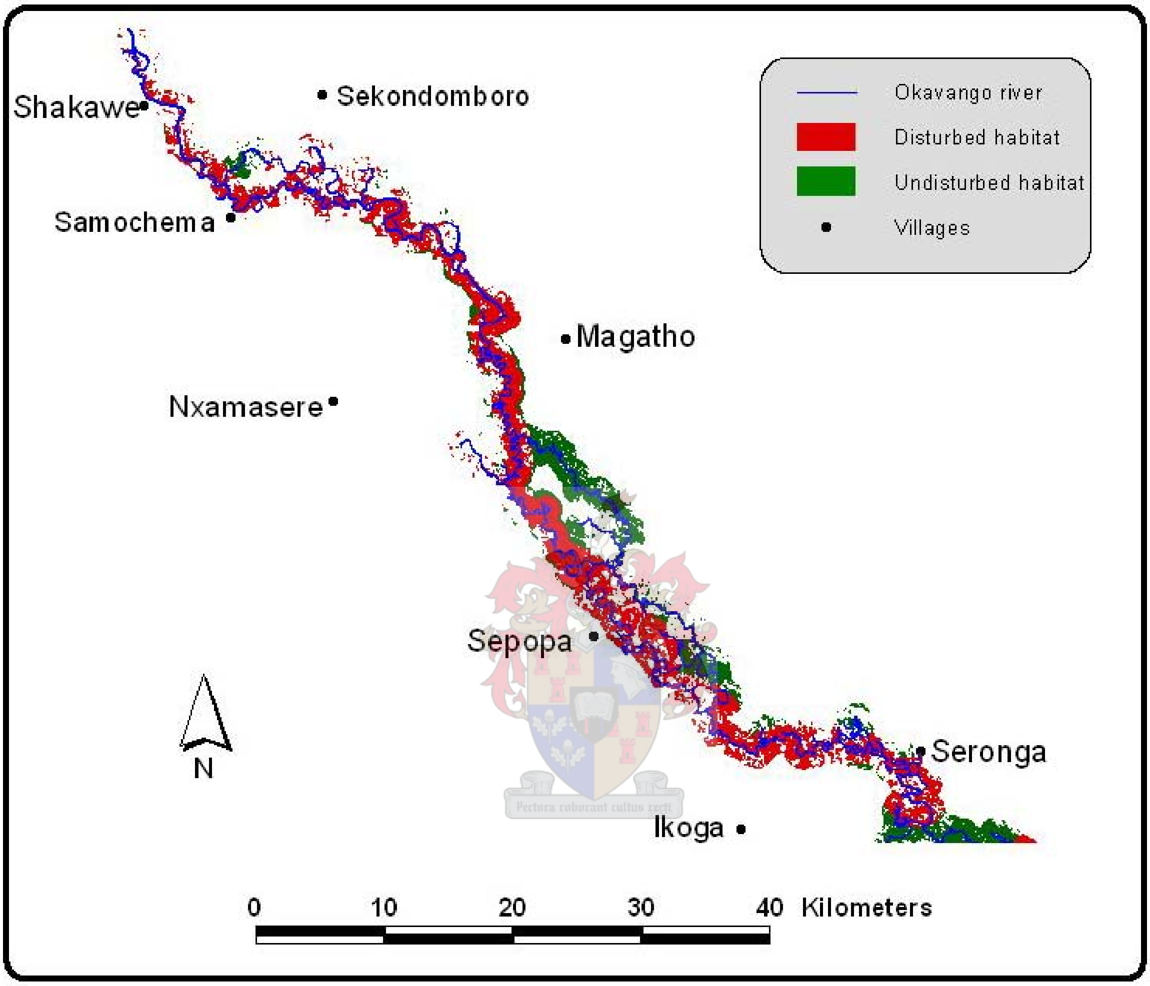


Figure 4.7 Habitat vulnerability

4.9 Nesting sanctuary: Conserving undisturbed nesting habitat

The Botswana Wildlife Conservation and National Parks act (Act No. 28 of 1992) divides the country into 163 Controlled Hunting Areas (CHAs) for managing the different types of wildlife uses. The Panhandle falls under NG/10, which is a community area zoned for the non-consumptive use of wildlife, except fisheries (NRP, 2001). The NG/10 area itself however, has no officially designated conservation areas and allows for the sustainable commercial production of veld products (NRP, 2001). The controlled use of resources is thus allowed within this zone.

Various International Conventions, treaties and protocols exist for the Delta, some of which include Agenda 21, The Convention on Biological Diversity and the Ramsar Convention on Wetlands of International Importance (Iran, Ramsar 1971). The above conventions all have similar objectives in the conservation of biological diversity and sustainable use of its components. The most important of these is probably the Ramsar Convention on Wetlands as the Okavango is one of the largest Ramsar sites in the world. Botswana became the 97th contracting party to the Ramsar Convention in April 1997. The convention was one of the first to recognize habitat as opposed to animal or plant species. Article 4.1 states "…each Contracting Party shall promote the conservation of wetlands and waterfowl by establishing nature reserves on wetlands, whether they are included in the List or not, and provide adequately for their wardening" (NRP, 2001).

The Okavango Delta already has the Moremi Game Reserve as a protected area, but the ecological significance of the panhandle as the breeding site for Nile crocodiles deserves its own form of protection. Using the habitat suitability maps created in this study it would make sense to provide the breeding crocodiles with a protected sanctuary. Because the surrounding villages are so reliant on the system for its resources it would then be essential to find a balance on which areas would be selected. The habitat vulnerability map gives a good indication of areas still totally free of any human disturbances (Figure 4.7) and the extent of such areas. This map would thus be the perfect foundation on which to base the selection of a sanctuary zone. Therefore protection of areas which are undisturbed would not be taking anything away from the locals as these areas represent untouched sections of the river which are currently not being extensively utilized.

As seen by the results of this study, the crocodiles are losing valuable habitat to encroaching human settlement and are making use of the quieter side channels for nesting. Quality habitat is not being destroyed to a large extent by humans, but rather being made unavailable for nesting as human activities are forcing crocodiles away from these areas. So essentially, quality nesting habitat is being wasted. The crocodile population all gather in the Panhandle of the Delta to nest every year, which makes this section of the river ecologically significant.

The Okavango River Panhandle Management Plan prepared for the Tawana Land Board (NRP, 2001) makes recommendations for zonation on the river to try and control the operation of boats on the Okavango. They target boats as they are seen as playing a central role in accessing and so unlocking the resources in the river system (NRP, 2001). The study identifies different categories of zonation for certain sections of the river such as a no-wake zone, propeller-free zone and restricted channels. The plan also describes procedures for zone enforcement and regulation of boating activities. This study supports the Okavango River Panhandle Management Plan in their strategy to implement zones or restricted channels. Due to the high density of nests in the area, the lack of human disturbance and the size of the unaffected habitat, the Moremi/Phillipa channel is clearly the candidate for formal protection by declaring it a sanctuary. Figure 4.8 provides an advanced depiction of the proposed sanctuary area.

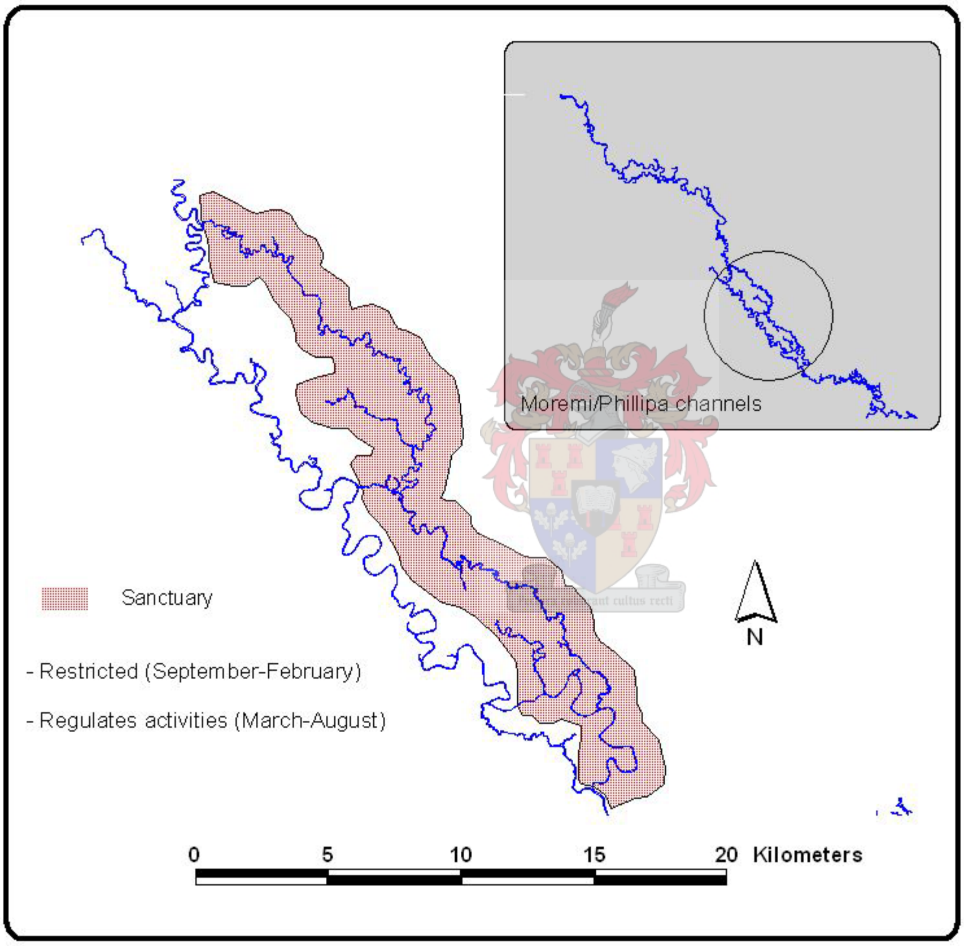


Figure 4.8 Proposed crocodile nesting sanctuary

Possible regulations that could be implemented for such a sanctuary could be restricted boat access throughout the year, with complete restriction during the breeding season. Proclaiming the area a “no collection” zone would ensure that no disturbances occur in that area. As seen by the maps created in this study, utilization in the area is still low which means a win-win situation for local inhabitants and the wildlife. This channel also houses other rare species threatened by habitat loss, such as the African Skimmer and the Wattled Crane (personal observation). These species would also benefit from the protection. The sanctuary could be promoted for regulated tourism during the non-breeding periods, which would promote the Panhandle as a tourist destination. This sanctuary could possibly be implemented as part of the Community Based Natural Resource Management (CBNRM) strategy, which aims to protect declining wildlife populations, while devolving greater responsibility to local authorities and communities for management and use of wildlife resources (NRP, 2001).

CHAPTER 5: MEETING THE OBJECTIVES

The study aimed to describe the nesting preferences of crocodiles in the Okavango river and to use these preferences to map suitable crocodile nesting habitat. The availability of this suitable habitat depends on the disturbance intensity from human activities. This chapter looks at each of the objectives of the study to see if they have been reached and the conclusions drawn from them. A technical evaluation of the research is done and the value of the results is considered.

5.1 Nesting characteristics and habitat suitability

The Okavango crocodiles start the search for suitable nest sites in September every year. The nesting period coincides with decreasing water levels in the Panhandle of the Delta. A lower water level ensures that more land is available for nesting and a lower water table allows deep enough excavations to be dug. The nests are always located very close to some water source to which the female can retreat if threatened. These water sources range from isolated ponds or backwaters to the main stream of the river. The females create "slides" which allow them to travel from the nest directly into the water. These slides are usually visible from the main stream and are a good indicator of a possible nest site during nesting surveys. Females also very often create two different slides with a small distance between giving the option of a second escape route if necessary.

The vegetation characteristics of the nest sites indicate that the crocodiles favoured *Phragmites* reeds as the vegetation cover around nest sites. This might simply be due to the fact that *Phragmites* along with papyrus is the predominant vegetation on the banks of the river. *Phragmites* is associated with elevated land and its' roots are buried in soil, as opposed to the papyrus which is "floating" and not actually rooted to the ground but connected by long interconnected root systems.

Suitable habitat exists throughout the length of the river and no substantial gaps in habitat are apparent. This data is backed by the fact that 88% of the nests located in the last three nesting seasons (2002, 2003, 2004) were found within the area designated as suitable nesting habitat for crocodiles. This indicates that in terms of physical habitat, sites suitable for nesting are still in abundance in the panhandle. The extent of disturbances on this habitat, however, will show whether this habitat is actually *available* for nesting.

5.2 Human disturbance potential

The placement of nests in the system is not as equally distributed along the river as the suitable habitat is. This might be due to additional factors not considered in this study, such as water temperature, river depth and water velocity. However, a factor which might be even more influential is human disturbance on the system. When examining the habitat vulnerability map (Figure 4.7) one notices the actual extent of human disturbance on nesting habitat. The remaining habitat is found in isolated patches along the river and significant patches are seen in the side channels of the Moremi/Phillipa channel, which also corresponds to high nest densities in this area.

The main channel has most of its habitat disturbed and thus makes the main channel a largely unsuitable area for nesting. A comparison of nesting patterns for the last three nesting seasons, indicate a distinct move by female nesting crocodiles away from the main channel and into the side channels. Studying the disturbance potential map (Figure 4.6), one notices that the high disturbance areas are situated close to villages. The high disturbance found in the south is largely attributed to the additional pressures of fires that were experienced in that area during the 2004/2005 season. The upper reaches of the river are normally burnt to similar intensities and will thus also have the added pressure when burnt.

Due to most access to the river being from villages, these points are seen as high disturbance zones for nesting crocodiles. The Moremi/Phillipa side channels are not accessed as often by people and offer the crocodiles undisturbed nesting conditions. The effort by crocodiles to use every bit of available habitat in the side channels is very apparent when studying the higher nest densities along the Southern section of the Phillipa channel which holds very small and scattered plots of suitable vegetation. The movement of nesting females from the main channel over the past three seasons can probably be attributed to a combination of the disturbance factors experienced. The results of the habitat vulnerability map correspond to these low nest densities on the main stream of the river, especially along its central course.

5.3 Habitat vulnerability

Habitat vulnerability is shown by displaying that habitat in the river system which is totally undisturbed (Figure 4.7). The image allows one to evaluate the extent of human disturbance on nesting habitat and identify which habitat remains vulnerable and would thus require some form of protection. The areas along the river system which seemed to retain most of its habitat were the Moremi/Phillipa side channels.

Two results can be drawn and used from this evaluation. Firstly, the habitat that remains undisturbed can be clearly identified and hopefully protected to ensure the continued survival of the crocodile population. Secondly, because this study uses human disturbance factors based mainly on human utilization of the system, this image also indicates that these undisturbed areas are not being heavily utilized by people. Thus protection of the Moremi/Phillipa side channel would be taking nothing away from the local people who utilize the system, but at the same time would benefit the crocodile population.

5.4 Technical evaluation of the research

The use of Geographic Information Systems requires a supply of thorough and accurate data sources in order to reach credible results. Not all factors can be spatially represented so an evaluation of this nature is limited by spatial data availability. The objectives of the study are thus set only once reliable data sources have been found or created. A limitation on this study was found in the vegetation map used to create the first habitat suitability map and on which all the other suitability maps were based. The vegetation characteristics of the nest sites as collected from the field, indicated that *Phragmites* was clearly the most predominant vegetation type found around nest sites. The vegetation map, however, never had a distinct class set only for *Phragmites* and was instead represented as a *Phragmites*/papyrus combination. This lead to an obvious over-representation of habitat as papyrus was included in the selected preferred habitat type. Even though a fairly large proportion of *Phragmites*/papyrus vegetation was found during the surveys, a single class only for *Phragmites* would have given a better indication of preferred habitat for crocodiles.

The graphics presented in this study are limited in that they are a representation of the 2004/2005 nesting season only and this is due to the fact that all measurements of habitat and disturbance factors were measured in this season only. The evaluations represented here do represent the general condition in the system, as most factors are consistent for every year, such as boat traffic, resource collection and grazing. The only factor that remains inconsistent over the years is the illegal burning practices as the practice follows no management principles.

5.5 Value of the results

The results of the research allow a clear database of existing nest positions to be used. This data has value for further researchers, conservation departments and ranchers. The nesting characteristics of the Okavango population have been described, allowing future researchers to use the data set if new nest sites are located. The mapping of factors such as habitat suitability, human disturbances and habitat vulnerability allow land-use and conservation planners to factor in these results during land-use assessments. Conservation strategies and protection of habitat could be based on the findings of this research. Results from such initiatives will show results for specific markets which rely on stable wild crocodile populations, such as the tourism sector of the Okavango Delta and the crocodile farmers in the area. Ultimately the value of the results from this research will allow officials to realize the impact of human disturbance on an exploited crocodile population and thus offer this phenomenal creature a protected future in its natural habitat.

5.6 Recommendations for habitat protection

The results of the study indicate that a substantial amount of suitable nesting habitat is made unavailable by human disturbance. This means that no serious destruction of habitat is taking place but that the presence of humans in the system and their corresponding disturbance during the nesting time period is having implications on nesting locations. It is recommended that the necessary steps are taken to protect the remaining undisturbed habitat areas, namely the Moremi/Phillipa channel, in the form of a formal conservancy.

This specified area could be managed as a partially utilized protected area which would allow for regulated activities to take place during non-sensitive breeding times (March-August), and ban all activities in the area during sensitive breeding periods (September-February). The activities in the area could be managed under the Community-Based Natural Resource Management (CBNRM) strategy which is explained in the Okavango River Panhandle Management Plan as "a strategy for arresting declines in wildlife populations, while devolving greater responsibility to local authorities and communities for management and use of wildlife resources" (NRP, 2001). This strategy would thus allow local communities to manage this area and benefit from regulated tourist activities such as bird-watching, camping and fishing.

Steps also need to be put into place to manage the utilization of resources in the panhandle and the timing thereof. This would place less stress on specific natural resources which are becoming over exploited, and on various species which breed during this collection period.

5.7 Future research

In terms of spatial analysis, further research needs to be carried out with regards to mapping the physiological patterns of the river system such as river depth and water velocities. Vegetation maps could be further classified into more specific vegetation classes for the panhandle area – perhaps by applying advanced remote-sensing techniques. A time series analysis of change in land-use in the panhandle area will assist in analyzing the impact of man on the system and determining whether these impacts are increasing or decreasing.

In terms of studies on the Nile crocodile, future research needs to be conducted on the response of nesting crocodiles to human disturbance. The tolerance of humans at wild nest sites needs to be established in order to understand the full effect that human disturbance will have on the breeding success of wild crocodiles. A study of this type combined with the results of the current study would allow accurate conclusions to be made regarding the effect of human disturbance on crocodile populations in the Okavango Delta and perhaps elsewhere

More research needs to be carried out with regards to reasons for nest abandonment by nesting females and whether or not this is a direct result of continued disturbance at nest sites. Included in this study could be an investigation on the average hatching rate of wild nests that have been abandoned by females. If nest abandonment is found to be the result of disturbance, then the question arises as to whether the females are of a specific age group, such as young and inexperienced females? Further more, if it is only young females that abandon nest sites when disturbed then population studies need to determine what the average age of the nesting females in the Okavango is. If the average age of the nesting females is very young (because of previous exploitation of the population), what will the effect on the future of the Okavango crocodile population be? By understanding the full effects of human disturbance to the well-being of the crocodile population, management principles can be implemented more effectively to ensure the survival of this Okavango Delta keystone species.

REFERENCES

Amitrajeet AB 2003. Human actions, the survival of keystone species, and the resilience of ecological-economic systems. *Resources Policy* 28: 153-157.

Applied Research Development Consultants (ARDC). 2001. A report on the socio-ecological survey of the Okavango basin. Gaborone: Kalahari Conservation Society.

Aras H, Erdogmus S & Koç E 2004. Multi-Criteria selection for a wind observation station location using analytic hierarchy process. *Renewable Energy* 29: 1383-1392.

Bendson H 2002. The dynamics of the land-use systems in Ngamiland: changing livelihood options and strategies. Discussion Paper. Maun, Botswana: Harry Oppenheimer Okavango Research Center and German Development Service.

Bengtsson J 1997. Which species? What kind of diversity? Which ecosystem function? Some problems in studies of relations between biodiversity and ecosystem function. *Applied Soil Ecology* 10: 191-199.

Ben-Wu X & Smeins FE 2000. Multiple-scale habitat modeling approach for rare plant conservation. *Landscape and Urban Planning* 51:11-28.

Blake DK 1993. The Nile crocodile *Crocodylus niloticus:* capture, care, accommodation, and transportation. In McKenzie AA (ed) *The capture and care manual*, pp654-675. Pretoria: Wildlife Decision Support Services CC and The South African Veterinary Foundation.

Blomberg GED 1976. Feeding ecology, nesting ecology and habitat preference of the Okavango crocodiles. Proceedings of Symposium. Okavango Delta and its future utilization. Gaborone, Botswana: Botswana Society.

Breytenbach A 2006. GIS-based land suitability assessment and allocation decision-making in a degraded rural environment. Master's Thesis. Stellenbosch: University of Stellenbosch, Department of Geography and Environmental Studies.

Bucini G & Lambin EF 2002. Fire impacts on vegetation in central Africa: A remote-sensing-based statistical analysis. *Applied Geography* 22: 27-48.

Cassidy L 2003. Anthropogenic burning in the Okavango panhandle of Botswana: Livelihoods and spatial dimensions. Masters Thesis. Miami: University of Florida.

Ceballos-Silva A & López-Blanco J 2003a. Delineation of suitable areas for crops using a Multi-Criteria Evaluation approach and land use/cover mapping: a case study in Central Mexico. *Agricultural Systems* 77:117-136.

Ceballos-Silva A & López-Blanco J 2003b. Evaluating biophysical variables to identify suitable areas for oat in Central Mexico: a Multi-Criteria and GIS approach. *Agriculture, Ecosystems and Environment* 95: 371-377.

Cott HB 1961. Scientific results of an enquiry into the ecology and economic status of the Nile crocodile (*Crocodylus niloticus*) in Uganda and Northern Rhodesia. *Transactions of the Zoological Society of London* 29:211-356.

Craig GC, Gibson St C & Hutton JM 1992. A population model for the Nile crocodile and simulation of different harvesting strategies. In Hutton JM & Games I (eds) *The CITES Nile Crocodile Project*, pp 1-52. Lausanne, Switzerland: Secretariat of the Convention on International Trade in Endangered Species of Wild Fauna and Flora.

Dai FC, Lee CF & Zhang XH 2001. GIS- based geo-environmental evaluation for urban land-use planning: a case study. *Engineering Geology* 61: 257-271.

Eastman JR 2001a. *Idrisi32 Release 2 Guide to GIS and Image Processing. Volume 2.* Worcester, MA: Clarke Laboratories for Cartographic Technologies and Geographic Analysis, Clarke University..

Eastman JR 2001b. Idrisi 32 Release 2 Tutorial. Worcester, MA: Clarke laboratories for Cartographic Technologies and Geographic Analysis, Clarke University.

Fowler GS 1999. Behavioural and hormonal responses of Magellanic penguins (*Spheniscus magellanicus*) to tourism and nest site visitation. *Biological Conservation* 90: 143-149.

Gibson LA, Wilson BA, Cahill DM & Hill J 2003. Modeling habitat suitability of the swamp antechinus (*Antechinus minimus maritimus*) in the coastal heathlands of Southern Victoria, Australia. *Biological Conservation* 117: 143-150.

Gill-Sanchez JM, Moleán M, Otero M & Bautista J 2003. A nine-year study of successful breeding in a Bonelli's eagle population in South East Spain: a basis for conservation. *Biological Conservation* 118: 685-694.

Graham A, Simbotwe PM & Hutton JM 1992. Monitoring of an exploited crocodile population on the Okavango River, Botswana. In Hutton JM & Games I (eds) *The CITES Nile Crocodile Project*, pp53-69. Lausanne, Switzerland: Secretariat of the Convention on International Trade in Endangered Species of Wild Fauna and Flora.

Gumbricht T, Wolski P, Frost P & McCarthy TS 2003. Forecasting the spatial extent of the annual flood in the Okavango Delta, Botswana. *Journal of Hydrology* 290: 178-191.

Gurnell J, Clarke MJ, Lurz PWW, Shirley MDF & Rushtan SP 2001. Conserving red squirrels (*Sciurus Vulgaris*): Mapping and forecasting habitat suitability using Geographic Information Systems approach. *Biological Conservation* 105: 53-64.

Hutton JM & Games I (eds) 1992. *The CITES Nile Crocodile Project.* Lausanne, Switzerland: Secretariat of the Convention on International Trade in Endangered Species of Wild Fauna and Flora.

Idrisi32 2000. Idrisi I32.11 Clarke University [Online help]. Online available: http:// www.clarkelabs.org. Accessed: 2005.

Kepe T 2005. Grasslands ablaze: Vegetation burning by rural people in Pondoland, South Africa. *South African Geographical Journal* 87 (1): 10-17.

Kgathi DL, Mmopelwa K & Mosepele K 2003. *Assessing natural resource scarcity in the Okavango Delta: Case studies of key resources.* Discussion Paper. Maun, Botswana: Harry Oppenheimer Okavango Research Center.

Leslie AJ 1997. The ecology and physiology of the Nile crocodile (*Crocodylus niloticus*) in Lake St Lucia, Kwazulu/Natal, South Africa. PhD dissertation. Drexel: Drexel University.

Leslie AJ 2003. Okavango Crocodile Research Project: Progress Report #1. Stellenbosch: Department of Conservation Ecology, University of Stellenbosch.

Mapedza E, Wright J & Fawcett R 2003. An investigation of land cover change in Mafungautsi Forest, Zimbabwe, using GIS and participatory mapping. *Applied Geography* 23:1-21.

Mbaiwa J 2002. The socio-economic and environmental impacts of tourism development on the Okavango Delta, north-western Botswana. *Journal of Arid Environments* 54: 447-467.

McCarthy TS, 1992. Physical and biological processes controlling the Okavango Delta - a review of recent research. *Botswana Notes and Records* 24: 57-86.

McClanahan TR 1999. Recovery of a coral reef keystone predator, *Balistapus undulatus,* in East African marine parks. *Biological Conservation* 94: 191-198.

McClung MR, Seddan PJ, Massaro M & Setiawan AN (In press). Nature based tourism impacts on yellow-eyed penguins *Megadyptes antipodes*: does unregulated visitor access affect fledgling weight and juvenile survival? *Biological Conservation*.

Mendelsohn J & Obeid S, 2004. Okavango river: Flow of a lifeline. Cape Town: Struik.

Mosepele K 2002. Water and ecosystem resources in regional development: balancing societal needs and wants and natural resource systems. Work package 4 - Socio-economic and environmental change. Maun, Botswana: Harry Oppenheimer Okavango Research Center, University of Botswana.

Murray-Hudson M 1997. *Fauna of the Okavango River basin (Botswana sector).* Report. Maun, Botswana: Permanent Okavango River Basin Commission.

Murray-Hudson M & Parry D 1997. *Biophysical environment (Botswana sector).* Report. Maun, Botswana: Permanent Okavango River Basin Commission.

Natural Resources and People (NRP) 2001. *Okavango river panhandle management plan.* Gaborone, Botswana: Natural Resources and People (Pty) Ltd.

Nevo A & Garcia L 1995. Spatial optimization of wildlife habitat. *Ecological Modeling* 91: 271-281.

Petram W, Knower F & Kaczensky P 2003. Human influence on the choice of winter dens by European brown bears in Slovenia. *Biological Conservation* 119: 129-136.

Raadsman S & Loveridge JP 1988. Ecological zoning - Okavango Delta. Final report, Government of Botswana, Vol. I. Cooma, NSW, Australia: Snowy Mountain Engineering Corporation.

Ross JP 1998. Crocodiles: Status survey and conservation action plan. Gland, Switzerland: IUCN-The World Conservation Union,

Rubino MJ & Hess GR 2003. Planning open spaces for wildlife 2: Modeling and verifying focal species habitat. *Landscape and Urban Planning* 64: 89-104.

Saaty TL 1980. *The analytic hierarchy process. Planning, priority setting, resource allocation*. New York: Mc Graw-Hill.

Sergio F, Pedrini P & Morchesi L 2002. Adaptive selection of foraging and nesting habitat by black kites (*Milvus migrans*) and its implications for conservation: a multi-scale approach. *Biological Conservation* 112: 351-362.

Simbotwe M 1988. Crocodile research and management. Kalahari Conservation Society Newsletter no 21: 8-9. Gabarone: Kalahari Conservation Society library.

Store R & Kangas J 2001. Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modeling. *Landscape and Urban Planning* 55: 79-93.

Taylor GW 1973. Nile crocodile in the Okavango Delta. Mimeographed. Francistown, Botswana: Botswana Game Industries.

Van der Merwe JH 1997. GIS-aided land evaluation and decision-making for regulating urban expansion: A South African case study. *GeoJournal* 43: 135-151.

Van der Merwe JH & Lohrentz G 2001: Demarcating coastal vegetation buffers with multi-criteria evaluation and GIS at Saldanha Bay, South Africa. *Ambio*30, 2: 89-95.

Van der Merwe JH & Steyl I 2005. Rural solid waste management: A planning strategy for higher density agricultural regions. *Journal of Public Administration* 40, 3: 295-313.

Yamada K, Elith J, McCarthy M & Zerger A 2003. Eliciting and integrating expert knowledge for wildlife habitat modeling. *Ecological modeling* 165:251-264.

PERSONAL COMMUNICATIONS

Amose 2004. Crocodile farm egg collector. Shakawe, Botswana. Interview on December 12, 2004 about egg collection areas and human disturbance.

Leslie AJL, Bourquin SL, Wallace K, Detouf-Boulade A 2004. Okavango Crocodile Research team. Ikoga, Botswana. Interview on August 14, 2004 on selecting criteria to measure at crocodile nesting sites.

Leslie AJL, Bourquin SL 2004. Okavango Crocodile Research principle investigators. Stellenbosch, South Africa. Interview on April 20, 2004 on selecting weights for nesting criteria using the pairwise comparison matrix.