

Fifty years of crocodile surveys in
Africa: A review of the surveys
and population trends

Daniela Laínez

Dissertation proposal, Dept of Geography,
UCL (University College London)

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MSc Conservation

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This thesis is dedicated to Ana María Guerrero Martínez

Abstract

The present study is a metadata analysis and literature review of the surveys carried out in Africa to obtain population indices of the three crocodile species since 1955. The species concerned are *Crocodylus niloticus*, *Crocodylus cataphractus* and *Osteolaemus tetraspis*.

The study presents a critical assessment of the surveys regarding their geographical scope, consistency and the quality of the data generated so far with the aim of estimating population trends based on consistent and comparable surveys. Unfortunately, due to the overall inconsistency of the surveys in terms of time, space and methods, it was not possible to use all the data generated to date to estimate the trends. Since *C. cataphractus* and *O. tetraspis* were extremely underrepresented it was not possible to estimate trends for these species. Conversely it was possible to estimate trends for *C. niloticus* due to the greater representation of this species. Nonetheless, it was only possible to estimate trends of *C. niloticus* for 4 populations, 3 in Tanzania and 1 in Zimbabwe. This is a reflection of how fragmentary surveys have been in the last 50 years or more.

Trends were estimated from the survey data collected from the literature research. Methods to estimate trends included linear regression, generalised additive models and analyses of variance commonly used for monitoring data. The trends obtained for the case study populations indicate they are all undergoing recent declines, although they experienced important increase in the 1990s. The trends seem to be chiefly driven by the commercial value of *C. niloticus* and the effects of the Convention on International Trade in Endangered Species of Wild Fauna (CITES).

The contributions of this study to conservation include a database of crocodile surveys in Africa that will aid crocodile researchers in the planning of future surveys. It also identifies key areas where knowledge is required and proposes a series of recommendations for future surveys. Additionally it provides a reflection of the importance of sharing knowledge and joining conservation efforts at regional levels.

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Introduction

1.1 Conservation relevance of crocodiles

Crocodylians are of immense interest for conservation. From a scientific perspective they are 'living monuments of almost unbelievable antiquity' (Cott, 1975: 136). Being the only survivors of the group of archosaurian reptiles which ruled during most of the Mesozoic era, crocodiles can provide invaluable evidence of past ways of life (Cott, 1975).

Now, crocodiles play a key role in wetland ecology. As keystone predators and scavengers, they help maintain the complex balance and biodiversity of wetland ecosystems and are crucial for their conservation of these ecosystems (Leslie and Strydom, 2002). In wetlands where crocodiles have been removed, it has been observed that the number of predator fish species increase immediately upon crocodile removal to the detriment of the insectivorous and herbivorous fish species and aquatic macrophytes, generating an ecologic disequilibrium in the system. As scavengers, crocodiles eliminate dead, decayed and rotting animals from wetlands, helping to keep the waters clean (Musambachlme, 1987). They also contribute to wetland biodiversity by creating microhabitats for a great array of species through the nests, trails and holes they make in the ground which would not be available otherwise (Doren, 2006).

They directly depend on prey density, salinity, water level and the timing, location and amount of freshwater flow, crocodiles are good indicators of suitable environmental conditions in wetlands. Hence, they serve as indicators of ecosystem health and are commonly designated flagship species for wetland conservation (Doren, 2006).

Economically, crocodiles represent a significant source of income for many human communities across the world. Crocodile hides have an important market worldwide which has allowed the establishment of successful management programs for the sustainable use of several crocodile species and the development of the human communities associated with them (Thorbjarnarson, 1999). In some countries wild crocodiles also serve as major tourist attractions, generating important revenues for the local people (Cott, 1969; Toonen, 2003), and their eggs and meat are also widely used as a source of protein in many rural human communities (Klemens and Thorbjarnarson, 1995).

Nevertheless, crocodiles are also feared and disliked by many as a consequence of the widespread cases of human crocodile conflicts. The relevance of their conservation is

controversial, especially in many African countries where apart from destroying fishing gear and killing livestock crocodiles kill over a hundred people a year (Fergusson, 2008). Efforts to conserve crocodiles in Africa could be regarded as offensive to the 'local communities who bear the physical and economic costs of living with dangerous animals' (McGregor, 2005: 1). However, it is also true that crocodiles have an important role in mythology and folklore and in some countries like Benin and Burkina Faso in Africa, humans have managed to coexist peacefully with crocodiles due to ancient religious beliefs. In these countries they play central cultural roles and represent sources of medicinal products and income from tourism (Kpera, 2003; Toonen, 2003), making their conservation important for the livelihoods of the local populations.

The many different aspects of crocodiles and their ecological roles consequently make their conservation essential while simultaneously finding and enabling the means to control them and reduce conflicts with humans.

1.2 Crocodile species in Africa

In Africa there are three species of crocodylians whose taxonomy (IUCN, 2007), distribution, conservation and utilisation will be introduced in this section. These species are the Nile crocodile, the Long-snouted crocodile and the African Dwarf crocodile (Cott, 1975) (Figure 1.1).

1.2.1 Taxonomy

1.2.1.1 The Nile crocodile

Kingdom	:	ANIMALIA
Phylum	:	CHORDATA
Class	:	REPTILIA
Order	:	CROCODYLIA
Family	:	CROCODYLIDAE
Genus	:	<i>Crocodylus</i>
Species	:	<i>Crocodylus niloticus</i> (Laurenti, 1768)
Common name	:	Nile crocodile (English)

1.2.1.2 *The Long-snouted crocodile*

Kingdom	:	ANIMALIA
Phylum	:	CHORDATA
Class	:	REPTILIA
Order	:	CROCODYLIA
Family	:	CROCODYLIDAE
Genus	:	<i>Crocodylus</i>
Species	:	<i>Crocodylus cataphractus</i> (Cuvier, 1825)
Common name	:	Long-snouted crocodile (English)

1.2.1.3 *The African Dwarf crocodile*

Kingdom	:	ANIMALIA
Phylum	:	CHORDATA
Class	:	REPTILIA
Order	:	CROCODYLIA
Family	:	CROCODYLIDAE
Genus	:	<i>Osteolaemus</i>
Species	:	<i>Osteolaemus tetraspis</i> (Cope, 1861)
Common name	:	African dwarf crocodile (English)

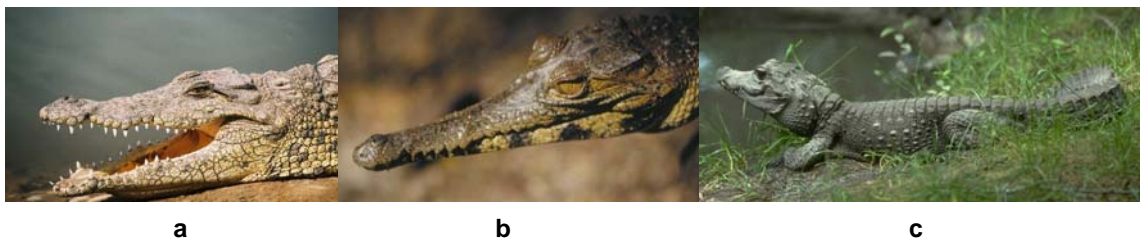


Figure 1.1 (a) Nile crocodile (b) Long-snouted crocodile and (c) African Dwarf crocodile (Sources: (a) Jimenez, M., 2005, (b) Schlüter, A., 2008, and (c) Croc City, 2008.

1.2.2 Distribution and habitat

The most recent distribution maps of the three species show that the distributions of *O. tetraspis* (Figure 1.2) and *C. cataphractus* (Figure 1.3) have much overlap, they are mainly present in the west and central regions of Africa whilst *C. niloticus* is more widely spread across Africa (Figure 1.4) (Table 2) (Britton, 2008).

The Nile crocodile's significant species distribution is a reflection of its wide habitat preferences. They occur in lakes, rivers, freshwater swamps, mangroves and brackish water. While *C. cataphractus* and *O. tetraspis* are comparatively far more habitat specific, the Long-snouted crocodile is highly aquatic and is mainly found in riverine habitats that have dense vegetation cover. However it has also been found in brackish waters, close to the coast and on offshore islands. The African Dwarf crocodile is typically restricted to permanent pools in swamps and slow-moving freshwater bodies in rain forests, but has been recorded in savannah pools. African Dwarf crocodiles are nocturnal and spend much of the day inside burrows that they construct (IUCN, 2007; Britton, 2008).

1.2.3 Conservation status

According to the 2007 IUCN Red List of Threatened Species, none of the three African crocodiles are classified as endangered. Nonetheless, *C. cataphractus* is categorized as data deficient (DD) which means there is not enough appropriate data on its abundance and distribution to assess its conservation status. *O. tetraspis* has been classified as vulnerable (VU A2cd) on the basis that it is dependent on conservation programmes and actually 'facing a high risk of extinction in the wild in the medium-term future' (IUCN, 2007). *C. niloticus* is considered a lower risk species (LW/lc), however it is stated that it 'may be threatened in part of its range'.

Conservation status of each of the three species throughout Africa is really uncertain; it was last assessed in 1996 and it is recognized by the IUCN (2007) that updating of their actual conditions is necessary.



Figure 1.2 Distribution map of *O. tetraspis*
 (Source: Ferioli and Britton, 2008)



Figure 1.3 Distribution map of *C. cataphractus*
 (Source: Ferioli and Britton, 2008)



Figure 1.4 Distribution map of *C. niloticus*
 (Source: Ferioli and Britton, 2008)

1.2.4 Utilisation

The most common and lucrative use of crocodiles is that of their skin. From the African species only the Nile crocodile has an important place in the international leather market. As a result they are legally ranched, bred and harvested from the wild to produce high quality hides in several African countries (Jenkins *et al.*, 2004). It is the only one of the three species which has been listed in the Appendix II of the Convention of International Trade and Endangered Species of Wild Fauna and Flora (CITES) for some countries, indicating that their skin can be traded under strict regulation (CSG, 2008). The other two species are both listed in Appendix I of CITES so their skins cannot be legally traded; however, it is possible and indeed common to find hides of these species in local markets which indicates that they are used for their skins although not as widely as the Nile crocodile (Eaton, 2006).

All three species are also used as protein sources and are especially hunted for their meat in Central and West Africa (Klemens and Thorbjarnarson, 1995). In the case of the Nile crocodile, meat is also a side product of the skin trade business, and since in many areas it has not been traditionally consumed by humans, it is used to feed livestock (Ross, 1998). In contrast, *Osteolaemus tetraspis* is widely hunted for human consumption, and due to its relatively small size and slow metabolism it is a convenient target species and can be easily transported alive for long distances without spoiling the meat. Sometimes they are even stored and sold only when other game is not available 'elevating the crocodile to the biological equivalent of a savings account' (Eaton, 2006).

Eggs are also collected as a food source but intensity is low and does not surpass that of the subsistence level (Klemens and Thorbjarnarson, 1995), however they are intensively collected for captivity breeding programmes in the skin trade business (Jenkins *et al.*, 2004).

Other important uses include their importance as tourist attraction, especially in the case of the Nile crocodile (McGregor, 2005) and as source of traditional medicine (Kpera, 2003).

1.3 Crocodile survey methodologies

Monitoring of crocodiles is crucial for their efficient conservation, harvest and control. Crocodile population surveys have been carried out across Africa since Cott's seminal work in 1952 (Cott, 1961), however, they have been independently planned (Ross, 1998) to the

point that it is not known if the methodologies used for some populations have been consistently repeated over the years as to make their results comparable.

Many different methodologies have been developed for surveying crocodiles in the effort of improving the precision and accuracy of the results as well as making them more cost effective (Magnusson, 1982; Bayliss, 1987; Graham, 1988; O'Brien, 1990). This section introduces the different crocodile survey methodologies by describing the field techniques and the counting designs possible for each type of survey, since it is the choice of methods that determines the precision and accuracy of the surveys. Special attention should also be given to recording the precise dates and locations of surveys. No matter how reliable the methods are, if surveys cannot be located in time and space they are useless for monitoring purposes (Sutherland, 2006).

Crocodile surveys can be basically separated into two groups: those which count animals and those which count nests as indicators of population size (Magnusson, 1982).

1.3.1 Animal counts

1.3.1.1 Field techniques

Field techniques for counting crocodiles can be separated into two subsets, those carried out from the ground and those from the air:

(a) Ground surveys

Ground surveys to count animals can be divided into those done at day and those at night. Day surveys can either be done by foot or boat. However, ground day counts are seldom done because they record only a small proportion of the animals counted on the same route during night and aerial counts (Parker and Watson, 1969). As a consequence the most common ground counting technique is the spotlight count done at night.

When exposed to light at night, crocodilian eyes reflect the light and shine in a distinct and recognizable way (Walker, 1938). Additionally spotlights dazzle crocodiles making them easier to approach for identification and size classification and the spotlight night count is based on these factors. These counts can be done by foot or boat, depending on the terrain, with the advantage that using boats allow for a greater coverage. The speed of the boat is important, the slower the better (Magnusson, 1982; Graham, 1988; O'Brien, 1990).

Advantages of boat based night counts include the following: they can be used in almost all habitats, they coincide with the nocturnal habits of crocodiles, eye reflections are visible from long distances and animals of all sizes can be detected (Magnusson, 1982; O'Brien, 1990). Nonetheless, Bayliss (1987: 163) states that in the case of *Crocodylus porosus* 'older and larger crocodiles are usually more wary and difficult to detect'.

The weaknesses of the method consist chiefly of the visibility bias that can be caused by the vegetation density on the banks and water, the size of the water body being surveyed, the number of bends and frequency in waterways, the position of the animals at the moment of searching for eye reflections (floating, submerged, etc.) (Bayliss, 1987) and the animals that 'learn to avoid the spotlight under heavy hunting pressures' (Magnusson, 1982: 393). The field technique can also be costly, considering the time taken relative to the area that can be surveyed in one night. Even so, it is a useful index as long as it is always understood that a significant proportion of the population is missed by the counting methodology and the procedures are standardised to keep this proportion constant in further surveys. Although intrinsically inaccurate, these surveys can provide with a precise index of abundance.

(b) *Aerial counts*

Aerial counts have been tried both during the day and night, however the night counts were done only once because the results, as compared to night ground counts, did not differ much and the cost of using an aircraft is much higher (Parker and Watson, 1970). Aerial day counts have been established as the most common cost-effective method for surveying crocodiles considering the large area that can be surveyed, the time taken and the repeatability of the method (Caughley, 1977). The other strength of aerial counts is that 'crocodiles are much easier to see from above water level and large animals in particular seem less apt to dive in the presence of an aeroplane than a boat' (Graham, 1988: 76).

The use of fixed-wing aircrafts dominates in aerial surveys. Helicopters have also been used but earlier research by Parker and Watson (1970) indicated that a fixed-wing aircraft can be as efficient as a helicopter and significantly cheaper. Microlight aircrafts have only been used recently by Combrink and Ross (unpublished) who assure they are 'the perfect aircraft' for crocodile surveys due to the 'manoeuvrability and slow flying speed which allowed for teardrop turns over the channels of the lake and, in some instances, could do a 360° turn with relative ease for a repeat observation'; while in comparison, fixed wing aircrafts impose height, speed and manoeuvrability limitations. However, the efficiency of

microflight surveys have yet to be tested and compared with more commonly used fixed-wing aircrafts.

When considering aerial counts, the pilot becomes very important, especially 'when surveying lakes where the experience and ability of the pilot to perform tight turns close to the ground are the order of the day and the counts increase the better the pilot' (Games and Severre, 1996: 19). In addition, as discussed by Graham (1988: 77), much is gained by the participation of 'biologist-pilots' who have the 'ecological know-how to position an aircraft for an observer to gain a consistent view of the features he needs to see,' and as opposed to professional pilots, are more keen to perform the 'uncoordinated turns at very low speeds near the ground which are essential when surveying meandering channels'.

The greatest problem with aerial counts is that they are 'strongly biased against small animals' (Magnusson: 392), hence they reveal a smaller proportion of animals than spotlight counts. In addition, they are not useful in all habitats, since areas with tall vegetation reduce visibility from the air greatly (Magnusson, 1982). Just like with all ground counts, in aerial counts it is not possible to count all animals, so they serve only as indicators of population size. Still, the indicators can be quite significant if sources of bias, error and variability are kept to a minimum by standardising and trying to keep constant within surveys the speed and altitude of the aircraft, the widths of the transects or size of samples, the type of vegetation cover (Graham, 1988) and of course the experience of the pilot and observers (Games and Severre, 1996).

Finally, in all crocodile surveys, water level and weather conditions have a direct effect on the number of animals to be seen (Hutton and Woolhouse, 1989; Games 1990), hence their variability should be minimized by standardising the time of the year of the surveys, and time of day. This is especially important for day counts, as results would be more accurate if surveys are performed during the times of peak basking behaviour of crocodiles since more animals will be out of the water and more likely to be counted (Modha, 1968).

1.3.1.2 Counting design

The counting design for any of the field techniques previously described can be planned to be a total count or sample count. The more practical and cheaper sample counts are more common. Sample counts involve selecting representative areas to count within a demarcated survey area and extrapolating the results of the samples to the whole area (Graham, 1988). As all of the field techniques are unable to produce exact counts of crocodile populations the surveys have to be used as population estimates of relative

abundance, and the consideration of precision and accuracy becomes crucial in the design of a crocodile count as it will help assess the quality of the estimates obtained. All surveys should try to use methods to give a quantifiable measure of accuracy and precision.

(a) Accuracy

In statistics the measure of accuracy is called bias, which makes reference to the difference between the real number of a population and the one estimated by the survey. In this case it depends directly in the capacity to observe all the crocodiles in the sampling area during a survey (Bayliss, 1987).

Three main classes of visibility bias have been identified and described in table 1.1 which also shows the effects these biases have on counting results and the methods developed to calculate their magnitudes of the bias. The compensation methods used to correct the estimates for better accuracy are based on the magnitudes of each bias.

Table 1.1 Main classes of visibility bias in crocodile surveys, their effects and methods to compensate for them (adapted from Graham, 1980)

Class	Description	Effects	Compensation method
Observer bias	Visible animals overlooked by observer	Usually evenly spread among habitats and seasons	Simultaneous double-counts or tandem counts (Magnusson and Caughley, 1978)
Diving bias	Animals submerged at the time of the count	Usually evenly spread among habitats and seasons	Mark-recapture experiments (Hutton and Woolhouse, 1989)
Concealment bias	Animals hidden by vegetation or other obstructions	Usually varies widely among habitats and seasons	Surveys done at low water levels in rivers and lakes for partial correction. No method for permanent swamps

The simultaneous double-counts or tandem counts proposed by Magnusson *et al.* (1982: 78) for incomplete counts aim to reduce observer bias. They rely on the fact that counts can be made more accurate if two observers count for crocodiles and it is possible to discern between those animals only seen by observer 1, those only seen by observer 2 and those seen by both. This allows for mathematical accounting of the number of crocodiles missed by both and arriving at a more accurate estimate by reducing the number of

crocodiles overlooked (Magnusson and Caughley, 1978). However this counting method is time-consuming.

Mark-recapture experiments are the only means of estimating the total size of a population and therefore the only way to test for visibility biases. However the methodology is complex and not practical enough to be included in conventional surveys (Graham, 1988).

To account for concealment bias, surveys done at low water levels have been used to calculate partial correction considering it is easier to see through vegetation when the water levels are low. However, this method can only be applied in rivers and lakes where water levels change (Graham, 1988), and even though visibility through vegetation improves a lot during low water levels vegetation is still present thus representing potential obstruction to the observation of crocodiles.

(b) Precision

To improve precision, variation among counts needs to be kept to a minimum. Apart from standardising field techniques, the stratification plan of a sample count must be made as the standard error obtained will be a direct reflection of it. By choosing the right areas into which a survey region is stratified, the sampling fraction, the length of the stratum to survey, and the number of samples it is possible to keep the coefficient of variance low and thus make the results more precise (Graham, 1988).

1.3.2 Nest counts

1.3.2.1 Field techniques

Nest counts are a good alternative where habitats are inaccessible for animal counts or where they can be coupled to egg collection programmes. Counts can be done from the air or ground. Aerial nest counts are quite similar to animal counts from air, with the difference that they search for sites likely to have nests such as banks of sand or soil above water level (1m approximately), exposed to the sun, several metres away from the water and usually being looked after by a mature female (2.7-3.5m long). Other signs for nests include areas where 'lies' or paths between vegetation are observable from the air. Use of aerial photography is also common to plot the nesting sites and have them as a guide for future nest counts (Magnusson, 1982; Graham, 1988; Riley and Huchzermeyer; 1999).

The ground counts use the same criteria in the search of nesting sites, they can be done either by foot, boat or both. However, since some nesting sites are not attended closely by crocodiles, probing with a sharp rod is sometimes used to find nests in possible nesting sites. As in aerial counts, experience of searchers is crucial in the detection of nests (Graham, 1988).

1.3.2.2 Counting design

Due to the fact that crocodile nests are, but for very few exceptions, always exposed to the sun, it is possible to estimate the absolute number of nests in a particular area. As a result visibility bias is the most significant source of error in nest counts and it is accounted to overlooked or misinterpreted nests by surveyors. Hence, estimation of this generally small error is the main feature to be accounted for at the design stage of the survey. The approach taken to reduce this error is to have both aerial and exhaustive ground surveys to count nests. For both methods all nests found should be accurately plotted on an aerial photograph or map so that exact comparisons can be done between methods and it is possible to identify the nests missed by each and calculate the resulting visibility bias (Magnusson, 1982; Graham, 1988). Since the nesting season lasts several weeks it is also important to decide on the most appropriate dates for the survey. (Graham, 1980; Waitkuwait, 1985).

1.4 Estimation of population trends

Population trends have not been estimated yet for the crocodile species in Africa. The closest efforts have plotted relative population densities against time in simple scatter graphs (Mafole *et al.*, 2003). These kind of yearly indices can provide important information regarding changes from year to year; however them alone are not sufficient if considered that changes often respond by stochastic factors of little conservation importance such as the weather conditions at the moment of surveys. It becomes more appropriate and relevant to test for systematic overall trends occurring over a period of years which provide with statistical parameters and significance levels (Ter Braak *et al.*, 1994; Morris and Doak, 2002).

Generally, to calculate population trends of any wild species it would be ideal to use count data together with values that account for the influence of demography, migration, habitat distribution and genetic processes in the growth rate of a population (Morris and Doak, 2002; Craig, 2004; Goodman, 2004). However, this level of knowledge is not common for the populations of all species; in fact, cases where it exists are rare and usually involve

species of commercial importance rather than those of conservation concern (Morris and Doak, 2002). Regarding African crocodiles, a population model has been proposed only for the Nile crocodile (Craig *et al.*, 1992). However there is much uncertainty involved in the model caused by the poor knowledge of survivorship to age one, the age of maturity and survivorship from age one to maturity.

As an alternative to complex population models for estimating population trends, Dennis *et al.* (1991) proposed a method to estimate population growth parameters from count data only. The counts do not necessarily have to include the whole population of certain species, they can be counts of subsets of the population, as long as the set counted represents a relatively constant fraction of the entire population. The minimum amount of survey data recommended to perform this analysis is ten years worth. This method, widely used and accepted in conservation (Morris *et al.*, 1999), entails estimating the population growth parameters, μ and σ^2 , by linear regression of the log population growth rate of a certain time interval ($\log(N_{i+1}/N_i)$) against the time elapsed ($t_{i+1} - t_i$). The parameter μ , represented by the slope of the regression, determines how fast the mean of a population increases ($\mu > 0$) or decreases ($\mu < 0$), serving as an indicator of the general trend of the population during the interval of the surveys estimated. The value of σ^2 , represented by the regression's error mean squares estimates, is a measure of how quickly the variance in the normal distribution of the population increases.

This method can be done with any statistics package. Although more complicated than to simply estimate them as mean and variance, the linear regression method has the advantages that it also provides the confidence intervals of the parameters and allows the identification of outliers and testing for temporal autocorrelation of the population growth rates (Morris and Doak, 2002).

The linear regression approach works very well when the main objective is to examine the overall trends in population count data over a number of years. In addition it can deal with considerable amounts of missing data (Morris and Doak, 2002). However, the fit of the model is likely to be poor when the patterns of change are noticeably non-linear; which often occurs with long-term non-linear trends of population numbers. The most common and accepted way to overcome this restriction is to perform the regression as a Generalised Additive Model (GAM). GAMs can be considered extensions of the traditional linear models, with the advantage that they provide with greater flexibility allowing any shapes and curves in trends. They can be applied to any settings where linear models are normally used, like count data and time series in this case (Hastie and Tibshirani, 1990; Ter Baak *et al.*, 1994).

In the population trends context, GAMs are especially useful when dealing with long-term datasets as they allow further and more complex investigation than overall trends. With long-term datasets it is possible to reliably identify key years when significant changes occur in the tendency of a population. This is done by using the simple curve of abundance indices to estimate a curve of second derivatives and identifying the years when the second derivative is significantly different from zero. These points indicate a drift in the direction of the trend and aid to suggest causes for these changes. GAMs are also useful tools to identify the timing and extent of population declines. Nonetheless, they are more complex to undertake than linear regressions and require considerably larger computer power when dealing with large datasets (Ter Baak *et al.*, 1994; Dennis *et al.*, 1995; Fewster *et al.*, 2000, van den Hoff *et al.*, 2007).

1.5 Research rationale and scope

Given that there is no integrated view of the status of the crocodile populations throughout Africa, despite the fact that surveys have been conducted for more than fifty years, before continuing to survey crocodile populations in this fragmentary manner it is of crucial importance to analyse and incorporate all the surveys carried out so far. Assessment of the approaches used can be conducted with the purpose of investigating the possibility of obtaining reliable population trends from their results and to use the knowledge generated to plan further monitoring of the three species. For this purpose the present study draws upon the data generated by the crocodile surveys carried out in Africa since 1955. It is a metadata analysis and a literature review of the crocodile surveys carried out to date.

Previous efforts to reflect on the conservation status of the three crocodylian species across Africa (Cott and Pooley, 1971; Pooley, 1982) have collated data from different countries resulting in descriptive compilations, but with almost no data for West and Central Africa. In addition, a project by CITES (1993) carried out surveys in countries in these regions in the effort to extend the knowledge of their status across Africa. Yet, there has been no analysis of the surveys carried out, their methodologies or the results produced by these surveys so far, and no recent effort to put current knowledge of the African crocodile surveys together.

Apart from the results obtained by this study, the database produced and literature compiled will provide an important reference tool for the IUCN/SSC Crocodile Specialist Group. The tool will be managed by the World Conservation Monitoring Centre (WCMC-UNEP) after the project and will be made freely available to all users in the hope and expectation that more surveys will be done for the benefit of the three species. In addition

the database will allow researchers to upload up new data from their further research to keep it functional.

1.6 Aims and objectives

Considering the need for a current review of the conservation status of the African crocodiles which is based on an analysis of the actual surveys and methodologies, this dissertation has two overall aims which are to:

- 1- Critically assess current knowledge of crocodile surveys in Africa, and
- 2- Estimate the population trends of the African crocodile species

The objectives addressed to achieve these aims are to:

- 1- Construct a database of crocodile surveys in Africa from 1955 onwards
- 2- Map all crocodile surveys on distribution maps of the species
- 3- Analyse the surveys for consistency in terms of their spatial and temporal distribution and the quality of the data they have produced, and
- 4- Identify crocodile populations for which there is enough survey data to estimate trends and quantitatively analyse these trends

2 Methodology

2.1 Collection of survey data

Three channels were used to collect the literature from which to extract the survey data required for this study.

The initial search for literature identification was done in the personal library of Dr. Hutton, Director of WCMC-UNEP and Chairman of the CSG in Europe.

The second search was for electronic sources. Recent literature-based studies have found the *ISI Web of Science* very effective in the search of peer reviewed and copyrighted material (Molony, 2003; Gottschalk *et al.*, 2005). This study made use of the MetaLib system available at the library of University College London to increase the universe of literature searched. This allowed to carry a cross-search of the *ISI Web of Science*, *JSTOR*, *Science Direct (Elsevier)*, *Blackwell Synergy* and *Wiley InterScience* journals. Since most of the crocodile survey literature was thought to be in the form of 'gray' or unpublished literature the search was also extended to *Google Scholar*. All searches focused on the terms "*Crocodylus niloticus*", "*Crocodylus cataphractus*", "*Osteolaemus tetraspis*" or "crocodiles", in any combination with the terms "survey" and "Africa". Additional web searches were also done for references found through the 'snowball system' in related literature.

The third via to data sources was through contact with key crocodile researchers. First, contact was established by Dr Hutton with Professor Webb, Chairman of the CSG, and another 9 crocodile researchers. These contacts provided contact details of a further 14 researchers involved in crocodile surveys. All 23 researchers were contacted in request of survey data. Replies were received from 21 researchers and to date, 11 of them have provided with crocodile survey data.

2.2 Collation of survey data

Metadata is the "data about data", and is used to facilitate the storage, management and analysis of large sets of data. In conservation, the purposes for which metadata is used vary greatly. There are metadata of the world's natural history collections, the world's ecoregions, inventories of wetlands, deforestation, biodiversity, protected areas and wildlife surveys (NRCS, 1998; NBII, 2008a and 2008b; WWF-SARPO, 2008). All of these store

different kinds of information but share the same basic components of metadata standards defined to make data management efficient (ANZLIC, 2008) (Figure 2.1)

Data regarding population censuses and surveys is of special importance in conservation since it can be used to estimate the trends and conservation status of populations. This kind of data is usually collected, stored and managed by governmental institutions and is more commonly found for groups of species of commercial importance (NBII, 2008a). For species of extensive natural distributions that include the boundaries of several countries within them, metadata can be of great importance. It allows storing, comparing and analysing information on the population status of a species over the entire range of the species. Metadata can therefore be used to identify areas of special conservation concern for species and to integrate conservation efforts within nations (Odongo and Rodrigues, 2008).

For this study, a database was constructed to collate the data of crocodile surveys in Africa. It was built in *Microsoft Access 2000* considering *Access* is lightweight and can accommodate large databases convenient for future use by WCMC-UNEP. The fields included in the database were selected based on the metadata standards and the principles which dictate crocodile surveys as identified from the literature review, these are shown in Figure 2.1. With the design of the database ready, the relevant data was extracted from the literature and added to the database.

Data concerning the location of the survey sites had to be standardized to a common geographic system of coordinates since it was presented in different formats in the literature. These formats ranged from the basic location names only to the highly specific GIS produced maps showing the routes of the surveys. To standardise the data, the geographical references available were used to search for the survey sites in the Global Positioning System (GPS) of *Google Earth version 4.2*. Once found, the mouse pointer was located in the middle point of the survey site to record its latitude and longitude coordinates and add them to the database all in a same decimal degrees unit system. The field of the database named 'locator coordinates' was thus the only field which was completed using indirect data.

2.3 Descriptive analysis of the surveys

The data were imported to *Microsoft Excel* for the respective analyses since *Microsoft Access* is an application for storing data and not suitable for analysis.

Given that occasionally multiple surveys were undertaken as part of a single expedition, surveys were all grouped into their corresponding expeditions to be assessed for quality and temporal distribution. Expeditions were then assessed instead of the surveys themselves. This was for two main reasons. First, to avoid 'pseudoreplication' as surveys undertaken during the same expedition would not be independent; they would most likely have the same quality parameters and measures to account for bias and precision. And secondly, out of necessity because the specifics of all surveys were not always provided in the literature, and were simply stated for the expeditions as a whole. Hence, even though it would have been interesting to compare results obtained when treated as expeditions and as independent surveys, this was not possible with the available data.

2.3.1 Temporal distribution of surveys and methodologies

To get a general idea of how the survey expeditions have been distributed in time since the first survey in 1955, the number of expeditions per year were plotted in a scatter graph. To compare the distribution of the two basic types of survey over time, a graph was produced which showed animal counts and nest counts against time.

To analyse how survey techniques have changed over time, only animal counts were assessed. Methodologies for surveying crocodile nests have remained the same since the first nest counts (Graham, 1987). The animal counts were separated into aerial, spotlight, day boat counts and foot counts, and each category was then analysed for changes in survey techniques.

All expeditions that included surveys undertaken from air were grouped together. These included surveys from helicopters, planes and microlights. Surveys carried out from helicopters and planes are perfectly comparable (Parker and Watson, 1970). Results obtained from microlights are yet to be compared with the results from planes and helicopters, nonetheless microlight were included as aerial surveys since they only account for one expedition and the technique used is basically the same as that for plane and helicopter surveys (Combrink, unpublished).

All night counts were grouped as 'spotlight counts' considering they work under the same principles.

Day counts from ground were separated into boat counts and foot counts, and in the case of foot counts a distinction was made between day and night counts they rely on different principles.

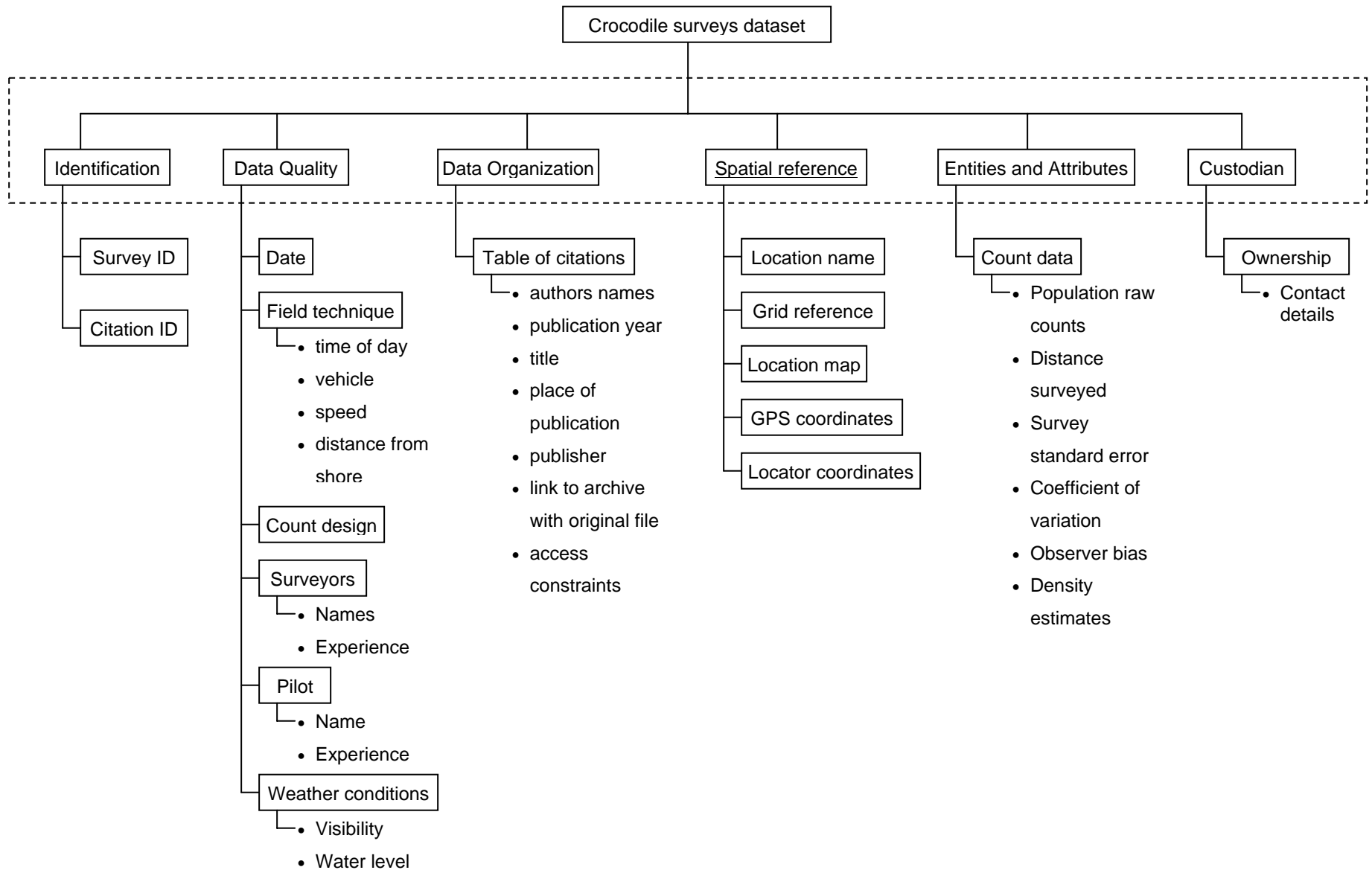


Figure 2.1. Scheme of the database design (the dotted rectangle indicates the metadata standards that guided the organisation of the data and the boxes below present the fields of the database).

2.3.2 Quality of the survey data

The quality of a population survey is determined by its repeatability and the reliability of its methods. Only if the specifics of a survey are recorded and presented precisely with the survey results, can the survey be repeated consistently and the data used. It is also important to ensure the collected data is reliable and adequate enough to estimate population trends and make judgements on the status of the population surveyed.

For crocodile surveys, the ideal fields of information that would be required to assess the quality and consistency with which the methods have been applied are outlined under the headings *Data Quality* and *Spatial Reference* in figure 3.1. These fields were intended to be used to analyse the consistency of the survey methodologies, however, through the data collation phase of this study it was noted that very few survey expeditions collected or recorded all this data. Due to the time constraints of this study and the great number of surveys to be assessed it was decided to analyse quality based on the precision with which the basic features required to repeat a survey were recorded. These features are the location, date and the methodologies to account for sources of bias and error.

Location can be recorded with different levels of precision. These levels include, in decreasing order of precision, GPS coordinates, maps, grid references and location names. With the use of *Microsoft Excel 2000*, pie charts were drawn to illustrate the proportion of differing levels of precision in recording survey locations.

In the effort to standardise survey methods it is always important to repeat surveys at least in the same season. Dates can be excellent references of the environmental conditions under which a survey may have been undertaken, i.e. weather conditions. Hence, recording the date of a survey as precisely as possible is important. The dates of surveys like the survey location variable, were recorded with different levels of precision, ranging from exact dates, to month of the year, and year only. As with the location data, pie charts were produced to illustrate the differing categories of quality with which this data has been recorded.

Finally, the percentage of survey expeditions which have included a compensation method to account for sources of bias and error was also illustrated.

2.4 Mapping of surveys

2.4.1 Distribution of all crocodile surveys

The software used for the mapping procedures was *ArcGIS version 9.2*. For an overall assessment of the distribution of crocodile surveys across Africa, all survey locations were mapped on a political map of Africa that shows the area of the continent where crocodiles are present. The map chosen as political map was one used by Britton (2008). Since the map was in the .JPEG image format it had to be georeferenced first so that the layer with the survey locations could be further added. Ten control points were used to georeference the image while keeping the residual error at a minimum. The control points selected were conspicuous physical features of the African continent. These points were first viewed in *Google Earth version 4.2* to record their coordinates. The coordinates recorded for each selected point were then added to the image in decimal degrees with the use of the georeferencing toolbar in *ArcMap version 9.2*. Once the ten control points were added they were saved as a text file so that they could be loaded and used whenever required again. Since the distribution maps of all three species used the same base map, the georeferencing layer was loaded to each distribution map. The distribution maps of the three species (Britton, 2008) were overlaid on top of each other with different levels of transparency and the merged distribution of all three species was used to output a single shape file. The last step was to add the coordinate data of all the survey locations on to the final map. The longitude and latitude were exported from the database to *Microsoft Excel 2000* where it was saved as a tab-limited text file and then added to the map in *ArcMap*. The data was displayed as XY coordinates on the map of Africa. Circled symbols of different sizes were used to show the number of surveys carried out in each survey site.

2.4.2 Distribution of the three species

Three different maps were produced, one map for the distribution of each species by Britton (2008) and were used to create a shape file for the latest distribution of each species. These shape files were each overlaid over a land cover map of Africa (GEM, 2000). As with the previous map produced, this vegetation map was georeferenced using ten control points of known geographical coordinates.

On the distribution map of the Nile crocodile, two text files turned into shapefiles were added; one containing the geographic coordinates of the survey sites which had found crocodiles and the other with the coordinates of the surveys where the species was absent. These coordinates were displayed as different features over the map. This served to

illustrate the distribution of the surveys that have had the Nile crocodile as a target species, differentiating between the sites where it was found and where it was absent; all in relation to the currently recognised distribution of the species. The same process was repeated for the Long-snouted crocodile and the African Dwarf crocodile survey data.

2.5 Population trends

2.5.1 Identification of case studies

The first step in calculating the population trends of crocodiles in Africa was to identify those populations that counted with sufficient and consistent surveys. Considering that a minimum of ten years of data is required to calculate reliable population trends (Morris and Doak, 2002), countries which had 10 or more years of survey data were identified. The selected countries were then analysed to establish whether the surveys were comparable; namely, if they had been carried out in the same locations and if the survey methods had been the same.

Count data from locations found to have sufficient and consistent data were selected as case studies to calculate population trends. Data from different locations was treated separately but with the same methods.

2.5.2 Quantitative analysis of case studies

The main objective of the quantitative analyses was to estimate the trends of the abundance indices of the case study populations. Linear regressions proposed by Dennis *et al.* (1991) were first applied. However, in the effort of improving the fit of the models GAMs were also performed (Fewster *et al.*, 2000). More complex investigations regarding GAM analyses were not performed due to the time constraints of this study and the small amount of data that could be reliably analysed. Nonetheless, analyses of variance were also applied to find if there was an overall trend in the data.

Prior to the analyses, count data was entered to *Microsoft Excel 2000* to be log-transformed in order to remove the variance on the uncertainty of the points (van de Hoff, 2007).

2.5.2.1 Linear regression

One of the assumptions of linear regression is that the variance of the dependent variable should be constant over different values of the independent variable (Freund and Wilson, 1998). In this case, count data was not available for equal time intervals; hence μ and σ^2 would be larger in the pairs of surveys separated by longer time intervals. To avoid violating the assumption of equal variances, the first step of the linear regression was to eliminate this dependence. The transformation equations proposed by Dennis *et al.* (1991) were used for this purpose. Equation 1 was used to eliminate the dependence between the time elapsed within surveys ($t_{i+1} - t_i$) and equation 2 to eliminate the dependence of the log-population growth rate ($\log (N_{i+1} / N_i)$):

$$x_i = \sqrt{t_{i+1} - t_i} \quad (1)$$

$$y_i = \log (N_{i+1} / N_i) / x_i \quad (2)$$

where,

X_i = transformed variable of time elapsed between surveys (independent)

y_i = transformed variable of population change (dependant)

t_i = year i

t_{i+1} = year $i+1$

N_i = number of individuals in the population in year i

N_{i+1} = number of individuals in the population in year $i + 1$

All transformations were done *Microsoft Excel 2000*. Once the data was transformed, the next step was to perform the linear regression. *SPSS v.14* was used to regress the y_i 's against the x_i 's. The intercept of the regression was forced to be zero by choosing "no constants" in the regression options. Other options chosen to run the regression were the Durbin-Watson statistic (d) to test for autocorrelation in the population growth rate and the regression diagnostics to test for outliers. Sets of data found to be outliers or autocorrelated were assessed to decide if they should be included in the linear regression. The value of μ would be given by the slope of the regression and σ^2 by the regression's error mean square.

2.5.2.2 Generalised Additive Models (GAMs)

Non-linear models were used to test if they provided better fits. For this purpose the free and specialised software *R version 2.5* was used (R Development Core Team, 2007). To

perform the non-linear models, GAMs were applied to the log-transformed count data using the default settings provided by the GAM fitting routine function which estimate the adequate smoothness (Hastie and Tibshiranie 1990). Once the models were fitted, the fitted values were transformed back in to count data in order to display them graphically as such and facilitate interpretation.

2.5.2.3 Analysis of Variance (ANOVA)

In order to see if it is possible to observe an overall trend in the data, *SPSS version 14* was used to perform One-way ANOVAs to test for differences between the means of the population abundances. First a One-way ANOVA was executed to all the population abundance data, which is the animal counts of Ulanga, Ruaha and Kilombero and the nest counts of the Zambezi. Next, to see if there was an improvement, the analysis was rerun but comparing only the data collected in same years to have the same number of replicates in each groups and avoid entering missing values. Finally, a One-way ANOVA was performed only to the data of animal counts for same years considering it would be more appropriate to compare between same indices of abundance only.

3 Results

3.1 Sources of data collected

A total of 89 sources of survey data (Appendix 1) were collected from the three different search engines. Most of these sources were collected from the personal library of Dr. Hutton (46%) and through personal contact with key crocodile researchers (43%). Only 11% of the literature collected was found on the internet. The data sources collected included institutional reports, journal articles, theses, books, conference proceedings, letters, e-mails, report extracts and material that has not been published yet (Table 3.1).

Table 3.1 Contribution of the different types of survey literature to the study

Type of reference	Percentage
Institutional reports	46
Journal articles	19
Books	8
CSG Newsletter	6
Unpublished material	6
Letters	6
Conference proceedings	4
Theses	3
E-mails	1
Report extracts	1

3.2 Survey data collated

3.2.1 General description of the survey expeditions

Two hundred and fifty crocodile survey expeditions have taken place in Africa since 1955, and each expedition involved several surveys. The total number of surveys was calculated as 828, however for 68 of the 250 expeditions (27.2%), the number of surveys undertaken was not provided in the literature and were considered as single surveys in the overall count. The number of surveys per expedition, calculated only from those expeditions for which the number of surveys was recorded vary considerably (mean \pm SE = 3.74 \pm 5.90, range = 1-33, n = 182).

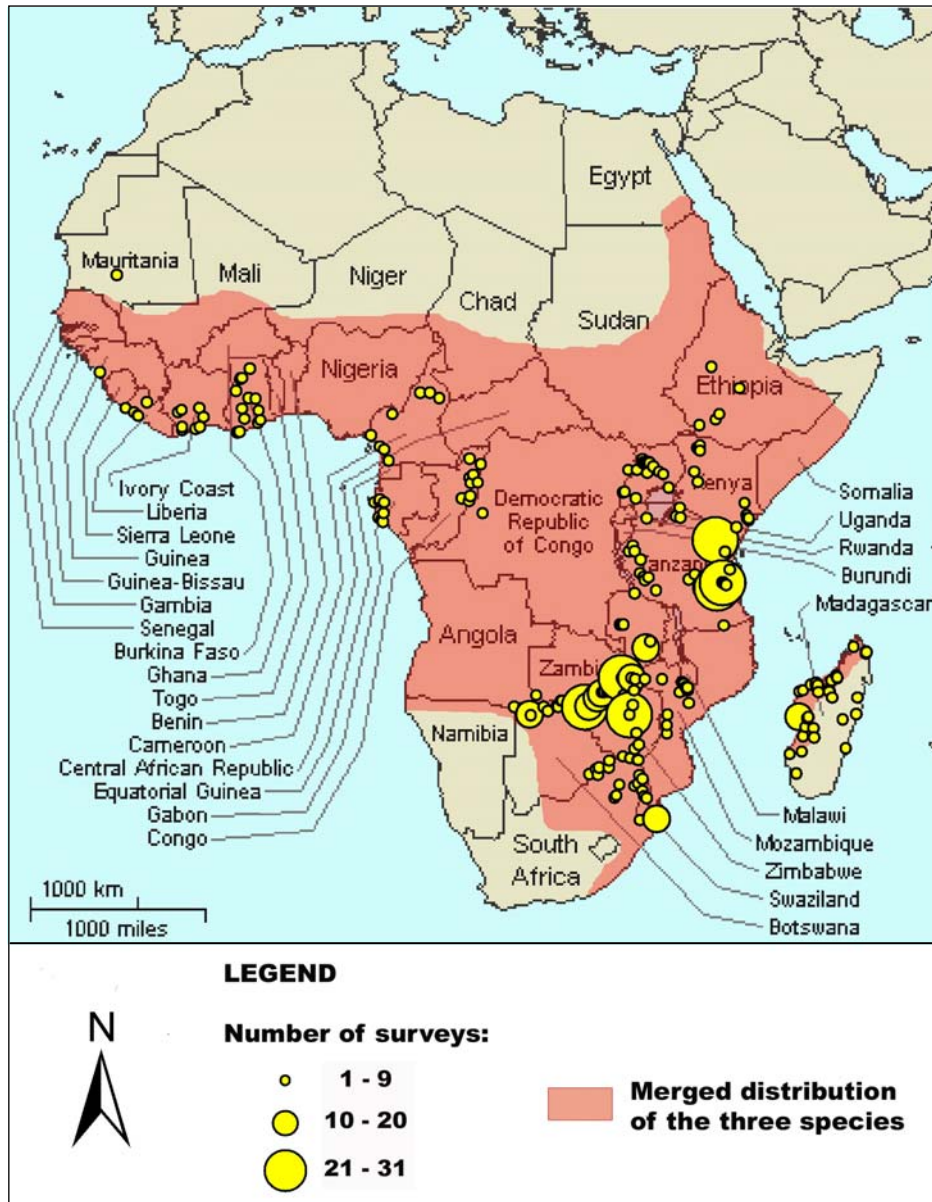


Figure 3.1 Distribution and abundance of surveys throughout Africa.

The Southern region of Africa showed the largest number of survey expeditions, followed by East Africa. Comparatively Central and West Africa showed very few expeditions (Figures 3.1 and 3.2a). The majority of expeditions had *C. niloticus* as target, whilst *C. cataphractus* and *O. tetraspis* were largely underrepresented by the surveys (Figure 3.2b). Expeditions that counted both animals and nests are also rare. Most of the expeditions counted animals as indicators of population size; however the number of expeditions counting nests was also important (Figure 3.2b). Field techniques to count animals are diverse, and expeditions usually involved more than one technique. Spotlight counts were the most common technique included in survey expeditions followed by aerial counts as the

second most numerous method employed. Day boat counts were less common and foot counts rare (Table 3.2).

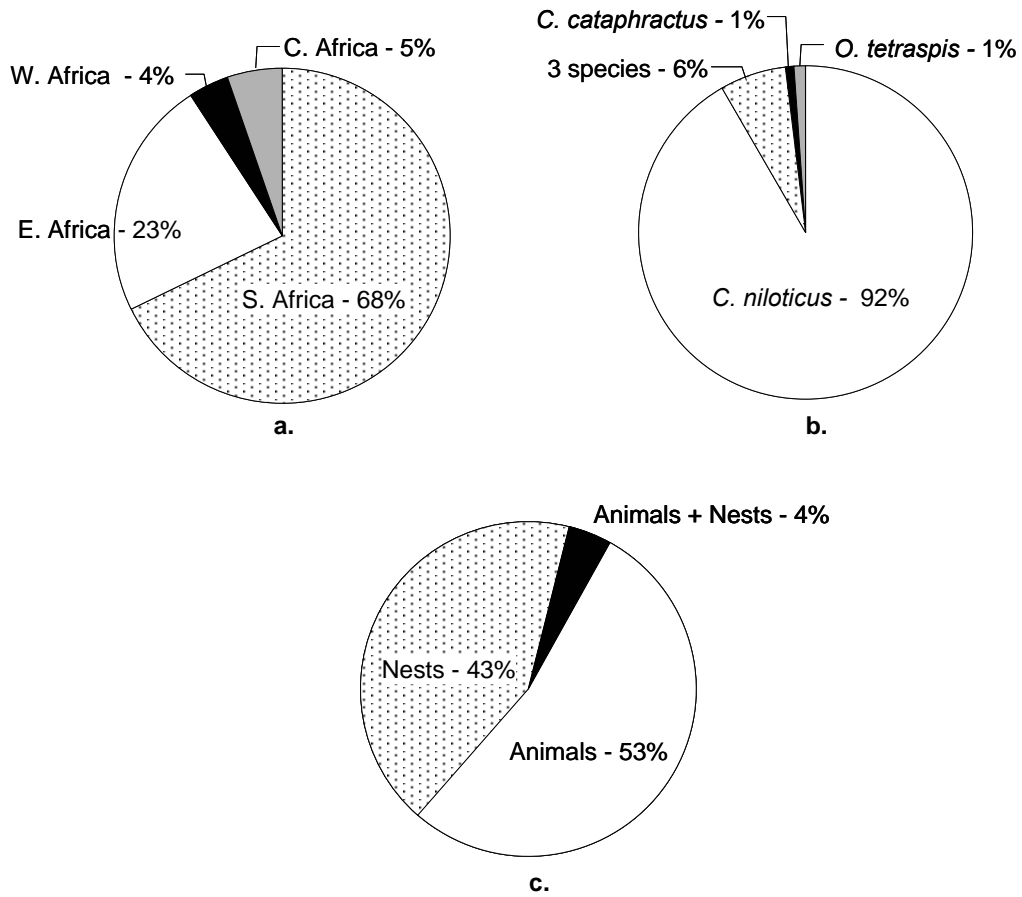


Figure 3.2 Description of survey expeditions by:
(a) Region surveyed
(b) Target species
(c) Indicator counted

Table 3.2 Frequency of the inclusion of different field techniques in survey expeditions

Field technique	% of expeditions
Spotlight	51
Aerial	43
Day boat	24
Day foot	8
Night foot	2

Prevalence of counting methods, in terms of frequency of usage, differed from region to region. Spotlight counts dominated in Central and West Africa, whilst in East and Southern Africa there was little difference between the numbers of spotlight and aerial counts. In Central Africa there was only one expedition that included aerial techniques in Cameroon, and in West Africa there were no aerial counts. Foot counts were few, but relatively more common in West and Central Africa than in the other regions. Day boat counts were also a minority but more common in East and Southern Africa than in Central and West Africa (Table 3.3a).

C. niloticus was surveyed both with aerial and spotlight techniques in equal quantity. Day boat counts were also used but rare and foot counts were even rarer. Expeditions that had the three species as target made use of spotlight methods generally. Foot counts were used but not common and day boat counts and aerial counts were very rare. In fact, there was only one expedition that included aerial techniques in Cameroon. Only three expeditions targeted *O. tetraspis* and each survey used one or more of the following methods: spotlight techniques, foot counts and day boat counts. For *C. cataphractus* there was only one survey expedition and it made use of foot counts (Table 3.3b).

Table 3.3 Use of the different field techniques (a) by region and (b) by target species

	<i>Field technique</i>				Total
	Spotlight	Aerial	Day boat	Foot	
<i>a. Region</i>					
Central Africa	10	1	1	5	13
West Africa	8	0	2	6	9
East	18	25	13	3	41
South	48	37	7	4	80
<i>b. Target species</i>					
3 species	15	1	2	7	16
<i>C. cataphractus</i>	0	0	0	1	1
<i>O. tetraspis</i>	1	0	1	2	3
<i>C. niloticus</i>	68	62	20	8	123

3.2.2 Quality of the survey data

The dates in which surveys took place were not recorded with much precision. Almost half of the survey expeditions recorded only the year of the survey without any reference to the season or month when it occurred. Forty percent of the expeditions recorded the exact

dates and only a few more expeditions recorded month and year. Only 1% of the survey literature did not provide any dates for the surveys (Table 3.4).

Table 3.4 Overall precision of the survey expeditions to record dates and locations

Type of record	% of expeditions
<i>Date</i>	
Exact date	40
Month and year	13
Year only	46
None	1
<i>Location</i>	
GPS coordinates	19
Location map	53
Grid reference	7
Location name	98

The most commonly used approach to record the geographical reference of a survey site was to simply record the name of the location, almost all surveys recorded the name. Location maps are also common; more than half of the literature presents maps. GPS coordinates are less common but are still provided by an important proportion of the survey literature (Table 3.4). Grid references were rarely used as method to provide a geographical reference (Table 3.4). It is important to highlight that 29% of all the surveys only used location names as geographic references.

Methods to compensate for visibility bias were only considered in 12% of the expeditions. Only 7% percent of the expeditions included tandem counts to account for observer bias and 5% included mark-recapture methods to account for diving bias. The use of these methods was exclusive, i.e. no expedition used both methods. Methods to account for concealment bias have not been mentioned in any of the referenced literature (Table 3.4).

3.2.3 Temporal distribution of survey expeditions

Survey expeditions occurred in Africa for almost every year since the first expedition took place in 1955. There has only been a gap between 1957 and 1962 when no survey expeditions occurred. The number of expeditions per year since 1955 increased until it reached its peak of 14 expeditions in 1986. Thereafter the number of expeditions per year decreased slowly and from 1989 it has ranged between 4 and 10 expeditions per year; with the exception of 2005 when there were only 2 expeditions carried out (Figure 3.3a).

The temporal distribution of expeditions that counted animals and the expeditions that counted nests is very similar. Both follow the same pattern as the overall number of expeditions, with an increasing number since the first expeditions until they reach a peak in the late mid 1980s. (Figures 3.3b and 3.3c). Expeditions that include both animal and nest counts rarely exceed one per year, and they have only started to be more common since the mid 1990s (Figure 3.3d).

3.2.4 Temporal distribution of animal count methodologies

Aerial counts started in 1963. Expeditions that included aerial surveys had their peak in 1988 with 6 expeditions using the method. However its inclusion in survey expeditions decreased in the following years. Since 1999 this field technique has not been considered in more than 2 expeditions a year even though the number of expeditions has been between 4 and 10 a year (Figure 3.4a).

Spotlight counts started in 1965 and were seldom included in expeditions until 1985. They have been used every year, presenting only one gap between 1973 and 1975. This method also reached its highest value in 1988 with a total of 6 expeditions (Figure 3.4b).

Both spotlight and aerial techniques respond to the overall tendency of the survey expeditions. After the peak numbers of surveys in 1988 there is a clear decline in the use of both techniques, however despite this decline there are still more expeditions using spotlight counts than aerial counts (Figures 3.4 a and b).

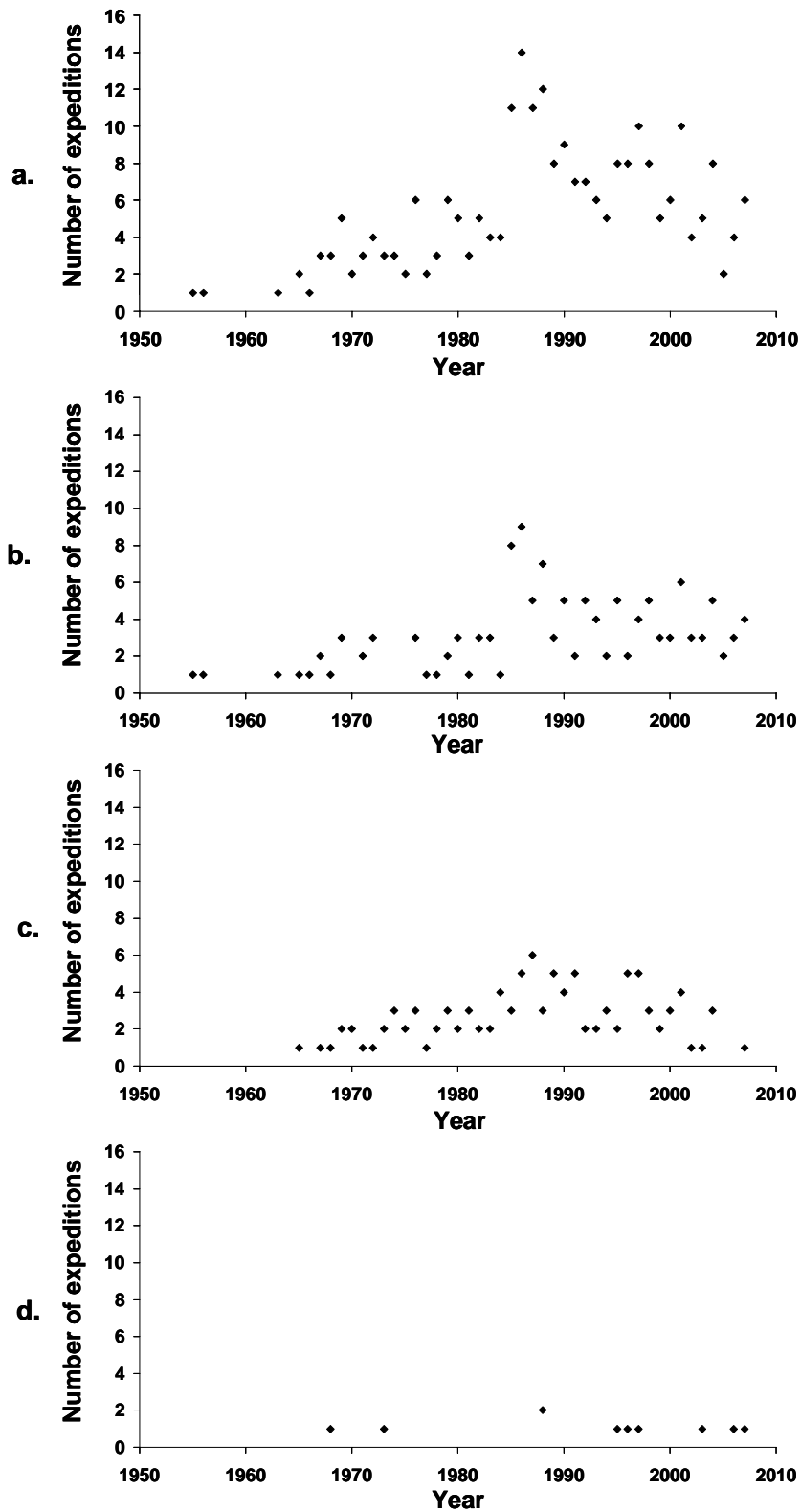


Figure 3.3 Temporal distribution of:
 (a) All survey expeditions
 (b) Expeditions that counted animals
 (c) Expeditions that counted nests
 (d) Expeditions that counted animals and nests

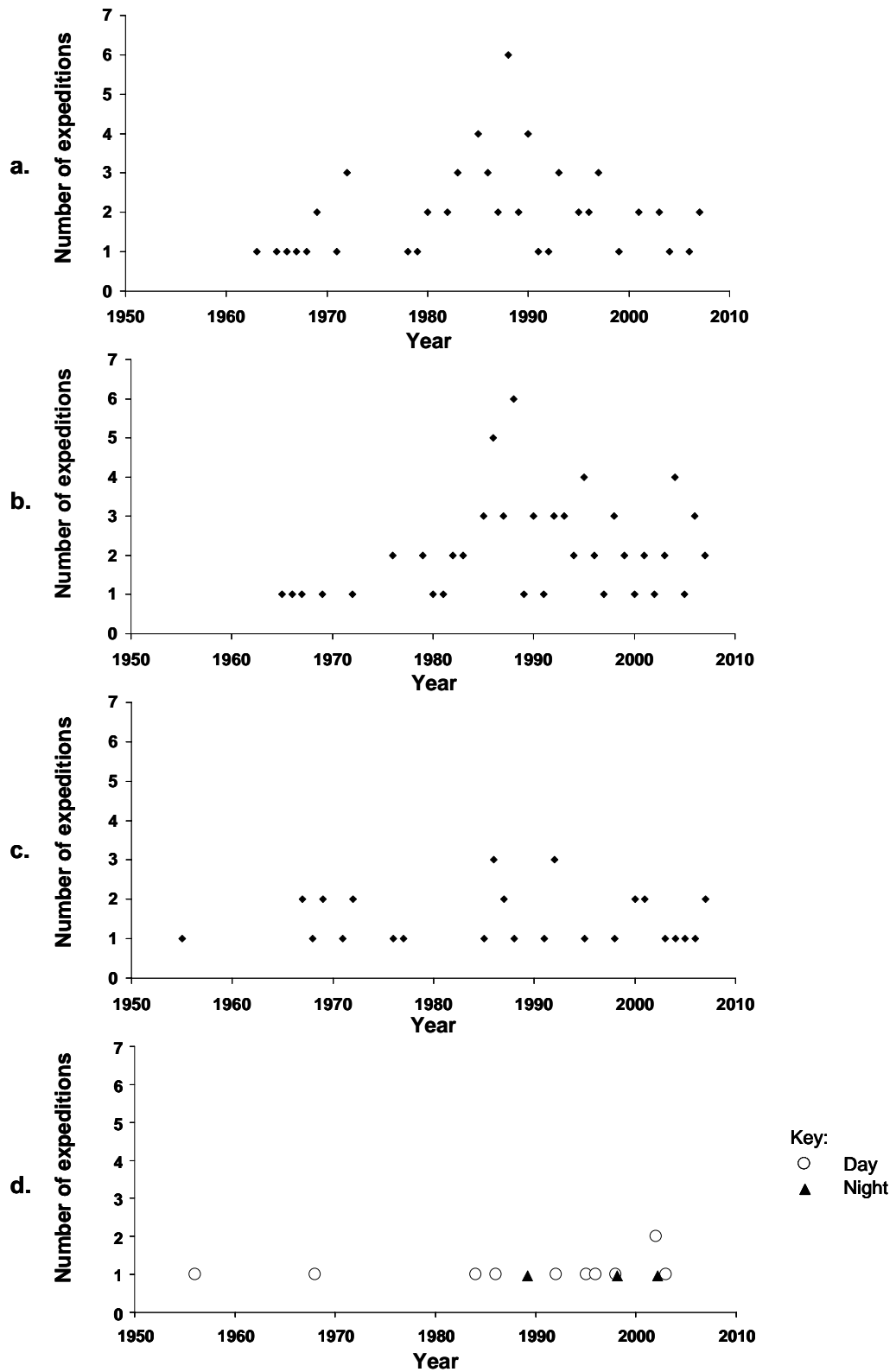


Figure 3.4 Temporal distributions of animal count methodologies:
 (a) Aerial counts
 (b) Spotlight counts
 (c) Day boat counts
 (d) Foot counts (day and night)

Boat day counts together with foot counts are the pioneer methodologies for surveying crocodiles. They started in 1955 but have not been as popular as aerial and spotlight counts (Figures 3.4 c and d).

3.3 Geographical distribution of the surveys

3.3.1 Overall distribution of crocodile surveys

Three hundred and fifteen different locations were found to have been surveyed across Africa. Of these, 290 could be located in *Google Earth ver.4.2* with the geographical references provided. The other 25 locations could not be located and hence could not be included in the mapping. The locations that could not be found, due to lack of adequate geographical references, were meant to be in Ethiopia, Ghana, Guinea, the Ivory Coast, Liberia, Madagascar, Niger, Nigeria, Zambia and Zimbabwe. Niger and Nigeria were the only of these countries not represented in the mapping because none of the surveys carried out here could be geographically located.

The majority of the crocodilian territory in Africa has not been surveyed. Sixteen of the African countries included in crocodilian territory have never been surveyed, 17 have had less than ten survey expeditions undertaken and only 8 countries had more than 10 survey expeditions take place in their area (Table 3.5).

Southern and East Africa are the regions best represented by surveys. In Southern Africa, surveys have concentrated in the Zambezi river basin which comprises the borders between Botswana, Zambia, Zimbabwe, Mozambique and bits of Malawi, Namibia and Angola. In East Africa surveys have focused in Tanzania and Kenya. The Western and Central regions are the least surveyed, all the locations in these regions have been surveyed less than 10 times (Figure 3.1).

3.3.1 Distribution of surveys by target species

The distribution of surveys that had *C. niloticus* as target species has not been comprehensive, much of the species territory remains unsurveyed. However, six new locations were surveyed outside the previously known distribution of the species and two of them found crocodiles present. One of these locations is in Mauritania (Shine *et al.*, 2001) and the other one is in the East coast of Madagascar (Games *et al.*, 1997) (Figure 3.5).

Most of the locations surveyed for Nile crocodiles have found the species present. The majority of the locations surveyed that have yielded no Nile crocodiles are located in Central and Western Africa. Here, forests are dominant and densely vegetated when compared to the East and Southern Africa regions where the dominant types of land cover are croplands, open grasslands, open grasslands with sparse shrubs, open deciduous shrublands and deciduous shrublands with sparse trees. The few locations where *C. niloticus* was observed in Central and West Africa corresponded to areas of swamps and deciduous scrublands, coastline areas, and forests with sparse trees (Figure 3.6).

Regarding the other two species, again surveys have not been comprehensive. However, as opposed to the results of *C. niloticus*, locations where *C. cataphractus* or *O. tetraspis* were are proportionally lower in relation to the number of locations that have been surveyed. *C. cataphractus* was more commonly seen in Central Africa, whilst *O. tetraspis* was observed more frequently in Western Africa (Figures 3.7 and 3.8). For both species, surveys that found them present were conducted in areas close to the coastline, in mosaic forests/croplands and swamp forests. Locations surveyed in deciduous forests and evergreen forests have not found any of the species (Figures 3.9 and 3.10).

Table 3.5 Number of expeditions carried out in each of the countries included in crocodilian territory

Country	N° of expeditions
Benin	0
Burkina Faso	0
Gambia	0
Mali	0
Senegal	0
Sierra Leone	0
Togo	0
Burundi	0
Central Afrcian Republic	0
Chad	0
Equatorial Guinea	0
Rwanda	0
Egypt	0
Sudan	0
Somalia	0
Swaziland	0
Guinea	1
Guinea-Bissau	1
Ivory Coast	1
Mauritania	1
Niger	1
Nigeria	1
Democratic Republic Of The Congo	1
Angola	1
Ghana	2
Cameroon	2
Liberia	3
Namibia	3
Congo	4
Malawi*	4
Gabon	6
Kenya*	7
Madagascar*	9
Tanzania*	10
Botswana*	15
Mozambique*	15
Uganda*	17
South Africa*	18
Ethiopia*	26
Zambia*	38
Zimbabwe*	100

*Countries with ongoing ranching programmes (Jenkins *et al.*, 2008)

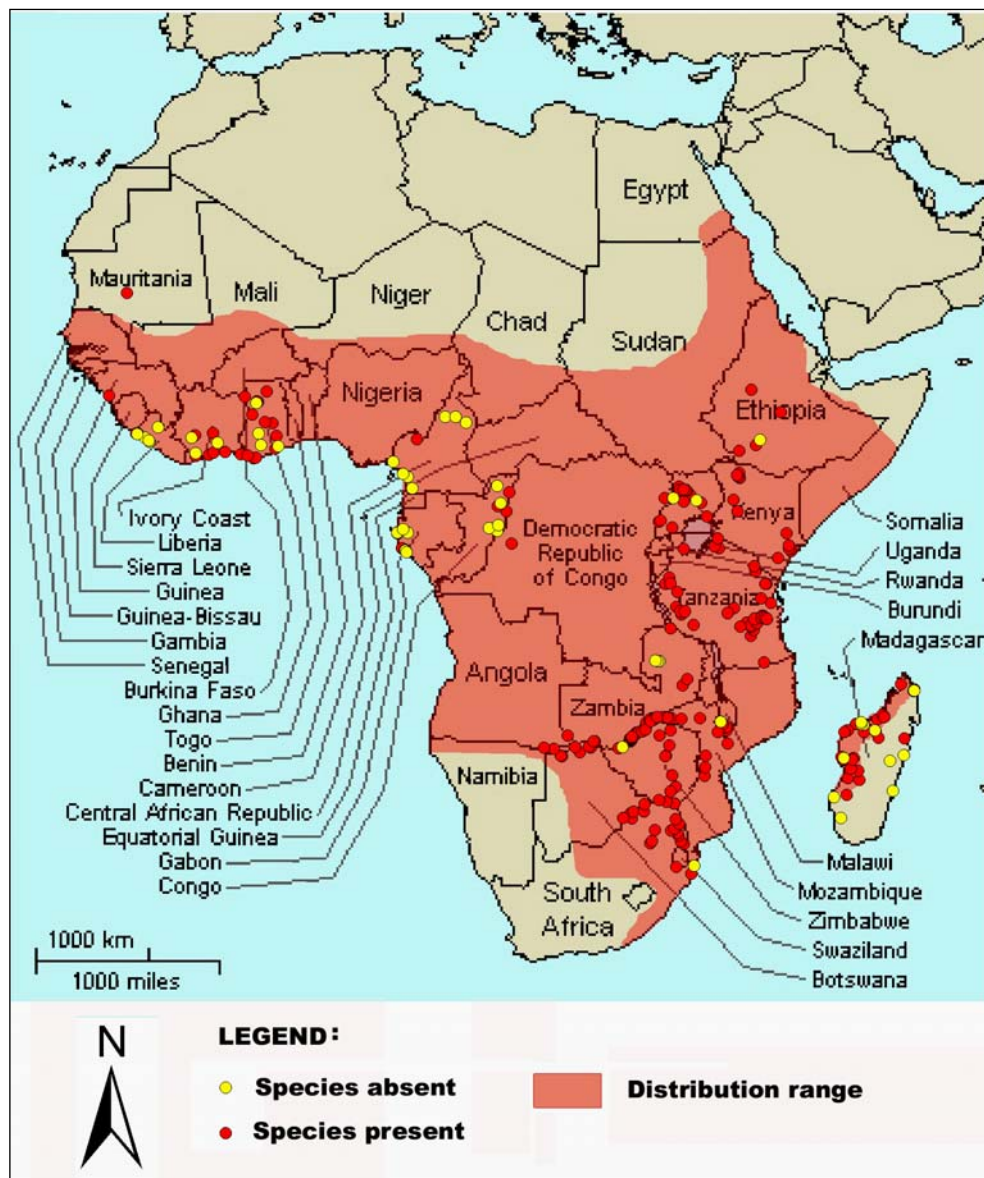


Figure 3.5 Distribution of Nile crocodile surveys in relation to the species range.

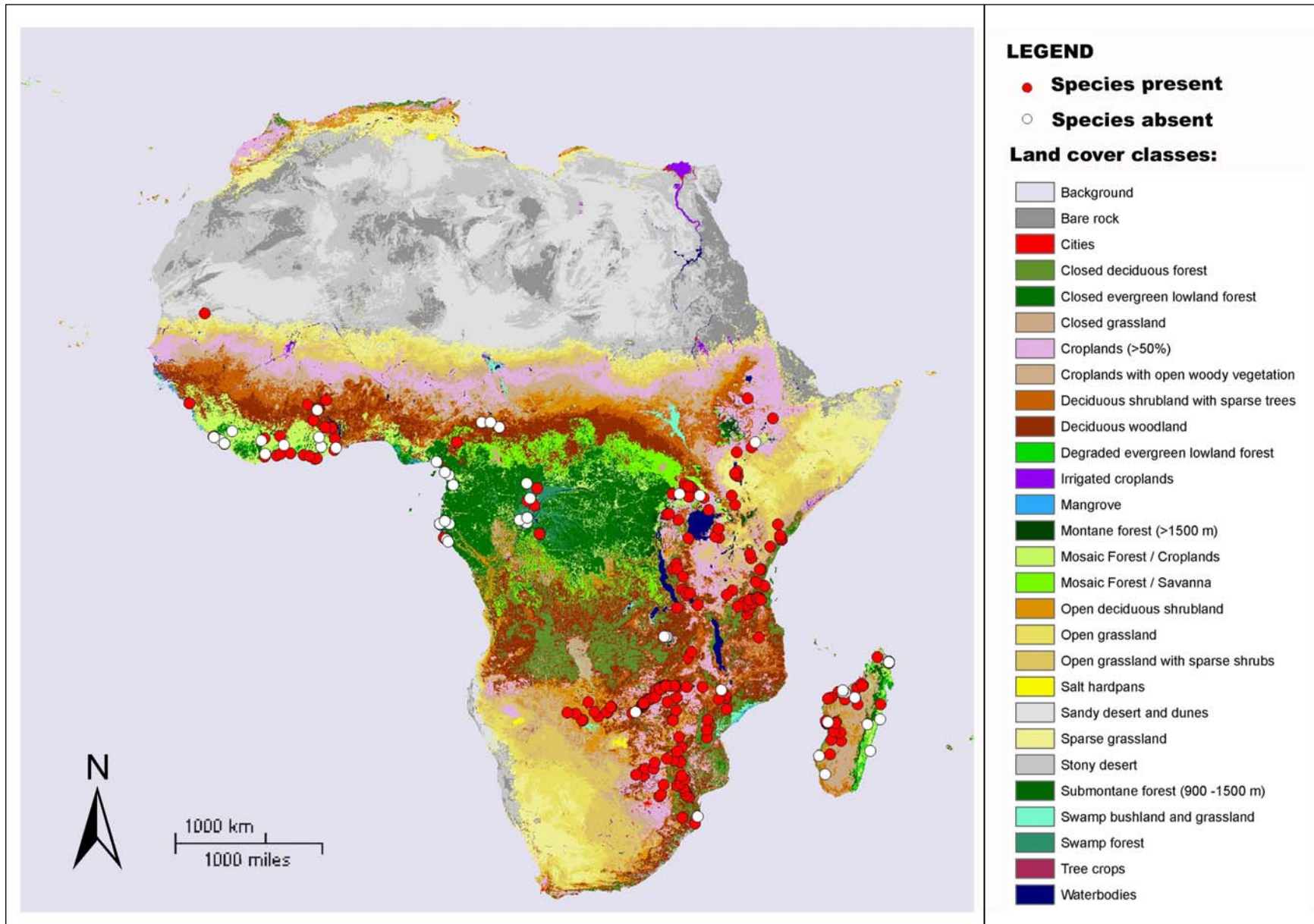


Figure 3.6 Distribution of Nile crocodile surveys in relation to land cover.

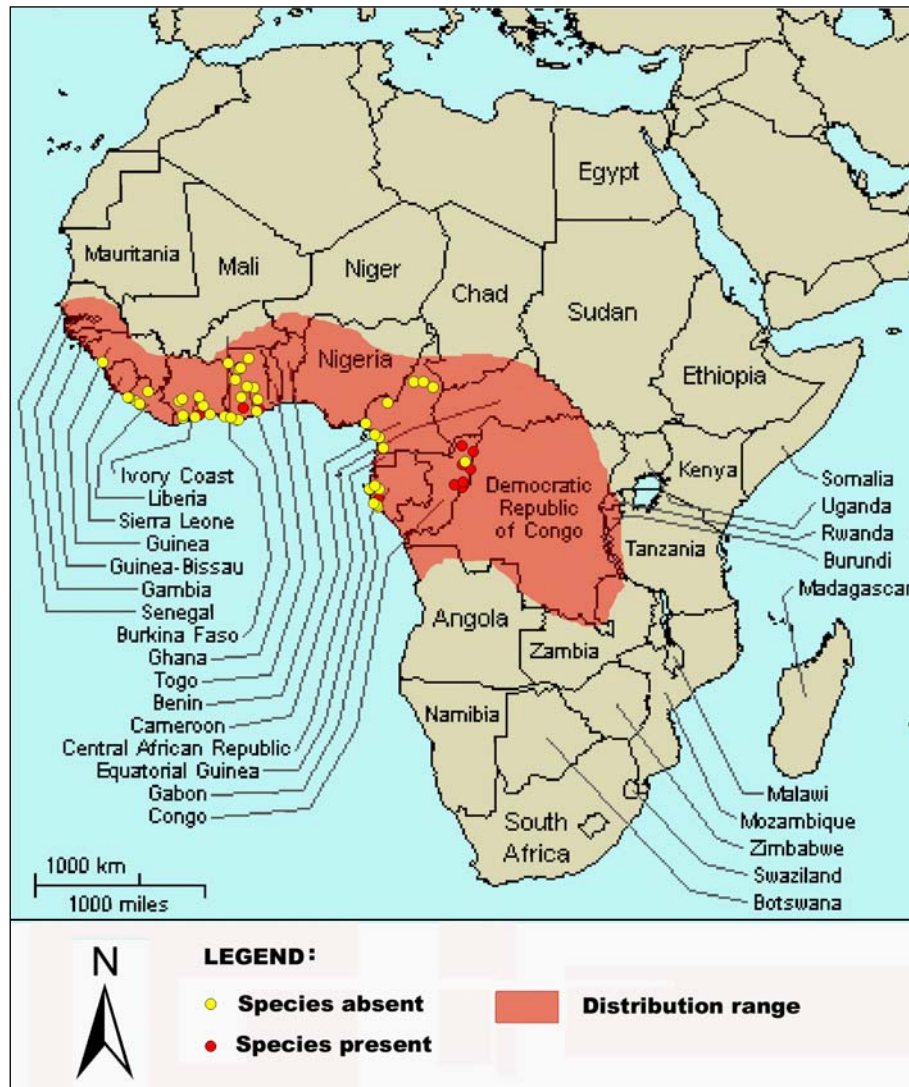


Figure 3.7 Distribution of Long-snouted crocodile surveys in relation to the species range.

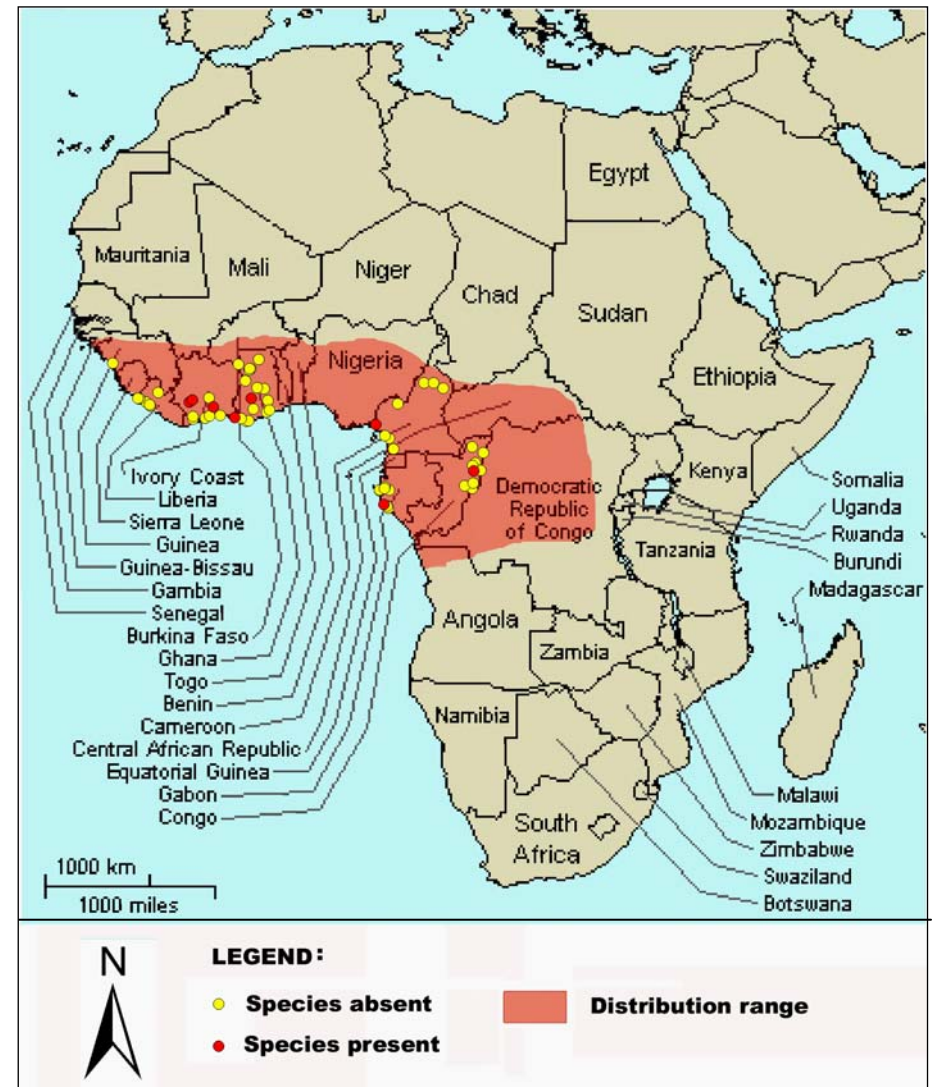


Figure 3.8 Distribution of African dwarf crocodile surveys in relation to the species range.

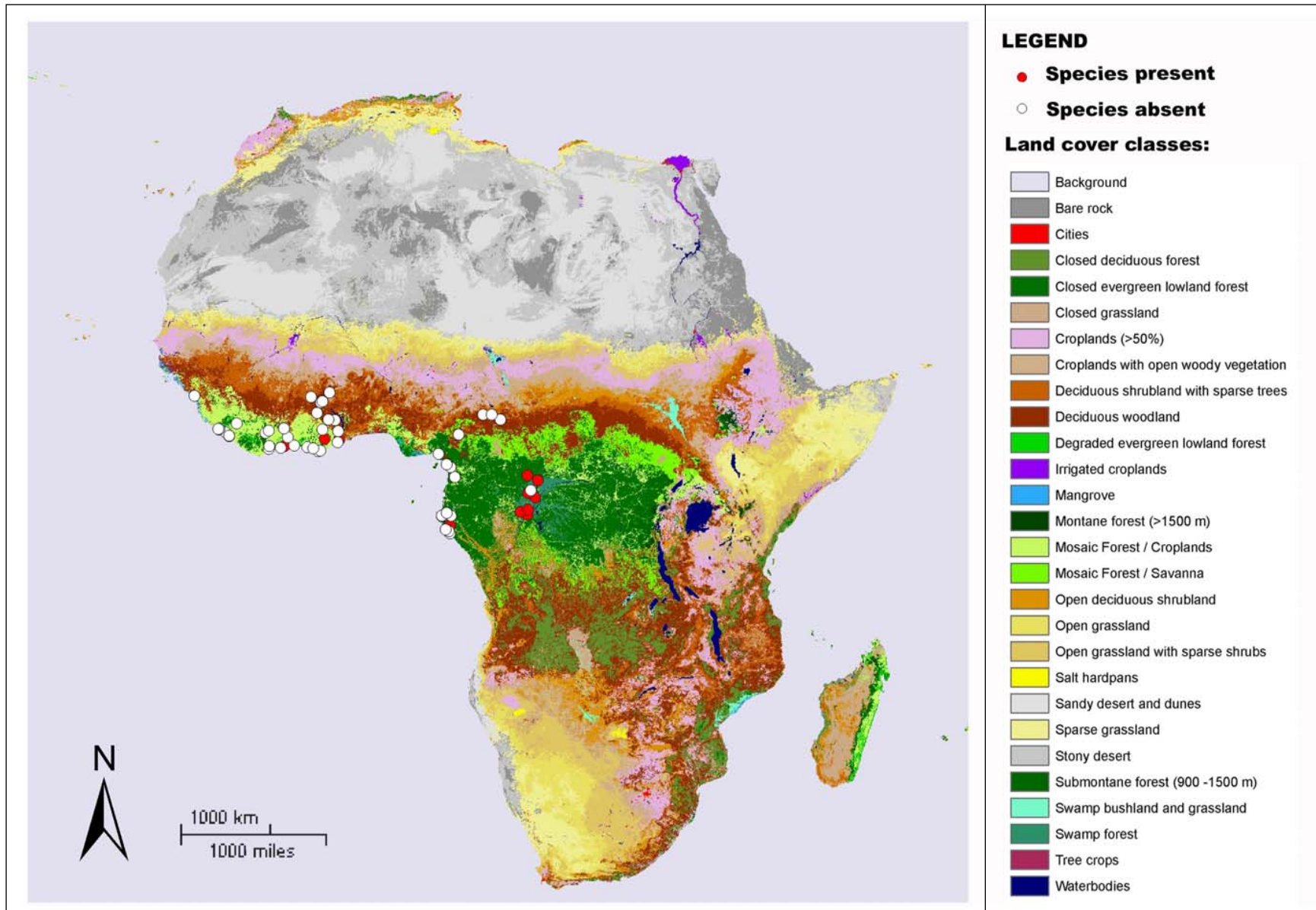


Figure 3.9 Distribution of long-snouted crocodile surveys in relation to land cover.

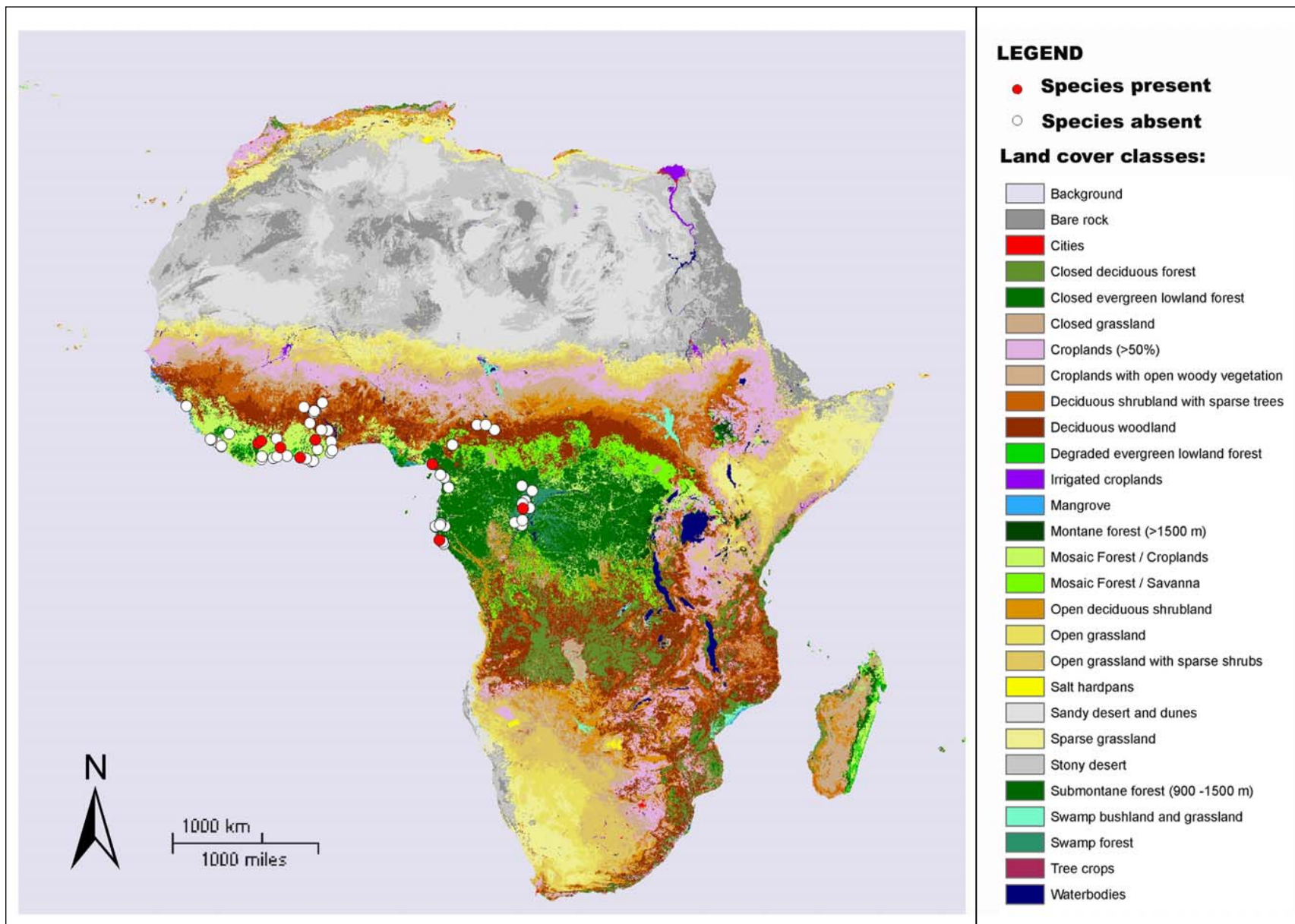


Figure 3.10 Distribution of African dwarf crocodile surveys in relation to land cover.

3.4 Population trends

3.4.1 Identification of study cases

Eight countries were identified to have more than ten survey expeditions (Table 3.5). From these countries, consistent survey data was found only for Tanzania and Zimbabwe. This is that only these two countries counted with sufficient data collected in a same location with comparable methods. Data from surveys in Botswana, Mozambique, Uganda, South Africa, Ethiopia and Zambia, could not be assessed due to the inconsistency of the sites surveyed and the methods used.

In Tanzania, three locations had consistent and enough animal counts to be assessed for trends; these were Ulanga, Ruaha and Kilombero. Even though the counts for these locations did not add up to ten, they were the best data available to assess the trends from animal counts. Table 3.6 shows the raw count data used to estimate the trends. It can be noted that from 1995 onwards, effort was given to repeating the animal counts during same expeditions. For years when more than one count was available, the average of these counts was used.

In Zimbabwe, animal surveys were plenty but scattered all throughout the country not having much consistent data to be assessed. For instance, in Lake Kariba 48 animal counts have been undertaken, however, due to the lack of precision with which locations were recorded data cannot be compared. On the other hand, nest counts in Zimbabwe have been consistently repeated since the late 1970s and series of survey data exist for Ngezi, the Zambezi and the Lake Kariba area (Deka, Gwai and Ruziruhuru rivers). Unfortunately, from the literature collected nest count data is only available for the Zambezi nest counts (Table 3.7).

3.4.2 Estimates of population trends

3.4.2.1 Linear regression

The statistical parameters that indicate linear trends in the case study locations are shown in Table 3.8. All regressions were statistically non-significant ($p > 0.05$). Outliers were found in the Zambezi and Kilombero (Student residuals > 2) (Table 3.8). For the Zambezi it was not possible to assess if the outlier pair should be eliminated from the regression since information to explain the data as outlier was not available.

Table 3.6 Crocodile count data for Ulanga, Ruaha and Kilombero, Tanzania (N= number of crocodiles)

Year	N°surveys	Ulanga		N°surveys	Ruaha		N°surveys	Kilombero	
		Mean	SD		Mean	SD		Mean	SD
1963	1	227	-	0	-	-	0	-	-
1988	1	81	-	1	181	-	1	28	-
1989	1	110	-	1	177	-	1	200	-
1990	1	138	-	1	114	-	1	232	-
1993	1	242	-	1	135	-	1	345	-
1995	2	248	59	3	140	30	2	282	67
1996	3	401	206	3	168	25	2	452	94
1999	3	286	22	2	204	53	3	493	121
2003	2	305	37	2	88	4	2	153	45

Table 3.7 Nest count data for the Zambezi. Zimbabwe

Year	N° nests
1989	101
1990	282
1991	246
1992	305
1993	226
1994	272
1995	309
1996	269
1997	325
1998	473
1999	525
2000	473
2001	413
2002	481
2003	358
2004	300

For the Kilombero, the data identified as outlier (Figure 3.11) corresponds to a survey in 1988 when the Kilombero was particularly affected by very high water levels. The water level in Ulanga was only moderately affected during the expedition and in Ruaha it was not affected because it is artificially controlled by the dam (Hutton and Kathaliwa, 1992). Since high water levels make observation of crocodiles from the air very difficult, the pair of data identified for Kilombero as an outlier was not considered in the analysis of the data.

Table 3.8 Population growth parameters of the case study populations.

Location	μ	95% Con. Int.		σ^2	Significance	Std.Residuals
		Lower	Upper			
<i>Tanzania</i>						
Ulanga	0.007	-0.99	0.113	0.08	0.874	< 2
Ruaha	-0.048	-0.210	0.113	0.066	0.491	< 2
Kilombero (w/ outlier)	0.113	-0.424	0.650	0.723	0.624	> 2
Kilombero (no outlier)	-0.19	-0.268	0.230	0.132	0.851	< 2
<i>Zimbabwe</i>						
Zambezi (w/ outlier)	0.073	-0.112	0.257	0.111	0.414	>2
Zambezi (no outlier)	0.004	-0.118	0.127	0.045	0.939	< 2

The estimates for the populations in Ulanga and the Zambezi were the only ones to show an increasing overall trend ($\mu > 0$). Despite this, the lower limits of the confidence intervals are negative for both, indicating that the possibility the populations could eventually tend to decline cannot be ruled out. In addition, for both cases $\sigma^2 > \mu$; this indicates a great interannual variability that does not allow to state definitively that the population is growing (Table 3.8).

The estimates for the Ruaha and Kilombero populations showed a tendency to decline with $\mu < 0$ and negative values for the lower limits of their confidence intervals. For the Ruaha $\sigma^2 > \mu$ and for the Kilombero σ^2 represents a great proportion of μ , this indicates a great interannual variability of μ (Table 3.8).

There was no significant autocorrelation in the population growth rates ($d > d_L$ and $4 - d > d_U$; 5% significance) (Table 3.9).

Table 3.9 Durbin Watson statistics (d) and the critical values for a two-tailed test of 5% significance (q = number of data points in a linear regression; d_L and d_U = lower and upper critical values) (adapted from Savin and White, 1977)

Location	q	d_L	d_U	d
<i>Tanzania</i>				
Ulanga	8	0.763	1.332	2.025
Ruaha	7	0.700	1.356	2.046
Kilombero (no outlier)	6	0.610	1.400	1.651
<i>Zimbabwe</i>				
Zambezi (w/ outlier)	15	1.077	1.361	1.674
Zambezi (no outlier)	14	1.045	1.350	2.155

3.4.2.2 *Generalised additive models and scatter plots*

The data of two populations showed significant fits for the GAMs, they were Ulanga ($F=9.885$, $n=8$, $p<0.01$) and the Zambezi ($F=8.776$, $n=16$, $p<0.01$). Conversely data from Ruaha ($F=0.636$, $n=8$, $p=0.456$) and Kilombero ($F=5.58$, $n=7$, $p=0.0506$) did not show significant fits under GAMs, but still the fits were improved from those observed with linear regressions (Table 3.8).

Nonetheless, graphically all the GAMs appear to be a good representation of the trends in the data (Figure 3.11). Only the plot of Ulanga does not show the complete series of data. The first count in 1963 was omitted from the plot for ease of interpretation since the gap between that first and second count was too large.

For Ulanga, Kilombero and the Zambezi there is an increase in the counts since the first surveys until the mid late 1990s. Thereafter there appear to be declines in the sets of data of the three populations, although at different rates. The counts in Ruaha appear to be declining overall, although it is difficult to interpret the pattern of the data (Figure 3.11).

3.4.2.3 *Analysis of Variance*

The first analysis of variance was performed to all the population abundance data; that is the animal counts of Ulanga, Ruaha and Kilombero and the nest counts of the Zambezi. The result was that there were significant differences between the data ($F=5.196$, $n=39$, $p<0.01$). For the second ANOVA which compared only the data collected in same years, the data also showed significant differences ($F=3.402$, $n=27$, $p<0.05$).

Conversely, the third ANOVA performed only in the data of animal counts for same years did not show significant differences in the data ($F=2.460$, $n=23$, $p=0.11$) suggesting that between the three populations and years the abundance data shows a similar trend.

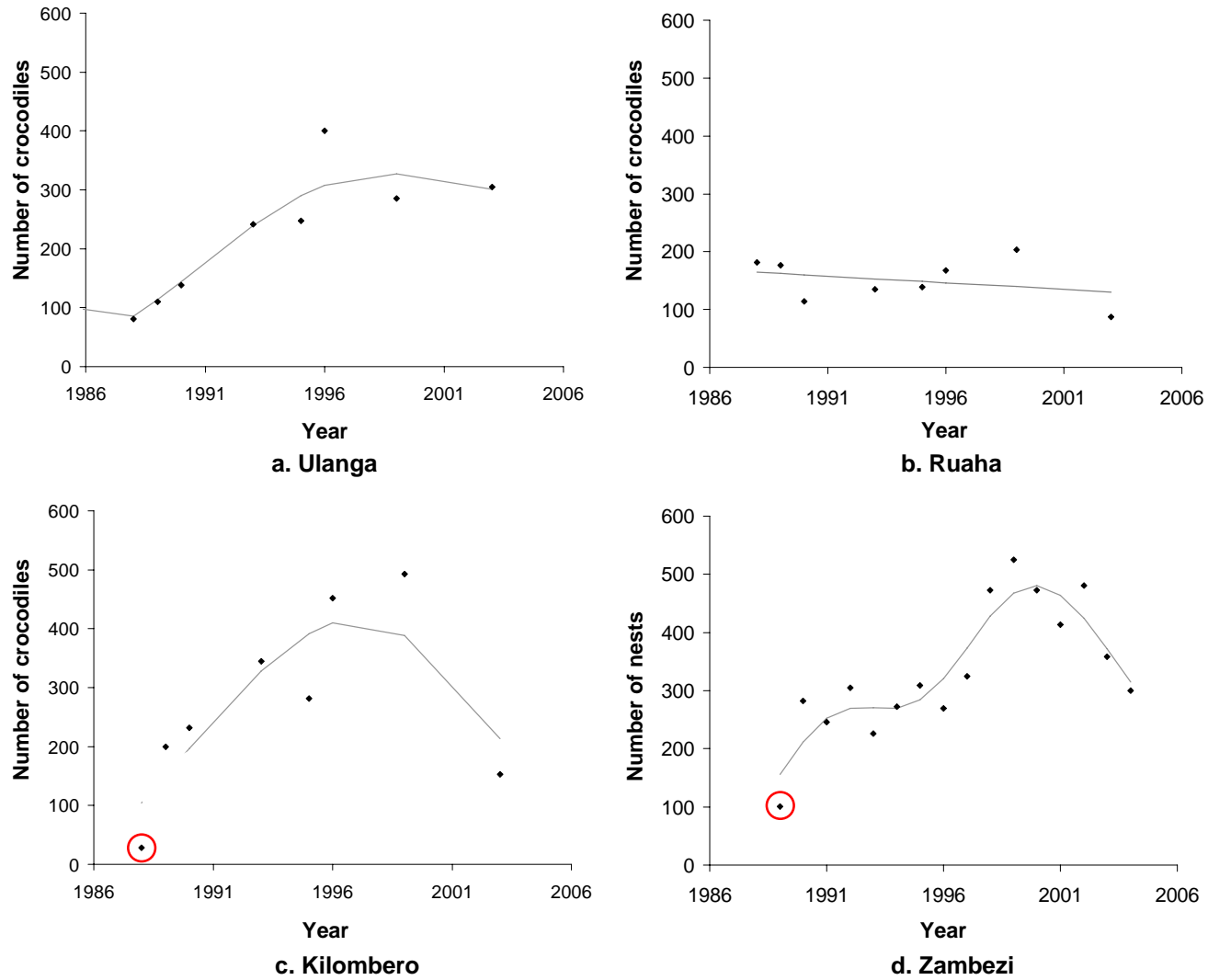


Figure 3.11 Numbers of non-hatchling *C. niloticus* counted by aerial surveys since 1988 in (a) Ulanga (b) Ruaha and (c) Kilombero; and (d) numbers of *C. niloticus* nests counted in the Zambezi. Black dots represent the counts and lines represent the GAMs (outliers are circled in red).

4 Discussion

4.1 Limitations of the study

4.1.1 *Quality of the data collected*

Judging from the collaboration of key crocodile researchers, the data collected is very representative of the African crocodile surveys, however it is not exhaustive. There is a series of survey data for Botswana that is known to exist (Leslie, pers. comm) but to date it has not been retrieved and therefore has not been included in this study. Possibly there is more un-retrieved data like this for other countries. Results obtained are thus not definitive, but they are representative of the crocodile surveys in Africa from 1955 until 2007.

The quality of the data collected is not completely consistent, it varies due to the different types of references consulted (Table 3.1). Although most of the data came from 'grey' literature, the bulk of it was conformed by institutional reports of comparable quality standards dictated by the wildlife authorities in Africa. In addition, a great deal of the literature was peer reviewed; hence the variability of the data did not pose major constraints in the analysis. Still, not all the surveys could be mapped or located in time, and the raw data collected by the surveys was not available in all the literature consulted, although they represent only a small proportion of the data.

Not all survey sites could be mapped with the same accuracy, since 29% of the data did not present GPS coordinates, location maps or grid references. However, considering the size of the African continent and the purpose of the study, this should not affect the analysis of the data.

It is also important to consider that Figure 3.1, which shows the number of surveys per location, is based on the minimum number of surveys identified, so the map is just an approximation of the number of surveys per site.

4.1.2 *Biological representation of the population trends*

The methods used to estimate the population trends are only based in population abundance data, hence it must be highlighted that the trends presented in this study are not a pure reflection of the biological processes underlying the populations. Instead, they are more statistically based, which is valid enough as a management tool in conservation studies where shortage of data is a constant problem. Although it would be preferred to

make decisions with results near to certainty ($p=0.05$), conservation demands are usually higher than what can be done with the information available. Consequently, methods like the herein used were especially developed to deal with the limited and uncertain monitoring data normally available in conservation biology. They do not eliminate the uncertainty of the trends estimated, but they do reduce and quantify this uncertainty (Fewster, 2000; Morris and Doak, 2002).

In addition, when estimating the trends it would have been better in terms of comparison between localities, to use densities as indices of abundance instead of counts. However it was decided to use the raw data of the counts because densities were not available for all the counts and that would have compromised an important amount of data.

4.2 Assessment of the crocodile surveys

4.2.1 Species representation

Considering the wider distribution of the Nile crocodile as compared to that of the other two species, it was expected that *C. niloticus* would be better represented by surveys. Nonetheless, the disparity of this representation where almost all surveys had *C. niloticus* as target species was not anticipated.

One reason to explain this particular interest in surveying *C. niloticus* can be its commercial importance over that of the two other species. Skins of *C. niloticus* are very valuable in the international leather market and it is the only species to be listed in Appendix II of CITES for some countries. Its skin is legally traded in 15 countries where constant surveys are a requirement of CITES to demonstrate that no detriment is caused to the exploited populations (Jenkins *et al.*, 2004).

More recently, crocodile surveys have also been planned in the effort of assessing human-crocodile conflicts in Africa. Since *C. niloticus* 'is the main culprit in attacks on humans, livestock and fishing gear' (Fergusson, 2008:1) it has been the target of these surveys, whilst *O. tetraspis* and *C. cataphractus* have not been considered due to their smaller size and more docile behaviour (Fergusson, 2003, 2005a, 2007).

4.2.2 Quality of the survey data

Results indicate that not much attention has been given to recording with precision the dates and locations where surveys occurred. This suggests surveys have been

fragmentary as a whole since the basic information necessary for their continuity and replication is not available.

Methods to compensate for bias were not a common practice either. Mark-recapture techniques were included only in doctoral research studies (Hutton and Woolhouse, 1989; Games, 1990; Eaton., 2006). Due to the complexity and long time involved in mark-recapture experiments, they are hardly ever considered in common survey expeditions.

Tandem counts were slightly more common but still rare as they would involve greater human input which could be invested in further surveys of different locations rather than in a same location. Their inclusion is more diverse than that of mark-recapture methods due to its relative ease. It has been included in doctoral research as well as in common crocodile monitoring programmes (Graham, 1988; Games and Severre, 1990 and 1993; Hutton, 1992; Hutton and Kathaliwa, 1992; Games *et al.*, 1992 and 1996; Combrink, unpublished; Graham *et al.*, unpublished).

4.2.3 Temporal distribution of surveys

The overall distribution of crocodile surveys in Africa appears to be strongly influenced by the CITES. When the CITES came into effect in Africa on July 1st, 1975, all crocodile species and populations were listed in Appendix I. Thereafter, to be able to legally trade crocodilian skins again, the crocodile populations needed to be transferred to Appendix II. The requirements for this downlisting involved demonstrating that the populations were not endangered and that their recovery would benefit from a ranching programme (Jenkins *et al.*, 2004). Since transfer was sought by many parties, it apparently triggered a series of survey expeditions to assess the status of the populations concerned. From 1975 onwards the number of survey expeditions increased noticeably until they reached their peak in 1988. By 1987, 11 of the 15 countries achieved the transfer of *C. niloticus* to Appendix II, with nine of these countries having them downlisted in 1985, explaining the high frequency of surveys around 1988. From 1987 to 1989 several survey expeditions were conducted under the auspices of the CITES Secretariat as part of the CITES Nile crocodile Project. Later on, quite a few survey expeditions have been carried out to report on the status of the exploited populations to CITES (Hutton and Games, 1992).

4.2.4 Methodologies used and their change over time

The reason why spotlight counts are the technique used in most survey expeditions might be related to their practicality and to the fact that they can provide accurate and precise population indices. Nonetheless, aerial methods are also common and widely used in survey expeditions; this could be related to the cost-effectiveness and repeatability of the method when surveying large areas. As expected, day boat counts and foot counts are not common probably due to the significantly small proportion of individuals they can record.

Aerial techniques were mostly used to survey *C. niloticus* in Southern and East Africa. This may respond to the suitability of the methods for large species and areas with sparse vegetation. On the other hand, for *C. cataphractus* and *O. tetraspis*, aerial methods were only used once, a reflection of their inadequateness when considering the smaller of the species and those restricted to Central and West Africa where tall vegetation occurs. However, spotlight counts were more widely used in all regions and for all species, due to their suitability for almost all habitats and to the fact that they are not biased against small individuals.

The pattern in the frequency of field techniques used seems to be also influenced by the requirements of the CITES. In the last 10-15 years it appears that spotlight counts have been preferred over aerial counts, despite the overall decline of both. This could be explained by the higher costs involved in aerial surveys, since although they are the most cost-effective method in terms of the area that can be surveyed in a short time, it appears that the higher costs of the technique were only justified in the 1980s-1990s when it was of prime importance for the concerned countries to provide evidence of the population status of *C. niloticus*. During this decade, aerial surveys were thus the most convenient technique considering their scope and quickness. Once the majority of the concerned countries had proven that their populations were not endangered and had achieved the downlisting of the species, the surveys did not need to be that extensive anymore. Hence the preponderance of including spotlight techniques over aerial counts afterwards. Spotlight techniques are cheaper, easier to organize, and more accurate than aerial counts. They also provide with precise population indices but can only cover a small fraction of the area that can be surveyed with aerial techniques at a same time. For that reason, the preference for spotlight techniques seems logical when extensive areas do not need to be surveyed anymore.

Day boat counts also seem to be affected by the increase in surveys related to the CITES, however this effect is shown in a much lower scale. Both day boat counts and foot counts

have been more used from the mid 1980s onwards and with almost yearly occurrence, even though they are not the best method to use, which could be a reflection of the lower expenses and the easier planning involved.

4.2.5 Geographic scope

4.2.5.1 Political distribution of surveys

Judging from the geographical distribution of the surveys, it is not possible to assess the overall population status of the African species throughout Africa. Much of the territory remains unsurveyed, with most of the attention focused in Southern and East Africa where only *C. niloticus* is distributed.

Coincidentally but not surprisingly, surveys are concentrated in countries where crocodile ranching programs occur in Africa, which explains the need and frequency for crocodile surveys in these regions (Figure 3.4 and Tale 3.5) (Jenkins *et al.*, 2004).

In addition, activity and support of non-governmental organizations (NGOs) towards conservation issues is also concentrated in Southern and East Africa (Scholfield and Brockington, unpublished), where crocodile surveys have specially benefited from the support given to the Miombo Eco-region (Fergusson, 2003, 2005a, 2005b, 2006, 2007; Fergusson and Pentolfe, 2007).

In contrast, Central and West Africa receive very little conservation support from NGOs (Scholfield and Brockington, unpublished). Moreover, the Central and Western regions and the Horn of Africa have been particularly affected by war periods, especially during the 1990s when crocodile surveys blossomed. Understandably, environmental issues in these regions have not been top priority concerns and might still not be (Kanyamibwa, 1998; Blom and Yamindou, 2001). This is reflected in the fact that the sixteen countries for which there are no records of survey expeditions are all located within these regions. Not surprisingly, surveys in these regions are scarce, even though *C. niloticus* distributes here. Surveys and current knowledge of *C. cataphractus* and *O. tetraspis* have been particularly affected by this regional disparity since their distribution is restricted to the Central and Western regions.

4.2.5.2 Presence / absence of crocodiles according to survey distribution

The fact that *C. niloticus* was more frequently found present during surveys than the other two species might be a reflection of the greater effort with which it has been searched. However, in Central and West Africa, surveying effort was evenly spread regardless of the species, and still *C. niloticus* was more frequently found than the other species. This suggests that *C. cataphractus* and *O. tetraspis* are harder to observe and coincides with the more evasive behaviour of the species and their relatively small size, which would make them less conspicuous.

Overall, the three species were surveyed with less success in Central and West Africa. This could be due to the lower frequency of surveys in these regions but to the methods used, which may not have been appropriate enough for these regions where high vegetation density may have affected the survey results adversely. This is supported by the fact that surveys that yielded no crocodiles in Central and West Africa were undertaken in densely vegetated evergreen and deciduous forests, whilst those where crocodiles occurred were found in coastline areas, swamps, croplands and forests with sparse trees. Consequently, preference has been given to surveying open areas rather than densely vegetated ones. It might be a reflection of the effort to reduce the visibility bias caused by tall vegetation. Nonetheless, this preference is arguable in the basis that important crocodilian territory is being underrepresented by surveys. These habitats include montane forests, submontane forests, closed evergreen lowland forests, closed deciduous forests and degraded evergreen lowland forest, which altogether account for a great proportion of the crocodilian territory that has rarely been surveyed.

4.3 Population trends

4.3.1 Case study populations

Population trends were not possible to estimate for the three African species as was aimed in this study. It was only possible to estimate trends of *C. niloticus* and for 4 different populations not representative of the species throughout Africa. The reason for this was the inconsistency with which the African crocodiles have been surveyed.

The data used to estimate the trends was collected by 25 expeditions, 9 in Tanzania and 16 in Zimbabwe. There were 4 other locations mentioned in the results, which also have produced consistent nest count data; however it was not possible to collect the count data for this study. The number of expeditions in these locations adds up to 78. This means that

the rest 147 expeditions out of 250 have not produced sufficiently consistent data to allow for reliable population trend estimations. Moreover, there have been surveys in 315 different locations and only for eight of them there is consistent data collected. This scatter suggests that continuity and standardisation have not been a priority when planning crocodile surveys. Although it might also be a reflection of the lack of diffusion of the results obtained by these surveys, which this study looks to overcome with the database produced. The database will be available to all those concerned in the conservation of African crocodiles enabling to share and exchange the data collected by crocodile surveys through the internet. Hopefully, this initiative will provide with useful information for the future planning of survey expeditions and the effort will serve to make surveys more consistent and representative of the three species and the whole crocodylian territory across Africa.

Although surveys have been fragmentary trends in the abundance of 4 populations of *C. niloticus* could be estimated. Three of these populations were located in Tanzania, where there is an ongoing programme of crocodile surveys since 1989 which had pilot surveys in 1988 and 1963 (Mafole, 2003). Although the programme now includes surveys in 17 different locations across Tanzania, sufficient data to estimate reliable trends was only found for 3 locations. This because the number of locations included in the monitoring programme increased from 1993 onwards. If the monitoring programme continues to work consistently as it has, a few years from now there should be enough data to assess population trends for *C. niloticus* throughout Tanzania, since the spread of the 17 locations being surveyed is quite representative of the species territory in Tanzania (Mafole, 2003). The other population for which it was possible to estimate trends was located in the Zambezi River in Zimbabwe.

4.3.2 Trends

Linear regressions provide with the simplest interpretations of the data. Even though they are non-significant ($p > 0.05$), their purpose in this study is to find the best fit values of these parameters with the given data, not to test for statistical parameters (Morris *et al.*, 1999), hence it is not a deterrent to use μ and σ^2 as indicators of trends. Thus, these parameters indicate the overall tendency of the count data in linear terms, showing that in the case of Ulanga and Zambezi overall trends are positive whilst for Ruaha and Kilombero they are negative. However, taking into consideration the range of the confidence intervals it should be stated that the trends obtained are not definitive and do not allow for any linear predictions.

The GAMs, although more difficult to interpret, provide a better fit for the data and allow more complex interpretations. They confirm the overall increases for Ulanga and the Zambezi since the first surveys but also account for the recent declines. The GAMs for Ruaha and Kilombero were not significant ($p > 0.05$), but provide better fits than the linear regressions. Nonetheless, from the ANOVAs it is apparent that the data for all the surveys in Tanzania follow a similar trend. And although the data for the Zambezi shows differences, it might just be a reflection of the different indicator used here. If the scatter plots (Figure 3.11) are given a closer look it is apparent in all cases that for most of 1990s decade there are increases in the populations which fall by the end of the decade. These trends suggest that, independently of the locations surveyed, there are factors external to the populations that have driven similar trends in them.

Since the surveys of the case studies were conducted by the same teams of surveyors and usually under the same conditions, the counts should be reliably and largely comparable. Hence, the trends observed may be real, however it is important to note that both Games *et al.* (1996) and Fergusson (2005b), who have written the respective reports for these surveys comment that the results over the years could be influenced by the team of surveyors gaining more experience in the field.

Considering the gain of surveying experience over the years as punctual events that do not pose major changes in the data collected, there are several factors that could explain the observed trends. For instance, it could be speculated that the initial increase in the counts might be the result of the CITES coming into effect in 1975 and reducing the hunting pressure over the wild populations (UNEP-WCMC, 2008). This would be an external factor that should affect all populations in a similar manner. As for the consequent declines by the end of the 1990s, the reasons behind could be different for locations in Tanzania and Zimbabwe.

In the case of Tanzania the declines could be a reflection of the increase of wild harvest quotas of *C. niloticus* skins. From 1994 to 1995 there was a five-fold increase in the quotas from 200 wild crocodile skins to 1000. This figure was maintained until 1998 when 2000 crocodiles were given on quota to remove nuisance animals. In 1999 the quotas were set back to 1000 crocodiles but in 2001 the quota was increased again to 1500 to remove problematic animals. Thereafter since 2002 the quota has been set to 1600 and maintained (UNEP-WCMC, 2008). This large and constant removal of crocodiles could be playing a major role in the trends observed. Nonetheless, it is difficult to ascertain without further investigation. For a better appreciation, it would be necessary to investigate the actual number of crocodiles removed each year and the locations from where they were taken;

only this information would allow assessing the effects of the quotas on the trends observed reliably.

Further, the fact that the locations in Tanzania were surveyed within the boundaries of protected areas do not suggest much of the trends obtained since these were designated long before the first surveys as to show any direct effects on the count data.

For Zimbabwe, the case cannot be explained in the basis of wild crocodile skin quotas since the numbers have remained almost constant over the years with quotas of about 150-200 wild crocodile skins (UNEP-WCMC, 2008). And regarding egg collection quotas, these have remained open since 1987 so that the monitoring value of the nest counts are not compromised by changes in the nest collection effort. Since the effort has kept the same it would be likely that some other external factors explain these trends. The decline in nest counts from 2000 is a reflection that from that year egg collectors could not find nests in some areas previously harvested and stopped surveying those areas. The reason for this nest decline is not known, but it has been suggested that the crocodiles have either moved to more remote areas due to increasing human encroachment or are being affected by undetermined ecological causes (Fergusson, 2005b). Nonetheless it could also be related to the recent decline of the crocodile industry in Zimbabwe which of course would be directly reflected in the monitoring data (Hutton, pers. comm.).

5 Recommendations

The simplest recommendation resulting from this study is the update of the most recent map for the distribution of *C. niloticus*, since two new locations not represented in the map were identified outside its currently recognised range by the results of this study.

It also seems imperative to plan future surveys to investigate the conservation status of *C. cataphractus* and *O. tetraspis*, since very little population data has been produced for the two species. This is especially important considering their current conservation status is uncertain and, that from the few surveys that had the species as target, only a small proportion found individuals present. This suggests that either, the species are endangered or the methods used to survey them are not appropriate considering their evasive behaviour. Survey methods for this species should be re-evaluated and future surveys should be supported by additional indicators of presence/absence of the species such as market surveys for dead individuals or interviews with local people, as was done by Abercrombie (1978).

Furthermore, planning of further crocodile surveys as regional approaches with standardised methods is also a priority to avoid continuing to survey crocodile populations in a fragmentary and not transcendental manner. The standardised methods should account for the differences in habitats and habits of the species, since they pose different sources of bias which should be estimated by further research.

Finally, general factors that should be standardised in the effort of making surveys comparable have been identified in this study (Figure 3.1). These factors have been used to produce a surveying sheet to aid in the effort of standardising surveys by recording important information required to accurately assess the comparability of surveys. The sheet produced is presented on the next page.

Please mark with an 'X' or fill in the blanks where applicable:

(1) Species	<i>C. Crocodylus:</i>			(12) Time survey started	
	<i>C. cataphractus</i>			(13) Time survey finished	
	<i>O. tetraspis</i>			(14) Names of surveyors and experience <i>(expressed in brackets in a scale from 1-3: 1- inexperienced, 2- moderately exp. 3- highly exp)</i>	1
(2) Country			2		
(3) Location			3		
Starting coordinates	Latitude:		4		
	Longitude:		5		
Finish coordinates	Latitude:		(15) Name of pilot and experience (1-3 scale)		
	Longitude:		(16) Visibility (1:clear, 2: some clouds, 3: overcast)		
(6) Date			(17) Altitude of aircraft (m)		
(7) Indicator counted	Crocodile			(18) Speed of vehicle (km/h)	
	Nest			(19) N° of nests	
(8) Time of day	Day			(20) N° of nesting sites	
	Night			(21) N° of crocs	
(9) Transport	Plane			(22) Distance surveyed (km)	
	Helicopter			(23) Crocodile density (crocs/km)	
	Boat			(24) Coefficient of variance of the survey	
	Foot			(25) Observer bias (CV tandem counts)	
	Other (specify):			(27) Authors or formal reference	
(10) Was a GPS used? Y/N				(28) Any comments on issues that could have affected survey results	
(11) Were tandem counts carried out? Y/N					

Name		Date	
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6 Conclusion

The aim to estimate the population trends of the three crocodile species throughout Africa could not be attained due to the inconsistency of the surveys. Nonetheless the assessment of the crocodile surveys presented in this study should serve as a reflection of the importance of sharing survey information with key audiences and setting conservation efforts at regional levels. This reflection should serve for further planning of wildlife monitoring, not only for the African crocodile species. Otherwise, vast amounts of survey data useless for monitoring purposes will continue to be produced.

The amount of data presented in this study of African crocodiles is vast, especially for *C. niloticus*. Nonetheless, the lack of wider planning has led to the generation of survey data which is in its majority useless for monitoring populations or estimating trends. Most certainly this is the result of the lack of diffusion of the knowledge generated by wildlife surveys (Guralnick, R.P. *et al.*, 2007), which this study aims to overcome for the African crocodiles through the initiative of collating the data of all the crocodile surveys carried out in Africa in a same database of open access to concerned crocodile researchers. As such, this study should specifically serve as basis for further planning of surveys and the development of joint standardized programmes of crocodiles across Africa.

Future surveys are especially important for *C. cataphractus* and *O. tetraspis*. Knowledge of this species is scarce, although a priority considering their limited distributions and dependence on specific habitats such as wetlands and rainforests which are continuously degraded across Africa due to human population growth (Eaton, 2006).

Considering the recent declines observed for *C. niloticus* in this study, and the fact that the species is of invaluable ecological importance for wetland conservation, standardised monitoring programmes of the species are also important to assess their status across Africa. Not to mention the monitoring importance of the species for management and problem control purposes.

The study also points Central and West Africa as regions which require urgent surveys, especially in forested areas since there is no information generated in these habitats. Even for Southern and East Africa, which are better represented by surveys, forested areas remain unsurveyed.

The study makes it also clear that the main reason for the under-representation of *C. cataphractus* and *O. tetraspis*, and Central and West Africa in surveys, is the commercial importance of *C. niloticus* and the need to survey the species as requirement of the CITES. The CITES appears as a determinant engine driving surveys and influencing the numbers of crocodiles counted in the case study populations. Armed conflicts and funding distribution also seem to influence the distribution of surveys across Africa, although there is not as much evidence as for the CITES.

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8 Appendix

Appendix 1. List of references from where the survey data was extracted

Author(s)	Year
Abercrombie III, C. L.	1978
Anon.	2007
Anon.	n.d.
Anon.	1971ca.
Aust, P. W.	unpublished
Behra, O.	1987a
Behra, O.	1993
Behra, O.	1987b
Behra, O. and C. Lippai	1993
Behra, O. and J. M. Hutton	1988
Blomberg, G. E. D.	1976
Brown, C. J. <i>et al.</i>	2004
Bruessow, D. M.	1992
Combrink, X. and P. Ross	unpublished
Cott, H. B.	1961
Cott, H. B. and A. C. Pooley	1972
de Buffrenil, V	1993
Dore, M. P. O.	1996
Eaton, M. J.	2006
Fergusson, R. A.	1995a
Fergusson, R. A.	1998a
Fergusson, R. A.	1998b
Fergusson, R. A.	1998c
Fergusson, R. A.	1999a
Fergusson, R. A.	1999b
Fergusson, R. A.	1999c
Fergusson, R. A.	2000a
Fergusson, R. A.	2000b
Fergusson, R. A.	2000c
Fergusson, R. A.	2000d
Fergusson, R. A.	2001a
Fergusson, R. A.	2001b
Fergusson, R. A.	2001c
Fergusson, R. A.	2003a
Fergusson, R. A.	2003b
Fergusson, R. A.	2005a
Fergusson, R. A.	2005b
Fergusson, R. A.	2006
Fergusson, R. A.	2007
Fergusson, R. A. and N. W. Pentolfe	2007
Fergusson, R.A. and J. Hutton	1998

Continuation of Appendix 1.

Author (s)	Year
Games, I.	1990
Games, I. and Severre, E. L. M	1989
Games, I. and Severre, E. L. M	1990
Games, I. and Severre, E. L. M	1993
Games, I. and Severre, E. L. M	1995
Games, I. and Severre, E. L. M	1996
Games, I. and Severre, E. L. M	1999
Games, I. <i>et al.</i>	1992
Games, I. <i>et al.</i>	1996
Games, I. <i>et al.</i>	1997
Graham, A.	1968
Graham, A.	1988
Graham, A. <i>et al.</i>	unpublished
Graham, A. <i>et al.</i>	1992
Hutton and Katalihwa	1992
Hutton, J. and L. Chingwendere	1996
Hutton, J. and L. Chingwendere	1997
Hutton, J. M.	1984
Hutton, J. M. and M. E. J. Woolhouse	1989
Huttton, J. M.	1992
Jacobsen N. H. G and Kleynhans, C. J.	1993
Jacobsen, N. H. G.	1984
Kofron, C. P.	1989
Kofron, C. P.	1992
Leslie, A. J. and J. R. Spotila	2001
Loveridge, J. P. and J. M. Hutton	2000
Luiselli, L.	1999
Mafole, S. <i>et al.</i>	2003
Mitchell, S. A.	1968
Mitchell, S. A.	1969
Modha, M. L.	1967
Muhamued, A.	1984
Owusu-Nsiah and W. Oduro	1997
Parker, I. S. C. and R. M. Watson	1970
Pauwels, O. <i>et al.</i>	2004
Pauwels, O. <i>et al.</i>	2003
Ranot, S.	1995
Riley, J. and F. W. Huchzermeyer	1999
Shine, T. <i>et al.</i>	2001
Shirley, M. H. <i>et al.</i>	unpublished
Simbotwe, M. P.	1993
Soorae, P. S.	1994
Swanepoel, D. G. J. <i>et al.</i>	2000
Taylor, R. D. <i>et al.</i>	1992
Waitkuwait, W. E.	1985
Whitaker, R.	2007
Whitaker, R.	unpublished