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6.6 METHODS OF SURVEYING AND MONITORING CROCODILES.

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Introduction

The surveying of Nile crocodile (*Crocodylus niloticus*) populations to support management programmes probably began with Parker and Graham's (1964) survey of part of the Rufiji river population for the Tanzania Game Division who proposed to implement a sustained yield cropping operation. These authors compared aerial survey with ground surveys on foot by night and by day, and day and night surveys by boat. Surveys on foot or by boat by day were quickly rejected while the other three methods all found good application depending on terrain. These survey techniques had long been used for American alligator (*Alligator missisippiensis*) populations (Giles & Childs 1949; Chabreck 1966), and more recently they have been applied in Australia Messel 1978, Bayliss *et al.* 1987), Papua New Guinea (Graham 1981, Hollands 1985) as well as many other parts of Africa. The field techniques have changed little over the last 40 years. Helicopters have been compared with fixed wing aircraft (Parker & Watson 1969) without leading to any innovation. An added technique has been vertical aerial photography to sample length frequency distributions and habitat preferences (Parker & Watson 1969).

While field techniques have stayed the same, methods of data analysis have improved. But before these analyses can be used surveys must be designed to yield the required data. While this may seem obvious, it is a fact that most surveys are not designed to allow more than the simplest of analyses and the time-honoured practice of making a survey first and then seeing what can be done with the results, usually very little, is all too common.

What follows is a review of the survey and monitoring methods suitable for Nile crocodiles, supplemented by references to other species where appropriate. Their utility is evaluated mainly in the context of assessing population status and monitoring trends following management for exploitation.

Each survey method is considered separately, with a description of the techniques, recommendations on design and examples of analysis for each. The range of analyses is not exhaustive, and reference to additional methods is made in the text.

Since this chapter is quite long and complex, a contents list is given to assist clarity.

Contents

A. Counting Crocodiles

1. Techniques

1.1. Ground survey: Ground surveys by day, whether on foot or by boat are seldom done. Parker & Graham (1964) reported that daytime boat surveys recorded only 23% of animals seen on the same route surveyed by air. Parker & Watson (1969) recorded an even smaller proportion (7%). Spotlight counts at night have been the most widely used technique to survey crocodiles. Spotlight counts developed from the experience of hunters who found that dazzling crocodiles with a spotlight made them easier to find and approach than by day. Spotlight counts are made from a boat or on foot, depending on circumstances. Parker & Graham (1964) made foot surveys along the Rufiji River, as did Graham (1968) at Lake Turkana, in situations where boatwork was impractical. Usually, though, spotlight counts are made from a boat as more ground can be covered, and many rivers cannot be traversed along their banks. Any small, engine-driven boat will do. Choice of light depends on the distance at which crocodiles are to be observed. Narrow (<50m) waterways are adequately searched with a 4.5 V, 3-cell torch; wide rivers or lakeshores need more powerful lights. An automotive spotlight powered by a 12V car battery is the most practical equipment because these are readily obtained and serviced. Further recommendations on technique are given in Pernetta & Burgin (1980), Murphy & Coker 1983, Montague (1983), Woodward & Marion (1978) and Hutton & Woolhouse (in press).

1.2. Aerial survey: This technique developed from 2 general observations: a. that crocodiles are much easier to see from above than at water level; and b. large animals in particular seem less apt to dive in the presence of an aeroplane than a boat. A single-engined high wing machine capable of steep, tight turns at speeds of 95-130 km/h is essential. Cessna models in the range C150-210 have all been successfully used of which the 180-series models (particularly with Robertson STOL conversions) are the best all-round machines. Piper Supercubs, Helio Courier H295s and other types are also suitable. Parker & Watson (1969) found little advantage in using a helicopter, either for daylight or spotlight counts, particularly when the high hourly cost (3-5 times that of a fixed wing) was taken into account. This cost factor is easily doubled if the slower speeds available from helicopters are exploited; if they are not, then there is no point in spending the extra money in the first place. In general, only extravagantly funded agencies can justify helicopters. Recent developments in microlight aircraft design have resulted in machines such as the Shadow Mk1 and Zenair STOL CH 701 with impressive specifications for safety and performance, and low capital and operating costs. While they have yet to be applied to crocodile surveys they could revolutionize cost-effectiveness, and are almost certain to find an important place in monitoring programmes.

Choice of pilot is critical. Best use of an aeroplane is usually obtained if one observer doubles as pilot. Experienced biologist-pilots are almost indispensable to good survey practice for two reasons: a. Professional pilots rarely have the ecological know-how required to position an aircraft for an observer to gain a consistent view of the features he needs to see; b. professional pilots are typically reluctant to make the uncoordinated turns at very low speeds near the ground which are essential when surveying meandering channels. Watson, Tippett & Jolly (1981) found no difference in counting efficiency between observers only, and observer-pilots.

Crocodiles are commonly surveyed from 25-50 m above water level. In the case of strongly meandering rivers and dendritic lakeshores a spiral flight path is usually the best way of following the waterline.

2. Design of Counts

Before discussing design certain terms need to be defined. Because a count of wild animals is never exact it is always an estimate. An **estimate** can be made by attempting to count all crocodiles in the survey region (a total count) or only some of them (a sample count). In a sample count typical parts of the region- **samples** - are chosen, the crocodiles in them are counted and the results extrapolated to the whole region. Unless a survey region is very small it is inefficient to attempt a total count. Much better use of resources is made by sampling, and most of what follows concerns sample counts.

The quality of an estimate of population size, Y, is assessed in two ways: by its precision and its accuracy. Accuracy is the closeness of an estimate to the actual numbers, and the statistical measure of accuracy is called **bias** - the difference between the true numbers and the estimate. Bias is caused by the failure to see all the animals in the sample areas. Precision is the random variation among counts, and the statistical measure of precision is the sampling error, usually shown as the mean estimate + its **standard error** (SE). Another way is to show it as the **coefficient of variation** (CV) which is the SE as a percentage of the estimate. An example may help to distinguish between precision and accuracy. Consider a population of 300 crocodiles. A sample count might return an estimate of 200 ± 12 (SE). Although this is an inaccurate (i.e. biased) estimate of the actual numbers it is very precise because the standard error is very small (CV of 6%). Alternatively the count might have led to an estimate of, say, 295 ± 18(SE). This is a very accurate (i.e. unbiased) estimate of the actual numbers, and has the same precision (CV of 6%). Had the CV of the accurate estimate been, say, 12% instead of 6% the accuracy would of course have remained the same but the precision would have deteriorated. In terms of design, precision is largely a matter of reducing the variation among counts, and accuracy largely a matter of estimating (and then correcting) the various sources of visibility bias that are invariably present in crocodile counts.

If an estimate always reflects the same proportion of the true population it can be used as an **index** of population size. Any change in the population would be reflected in the index. Clearly, for such changes to be detectable precise estimates are needed. To determine whether two estimates are statistically different a further measure of precision, the **confidence limit**, (CL) is used. Confidence limits are calculated from the SE (see Section 3) and measure the range of uncertainty around an estimate. Only if their CLs do not overlap can two estimates be taken as significantly different.

To estimate a population by sampling, each count of crocodiles is expressed as a **density**, the number of crocodiles/km. The average of all the sample densities is then calculated and this mean density multiplied by the total length of river in the region to give an estimate of the whole population. The region to be surveyed is generally divided into sections or strata. A **stratum** is usually a distinct habitat type, modified by, for example, a reconnaissance survey or local knowledge, to define an area with reasonably uniform crocodile densities. **Sampling fraction** is the percentage of the length of a stratum that is sampled. The most important design features to bear in mind are outlined below. They apply equally to aerial and ground surveys, and address the two main concerns of any sample count - precision and accuracy.

2.1. Precision: The main factors influencing precision are outlined below.

2.1.1 Stratification. Crocodiles, even in comparatively homogeneous environments, are not uniformly distributed. Graham (1968) observed densities on the east shore of Lake Turkana ranging from 1-112.5/km. Similarly Parker & Watson (1969) recorded densities ranging from 1.7-86.7/km on the Victoria Nile where it traverses Murchison Falls National Park. The practical implication is that if samples are taken from the whole region these may yield an accurate mean density, but the large variation among counts will result in a large CV. The CV can be substantially reduced by stratifying the region into areas of similar density, sampling each of these separately, and then merging the stratal estimates (see Section 3).

2.1.2 Sampling fraction. Of all the design factors which can be manipulated, sampling fraction exerts the strongest influence on the CV, which decreases by the square root of increased fraction of stratum sampled.

2.1.3 Stratum length. For a given sampling fraction the CV decreases by the square root of increasing stratum size. As stratum size is fixed a larger sampling fraction has to be applied in the smaller strata to achieve a given target CV.

2.1.4 Number of samples. The sampling fraction may comprise a few large or many small samples. For a given sampling fraction the number of samples has no effect on CV, but it does determine precision in terms of confidence limits, which narrow with increasing number of samples up to about 30. A given sampling fraction should be broken into as many small samples as possible rather than into a few large ones.

2.1.5 Crocodile density. To obtain a given CV high density strata require a large sampling fraction because the CV is proportional to animal density. Sampling effort should be allocated among strata in proportion to the square root of density of crocodiles in each stratum.

There is no cut and dried procedure for designing the most economical sampling programme prior to a survey. Some idea of the sampling error has to be obtained first which can be done by taking a commonsense approach along the following lines. After stratification, concentrate sampling effort on the high density strata. Low density strata contribute little to the total population and though large CVs are likely from small sampling fractions these will represent, in terms of variance, only small contributions to the total pooled variance. Likewise, inaccuracies will have relatively small effects. Most surveys apply a sampling fraction of 5-20% to each stratum, the limit usually being set by budget. A practical solution is to start sampling, calculate the CV on the spot after a few samples, and then use Caughley's (1979) formula to predict the total sampling fraction required to achieve the desired CV as follows:

$$\text{Required sampling fraction (\%)} = \text{pilot sampling fraction (\%)} \times \frac{\text{Variance } \hat{Y}}{(\hat{Y} \times \text{target CV})^2}$$

If necessary, the sampling is then increased to the predicted level.

The question then arises as to what CV to aim for. The answer can be inferred from Caughley's (1979) rule of thumb which states that for two successive population estimates to have a 95% chance of being significantly different their CVs must be <33% of the percentage difference between the estimates. This means that an apparent 12% increase in density needs to be estimated with a CV of <4% - a rarely encountered precision. Even a 50% increase (or decrease) in density needs to be estimated with CVs <16%, which will only be possible in strata with fairly uniform densities. The point to note is that if population trends are to be monitored a well designed sampling programme which aims for CVs in the 5-15% range is essential. Otherwise only drastic changes will be statistically detectable.

To sum up sampling design: Stratification is part of the sampling process; do not skimp it. Concentrate on the denser strata. Press for the largest sampling fraction time and money will allow and divide it into as many randomly located samples as possible. Ideally, at least 30 samples should be taken, which is often an impractical number. A rule of thumb for deciding on the number of samples, n, is

$$n = (4/\text{confidence limits desired}) \times CV^2$$

To fit approximate confidence limits to an estimate, $\hat{Y}$, add or subtract

$$\underline{t} \times \sqrt{Var(\hat{Y})/4\hat{Y}} \text{ to } \sqrt{\hat{Y}} \text{ and square the results.}$$

(t is Student-t value from tables for the appropriate degrees of freedom). This method (Jolly 1981, p.214) avoids negative values for the lower limit.

2.2 Accuracy: All counts of free-ranging wild animals underestimate true numbers because some animals, though visible, are overlooked, and some are hidden from the observer. The control of these errors (collectively termed visibility bias) is one of the principal tasks of design. Conscientious technique and sophisticated analyses are wasted in the aftermath of poor design. In addition to observer bias from visible but overlooked animals it is necessary to recognize 2 categories of invisible crocodiles: a. those hidden by vegetation (or other obstructions); and b. those underwater at the time of observation. These three categories of visibility bias (see Table 1) have different effects and require different designs to deal with them.

2.2.1 Observer bias. The only practical method of estimating observer bias in the visible population is to make simultaneous double-counts.

The simultaneous double-count (Caughley & Grice 1982, Graham & Bell in press) requires two observers working in tandem to independently count the same crocodiles. The rear observer notifies the front observer of every crocodile he sees which the front observer records as either as seen by him also, or by the rear observer only. At the same time the front observer records a third category of crocodiles seen only by him. This procedure is simple and need not interrupt a wide-ranging survey, as the front observer is needed only to make a double-count of a few sample areas which can be part of the main survey. The critical requirement is that the tandem observers must not collude in spotting a crocodile. If densities are very low and good photos or maps exist on which animals can be precisely plotted there need be no communication between observers, as the three categories of sightings can be created afterwards from their respective maps.

2.2.2 Diving and concealment bias. Problems of diving and concealment bias will be discussed together as no studies have yet been made which aportion the relative contributions of these errors. A study by Hutton

Table 6.6(1): Main sources of visibility bias in crocodile counts, their comparative effects and methods of compensating for them.

Class of visibility bias	Effect	Appropriate methods for deriving correction factors
OBSERVER BIAS Visible animals overlooked by observer	Likely to be comparatively evenly spread among habitats and seasons	Simultaneous double-counts Bounded counts
DIVING BIAS Animals under-water at time of observation	Likely to be comparatively evenly spread among habitats and seasons	Mark-recapture experiments
CONCEALMENT BIAS Animals hidden by vegetation or other physical obstructions	Likely to vary widely among habitats and seasons	Survey at low water (rivers & lakes) for partial correction. No methods for swamps
TOTAL VISIBILITY BIAS Causes not identified	Highly variable	Mark-recapture (except in swamps) Index by reference to nest effort Index with harvest removal data

(1984) of a population of Nile crocodiles at Lake Ngezi (Zimbabwe) quantified both the total visibility bias caused by unseen crocodiles during spotlight counts and the effects of 11 environmental factors on the proportion of the population counted on a given occasion. Forty six spotlight counts were made over a 3-year period. At the same time total population estimates were made from a continuous mark-recapture exercise. Of the 11 factors tested, water level alone accounted for 61.0% of total variation, with maximum day temperature and minimum previous evening temperature accounting for a further 12.0%. Under the best survey conditions possible, as determined from the environmental influence measurements, there was only a 63% chance of counting a crocodile. Under the worst conditions only 10% were seen (Hutton & Woolhouse in press).

Bayliss et al. (1986) in a mark-recapture experiment in Northern Australia, similarly recorded 62% of the total population of saltwater crocodiles (*C.porosus*) during spotlight counts in rivers free of vegetation, which dropped to 34% in winding channels with thick vegetation.

The finding of Hutton & Woolhouse (in press) that under the most favourable conditions, when water level was low with little vegetation or other cover, only 63% of the total crocodiles were seen leads to the conclusion that 37% were underwater. The Bayliss et al. (1986) figure of 62% in open rivers can be similarly interpreted. Only further studies will determine whether this diving statistic is widely applicable, or a variable and strongly population-specific parameter. The Bayliss et al. (1986) found that large saltwater crocodiles were more likely to dive than small ones. A fairly constant probability of ± .7 of seeing a crocodile up to 2 m in length declined to only .15 in the case of animals >3 m long. A similar size related effect may prove to apply to Nile crocodiles.

These mark-recapture experiments emphasize a crucial feature of the design of crocodile counts: stabilization of counting technique. Aerial or spotlight counts will always contain large errors due to observer, concealment and diving bias. While there are designs to cope with observer bias, mark-recapture is the only method so far developed for estimating concealment and diving bias. A mark-recapture programme is a major undertaking not likely to form part of a conventional survey. In the absence of a model to adjust counts for visibility bias the count must be used as an index of population density or size. Since the relationship between an index and the true density is known to be strongly influenced by environmental factors such as water level and temperature these influences should be held constant between surveys, or an index from one survey cannot be compared with that from a second survey of the same area. In practice, stabilization will be more or less limited to surveying at the same time of year (or same water level) which will usually be the end of the dry season when water level is lowest and crocodiles most concentrated. Observers, equipment and technique can also be stabilized. But plans to survey only under identical conditions of maximum day temperature, minimum previous evening temperature, cloud cover and all the other variables known to influence counts will obviously not travel well from office to field. Where compromises must be made these should be noted.

Data recording: Whenever possible, all animals seen should lotted on 1:25,000 scale (or larger) maps, or aerial photos. purpose of this becomes clear when methods such as le-counts are considered, but it is important for several ons not necessarily of immediate relevance. It is often d that crocodiles favour one river bank over another which bias results if not detected. Where more than one observer sed, it is desirable to test for differences between their ts. It is sometimes found that stratal boundaries need ring after a time which means a loss of previous data if rvations cannot be reallocated because they were not linked eographical position. Generally, any data set is easier to yse, or reanalyse retrospectively, the more detailed the inal records are.

als seen should be classified by size, wariness and activity. ably the most useful size ranking is into mature length class 7 m) and immature. Wariness can be ranked by the distance at h approached animals dive. Activity such as whether animals ashore or afloat, can be useful, for example in planning al photographic exercises. A high proportion of animals seen be in the water early in the morning, or at midday, from h only head measurements will be available.

lly, a set of ancillary data should be recorded describing circumstances of the survey in sufficient detail for others epeat it exactly. Environmental conditions likely to uence crocodile sightability should be recorded on standard at data sheets. Factors known to be influential are water l, water temperature, maximum and minimum air temperatures, height, wind speed, cloud cover, moonlight, precipitation, human activity. Detailed records of all these factors, and others thought to be relevant, are essential for the dardization of counting procedures.

nalysis of Crocodile Counts

od standard text on the range of analyses applicable to odile survey data is that of Caughley (1977). Some of the ods most likely to apply to Nile crocodile management are n below illustrated by worked examples. The sampling methods commonly used are those of Jolly (1969a), and Jolly and on (1979). The underlying theory is given by Cochran (1963). r (1973), and Norton-Griffiths (1978) provide good accounts ampling methods for counting animals.

3.1. Total counts: If a survey has been made of the whole river, lake or swamp under consideration (i.e. a single total count) then the estimate of the visible population is simply the count to which no statistical estimate of the error can be attached.

3.2. Sample counts: A generally applicable analysis of a sample census is Jolly's Method 3 (Jolly 1969a) where sample areas of either equal or differing sizes are chosen with a probability of selection proportional to their size. The following notation is used:

$\hat{Y}$ = estimated population
y = the count in a given sample
z = the length in km of each sample
Z = the total length of crocodile habitat in the survey stratum, i.e. the length of all the possible samples.
d = y/z, the density of crocodiles in a smaple

The population, Y, is then estimated as

$$\hat{Y} = Z\bar{d}$$

The variance of Y is estimated as

$$\hat{Var}(\hat{Y}) = (Z^2/n)s_d^2$$

where n = the number of samples taken, and

$$s_d^2 = (\Sigma d^2 - (\Sigma d)^2/n)/(n - 1).$$

The standard error of $\hat{Y}$ is $\sqrt{\text{variance}}$, and the CV of $\hat{Y}$ is the standard error divided by $\hat{Y}$. To express the CV as a percentage multiply by 100.

The method is illustrated with an imaginary example of a river 600 km long. From local knowledge combined with the river's physical characteristics it has been divided into 4 strata of 280, 110, 150 and 60 km respectively. Each stratum is to be sampled separately to estimate the density and hence population of crocodiles. It has been decided to sample by aerial survey, and partially adjust these counts for visibility bias with a correction factor derived from spotlight counts on a sample stretch of river.

For simplicity only stratum 1 will be discussed, though the same procedure would apply to the other 3. The 280 km of stratum 1 are divided into, say, 33 samples of varying length defined by easily recognizable landmarks. Three of these (in practice aim for at least 10) are selected with a probability proportional to size. A fourth is selected for aerial and night counts for a correction factor, R, calculated as $\Sigma x/\Sigma y$ where x equals a night count and y the corresponding aerial count. In the example 293 crocodiles were counted at night where 159 were seen from the air to give a value for R of 293/159 = 1.842.

The counts are made and the data tabulated.

Sample No	Length z	Counts y	Adjusted count $(y \times R)$	Density d	d^2	$\bar{d}$
1	15	112	198	13.2	174.2	
2	8	65	115	14.4	207.4	
3	6	55	97	16.2	262.4	
3	29	232	410	43.8	644.0	14.1

The estimated population, $\hat{Y}$, of stratum 1 is $\hat{Y} = Z\bar{d}$, where Z is the total length of stratum 1 and $\bar{d}$ is the mean density. Thus

$$\hat{Y} = 280 \times 14.1$$
$$= 3958$$

To estimate the variance of $\hat{Y}$ first estimate the sampling variance, s_d^2, as

$$s_d^2 = (\Sigma d^2 - (\Sigma d)^2 / n)/(n - 1)$$
$$= (644.04 - (43.8^2/3))/2$$
$$= 2.28$$

Then the variance of $\hat{Y}$ is

$$var(Y) = (Z^2/n)s_d^2$$
$$= (78400 \times 2.28)/3$$
$$= 59584$$

The total population of the river is simply the sum of the 4 stratal estimates of $\hat{Y}$, and its variance (and hence CV) the sum of the stratal variances. Assuming the following data for the 4 strata:

Stratum	Length	$\hat{Y}$	$Var(\hat{Y})$
1	280	3958	59584
2	110	1210	210256
3	150	1125	32400
4	60	960	5898
	600	7253	118907

Altogether, 7253 crocodiles are estimated with a CV of 4.75%

If, after a survey, two or more strata return apparently similar estimates these can be merged to yield a more precise overall estimate. First, test the estimates for a significant difference. A quick approximation is that if

$$(\hat{Y}_1 - \hat{Y}_2)/ \ (Var(\hat{Y}_1) + Var(\hat{Y}_2)) > 2,$$

then there is a 95% chance that the 2 estimates are different.

If they are not significantly different, then, from the product of the estimates

$$\text{merged } \hat{Y} = (1/Var(\hat{Y}_1) \times \hat{Y}_1) + (1/Var(\hat{Y}_2) \times \hat{Y}_2)/(1/Var(\hat{Y}_1) + 1/Var(\hat{Y}_2)$$

$$\text{and merged } Var(\hat{Y}) = 1/(1/Var(\hat{Y}_1) + 1/Var(\hat{Y}_2))$$

Strictly speaking, the variance of Y in the above examples should include a component representing the variance of the correction factor used to adjust the aerial counts. This would normally make a negligable difference to the $CV(\hat{Y})$ and for most practical purposes can be ignored. The procedure for handling the variance of the correction factor is given by Jolly and Watson (1979).

3.3. Observer bias: Two analyses are worth considering.

3.3.1 The double-count. All double-counts, whether of crocodiles counted simultaneously or from two independent maps, are analysed by the same method. Following Magnusson, Caughley & Grigg (1978) the crocodiles seen only by observer one (or survey one) are labelled S , only by observer two, S_2, and by both observers, B.

The probability of each observer seeing a crocodile is given by

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

and a correction factor, R, for a given observer, or survey method, is therefore

$$\hat{R} = 1/\hat{P}$$

Graham and Bell (in press) give a procedure for estimating $\hat{Y}$ and its SE directly from the double-counts.

3.3.2 Mark-recapture. Hutton (1984) and Hutton & Woolhouse (in press) reported an application of the Petersen estimator modified after Bailey (1951) in which an estimate of the population, $\hat{Y}$, is given by

$$\hat{Y} = M(n + 1)/m + 1$$

Where M = number caught, marked and released, m = number of marked animals recaptured and n = number of occasions on which animals are recaptured.

The analysis of mark-recapture data is sensitive to differences in catchability among individuals, and sample size, as well as other factors. Since unequal catchability is probably inevitable its possible effects must be carefully considered particularly if only small fractions of the population are marked or recaptured. Otis et al (1978) give an extensive review of the analysis of mark-recapture experiments while Hutton & Woolhouse (in press) and Bayliss et al. (1986) discuss applications to crocodiles.

B. Counting Crocodile Nests

1. Techniques.

The complete inaccessibility of habitats consisting mainly of dense reed swamps has led to the search for other methods of assessing population status. Graham, Patterson and Graham (1976) developed a method for monitoring the Okavango River (Botswana) population based on estimating the number of nests made each year from aerial surveys. The general technique was similar to that for counting crocodiles, the main difference being the data recording procedure. Existing aerial photos at a scale of 1:70,000 were enlarged to 1:12,000, on translucent AK Polygraph film, from which dyeline copies for field use were made. Nest sites in use were plotted on the dyeline copies and later transferred to the original prints. Dyeline copies for the next season thus incorporated all previous seasons' data. Each aerial photo constituted a convenient quadrat to search at a height of 90-150 m. Searching avoided the hotter time of day from 0900-1600 h because nesting crocodiles took to the water at these times. Nests were indicated by the presence of a mature female (2.7 - 3.5 m long) on a likely site i.e. a bank of sand or soil about 1 m above water level, exposed to the sun, and usually several metres from water. Crocodiles merely resting ashore were usually cose to the water, and were more likely to take to the water when circled than a nesting female. A well used path, or paths, and a "lie" were usually apparent from the air, and in the absence of the crocodile were the criteria for recognizing a site.

Ground searches employ the same criteria for identifying sites. At a site most nests (there may be more than one) are swiftly located as they are generally closely associated with a lie. Some, however, are either not regularly or closely attended and can be found only by systematic probing or digging. Probing is done with a sharp rod of 6.5 mm diameter steel. A typical nest is readily detected by an experienced searcher by the characteristic "feel" of the rod piercing the roof of the egg chamber followed a little deeper by contact with an egg.

2. Design of nest counts

Nest survey design is based on the assumption that all but a negligable number of nest sites are visible because they are exposed to the sun. Visibility bias therefore consists almost entirely of observer bias from overlooked or misinterpreted sites, with only a very small component caused by hidden nests. Graham et al. (1976) considered this assumption for the Okavango River population in the light of two observations. The first was a comparison of an aerial and ground search of an 800 m channel with patches of closed-canopy forest (judged a particularly difficult habitat to search from the air). The same 11 sites were found by both methods. The second was a test of the efficiency of aerial search in finding nests in Phragmites karka reedbeds along the main riverbank (another habitat in which nest sites are sometimes hard to see). Ground survey of 31 km of riverbank on which 11 nests had been found from the air revealed a further 2 nests missed on the aerial survey but judged visible from an aeroplane. An estimate of this error is the principal design feature of a nest survey. The most straightforward design is a two-stage survey in which an extensive aerial survey of all potential sites is made in conjunction with intensive ground surveys of sample nesting areas readily accessible from the ground. This deals equally well with large, inaccessible swamps, rivers or lakeshores. A critical specification is that all nests found on both types of survey are accurately plotted on aerial photos or maps. This is because the analysis requires that nests seen on both surveys are clearly distinguished from nests found only from the air or ground surveys.

The aerial survey should aim to cover all possible sites as uniformly as possible; undue effort should not be put into attempting to determine how many nests there are at sites where several crocodiles nest, or in deciding on sites with ambiguous characteristics. Only clearly defined sites should be mapped, as the analysis does not require that all sites are found, only that they are looked for. Care must be taken to view each possible site from a near-vertical angle because surrounding vegetation is apt to block oblique views. The principal pitfall in nest survey design is failure to bring all potential sites under observation. If the survey cannot cover all possible nesting habitat, or its extent is unknown, the stratification should explicitly reflect this. It may take several seasons to locate and accurately map all potential nesting habitat. The sample areas chosen for ground survey must be thoroughly searched and their boundaries carefully mapped so that exact comparison with the aerial search is made.

Care must be taken to establish the number of nests (clutches of eggs) actually present at a site. Graham et al. (1976) recorded two Okavango sites apparently attended by a single female, at which 2 and 3 clutches respectively were found. While most nests are easily located near to the tracks made by the attendant female, an exhaustive count of all clutches requires diligent searching by probing of any sign of digging by a crocodile. Nests destroyed by other animals must be included in the nest count.

Finally, one other important aspect of nesting must be addressed by the design. Nest making extends over several weeks and therefore the timing of a count must be established relative to the nest-making season. Counts made before the end of nesting clearly are only indices of total nest effort and must be adjusted by a correction factor. Two items of information are required to estimate this: the start and duration of nesting. The start is easily determined from foot patrols or aerial reconnaissance of a known nesting location at the expected beginning of the season. In Zimbabwe, Zambia and Malawi the start can be expected in early September, in Botswana, late September, in Uganda early December, in Kenya and the Sudan mid-November. In large populations the duration is likely to be about 80 days. Aerial and ground counts should be made concurrently, preferably about mid-way through nest-making.

3. Analysis of nest counts

The estimate of nest effort can be made using the same method as for the analysis of crocodile counts (see above) in which sample aerial counts are adjusted for visibility bias by a correction factor derived from sub-samples surveyed on the ground. A second correction factor corrects for nests made after the count.

3.1. Visibility bias: Since all but a negligable number of nests are visible, visibility bias consists mainly of observer bias, and a correction factor, R, is estimated as $\hat{R} = y/x$ where y = ground count and x = corresponding aerial count. This correction factor is then applied to the total, or sample aerial count, n, whichever has been made, to estimate the population of nests as $\hat{N} = Rn$.

3.2. Correction for nests made after the count: The nest count, N, now free of observer bias, is used to predict total nest effort by reference to Table 6.6(2). The number of days after start of nesting is divided by duration of the nesting season (if this is unknown it is approximated by 80 days). olumn A of Table 6.6(2) is entered at this fraction and read off the corresponding value in column B. This value is the fraction, F, of the total expected nests that the count at time A indexes. The estimate of nest effort, E, is then

$$\hat{E} = \hat{N}/F$$

4. Nest effort as an index of crocodile numbers

It can reasonably be assumed that nest effort is correlated with the population available for breeding, and ultimately to population size. The calibration of R , the ratio of mature-length crocodiles to nests, together with nest effort, E, could then index population size, Y, as

$$\hat{Y} = \hat{E}\,\hat{R}_1\,\hat{R}_2$$

where R_2 is the ratio of immature-length class to mature-length class derived independently from a length frequency analysis by vertical aerial photography or from a wild harvest.

Table 6.6(3) lists values of R_1 and R_2 from four populations of Nile crocodiles. The partitioning of the mature and immature segments of the populations is based on the relationship between length and potential maturity for each population. Only for the Ngezi and Lundi populations are the actual proportions of breeding

Table 6.6(2): The relationship between time of nest count relative to duration of nest-making, and fraction of expected total nests in Nile crocodiles (after Graham & Martin, in prep.).

Column A = Time of count as fraction of season.
Column B = Count as fraction of nest effort.

A	B	A	B
.020	.012	.500	.500
.040	.014	.520	.546
.060	.017	.540	.591
.080	.021	.560	.634
.100	.025	.580	.676
.120	.030	.600	.715
.140	.035	.620	.751
.160	.042	.640	.784
.180	.050	.660	.813
.200	.060	.680	.839
.220	.071	.700	.863
.240	.084	.720	.883
.260	.099	.740	.901
.280	.117	.760	.916
.300	.137	.780	.929
.320	.161	.800	.940
.340	.187	.820	.950
.360	.216	.840	.958
.380	.249	.860	.965
.400	.285	.880	.970
.420	.324	.900	.975
.440	.366	.920	.979
.460	.409	.940	.983
.480	.454	.960	.986
		.980	.988
		1.000	.990

Table 6.6(3): The relationship between length class and nest effort in 4 populations of Nile crocodiles. Because of the difficulty in transforming length classes to age classes, "mature" crocodiles are approximated by length class >2.7 m, except for L. Turkana where the value of > 1.8m applies.

R1 = column 3/column 2.
R2 = column 5/column 3.

Population	Number of nests	Number mature length class	R1	Total population	R2
1	2	3	4	5	6
Ngezi (Zimbabwe) a	10	28	2.8	125	4.5
Lundi (zimbabwe) b	19	66	3.47	99	1.5
L.Turkana (Kenya) c	129	386	3.0	800	2.1
Murchison Nile (Uganda) d	178	412	2.3	1064	2.6
Mean values			2.65		2.34

a. From Hutton (1984). Observed values.

b. From Kofron (in prep.). Observed values.

c. R1 from Graham (1968) from shot sample. Population from Watson et al. (1971).

d.. Nest effort from Graham & Martin (in prep). Population from Watson et al. (1971).

length animals known. For the other two populations the estimates of population size contain unknown biases which will have resulted in slight underestimates of R_1 and R_2.

Given the limitations on data quality, present indications are that the mean value of R_1 for Nile crocodiles is 2.65 and of R_2 is 2.68.

This method has been standard practice for alligators in Louisiana for more than 20 years (Chabreck 1966, McNease and Joanen 1978), using a value of 20 for the equivalent of the product of $R_1 R_2$.

C. Aerial Photographic Methods of Determining Length Classes

Changes in the length frequency distribution of an exploited crocodile population are a potentially useful indication of the effects of management. Because crocodiles grow throughout life length is an index of age. The relationship is however complex and poorly understood and it has been suggested (Nichols 1985) that length classes may be substituted for most analyses based on age distribution because size rather than age may determine when a crocodile starts breeding. A brief description follows of the techniques, design and analysis for vertical aerial photography to determine length frequencies.

35 mm cameras give satisfactory results. Technically superior images can be obtained from 70 mm cameras but these are much more expensive and less manoeverable. While it is possible to hold a camera out of an aircraft window or door it is far better, if funds permit, to have a vertical mount installed in the aircraft floor. The overriding objective, irrespective of equipment, is to ensure that the photos are taken vertically above the target; even slightly oblique images will contain scale distortions that are impossible to compensate for. Tilt is evident if more of one side of an animal shows than the other.

As a rule of thumb, an image scale of about 1:1000 should be aimed for. This is an arbitrary scale set by two practical constraints: convenient flying height and realistic lens focal length. Generally, aerial photography with lenses >200 mm focal length is apt to give poor results due to camera shake, and flying heights <300' lead to blurred images and large relative errors in height control. Given these constraints it can be seen from the table below that within a practical range of height (300-500') a scale of 1:1000 dictates a lens in the 100-150 mm range. Measuring small crocodiles at scales <1:1000 is difficult.

Flying height (feet)	Equivalent height (h) in mm	Scale (s) (f/h)	Lens focal length (f) (f = hs)	Ground covered (m)
300	91440	.001	91.4	
400	121920	.001	121.9	24 x 34.5
500	151400	.001	152.4	

The most useful results are obtained from a fast colour transparency film (e.g. HS Ektachrome) exposed at not less than 1/500 of a second, and preferably 1/1000 or faster.

Image scales can be determined either by reference to radar altimeter height, recorded for each exposure, or from a reference length on the image. If a radar altimeter is used (the only practical method for very long shorelines or inaccessible swamps) instrument and other errors must be calibrated. These errors need not be identified as calibration accounts for all of them. Ten or more replicate photos are taken at survey height of a crocodile model, e.g. a 5 m pole placed at the water's edge. Each photo must be linked to the indicated radar height at the moment of exposure.

If scaling by a reference object on the photo, this object has to be placed on the ground before the survey. Clearly if many photos, or large areas, are involved this can be a considerable exercise in itself. A quick technique (I. Games pers. comm.) is to paint pairs of stones 5 m apart in a conspicuous colour along the shore in question.

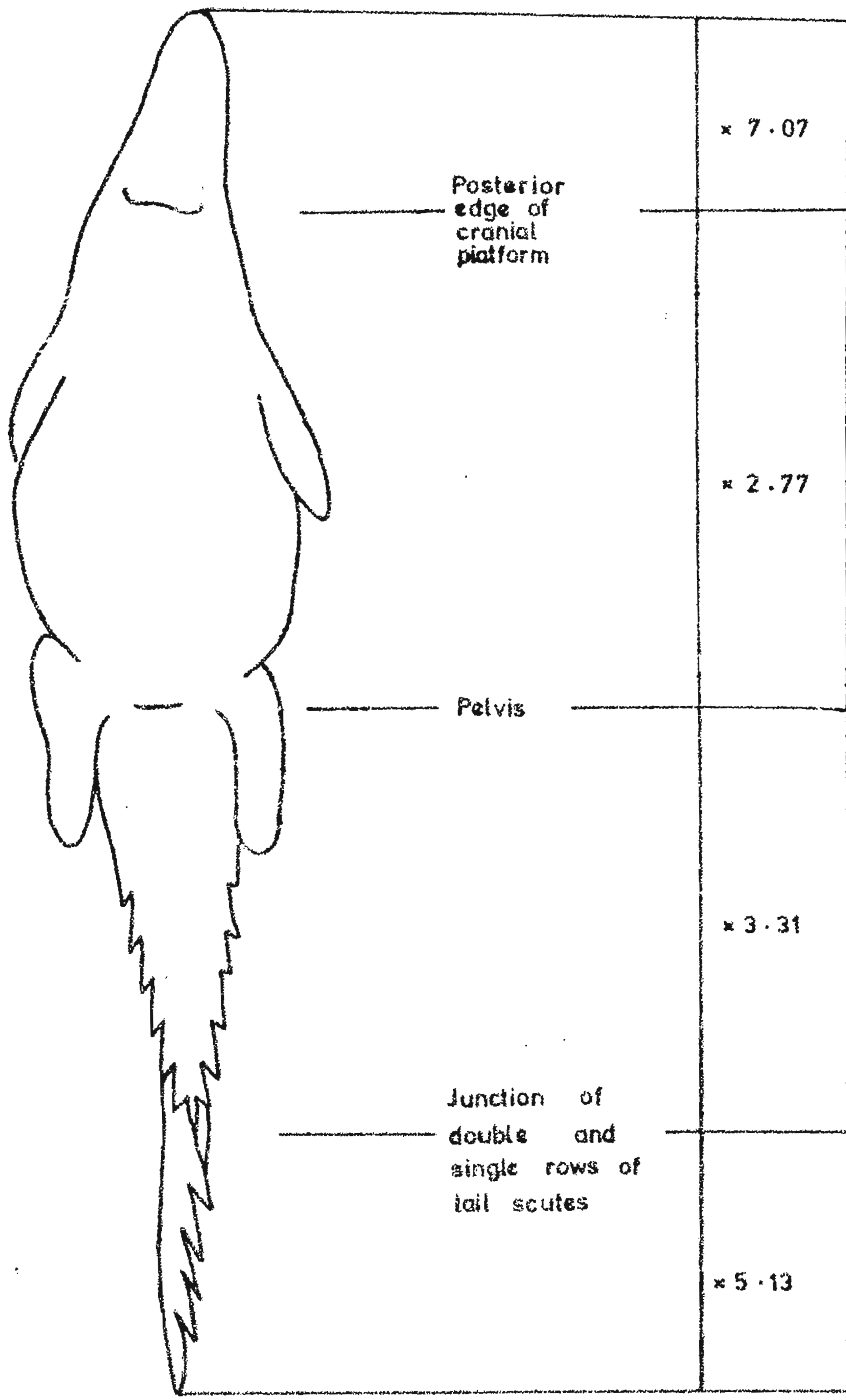
Measuring image lengths on the photos depends on the scaling technique. If scale is to be estimated from radar heights the unmounted transparency is placed emulsion side down between microscope slides and viewed through a dissecting microscope at 25 magnifications. A micrometer eyepiece calibrated with a 0.1 mm micrometer scale is fitted to measure image lengths. If scale is estimated by reference lengths on the transparency a much easier technique is possible. The transparencies are mounted and projected at about 60x magnification. The crocodile centrelines, and the reference lengths, are traced onto a piece of paper. Using a flexible ruler or cartographer's cyclometer measure the animal and reference lengths are measured for each transparency.

1. Scaling by radar altimeter

If the photos have been scaled by reference to radar heights then an estimate of the bias in observed image length caused by altimeter, camera and microscope instrument errors must first be made. These need not be individually estimated as a combined error estimate will suffice. This can be expressed as the ratio, $\hat{R}$, of the observed image length (y) to the true length (x). Then $\hat{R} = y/x$

The steps to be taken are illustrated in the following example.

Figure 6.6 (1). Outline of nesting female crocodile to show points at which measurements can be taken from aerial photographs.



Assuming a calibration exercise was done at a nominal height of 300', lens focal length (f) of 100 mm, using a crocodile model 3 m long, the expected image length on the transparencies of the model = actual length x scale. From the formula, scale = f/h the scale at 300' (91440 mm) = 100/91440 = 0.001094 and expected image length = 3000 x 0.001094 = 3.282 mm. This is then compared with the image length observed under the microscope. Assume that 6 replicate photos were taken of the crocodile model at heights close to the nominal 300', and the following data recorded.

Radar height (feet)	Equivalent height mm (x .00328)	True scale f/h	Image length expected x	Image length observed y
310	94488	.001058	3.174	3.424
290	88392	.001131	3.394	3.626
310	94488	.001058	3.174	3.395
300	91440	.001094	3.282	3.540
300	91440	.001094	3.282	3.540
290	88392	.001131	3.394	3.665
		Mean lengths:	3.283	3.544

$$\text{Then } \hat{R} = \bar{y}/\bar{x} = 1.0795$$

Observed crocodile image lengths would then be multiplied by 1/1.0795 = .9264 to adjust them for instrument and measurement errors.

Crocodile images measured on the transparencies would be converted to actual lengths as

actual length (m) = (image length x R/scale)/1000

2. <u>Scaling by reference marks</u>

This allows a more straightforward procedure without the need for any calibration. Crocodile lengths are calculated from their projected image lengths by proportion as

$$\text{crocodile length (m)} = \frac{\text{reference length (m) x croc image (mm)}}{\text{reference image (mm)}}$$

Where only part of a crocodile is visible refer to Figure 6.6(1) to estimate total length from other body measurements.

A histogram of length frequencies can then be constructed from the photographed sample of crocodiles after sorting them into length classes with pivotal intervals set by the resolution quality of the imagery.

D. Harvest data as an index of crocodile numbers

If a crop of crocodiles is taken it can be used as a potentially powerful index of population size provided an index of density is obtained before and after the crop. An estimate of the population, Y, is then

$$\hat{Y} = y\ C/(\hat{y}_1 - \hat{y}_2)$$

where C is the number cropped, $\hat{y}_1$ the density before, and $\hat{y}_2$ the density after the crop.

A detailed account of the method's assumptions and limitations is given by Eberhardt (1982), the main point to note being that $\hat{Y}$ will have a large CV if the harvest is less than about 20% of the population, or the densities estimated from small sampling fractions.

E. Monitoring

Two main activities are needed to monitor the status of a crocodile population - measurements of the extent and quality of the habitat, and measurements of key features of the crocodile populations.

Any expansion of human settlement or other exploitation of the habitat must be assessed for its effect on crocodiles. No forms of human use are known to facilitate crocodile use of the same habitat, but some forms of fishing, reed-cutting, stock-keeping, burning and tourism appear to be comparitively benign. Competition in the form of extensive fishing with nets, arable agriculture on shorelines or denudation of vegetation is likely to be at the expense of crocodiles. Other habitat features to be monitored are changes in river or floodplain channels and associated changes in important features such as nesting sites.

Monitoring population status requires tracking of the rate of increase. This can be done by observing the trend of any index, or absolute value, of population size with time. The observed exponential rate of increase (or decrease), r, can be calculated by least squares regression analysis of a series of counts or densities. An example is the following series of nest counts made on the Okavango river in Botswana:

Year	1975	1976	1977	1978	1979
t	1	2		4	5
Count	82	80	-	94	101
Log count ($\hat{Y}$)	4.41	4.38		4.54	4.62

$$\bar{r} = (\Sigma Yt - (\Sigma Y)(\Sigma t)/n)/(\Sigma t^2 - (\Sigma t)^2/n)$$
$$= 0.058$$

where n = number of estimates of $\hat{Y}$. This is the instantaneous rate of increase. The finite rate of increase is the antilog of

$\bar{r}$ = 0.058 = 1.0597 or 5.97%. Gerrodette (1987) discusses the analysis of trends in the context of population monitoring.

The key problem is to choose the parameter which is most precise, stable and economical for measuring population change. Evidence continues to accumulate to suggest that crocodile counts are liable to be very imprecise indices, particularly in swampy habitats. Wood et al (1985) concluded, after an evaluation of many years of alligator night counts in Florida, that no trends could be discerned from the data because of its imprecision, and that only strict standardization of future counts could justify their continued use as a monitoring method. In the case of very open habitats which characterize some rivers and lakes, precision may be better if strict standardization is observed.

Another disadvantage of counts is that, with one exception, none of the survey counts yet made of Nile crocodiles can be related to actual numbers present. Only Hutton's (1984) study has evaluated a survey count index of population size, and the mean correction factor implied of 1.6 under the best possible survey conditions is a large one to apply to other populations. Nest counts, on the other hand, would seem to have advantages over counts of the animals themselves. A robust analysis is available to estimate true nest effort from sample counts, with good expectation of a small CV. Predictable location and timing offer a high degree of repeatability. The techique of mapping the location of all nests found establishes an accumulating data base with several important features. One is that as technique improves previous counts can be re-analysed to yield more precise and accurate trends. A second is the opportunity for long-term analysis of the pattern of nesting activity. A third is the facilitation of egg harvesting programmes, and a fourth is as an aid to identifying areas important to crocodile conservation.

Nest effort by itself constitutes an index of population status adequate for most purposes. If, however, an estimate of population size is essential it can be indexed by a combination of nest effort and length frequency distribution from aerial photographic samples with a higher degree of confidence than is possible from crocodile counts.

There is, therefore, a strong argument for channelling what are almost invariably scarce resources into a monitoring programme based on, say, annual or bi-annual nest surveys and aerial photographic samples of length frequency distributions, and abandoning continued attempts to count crocodiles. The trade-off will not be one for one. Conventional one-off survey counts will be cheaper, simpler and quicker, and therefore tempting as a strategy. Superior information is almost bound to be more expensive. Management authorities will have to weigh up the adoption of technically more advanced monitoring programmes against their cost.

Conclusions

In general, surveys of crocodile populations are commissioned because a management authority seeks to know their numbers and range to plan a harvest or conservation strategy. Before choosing a survey method the type of information each method yields should be considered. As was emphasized in counting design, no Nile crocodile survey (as distinct from the long-term study of Hutton, 1984) has ever estimated the actual number of crocodiles in the survey area. The estimates contain errors due to visibility bias which are always unknown, which probably vary widely among populations and which may vary between successive estimates of the same population. No simple method exists for estimating concealment and diving bias as mark-recapture is too expensive and technically demanding for a general survey method.

If crocodile counts are to be made it must be fully appreciated that they are only indices of unknown density. To be useful as indices their precision and stability must be evaluated. Precision can only be estimated from sample counts, and stability can only be hoped for from rigorous standardization of technique. Total counts should be avoided, except as a basis for initial stratification of crocodile habitat in a given river system. Total counts cannot be used to track changes because no estimate of their precision is possible.

Since the value of an index depends heavily on its CV it follows that the common practice of making an aerial count and adjusting this with a correction factor from spotlight counts degrades precision, because the variance of the correction factor must be added to the count variance. Since the gain in accuracy is small and of an unknown amount the practice is of little if any value. Either a spotlight or aerial sample count by itself is a better index.

Once the distribution of crocodiles in a system is known a superior measure of status is nest effort, because visibility bias is readily estimated and therefore actual nest effort is estimated. Good precision and stability can be expected from practical survey designs. In addition, nest effort can index crocodile numbers, at least as well or better than crocodile counts. If used in conjunction with aerial photographic estimates of the ratio of mature-length to immature-length classes nest effort can be expected to provide management with all the information needed to adequately monitor population status. Although no instances appear to have been reported it should be noted that aerial photographs taken along a shoreline can be analysed to estimate crocodile density by the method described above for visual counts, treating each photo as a sample count. Such an analysis can be carried out on the same photos used to determine length frequencies, and is another reason for phasing out conventional counts.

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