CHAPTER 21

A Photographic Technique for Estimating the Size of Crocodiles Seen in Spotlight Surveys and for Quantifying Observer Bias

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SPOTLIGHT surveys are frequently employed to give an index of the relative abundance of crocodilians (Chabreck 1963, 1966, 1973, 1976; Messel *et al.* 1981; Pernetta and Burgin 1980; Schaller and Crawshaw 1982; Webb *et al.* 1983a; Bayliss *et al.* 1986), to determine species composition within an area (Graham 1981; Montague 1983; Webb *et al.* 1983b), and to estimate the size structure of a population (Chabreck 1976; Woodward and Marion 1978; Messel *et al.* 1981; Montague 1983; Webb *et al.* 1984). All three uses entail observer errors and these ideally should be quantified (see Bayliss Chapter 16). Bias in counts can be quantified using a number of different methods that do not require capturing large samples of crocodiles (Messel *et al.* 1981; Bayliss *et al.* 1986). However, errors in estimating sizes and identifying species are difficult to quantify without a simultaneous catching effort (Magnusson 1983); this in turn is expensive, time consuming and is not without risk of injury to both crocodiles and investigators.

In this chapter we describe a technique which gives a scaled photographic negative of crocodiles seen during spotlight surveys. These in turn usually allow definitive species identification, and can be used to estimate the size of the crocodile photographed. The technique can be used to quantify observer bias, and with improvements has the potential of being a primary method of recording data during spotlight surveys. A further advantage is that it provides a definitive and permanent record of many of the animals sighted on a survey. This means that changes in the size structure of a population over time can be assessed by one person interpreting series of negatives, rather than by one-off "spotter" estimates accumulated over a period of years.

We discuss the technique generally here and present our early results on the precision and accuracy with which the total lengths of crocodilians can be estimated from it. We also compare size estimates made by two experienced observers with those derived from the same crocodiles (*Crocodylus porosus*) using the photographic technique. Ways in which the method could be improved without making it impractical for use in the field are discussed.

METHODS

The Camera

Any single lens reflex 35 mm camera can be used and our selection of "Pentax" K1000 SLR camera bodies was based on low cost and simplicity of operation. We used battery operated "Metz" 45 CT-1 or "Eva-Blitz" Auto-36SR flash guns, although again any similar electronic flash would be adequate. Fixed F=3.5, f=200 mm lenses ("Cosina" and "Tokina") were used as these provided the best overall focal length for obtaining reasonable photographs of heads at the distances to which crocodiles were normally approached during surveys. A millimetre scale was taped to the focusing ring (Figs 1 and 2), so that the camera to subject distance could be measured more precisely than with the standard distance scale on the lenses. "Kodak" Tri-X, 400ASA black and white film was used in all experiments.

Lens Calibration

Each lens was calibrated independently by photographing a one metre ruler, oriented at right angles to the camera to subject line, from various distances. The reading on the millimetre lens scale (LR) was recorded with each exposure. Each negative was then examined on the light stage of a "Wild" M650

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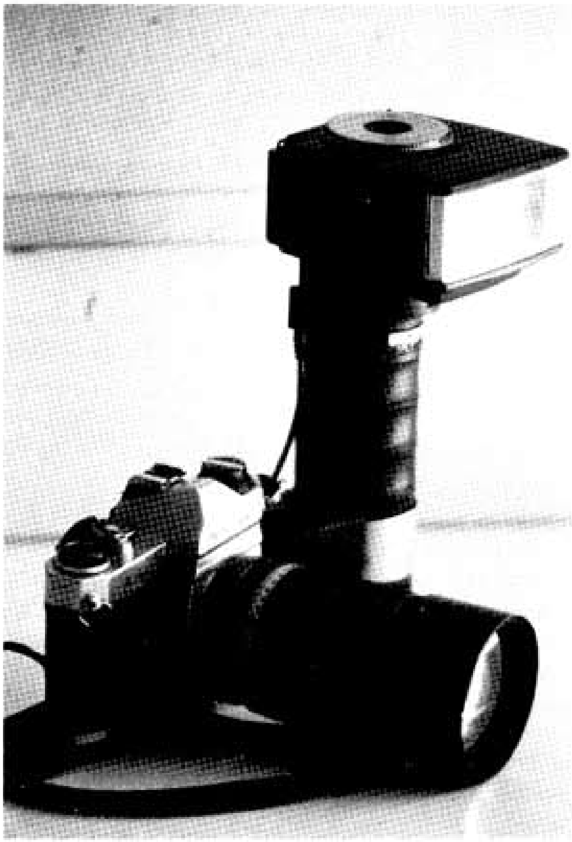


Fig. 1. One of the cameras used for obtaining scaled negatives of crocodiles seen in spotlight surveys.

Fig. 2. A millimetre scale taped to the focusing ring so that camera to subject distance can be measured with each photograph.

binocular dissecting microscope and the graduations on the ruler image on the negative were used to measure the relative length of the long axis of each negative; we refer to this as *relative frame length* (RFL in cm). The relationship between RFL and LR (measured in millimetres on the lens scale) was derived for each lens (Fig. 3). In practice, this meant that if the lens reading was recorded when a photograph was taken, the long axis of the negative could be scaled to real size. In reality this scaling is not constant along the length of the negative as a degree of distortion is introduced by the lens (Paine 1981). However, for our purposes the error involved was minor and we ignored it.

As can be seen from Figure 3, there is a somewhat "optimal" range of distances for a particular lens in which reasonably minor changes in RFL are associated with major changes in the LR (up to about 100 mm lens reading on Fig. 3). The accuracy with which size can be estimated from photographs taken well outside this optimal range decreases precipitously, although species identification may still be possible from animals photographed outside the optimal range.

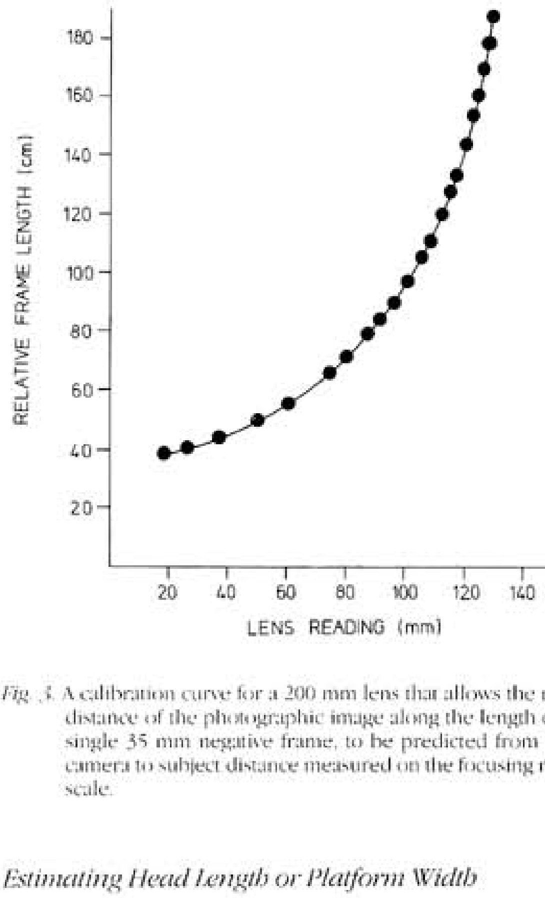


Fig. 3. A calibration curve for a 200 mm lens that allows the real distance of the photographic image along the length of a single 35 mm negative frame, to be predicted from the camera to subject distance measured on the focusing ring scale.

Estimating Head Length or Platform Width

In negatives where head length (or cranial platform width) was parallel to the frame base of the negative, both head length and the negative frame length were measured in units of a calibrated eyepiece graticule. Head length was then expressed as a proportion of the frame length, and by calculating the RFL at the distance the photograph had been taken (Fig. 3), it was scaled to real size.

In cases where the image of a crocodile's head was not parallel to the negative frame base, angular corrections were needed before length of the head (or width of the platform) could be estimated. We used reference templates (Fig. 4) derived from

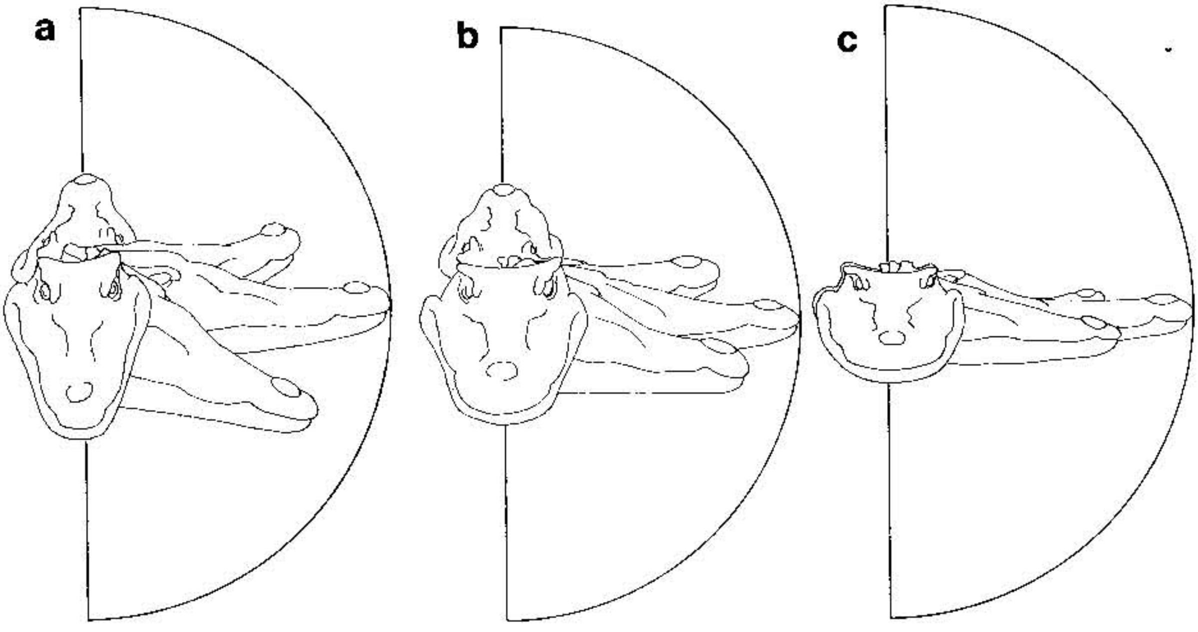


Fig. 4. Templates for making angular corrections to photographic images not at right angles to the camera to subject line. Drawn from a preserved *C. porosus* head photographed from 1.5 m above the ground at distances of 2.2 m (a), 4.0 m (b) and 8.0 m (c).

photographs of a preserved crocodile head rotated through 360°, as a guide to the extent of the correction required. Corrections were made under the microscope by fixing one end of the head image and visually estimating (with the assistance of the templates) where the other end would be if the head was rotated into a parallel position. This corrected head length was then measured in graticule units and scaled to real size as above.

Estimating Total Length from Head Dimensions

We used the morphometric relationships between head dimensions and total length that have been derived for both *C. porosus* (Webb and Messel 1978) and *C. johnstoni* (Edwards 1983) to predict total lengths. Similar predictive relationships are available for some other species of crocodilians (Kramer and Medem 1955; Wermuth 1964; Montague 1984) and can be readily derived for most others from reasonably small samples.

Testing the Method

In the first test, head photographs requiring minimal angular correction were obtained from thirteen wild *C. porosus*, either just prior to capture (N = 5) or after they had been captured and secured (N = 8). Head lengths (N = 9) or platform widths (N = 4) were estimated from the photographs and compared with the real head dimensions as measured with a ruler in the field.

In the second test, a series of photographs (N = 112) of a preserved *C. porosus* head were taken from various angles and distances which approximated the situations likely to be encountered in the field. The negatives were assigned codes according to the extent of angular correction needed and other factors affecting prediction accuracy: 1 = no angular correction, optimal range, in focus; 2 = slight angular correction, optimal range, in focus; 3 = reasonable correction, optimal range, in focus; 4 = major correction and/or excessive range and/or not in focus. Total length was predicted from head measurements derived from the negatives and these estimates were compared with the total length predicted from the real measured length of the preserved head.

Survey Trials

To test the technique under field conditions, standard spotlight surveys were carried out with two experienced observers estimating crocodile total lengths by eye, and two photographers taking photographs of a large sample of the same crocodiles. The observer estimates were then compared with the estimates derived from the assessment of negatives. These values are presented and discussed in units of feet rather than metres, as this is the unit most observers use to estimate crocodile total lengths during surveys (Chabreck 1966; Messel *et al.* 1981).

RESULTS

Estimating Real Sizes from Photographs

Differences between estimated and real head measurements of thirteen *C. porosus* are summarised in Table 1. Deviations are expressed as a percentage of the real head measurement, because errors are proportional to head size. For example, two photographs could require an identical correction to give identical head lengths relative to negative frame lengths. The error is thus a function of image size rather than real size, and to be expressed in terms of absolute units must be scaled to real length of the head. The mean error of the photographic estimate (0.63 ±0.77%; SE) was not significantly different from zero ($t=0.82$, $df=12$, $p>0.5$), and twice the standard deviation around that mean (approximately 95% of errors) ranged from +6.15% to −4.90% of the real head measurement.

Table 1. Crocodylus porosus head lengths (HTL) and cranial platform widths (HPP) measured from negatives and compared with the real dimensions (measured with a ruler). Deviations are expressed as a percentage of the real dimensions. Animals marked with an asterisk were photographed prior to capture, and others after capture. Mean % error was 0.63 ±0.77% (SE; SD=2.76%).

Animal No.	Measurement taken	Real Length (cm)	Estimated Length (cm)	Error (R-E) (cm)	% Error (R-E/R)
1	HTL	28.7	28.6	0.1	0.35
2*	HPP	2.9	2.8	0.1	3.45
3	HTL	31.4	30.7	0.7	2.23
4	HPP	6.5	6.1	0.4	6.15
5	HTL	37.8	38.1	-0.3	-0.79
6	HPP	11.2	10.7	0.5	4.46
7	HTL	31.8	31.9	-0.1	-0.31
8*	HTL	37.8	37.0	-0.8	-2.12
9	HTL	39.1	39.2	-0.1	-0.26
10	HPP	5.6	5.5	0.1	1.79
11*	HTL	42.3	43.1	-0.8	-1.89
12*	HTL	29.4	30.6	-1.2	-4.08
13*	HTL	11.8	11.9	-0.1	-0.85

When total length was estimated from head dimensions derived from photographs of a preserved *C. porosus* head (Fig. 5), no significant difference in accuracy could be attributed to using head length or platform width ($t = 0.24$, $df = 110$, $p>0.25$). The general results were:

1. Where no angular correction was involved (code 1 on Fig. 5), 95% of errors were within 6.6% of the total length estimated from real head measurements. The mean value derived from the photographic technique was not significantly different from that derived from using the real measurements of the preserved head to predict total length. [2SE's around the photographic estimates fell within 2SE's of the regression lines used to predict total length from both head length and platform width (Webb and Messel 1978)].

2. If angular corrections were required but were not major (codes 2 and 3 on Fig. 5), the range of errors increased, but the mean of the photographic estimates did not differ significantly from the mean value calculated from the real head measurements.

3. Using the worst photographs (code 4 on Fig. 5) resulted in a slight increase in the range of errors and a general tendency towards underestimating the real total length. This reflects a tendency to be

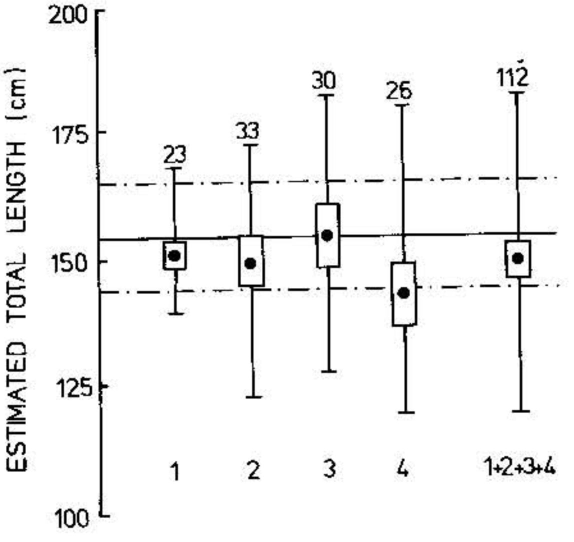


Fig. 5. The predicted total length of a *C. porosus* from 112 head exposures varying in the degree of angular correction (1 = none; 2 = minor; 3 = reasonable; 4 = major and/or excessive range). The horizontal line is the total length predicted from the real head length (Webb and Messel 1978), with twice the standard error of estimate of the prediction formulae (broken line). Means (dots), ±2SE's (boxes) and the range of estimates obtained for each code are presented. Upper numbers are sample sizes.

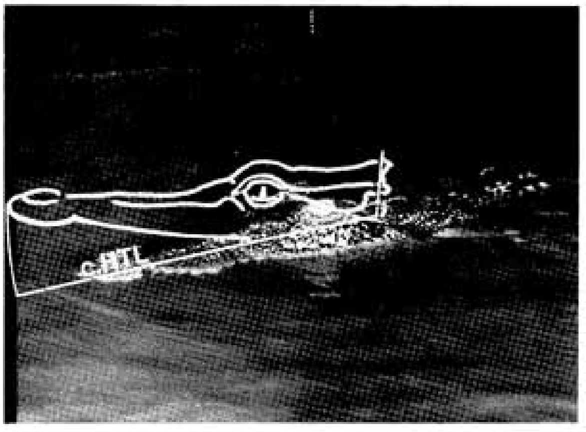
conservative when making large angular corrections, especially on small head images (animals photographed outside the optimal lens range).

It was concluded that the errors involved in predicting head length from scaled photographs were within about ±7% of the real head length. The additional error involved in predicting total length from head length is minor (Webb and Messel 1978). That mean errors were not significantly different from zero indicates that the estimate derived from a series of photographs of the same crocodile should allow a very accurate estimate of real head measurements, and thus of total length.

Using the Method during Surveys

1. *Practical considerations*

During initial field trials, the beam of the spotlight proved sufficiently strong to expose the film during the sixtieth of a second exposure needed to synchronise the flash. The resulting images, however, were not sharply defined. This problem was overcome by shifting the spotlight beam to one side of the head. In addition, boat drivers soon learnt to orient their approach to a crocodile so that photographs requiring minimal angular correction could be obtained. Wary crocodiles proved difficult to photograph and those photographs that were obtained were often outside the optimal range of the lens. The photographic technique required a slower approach than is generally used in surveys, but with experience, delays were minimized. With small crocodiles and crocodiles on the bank it was often possible to photograph the whole animal and to estimate either snout-vent length or total length of the animal from the negative.



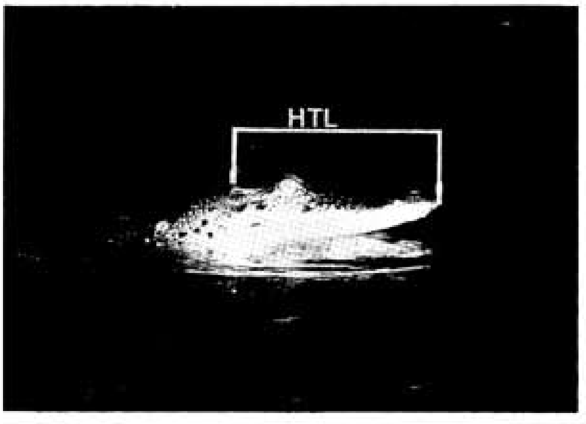


Fig. 6. Photographs of *C. porosus* taken during a spotlight survey. When photographed at an angle to the camera (upper) an approximate correction based on the templates in Fig. 4 was used. Photographs which did not require correction (lower) were often obtained (HTL = total head length; cHTL =approximate HTL).

2. *Estimating Size from Photographs of Wild Crocodiles*

Estimating head measurements and predicting total lengths from negatives of wild crocodiles (Fig. 6) proved as straightforward as from those obtained under controlled conditions. Species identification was possible from most photographs and we were able to definitively identify one *C. johnstoni* (Fig. 7) which was well outside its normal range, and had been identified by the observer as a *C. porosus* at an approach distance of 2.5 metres

3. *A Comparison with Observer Estimates*

When used in conjunction with observer estimates, the technique provided a number of insights into the precision with which observers were estimating crocodile sizes (Fig. 8). Because observers were estimating sizes to the nearest 0.5′ of total length, we subtracted or added 0.25′ to

Fig. 7. A *C. johnstoni* detected from the photographs that was within an area containing exclusively *C. porosus*, and which had been misidentified by the spotter: the enlarged post-occipitals are definitive.

the photographic estimates (depending on the direction of the error) to account for this possible source of error. The nett effect was to improve marginally the accuracy of the observer estimates. To interpret the results generally, we made the following assumptions:

1. With the animals nominated by an observer as being in a particular size class (say 5.5′), the mean estimate from the photographic technique applied to those same animals should indicate the direction and extent of observer bias;
2. Variance due to errors and biases within the photographic method should be the same with both observers and thus be contained within the variance of the least variable observer (all negatives were assessed by the one person);
3. Variance due to the photographic method should be scaled to total length of the crocodiles sighted. That is, the absolute error involved in photographically estimating the size of a crocodile with a 60 cm long head should be approximately three times that in estimating the size of a crocodile with a 20 cm long head.

Observer B estimated crocodile total lengths relatively accurately. With the exception of crocodiles noted as 6.5′ (N = 7) and two animals noted as 9.5′, means from the photographic technique were within 0.5′ of the estimated size. Among the smaller crocodiles, those estimated as 3.0′ and 3.5′ appear to be very accurately called. Those estimated as less than 3.0′ tended to be

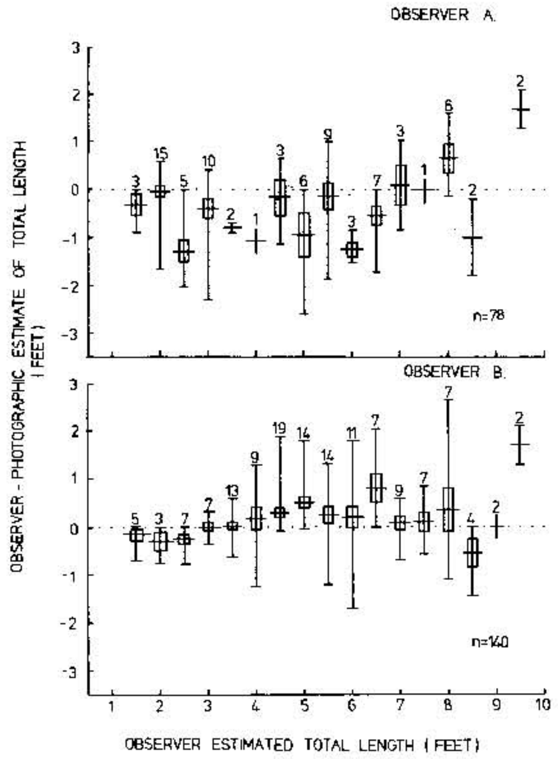


Fig. 8. A comparison of spotter estimated sizes (to the nearest half foot) and those estimated from the photographic method for samples of *C. porosus* in the Adelaide River. All photographs were analysed by the same person. Horizontal lines are the means and ranges; boxes are 1 SD on either side of the mean; numbers are the sample sizes for each half foot category. Values above the broken line indicate an observer is overestimating the size of crocodiles sighted.

underestimated and those estimated as being 4.0 to 5.0′ overestimated. For example, of 33 individuals estimated to be either 4.5′ or 5.0′, 82% were smaller than estimated. Crocodiles estimated as 7.0′ and 7.5′ (N = 16) also appear to be accurately called. If variance surrounding the 7.0′ and 7.5′ animals was all attributed to errors in the photographic method, it would indicate that the increased variance associated with some other sizes is largely attributable to the observer rather than to the photographic technique.

In comparison to Observer B, Observer A is less precise, less consistent, and has a tendency to underestimate the size of most crocodiles.

If attempting to combine estimates from Observers A and B, considerable errors must be expected. For example, the two observers recorded 20 *C. porosus* that were 5.0′ long. According to the photographic technique, the 14 recorded by Observer B had a mean size of 4.5′ and the six recorded by Observer A had a mean size of 6.0′.

DISCUSSION

Precise measurements can be obtained from photographs if image displacement and parallax theory are used to negate the need for approximating angular corrections (Paine 1981). However, such methods require the use of two calibrated survey cameras mounted in parallel and held at a constant camera to subject distance. In addition to being expensive, it would be difficult to incorporate into a standard spotlight survey programme. To estimate the sizes of nesting female *C. niloticus* from aerial photographs, Parker and Watson (1970) and Graham *et al.* (1976) used reference boards placed in areas frequented by crocodiles. Such an approach would also be impractical for spotlight surveys. Gorzula (1984) experimented with a technique similar to ours, but did not scale the negatives to real size. He relied on measuring morphometric ratios from photographs and quantified the relationship between those ratios and size in the crocodilians under study. The technique could only be used effectively when the head image was parallel to the negative frame length, but given that proviso, it could be used in conjunction with our method. The biggest limitation is that morphometric ratios do not necessarily change in a consistent fashion with size (Webb and Messel 1978).

Whether or not the increased precision available through the photographic technique is needed in spotlight surveys depends very much on the reasons surveys are being undertaken, and the nature of the population being studied. The use of photographs can effectively reduce observer bias and increase the overall precision of survey results, but it requires extra expense and effort and is only of use with that proportion of the population which allows a survey boat to approach it. Nevertheless, when attempting to determine whether or not a protected population is recovering, there would seem to be particular utility in having more precise size estimates and a permanent record of the crocodiles sighted, that can be examined by one person, at any time. If relying solely on one-off observer estimates, with different observers, over a period of years, size estimating biases between observers (Fig. 8) could readily mask real trends in the changing size structure, while giving spurious data on apparent changes in the relative proportions of different size classes from year to year. Many years of standard size-estimate data may be needed to separate underlying trends with time from the fluctuations caused by observer bias; a problem that could presumably be overcome with more accurate size estimates.

Observers could of course be calibrated, and the photographic technique provides an economical means of doing so. Once errors within the technique are themselves quantified, observer bias should be able to be quantified and data adjusted accordingly prior to pooling. If necessary, the technique could also be used to measure inconsistency and drift. The precision with which even experienced observers can estimate sizes is subject to many sources of potential bias (Magnusson 1983). During catching programmes observers test their size estimates each time an animal is caught, and many become particularly accurate in their ability to discern size prior to capture. However, as time passes between the catching experience and surveys in which no crocodiles are caught, a loss of accuracy is to be expected. Similarly, observers with experience in catching crocodiles of a particular size are not necessarily good estimators of all sized crocodiles. For example, Observer B (Fig. 8), assigned 7.0′ and 7.5′ size classes very accurately; he has had considerable experience in catching problem crocodiles within that size range.

When Magnusson (1983) compared his size estimates with the measured length of the animals after capture, he concluded that his ability to estimate total lengths of four species of crocodilians was poor. He suggested simple correction factors could be used to overcome the problem with three species (*Melanosuchus niger*, *Paleosuchus trigonatus* and *Caiman crocodilus*), but with the fourth (*P. palpebrosus*) there was no significant relationship between the estimated and real total lengths. He also identified a size related observer bias with *C. crocodilus*: the total lengths of smaller animals could be estimated with reasonable accuracy but those of larger ones could not. The two problems discussed by Magnusson (1983) are the ability to estimate total length *per se*, and the ability to relate total length estimating experience from one species to another. In both instances, the photographic technique would remove the problems if a reasonably close approach to the animals was possible.

Although the technique as described here has utility in the field now, it could be improved without making it impractical to use. One problem is that errors in the distance measurement may be introduced by having to read the scale after every photograph. This and the recycle time needed for the flash, restrict the number of photographs that can be taken of any individual crocodile, yet the more photographs of an individual that are available, the greater will be the accuracy of the size estimate obtained. These problems could be overcome by using a stroboscopic light that did not require recycling, and an adaptation whereby the lens reading was measured electronically and passed directly to a camera-back equipped with digitising facilities. A series of photographs could then be taken as the survey boat moved in on a crocodile, with each negative having the lens reading printed on it. As sizes are estimated from the negatives (negating a need to print photographs), the costs of employing such a method would not add greatly to the overall expense of a survey programme.

Correcting for angular displacement is perhaps the largest source of error currently limiting the technique. There are a number of approaches which could be adopted to refine these corrections and the three-dimensional reconstruction packages now available for microcomputers would seem to have considerable potential in this direction. If the image of a crocodile head was programmed into a computer, it could be rotated and angled until it matched the image on a negative (or the negative image itself could be digitised and matched by the computer). Since the straight line lengths of the programmed head are known, head dimensions on the negative could be more objectively and precisely measured.

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