USE OF NIGHT COUNT DATA FOR ESTIMATION OF CROCODILIAN POPULATION TRENDS[1]

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Night spotlight counts (Woodward and Marion 1978, Messel et al. 1981) are used throughout the world as a basis for evaluating crocodilian population trends (Wood et al. 1985, Bayliss 1987, Webb et al. 1990). They are particularly effective in habitats that render aerial basking (Webb et al. 1990) and nest (McNease and Joanen 1978) surveys logistically impractical.

Night counts represent an *index* of the total population (Davis and Winstead 1980, Bayliss 1987). Although the exact relationship between a count and the total population (*sighting proportion*) may be unknown, for trend analysis, we either assume that this relationship remains constant over time or that we can account for factors affecting the sighting proportion. Thus, any change in counts should reflect a proportionate change in the total population.

The purpose of trend analysis is to estimate the direction and rate of change in a population. These results allow investigators to make inferences about the status of a population or the response of populations to influences such as harvest, protection, habitat management, or restocking. However, violation of the assumptions of trend analysis and improper analysis of data can result in erroneous conclusions.

Recent investigations (Woodward and Moore 1993) provided some insight into factors affecting trend analysis of American alligator (*Alligator mississippiensis*) populations, the importance of meeting assumptions of trend analysis, methods of analysis, and interpretation of findings. In this paper, we summarize those findings and discuss their application to general problems with population trend analysis of crocodilians.

DESIGN

Objectives

Trend analysis is applicable when inferences are to be made about the status of a

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population over time. In general, trend investigations are initiated as part of a *monitoring* effort, designed to evaluate the status of a population over time, or an *experiment*, the purpose of which is to measure the effects of certain treatments (e.g., harvests, protection, restocking) on populations. The objectives of an investigation determine the optimum design and need to be clearly identified early in the planning process.

Sampling

Night counts are normally conducted as systematic samples of an area and usually entail driving a boat parallel to the shoreline of a river, canal, or small lake. In most cases, systematic surveys can account for a major portion of the population. However, habitats such as large, shallow lakes, marshes, and swamps may require transect sampling.

Monitoring Surveys.--Crocodilian population densities may affect population growth rates (Webb et al. 1990). Densities may vary by quality of habitat (McNease and Joanen 1978, Wood et al. 1985, Webb et al. 1990), water salinity (Messel and Vorlicek 1986), and trophic state (Wood et al. 1985). Therefore, sampling should generally be stratified by density-affecting elements (Eberhardt 1978). Within strata, areas of suitable habitat should be sampled at random. Although random selection of areas is preferable, frequently it is not possible because of accessibility or cost. In those cases, systematic sampling over a reasonable geographic range would be a practical but more biased approach (Eberhardt 1978).

Experiment Surveys.--If testing of the effects of a *treatment* is the objective, then *control* (no treatment) areas must be included in the sample to enable attribution of any changes to the treatment. Treatment and control areas should be replicated at random within strata so that standard statistical tests (see ANALYSIS) can be applied to the results.

Replication

Replication increases the *power* (the probability of detecting a real effect) of statistical tests (Eberhardt 1978, Gerrodette 1987) and can reduce the time necessary to detect population trends (Harris 1986, Gerrodette 1987). True replicate counts represent independent measures of the population; this will be discussed later. Replication of counts for monitoring can occur at 2 levels; within-year on individual areas and within strata (habitat, salinity, trophic level, etc.). Within year replication enhances the detectability of trends on individual areas (Harris 1986, Gerrodette 1987). If inferences are to be made about a regional population, then replication of areas at the expense of within-year replication on individual areas will provide the optimum allocation of resources (Gerrodette 1987). Funds for surveys are usually limited. Thus, investigators will have to determine the best application of replication based on the objectives of their study. For a more detailed discussion of the replication necessary to detect trends see Eberhardt (1978), Harris (1986), Gerrodette (1987) or Link and Hatfield (1990).

Power of statistical tests increases with sample size but decreases with variation in counts (Eberhardt 1978, Gerrodette 1987). Variation in counts of crocodilians can be caused by *detectability* or *availability* differences. Detectability varies due to the ability of the observer to discern a crocodilian or due to the efficiency of the equipment. The probability that an animal can be seen is dependent upon its availability in the survey area. Thus, those animals that are submersed or are in inaccessible areas are not available for counting. Seasonal or environmental influences may affect availability. Precision of counts can be increased by standardizing methodology and accounting for sources of variations (Eberhardt 1978, Gerrodette 1987).

Observer and Equipment

Observer experience can affect detection rates of crocodilians. In most cases, the ability of observers to detect crocodilians increases quickly with experience then stabilizes. Thus, it is important that observers be thoroughly trained before contributing observations to trend analyses. Size estimates of crocodilians can vary considerably among observers. To reduce this source of bias, we recommend observers catch a sample of alligators from representative size classes after first judging their sizes.

Equipment and its patterns of use can affect counts. Woodward and Marion (1978) reported that boat speed and light intensity affected counts. Therefore, standardization of equipment and operating procedures will reduce variability in detection rates.

Seasons

Seasonally, crocodilians may move in or out of a survey area to breed, feed, or seek shelter, thus changing their availability. Annual surveys should be conducted during a single season to minimize such variation. The more expensive alternative is to calibrate seasonal differences by conducting sufficient counts during other seasons.

Environment

Water Level.--Water level changes, caused by rainfall or tide, have a profound effect on the availability of crocodilians in wetlands with associated inaccessible marsh or swamp (Woodward and Marion 1978, Messel et al. 1981, Messel and Vorlicek 1986, Webb et al. 1990). In general, as water levels rise, a net emigration of crocodilians occurs from the survey area to surrounding swamps and marshes. During periods of low water, animals tend to concentrate in remaining deep water, usually the survey area. Water level should be

measured on all survey areas and used in analyses (see ANALYSIS) to isolate the water level effect (Fig. 1). Water levels in marshes and swamps associated with the primary wetland tend to be less stable than those in deeper water and may have a greater influence on crocodilian availability (Woodward and Moore 1993).

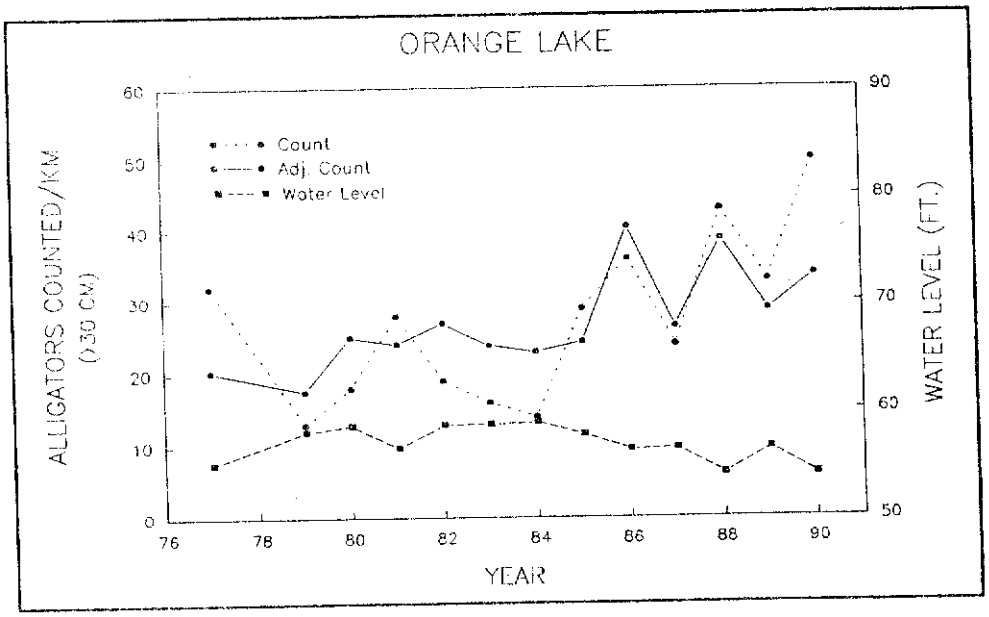

Fig. 1. The influence of water level on counts of non-hatchling alligators on Orange Lake, Florida. Original counts have been adjusted for mean water level (adj. counts).

Water Temperature.--Crocodilians tend to become less active under cooler conditions and apparently spend more time under water (Smith 1979), thus reducing the probability of being counted (Woodward and Marion 1978, Hutton and Woolhouse 1989). For some crocodilians (e.g., alligators) in cooler regions, counts are closely correlated with water temperatures at lower temperatures, but, at higher temperatures, the correlation fades (Woodward and Marion 1978, Brandt 1989). Thus, for alligators, counts conducted during warm water conditions would be most stable from year to year. The alternate, more expensive approach would be to conduct a series of counts over a variety of water temperature conditions to account for water level effects.

Vegetation.--Changes in floating and emergent vegetation can affect the detectability of crocodilians. Thus, vegetational changes should be quantified and measured. The availability of alligators can be influenced by the submerged plant, *Hydrilla verticillata*, that apparently provides added support for animals at the surface and encourages surface activity (Woodward and Moore 1993).

Other Variables.--Other variables, such as salinity (Messel and Vorlicek 1986), air and water temperature differentials (Hutton and Woolhouse 1989), and waves (Woodward

influencing counts.

ANALYSIS

Assumptions

Sampling.--To make unqualified inferences from statistical test results, the sampling scheme should be random and representative of the population on which inferences are to be made (see DESIGN).

Size Estimation.--When evaluating trends of specific size classes, unknown-size alligators must be distributed into size classes (unless the proportion and size distribution of unknowns is constant over years). This requires a systematic approach to allocation of unknowns into broad size classes. Allocating unknowns based on the known-size distribution was used for evaluating Florida alligator population trends (Woodward and Moore 1993), but this had some shortcomings. For instance, most unknowns were observed in habitat that was used by all size classes. Because wariness tends to increase with size in crocodilians (Webb and Messel 1979; A. R. Woodward et al., Final Alligator Rep., Fla. Game and Fresh Water Fish Comm., Tallahassee, 1992), it is likely that unknowns were disproportionately allocated into smaller size classes. However, if the same methodology is applied every year, inferences about trends would be minimally affected. Despite its weakness, we consider this approach to be superior to ignoring unknowns in analyses of different size classes or choosing not to analyze by size class.

Changes over years in observers and changes in observer skill of judging size can influence the size distribution of counts. Requiring observers to catch and measure several alligators after making size judgements will help calibrate their estimates (accuracy), increase precision, and minimize long-term biases. Woodward and Moore (1993) found that the biggest apparent problem was inconsistency among observers in placing deep water observations of alligator eye reflections into size classes. Larger, warier alligators tended to submerge before allowing observers to approach close enough to obtain a confident size estimate. However, certain characteristics, such as habitat type, water depth, water swirls, mud trails, wakes, and, occasionally, intensity of the eye reflection, can provide valuable clues to the size of an alligator. To minimize proportional allocation of unknowns, personnel were instructed to assign general size categories to eye reflections at the most precise level allowed by such qualitative information.

Assumptions of Trend Analysis.--Harris (1986) listed 4 important assumptions that need to be met when conducting trend analysis: (1) the population increases or decreases exponentially (the proportional change in population size is constant); (2) counts are lognormally distributed; (3) counts are independent; and (4) the mean percentage of the population counted is constant at all population levels. Closely related to assumption 4 is the

general assumption that: (5) a constant proportion of the population is observed over time or that factors affecting this proportion can be isolated. Violation of any of these assumptions can lead to bias in trend estimates, erroneous conclusions concerning significance of trends, or both. The following is an assessment of the consequences of failing to meet these assumptions for determining trends on individual areas:

(1) Exponential population growth.--Exponential growth (positive or negative) is a suitable growth form for many animal populations that are well below carrying capacity. Most animal populations tend to increase or decrease in a multiplicative rather than additive fashion (Eberhardt 1978). The model will never predict a population size below zero, as can be the case with linear growth. Conversely, linear growth is appropriate for populations observed over short periods of time relative to the life span of the animal. Unfortunately, neither growth form is suitable for populations observed near carrying capacity as both models can predict sustained population growth above that level. Woodward and Moore (1993) saw no clear advantage in one growth form over the other for alligator count data. Therefore, the exponential model was ultimately chosen. As populations are monitored longer, more counts are collected, and count variability is decreased, either model may become unsatisfactory for describing alligator population growth in lieu of more complex finite-growth models.

(2) Lognormal distribution.--The assumption of a lognormal distribution of errors goes hand-in-hand with the assumption of exponential growth. Under this assumption, errors due to unobservable effects multiply, rather than add together. Woodward and Moore (1993) found no consistent tendency for errors of log-transformed counts to increase in magnitude with either time or density, so, they assumed lognormally distributed errors. As before, with more data, this assumption may prove untenable.

(3) Independence of counts.--Regression analysis requires that each observation error or, in this case, count error, be independent. In crocodilian populations a random "mixing" of the population between counts generally would insure this condition. Insufficient mixing of the population increases the chances that variation among counts under similar conditions will be less than the overall variance for the population monitored over a variety of conditions. This phenomenon could introduce downward bias in variance estimates of growth parameters and lead to too-frequent conclusions of trend (increase in Type I error). Insufficient mixing may be an important consideration, as adult crocodilians tend to be territorial, and juveniles of some species remain in the vicinity of their nest site for several years. Movements may only occur during major environmental or seasonal changes, during breeding season, when certain sizes are attained, or possibly when densities become excessive after water level changes. Woodward and Moore (1993) postulated that a long interval between counts or a substantial water level change over a short time interval could induce mixing of alligator populations. Their findings indicate that under stable water levels, the minimum period to achieve independence was 40 days. However, such an interval between surveys may overlap seasonal movements that alter the sighting proportion. For alligators, the resulting time interval to achieve independence would be 1-40 days,

(4) Equal sightability at different population densities.--When counts are used as an index of population abundance, unequal sightability of animals available for counting at varying population densities can bias the trend estimate in either direction (Harris 1986). As population densities of some species change, so does their probability of detection, presumably because population pressures elicit changes in efficiency of detection relative to habitat use (Bart and Schoultz 1984, Harris 1986). This phenomenon may occur with crocodilians but would be very difficult to measure. Therefore, investigators may have to assume equal sightability under varying population levels in the absence of contrary evidence.

(5) Constant Proportion Observed.--The probability of detecting an animal on a survey route is a function of: (1) the ability of the observer to detect it; and (2) the position of the animal in the survey area. As mentioned earlier, standardizing observer skill levels over years can reduce observer variation. Variation in detection rates caused by vegetational changes can be isolated by including that variable as an independent variable in regression analyses. Accounting for water level changes can explain some of this variation in availability (Fig. 1) and scheduling annual surveys during the same season can minimize behavior-related distributional differences.

Transformation of Count Data

Count data rarely conform to the normal distribution and usually must be transformed for use in parametric statistics. Applying the natural logarithm ($\log_n$) to count data usually yields values with a stable variance (Eberhardt 1978).

Hypothesis Testing

Hypothesis.--Trend analysis is usually concerned with determining the direction and rate (slope) of population changes. Therefore, we are interested in testing the null hypothesis of no change in the population.

Power.--The power or sensitivity of the test and declaration of significance are important considerations in trend analysis (Eberhardt 1978, Gerrodette 1987). Few observations and high variation reduce the ability to detection of trends. Conventionally, Type I error (declaring a difference, or trend, when one does not occur) is considered less desirable than Type II error (declaring no trend when one occurred). In monitoring wildlife populations, the opposite is usually true, especially when management influences potentially decrease the population (Eberhardt 1978). In the case of crocodilian population trends, a 1-sided test, or relaxing the alpha level to $P = 0.1 - 0.2$ (or higher in cases where detecting declines are most critical) for declaring significance in a 2-sided test, will increase power for

enhanced detections of population declines in exchange for a greater possibility of mistaken declaration of declines.

Tests for Individual Areas.--Because we are interested in determining rates of increase, count data are best analyzed with regression techniques. By using linear regression of $\log_n$-transformed counts, we would model population growth exponentially. Variables such as water level, vegetation changes, temperatures, and other factors that affect detection rates or availability can be included in the overall model as covariates to isolate their effects. Regression analysis of the model:

$$\log_n(\text{COUNT}) = \text{YEAR COVARIATES} \ldots \text{ERROR}$$

will yield the rate (regression coefficient) and the direction (+ or -) of change, and the test statistic will provide a probability level for rejecting the null hypothesis.

Tests for Multiple Areas.--If the objective is to make inferences about regional population trends from a sample of areas, then further analyses may be conducted on the covariate-adjusted trend estimates (slopes). Either one-sample or multi-sample tests may be performed to test the slope mean(s) for equality to 0 or for homogeneity. For example, the effects of habitat type, density signature (Webb et al. 1990), or other variables may be examined by ANOVA. For slopes that do not meet normal distribution criteria, a non-parametric test may be appropriate (Woodward and Moore 1993). If sampled areas differ with respect to size and population densities, weighting of estimated slopes by these factors prior to analysis may be appropriate (Collins 1990, Geissler and Sauer 1990).

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