The Auk 116(2):316–323, 1999

FACTORS INFLUENCING COUNTS IN AN ANNUAL SURVEY OF SNAIL KITES IN FLORIDA

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ABSTRACT.—Snail Kites (*Rostrhamus sociabilis*) in Florida were monitored between 1969 and 1994 using a quasi-systematic annual survey. We analyzed data from the annual Snail Kite survey using a generalized linear model where counts were regarded as overdispersed Poisson random variables. This approach allowed us to investigate covariates that might have obscured temporal patterns of population change or induced spurious patterns in count data by influencing detection rates. We selected a model that distinguished effects related to these covariates from other temporal effects, allowing us to identify patterns of population change in count data. Snail Kite counts were influenced by observer differences, site effects, effort, and water levels. Because there was no temporal overlap of the primary observers who collected count data, patterns of change could be estimated within time intervals covered by an observer, but not for the intervals among observers. Modeled population change was quite different from the change in counts, suggesting that analyses based on unadjusted counts do not accurately model Snail Kite population change. Results from this analysis were consistent with previous reports of an association between water levels and counts, although further work is needed to determine whether water levels affect actual population size as well as detection rates of Snail Kites. Although the effects of variation in detection rates can sometimes be mitigated by including controls for factors related to detection rates, it is often difficult to distinguish factors wholly related to detection rates from factors related to population size. For factors related to both, count survey data cannot be adequately analyzed without explicit estimation of detection rates, using procedures such as capture-recapture. *Received 29 April 1997, accepted 24 July 1998.*

COUNT DATA have been widely used to monitor changes in bird populations (Barker and Sauer 1992, Johnson 1995). Counts are observation-based surveys in which an observer records some unknown portion of the birds actually present at a site. A complete census of a bird population is seldom feasible (Lancia et al. 1994), and alternative approaches (e.g. capture-recapture) often are too expensive or are logistically impractical (Link and Sauer 1997, 1998). However, count-based inferences about changes in population size can be severely biased if the detection rate (i.e. the fraction of animals counted) varies among counts, particularly if that variation has a temporal component (Burnham 1981, Nichols 1992, Johnson 1995, Link and Sauer 1997).

Unfortunately, many factors may influence the detection of birds during counts. Examples include: (1) temporal and behavioral differences among individuals, sometimes related to population density or habitat at sample sites (e.g. Gates 1966); (2) inconsistencies in counting methods among sample sites (Robbins et al. 1989, Geissler and Sauer 1990); (3) inherent differences in ability among observers when more than one observer conducts a survey (Faanes and Bystrak 1981, Sauer et al. 1994); (4) changes in observer ability associated with experience (e.g. first-time observer effects; Kendall et al. 1996); and (5) variation in effort (in terms of time or number of observers) expended for a given survey (Butcher and McCulloch 1990). Although some investigators feel that these sources of variability in detection rates can completely invalidate count-based surveys (Burnham 1981), most analyses of such surveys generally attempt to adjust for sources of variation in detection rate through use of covariates in the analysis, and then assume that changes in the covariate-adjusted counts reflect changes

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in the actual population. However, simple analyses of count data that do not adjust for sources of variation in detection rate may result in biased estimates of population change (e.g. Sauer et al. 1994).

Snail Kites (*Rostrhamus sociabilis*) in Florida were monitored from 1969 to 1994 using a quasi-systematic annual survey (Sykes 1979, 1982; Rodgers et al. 1988, Bennetts et al. 1994). The survey has been reported as: (1) a census (Sykes 1979, 1983; Snyder et al. 1989, Beissinger 1995); (2) an index of the relative number of birds in a given wetland over time (Rodgers et al. 1988); (3) a response variable for explanatory environmental variables (Beissinger 1995); (4) a basis for estimates of annual survival (Beissinger 1986, 1995); and (5) a basis for estimates of population trend (Sykes 1979, 1983; Bennetts et al. 1994).

Here, we analyze population change in the annual survey of Snail Kites using a generalized linear model. We then use the model to document several previously overlooked sources of variation that might influence detection rates of Snail Kites.

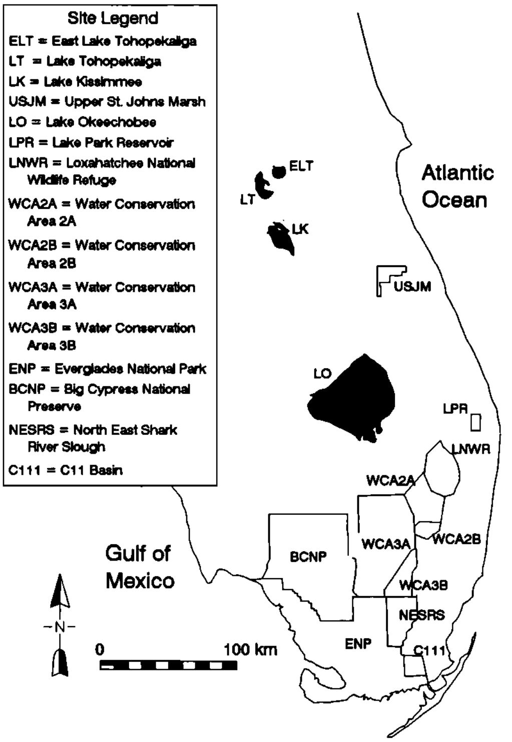

FIG. 1. Central and southern Florida showing wetland sites surveyed for Snail Kites and included in our analysis.

Methods

The annual Snail Kite survey.—Annual surveys were conducted in November and December, 1969 through 1994 (Sykes 1979, 1982; Rodgers et al. 1988, Bennetts et al. 1994). Counts were initially conducted via airboat using parallel transects about 0.5 km apart; however, we maintained the established protocol of using sites, rather than transects, as the sampling unit (Sykes 1982). As technology advanced, the position and alignment of transects were determined with a LORAN C navigational unit, and eventually a global positioning system. In large areas, where dense vegetation precluded placement of transects, or the number of birds (>10) indicated the presence of an evening roost, transect counts were corroborated or replaced with counts at communal roosts (Rodgers et al. 1988). Counts at roosts were conducted by positioning observers near the roost at least 1.5 h before sunset so that birds could be easily counted as they entered the roost.

Since 1969, three principal observers have conducted the annual survey: P. W. Sykes, Jr. (1969 to 1980), J. A. Rodgers, Jr. (1981 to 1990), and R. E. Bennetts (1991 to 1994), although each of these observers may have had from one to several observers assisting them (Sykes 1979, Rodgers et al. 1988, Bennetts et al. 1994, Sykes et al. 1995). No independent surveys were conducted during the transition from one principal observer to another, although Rodgers accompanied Sykes for much of the 1980 survey as an observer.

Sites at which the annual survey was conducted have been described by Sykes (1984), Rodgers et al. (1988), and Bennetts and Kitchens (1997a). The surveyed area of these sites ranged in size from approximately 5,000 ha at Lake Park Reservoir to 178,000 ha at Water Conservation Area 3A. A total of 15 sites was included in our analysis, 10 of which were surveyed in all 26 years (Fig. 1). As the distribution of kites became better known, and/or changed over time, the wetlands included in the survey changed accordingly. Thus, sites tended to be added over time, which generally corresponded with changes in observers. However, there was also considerable turnover in the surveying of smaller or more sporadically used wetlands. Such wetlands that were haphazardly surveyed with no consistency among observers or years were excluded from our analysis, although these wetlands generally accounted for a small percentage ($\bar{x} = 1.7\%$) of the total number of birds counted.

Modeling population change.—A common and frequently reasonable assumption for analyses of count data is that counts have Poisson distributions. The family of overdispersed Poisson distributions was introduced to generalize and improve such analyses by relaxing the restrictive assumption that the variance and mean are equal. Generalized linear models (GLMs) based on assumptions of overdispersed Poisson distributions are widely acknowledged as appropriate for analyses of count data (McCullagh and Nelder 1989, Diggle et al. 1994). They are easily fitted using software such as GLIM (Francis et al. 1994). We modeled population change in Snail Kites using an overdispersed GLM described by Link and Sauer (1997).

Patterns in counts of wildlife are a composite of patterns of population change and patterns induced by variation in detection rates; thus, the models we used included parameters describing site and observer effects, population change, and the effect of covariates on detection rates (Link and Sauer 1998). We used a loglinear model that included main effects for year, site, observer, water level, and effort and all two-way interactions of site, observer, water level, and effort.

We treated year as a factor with distinct values for each year of the survey. This "year-effects" model stands in contrast to models in which it is assumed that the pattern of population change can be represented by a polynomial or other smooth function. The latter have the advantage of parsimony, because they include a reduced set of parameters relative to year-effects models. Our choice of a year-effects model to describe the Snail Kite data was motivated by an important limitation of the data set: the time periods covered by distinct observers did not overlap. Thus, in years of observer change, population change was confounded with change in observer ability. Fitting a smooth pattern of population change across years involves interpolation across years of observer change on the basis of the patterns within each consecutive observer's periods. Doing so relies heavily on the assumption that the pattern of population change is smooth, and in particular that anomalous population changes have not coincided with changes in observers.

Because it was likely that observers differed in their methods of counting kites, we used primary observer as a factor in the analysis. Because time periods covered by distinct observers did not overlap, inclusion of this factor limits comparisons of population sizes to within periods of primary observers. Consequently, changes in counts coincident with observer change cannot be attributed to change in population; population change is confounded with any changes associated with observers.

We defined effort, Φ, as the number of observer days associated with a count. An observer day was considered to be one observer for one full day, or two observers for 0.5 days each, etc. We estimated observer days to the nearest 0.25 days (assuming a 12-h day) that we could reasonably determine from the original records of each observer. Each principal observer had from one to eight observers assisting, particularly during simultaneous counts at multiple roosts. We modeled the effect of effort as proportional to $\exp(-c/\Phi)$ for some $c > 0$; thus, $-1/\Phi$ was treated as an additive variable in the loglinear model. In this model, the proportion of animals counted is a concave upward function of effort for low levels of effort, then becomes a concave downward function of effort for high levels of effort, leading to a finite asymptote (i.e. more effort leads to proportionately less increase in counts as effort increases). The possibility that the effect of effort could vary among sites or observers, or in association with water levels, was examined by consideration of the relevant interaction terms.

Because water level can have an important effect on Snail Kite counts and population size (Sykes 1983, Beissinger 1995), the models we considered also included site-specific water levels, measured in "stage." Stage is defined as the elevation at the water surface relative to mean sea level. Stage is also the standard unit of measure for site-specific gauges at each location maintained by the South Florida Water Management District, St. Johns River Water Management District, U.S. Army Corps of Engineers, U.S. Geological Survey, and the city of West Palm Beach. The specific gauges used are reported in Bennetts and Kitchens (1997a). Yearly mean water levels were imputed for sites that could not be associated with gauges. Because water depth can be highly variable within sites, and reliable elevation data to estimate site-specific depth are lacking, we used variation in stage as the basis for our assessment of water levels. We estimated an average of the minimum annual stage over the 26-year period covered by the kite surveys. We then used the number of standard deviations above or below that average, for any given year, as a measure of relative water levels. This measure provides an objective assessment of water levels that can be applied to all areas and that corresponds well with the subjective designation of drought years reported in previous studies (e.g. Bennetts and Kitchens 1997a).

The final component of our GLM is the overdispersion structure. Following Link and Sauer (1997), we allowed a distinct overdispersion parameter for each of the 15 sites. This overdispersion accounts for unmodeled variation in counts, such as variation in patterns of population change among sites. Tests between nested models were carried out treating changes in scaled deviance as having a chi-squared distribution.

RESULTS

The data consist of 323 records obtained at 15 sites during 26 years. Eleven of the 15 sites were initiated by the first observer (team); data

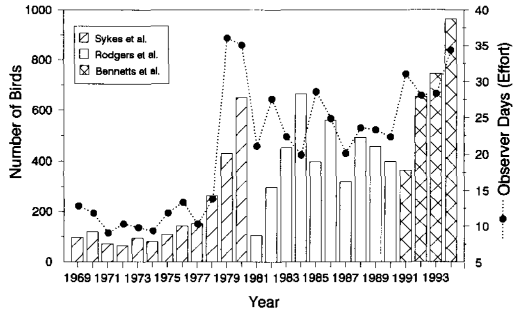

FIG. 2. Total number of Snail Kites counted during each annual survey by each observer from 1969 through 1994, plotted with amount of effort expended in each survey year. Line denotes effort as measured by the total number of observer days for a given year.

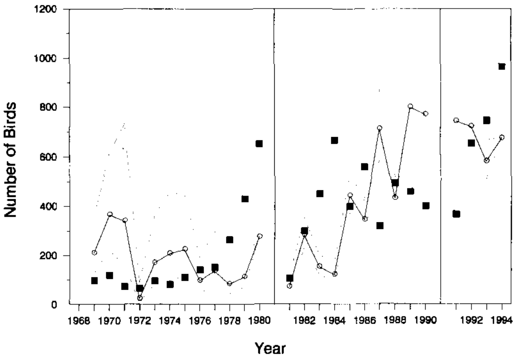

FIG. 3. Estimates (± SE) of Snail Kite population change controlling for effort, observer, site, and water level (open circles connected by lines). Population changes are scaled for comparability with the total counts within each observer. Solid squares denote unadjusted counts.

were collected in all 26 years at 10 of the sites. The total number of birds observed over all sites ranged from 65 birds in 1972 to 964 birds in 1994; counts clearly were associated with total effort (Fig. 2). Survey periods did not overlap among primary observers, so it was not possible to test for differences among observers. It was possible to test for observer-specific differences among sites (i.e. site by observer interactions), however, which were highly significant (χ^2 = 101.7, df = 24, $P < 0.001$).

The effect of effort did not vary among sites (χ^2 = 15.18, df = 14, P = 0.37) nor in association with water levels (χ^2 = 1.63, df = 1, P = 0.20). However, a significant interaction occurred between effort and observers (χ^2 = 16.04, df = 2, $P < 0.001$), which indicated that distinct values of the parameter c describing the effect of effort should be assigned for each observer. Examination of the data by observer revealed that effort had no significant effect on counts for the second (χ^2 = 1.56, df = 1, P = 0.21) or third (χ^2 = 0.90, df = 1, P = 0.34) observers, but that the effect of effort was significant for the first observer (χ^2 = 16.43, df = 1, $P < 0.001$).

Next, we considered the effects of water level. These did not vary in association with observer (χ^2 = 0.21, df = 2, P = 0.90) but did vary among sites (χ^2 = 36.09, df = 14, P = 0.001). The model with 15 site-specific effects of water level could be reduced to a model with only two distinct effects of water level (χ^2 = 20.10, df = 13, P = 0.093). The first of these effects is that water level at all sites was significant and was positively associated with counts. The second identified two sites as being even more sensitive to differences in water level.

Our final model thus included site effects and their interactions with observers, some effort effects, and some effects of water level; the hypothesis tests we have described reduced the number of estimable parameters by 31 without affecting the overall fit of the model (χ^2 = 37.92, df = 31, P = 0.18). Estimates based on this model suggested a quite different pattern of population change than that suggested by unadjusted counts. Although relative changes in population were not consistently higher or lower using adjusted counts, they indicated that population increases were more pronounced during the mid 1980s compared with the late 1970s as indicated by unadjusted counts (Fig. 3).

DISCUSSION

Our results show several previously unrecognized sources of variation inherent in counts during the annual Snail Kite survey. Failure to account for this variation can result in misinterpretation of most of the parameters estimated from the unadjusted counts.

Our results are consistent with previous conclusions that the overall population has increased over the 26-year period, reflecting restoration of long-hydroperiod marshes in several areas previously influenced by drainage programs (e.g. Sykes 1983). However, the pattern of population change we estimate within the period is quite different from that shown by simple total counts. In particular, the large increase in counts from 1978 to 1980 also coincides with a substantial increase in effort. The use of the unadjusted counts to evaluate year-to-year change is especially problematic when the primary observer differed. For example, the difference in counts between the 1980 and 1981 surveys, although widely interpreted as change in population size owing to a drought in 1981 (e.g. Beissinger 1986, 1988; Takekawa and Beissinger 1989), may also be explained by differences in detection rates related to effort and observers. The observer in 1980 was substantially more experienced, and more effort was expended on the survey in 1980 than in 1981. Without accounting for these factors, inferences about year-to-year changes in these data are not likely to be reliable.

Observer differences may reflect differences in experience (Kendall et al. 1996) or inherent ability attributable to such things as visual acuity (Sauer et al. 1994). They may also reflect differences in the way individual observers conducted the surveys. For example, Sykes often conducted his surveys alone and often over a period exceeding one month because the distribution of Snail Kites in Florida was poorly known at the time he initiated the survey. In contrast, Rodgers tried to keep the duration of the survey shorter (about 10 days) and more consistent among years, and he often used several different observers (J. A. Rodgers, Jr. pers. comm.). Another difference among observers was that Bennetts had prior knowledge of the distribution of numerous radio-tagged kites just prior to conducting his surveys. We believe that these differences are substantial enough to require the inclusion of observer effects in analyses of these data. Unfortunately, because there was no overlap in the periods counted by distinct observers, it is impossible to test for differences among observers using a year-effects model. Such a test requires modeling a smooth pattern of population change across periods of observer change. The results of such tests (which are not reported here) also suggest that differences among observers exist. The lack of overlap in periods covered by distinct observers is a critical deficiency of these data that limits their usefulness for estimating long-term trends.

A tendency also existed for each consecutive observer to include sites not surveyed by the previous observer. For example, Rodgers included three lakes within the Kissimmee watershed, only one of which had been previously included by Sykes during one year. Bennetts included portions of the Big Cypress National Preserve, which had not been included by either Rodgers or Sykes. Consequently, site effects were confounded with observer effects. Under these circumstances, we were able to fit a model with interactions of observer and site effects, but not an additive model of these effects. This feature of the data, along with the absence of overlap among observers, necessitated our approach of estimating population change within, but not between, the time periods corresponding to different observers.

Patterns of population change can be extracted from count data provided that researchers adequately control for factors that produce irrelevant variation in the data. The year effects that we estimated reflect patterns in counts that remain after having controlled for sources of variation known to influence detection. In attributing such patterns to population change, we assume that we have neither neglected temporally varying factors related to detection nor inadvertently removed variation related to actual population change. Often it is not clear whether these assumptions are legitimate. For example, although we are fairly confident that effort affects detection (and hence the count data) and is unrelated to population size, we are less confident in our treatment of water level as a factor that affects only detection.

Our results are consistent with previous studies indicating that counts are positively correlated with water levels, although the fitted year effects were less sensitive to our choice of whether to include water level effects than whether to include observer or effort effects. In our analysis, we treated water level as an effect on detection. This perspective is based on knowledge that kites disperse widely during droughts (Beissinger and Takekawa 1983, Takekawa and Beissinger 1989), often to areas not included in the annual survey (Bennetts and Kitchens 1997a). Thus, temporary emigration of birds to these peripheral habitats is an important component of detection (Bennetts and Kitchens 1997a, Valentine-Darby et al. 1998). In contrast, most previous investigators interpreted unadjusted counts (e.g. Sykes 1983; Beissinger 1988, 1995) and have assumed that water levels affect only population size, thus ignoring temporary emigration. In reality, water levels probably affect both detection rates and population size. Bennetts and Kitchens (1997b) suggested that the response of Snail Kites to droughts depends on the spatial extent of the drought. Rainfall patterns across Florida are quite variable, and small, localized droughts occur at a relatively high frequency (McVicar and Lin 1984). In contrast, widespread droughts that encompass the entire range of Snail Kites in Florida are relatively rare (MacVicar and Lin 1984, Duever et al. 1994, Bennetts and Kitchens 1997a). During these more localized droughts the response of kites may be largely behavioral: birds simply move to a different location (Bennetts and Kitchens 1997a, b). However, as droughts become increasingly widespread, both survival and reproduction may decrease as local food resources and refugia become less available (Sykes 1983, Beissinger 1986, Takekawa and Beissinger 1989). Without a reliable estimate of the detection probability of individuals in the entire population, it is virtually impossible to distinguish temporary emigration from real population change during droughts.

We have not included all factors that affect detection rates. Our analysis includes several such covariates but does not include other potential influences of detection for which we had no measure of the covariate. For example, Rodgers et al. (1988) suggested that transect counts of more than 10 birds indicated the presence of an evening roost, which was then used as a check on the accuracy (and often a replacement) of the transect counts. In areas where the survey relies on roost counts, failure to locate all roosts could result in a substantially lower count of birds. Bennetts and Kitchens (1997a) used radio telemetry to verify that all of the radio-tagged birds known to have been in a particular wetland were in known roosts. They found that they overlooked at least 64% of the birds in the area that had used other roosts. In addition, Darby et al. (1996) found that 57% of the Snail Kites that they observed either roosted solitarily (20%) or in roosts of fewer than 10 birds (37%). The effect of neglecting to include these covariates in analyses of population change depends on the magnitude of the temporal component of their variation.

Some of the difficulties related to identifying and modeling variability in detection of birds could be reduced by standardizing the survey protocol and hence limiting the range of variation in covariates known to influence detection. Our analysis suggests that standardization of site selection, the amount of effort expended, survey dates, and search strategies (transects) would lead to less variation in detection rates. Distance-based sampling (Buckland et al. 1993) also may improve estimates derived from transects for some species, but a pilot study indicated that the assumptions of this approach would have been severely violated (Bennetts and Kitchens 1997a). Although the use of different observers is inevitable over time, these changes should not occur concurrent with major environmental events (e.g. droughts). Moreover, whenever possible count years during which a new observer is present should overlap so that the new observer's results can be calibrated against those of the observer being replaced. During the change in observers that occurred from 1980 to 1981, the new observer accompanied the previous observer for much of the survey. Although this step may help reduce the variability between the two observers, it does not provide independent surveys from which an observer effect can be estimated.

Statistical calibration is also an intuitively appealing way to improve the reliability of counts. However, such calibration requires an independent benchmark for comparison. For an absolute calibration, this benchmark would be a known number of animals in the population (Osborne 1991), although comparative calibrations are possible using multiple counts or independent estimates of population size (Pollock and Kendall 1987, Rodgers et al. 1995). Except in strictly controlled settings, a known population size is highly unlikely. Multiple counts and independent estimates of population size are possible for Snail Kites but would require considerable effort and expense. Consequently, methods that estimate detection probability (e.g. capture-recapture) may be preferred for estimation of demographic parameters. These data are considerably more reliable than count data (Nichols 1992) and are obtainable for many species, including Snail Kites (Bennetts and Kitchens 1997a). For many species of birds in which no feasible way exists to obtain reliable estimates of population size or other demographic parameters, count data may provide the most reasonable substitute (Link and Sauer 1998). In such situations, surveys should be standardized as much as possible, should incorporate explicit tests for sources of variation in detection, and then should account for such variation.

ACKNOWLEDGMENTS

James A. Rodgers, Jr. generously provided us with unpublished data on effort from his Snail Kite surveys. We appreciate the helpful comments of Jonathan Bart, Brian Collins, Kathy Martin, B. Riley McClelland, James A. Rodgers, Jr., Graham W. Smith, and Len Thomas. Financial support for REB was provided by the National Park Service, the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, the U.S.G.S. Biological Resources Division, South Florida Water Management District, and St. Johns River Water Management District through the Florida Cooperative Fish and Wildlife Research Unit cooperative agreement 14-16-0007-1544, RWO90. This is contribution number R-06364 of the Florida Agricultural Experiment Station Journal Series, Institute of Food and Agricultural Sciences, University of Florida.

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Associate Editor: K. Martin