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ESTIMATES OF AVIAN POPULATION TRENDS FROM THE NORTH AMERICAN BREEDING BIRD SURVEY

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ABSTRACT.—One of the major purposes of bird population studies is to document changes in population size over a period of years. The traditional method used in Europe and North America to detect population change is to calculate annual ratios. However, this method can produce spurious results when ratios are accumulated over many years. Consequently, new methods of computing trends are needed. Several new methods of estimating population trends are developed and illustrated with data from the North American Breeding Bird Survey (BBS). Each method is compared in terms of its assumptions, biases, and limitations. On the basis of these comparisons we recommend one method that we feel most accurately detects true population trends. Both the biological and statistical justifications for the model selection are presented. Trends estimated with this model are then presented for two species.

The estimation of changes in the sizes of migratory bird populations provides important information for the management of these species. For many species, estimates of the absolute population size are not available, and the estimation of changes must be based on an index to the population size. In the North American Breeding Bird Survey (BBS) (Robbins and Van Velzen 1969), the numbers of birds heard or seen on randomly selected routes are counted under standardized conditions each year. These counts are used as an index to the population size in the vicinity of that route. The routes were selected as a stratified random sample and have been used each year since 1965 without drawing a new sample of routes. This survey is stratified by latitude degree blocks but does not have defined primary sampling units. Instead, the coordinates of the start and the direction of each route were selected at random. There are 50 stops on a route spaced at 0.8 km intervals. Routes are post-stratified into physiographic strata and into State and Province strata. Physiographic strata estimates are combined to obtain estimates for the three regions and for the continent. Bystrak (1981) gives a brief description of the physiographic strata and continental regions.

Much has been written on the use of population indices (e.g., Overton and Davis 1969, and Seber 1973). Many papers have focused on the relationship between the true population size (density) and the index (discussed in Caughley 1977). Although this is an important subject, it must be emphasized that this is not the subject of the present study. Here the index will be assumed to be proportional to the population size along a route although it is subject to some random measurement error.

It is generally assumed that the proportion of birds detected (the index) is independent of population size. However, the efficiency of the index likely changes with an increase in population size leading to a biased estimate of population change over time (Bart MS). We have not corrected for this bias in our analyses. As a result, our estimates of the number of significant population changes (increases or declines) are probably conservative.

In the development that follows, all of the models are restricted to considering species one at a time. The species index is implicit in the formulation.

AN OVERVIEW OF PREVIOUS METHODOLOGIES

A common method of estimating population change employs a proportional base year adjustment to allow for missing values resulting from the failure to run all routes every year (e.g., Erskine 1978). Starting with the number of birds recorded in some base year or from an arbitrary index value (e.g., 100), the adjusted number for succeeding and preceding years is calculated from the proportional change in comparable routes for each pair of years, working forward and backward from the base year. Routes are considered comparable if they are run in consecutive years or in some cases only if run by the same observer in consecutive years.

Let C_{iy} be the number of birds detected on the ith route in the yth year. Next the mean number of birds detected in year y on routes comparable to the year after is defined as

$$A_y = \sum_i [C_{iy} I_{iy(y+1)}] / \sum_i I_{iy(y+1)} \quad (1)$$

and the mean number on routes comparable to the year before as

$$B_y = \sum_i [C_{iy} I_{i(y-1)y}] / \sum_i I_{i(y-1)y} \quad (2)$$

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where

$I_{iy(y+1)}$ = 1 if route i was run in years y and $y + 1$.
= 0 otherwise.
$y = m, \ldots, n$ years

The adjusted mean number of birds per route (base year index) for the base year (b) is

$$Z_b = \sum_{y=p}^{q} (A_y + B_y)/2(q - p + 1) \quad (3)$$

and the index values for other years are

$$Z_{y+1} = Z_y B_{y+1}/A_y \text{ for } y \geqslant b \text{ and} \quad (4)$$

$$z_{y-1} = Z_y A_{y-1}/B_y \text{ for } y \leqslant b \quad (5)$$

where

b = base year and
p, q = first and last years (respectively) used to calculate the base year adjusted call counts, Z_b, $m \leqslant p \leqslant q \leqslant n$.

A problem with the proportional adjustment is that the adjustment makes annual indices dependent upon the adjacent year's index. As a result, the sampling errors accumulate and the annual indices tend to behave in the fashion of a random walk. Ten separate random series of artificial count means were generated with the same mean (9.2) and standard deviation (0.51) as the continental Mockingbird (*Mimus polyglottos*) mean counts per route. Four of these projected trends are presented in Figure 1. In the simulation, a new set of routes was used for each pair of years, demonstrating the maximum effect of the base year adjustment method. If the routes are run every year, the proportional adjustment multiplies each annual count by a constant, leaving the trend unchanged. In situations where the proportional adjustment does not change the counts, no distortions are introduced.

Although 95% of the generated annual means were between 8.2 and 10.2 birds per route, 95% of the adjusted index values were between 0.7 to 20.5 birds per route. The magnitude of the fluctuations seems to be greatly exaggerated by the base year adjustment. Although the artificial annual means were generated without any trends, the base year adjusted indices calculated from them seem to show realistic looking "trends." This phenomenon is similar to the infamous moving average, which generates apparent population "cycles" (Cole 1954).

Kozicky et al. (1954) estimated the trend of woodcock singing ground counts using a balanced analysis of variance. This model viewed the year effects as being predominant, with route effects nested within years, assuming that the counts on a route in successive years are uncorrelated. We take the opposite view that the route effects are important and that the year effects are nested within routes. In our view, estimating population trends is similar to estimating animal growth curves. Here each route has a "population trend," determined at least in part by the habitat (and its changes), drawn from some population of "population trends." In this view the error term for testing trends should be calculated among the route trends.

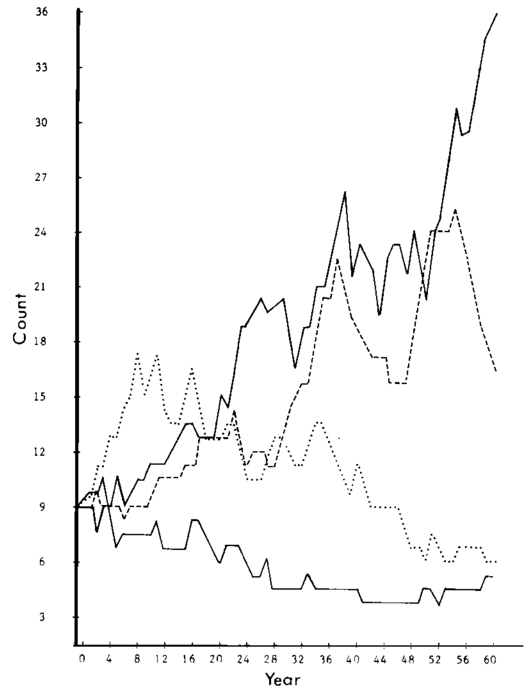

FIGURE 1. Simulated population fluctuations in the base year proportionally adjusted indices for the Mockingbird. See text for additional details.

Schultz and Muncy (1957), studying the counts of deer along transect lines, used an analysis of variance to compare months prior to the hunting season with months after the hunting season; a similar comparison could be made between groups of years. Duncan's multiple range test was used to compare the monthly counts.

Zimmerman (1979) provided a ten year summary of trends from the Kansas BBS. The mean number of birds per route for routes on which the species had been recorded were analyzed by the theory of runs (Dixon and Massey 1957). This method treated the entire State of Kansas as the sampling unit and therefore was insensitive to more local changes in populations. In addition, the runs test is only a qualitative index of population change and does not reflect the magnitude of population trends.

Dolbeer and Stehn (1979) estimated population trends of blackbirds and starlings from the North American BBS. In addition to using the base year adjustment, they used a paired t-test to compare each consecutive pair of years and to compare the first three years with the last three years. They also used an analysis of variance to fit a common slope to all routes within a physiographic stratum while allowing each route to have a separate intercept. Fitting a common slope with the model

$$c_{iy} = a_i + by + \epsilon_{iy} \qquad (6)$$

where

c_{iy} = count on ith route in yth year
a_i, b = parameters to be estimated, and
ϵ_{iy} = error terms

assumes that successive error terms (ϵ_{iy}, $\epsilon_{i(y+1)}$) are uncorrelated. These correlations will be unimportant only if counts are controlled primarily by stratum-wide effects (e.g., weather) that are independent of individual routes. However, if counts are controlled by route specific effects such as habitat, successive error terms for a route will be correlated and the common slope model would be inappropriate. If the primary controlling effect on local population size is habitat change, the variance should be calculated among routes.

DEVELOPMENT OF ALTERNATIVE METHODOLOGIES

Several alternative approaches are developed below. These methods are currently being used to analyze BBS data collected since 1965. The analysis is being conducted by staff at the Migratory Bird and Habitat Research Laboratory, U.S. Fish and Wildlife Service, Laurel, MD. An overview of their findings will appear as a 15 year summary of the BBS (Chandler Robbins, pers. commun.). Implicit reference is made in what follows to the results output from the computer program developed by Geissler.

ANNUAL MEANS

Annual mean counts are estimated to depict the dispersion about the fitted trends and to show possible systematic departures from these trends. Stratification in the analyses is based on physiographic regions (Bystrak 1981), but the routes themselves are allocated on a State (U.S.) or Province (Canada) basis, resulting in unequal probabilities of selection of routes within a stratum. However, probabilities of route selection are equal for individual States and Provinces within strata, but these areas are too variable in size and are often too small to constitute satisfactory strata.

An estimate of the stratum mean obtained by considering States and Provinces within strata as substrata is

$$\bar{c}_{iy} = \sum_j [(N_{ij}/N_i) \sum_k^{n_{ijy}} c_{ijky}/n_{ijy}]$$
$$= \sum_j \sum_k [c_{ijky}N_{ij}/(N_i n_{ijy})] \qquad (7)$$

where N_{ij} = area of the jth State or Province within the ith stratum
$N_i = \sum_j N_{ij}$ = total area of the ith stratum
n_{ijy} = number of routes in the sample from jth State or Province within the ith stratum with counts in the yth year
c_{ijky} = count from kth route in the jth State or Province within the ith stratum in the yth year.

(Note that throughout this paper, capital letters will used for population values and small letters for sample values.) The starting points of routes for the BBS were selected at random within a stratum without reference to well defined sampling units. Consequently, N_{ij} is taken to be the area in the jth State or Province within the ith stratum instead of the number of primary sampling units.

The variance of $\bar{c}_{iy}$ can be estimated by

$$\nu(\bar{c}_{iy}) = \sum_j \sum_k [(t_{ijky}N_{ij}/N_i n_{ijy})^2 \nu(c_{ijky})]$$
$$= [\sum_j \sum_k (t_{ijky}N_{ij}/N_i n_{ijy})^2]\nu(c_{ijky}) \qquad (8)$$

where $\nu(c_{ijky}) = \sum_j \sum_k (c_{ijky} - \bar{c}_{i..y})^2/(n_{i.y} - 1)$
$\bar{c}_{i..y} = \sum_j \sum_k c_{ijky}/n_{i.y}$
$n_{i.y} = \sum_j n_{ijy}$
t_{ijky} = 1 if count c_{ijky} was made
= 0 otherwise.

The means for regions or the continent over strata are

$$\bar{c}_y = \sum_i (N_i/N)\bar{c}_{iy} \qquad (9)$$

with variance

$$\nu(\bar{c}_y) = \sum_i (N_i/N)^2 \nu(\bar{c}_{iy}) \qquad (10)$$

where $N = \sum_i N_i$.

The annual means of the routes that were run each year can be influenced by which routes happen to be surveyed in a particular year. For example, if new routes were added in areas with few birds, the mean counts would be reduced although the population may not have changed. The other estimates that follow are calculated within each route to avoid this effect and to take advantage of blocking on routes.

To eliminate the effect on the annual mean counts of routes not run in certain areas, adjusted annual means can be calculated using predicted values whenever a route is not run. The predicted values are estimated from an analysis of variance for each stratum using the model

$$c_{ry} = a + b_r + d_y + \epsilon_{ry} \qquad (11)$$

where c_{ry} = count on rth route in yth year
a = intercept
b_r = effect of rth route
d_y = effect of yth year
ϵ_{ry} = error term.

When a predicted value cannot be calculated, the mean count on that route is substituted. Covariables such as weather can easily be included in this model, but care should be taken to avoid including a covariable that shows a time trend as this would remove desired time trends from the counts.

It is important to determine the relative stability of the bird populations as well as their relative sizes. The coefficient of variation calculated among the yearly point estimates for the strata, regions and continent provides an indication of their relative stability.

Quenouille Estimator and Jackknife Variance

In the development that follows, Quenouille's estimator (jackknife) is used to estimate parameters in order to reduce the bias from order n^{-1} to order n^{-2} (Cochran 1977:175–177). The basic form of Quenouille's estimator of a parameter p is

$$\hat{p} = mp' - (m - 1)\bar{p}' \qquad (12)$$

where $\bar{p}' = \sum_g^m p'_{(g)}/m$
p' = estimate based on all the data
$p'_{(g)}$ = estimate based on the remaining data after leaving out data from the gth group.

The jackknife variance is used to obtain variance estimates of ratios and of parameters which require weighting by random variables. An estimate of this variance of $\hat{p}$ is

$$v(\hat{p}) = [(m - 1)/m] \sum_g^m (p'_{(g)} - \bar{p}')^2. \qquad (13)$$

To calculate these estimates, the routes in each stratum are randomly grouped as evenly as possible into m groups. These groups are formed by sorting the routes within each stratum into random order and then assigning the routes to groups in rotation.

Ratios of Mean Annual Counts

The ratio of the mean annual counts in one span of years y to the mean annual counts in another span of years y' indicates the relative change in the populations between the two time periods. The estimator of this ratio for stratum $i(r_{iyy'})$ is obtained by substituting

$$r'_{iyy'} = \left(\sum_j \sum_k c_{ijky} t_{ijkyy'} N_{ij}/N_i n_{ij}\right) \Big/ \left(\sum_j \sum_k c_{ijky'} t_{ijkyy'} N_{ij}/N_i n_{ij}\right) \qquad (14)$$

for p' in equations 12 and 13 where

$t_{ijkyy'}$ = 1 if the counts c_{ijky} and $c_{ijky'}$ are available and not both equal to zero
= 0 otherwise
n_{ij} = number of routes in sample from jth State or Province within the ith stratum which have counts in years y and y'.

Here $r'_{iyy'}$ is the ratio of $\bar{c}_{iy}$ to $\bar{c}_{iy'}$ with $t_{ijyy'}$ selecting only those routes which have counts in years y and y'. The combined ratio estimator is used to obtain the estimate for regions and the continent over strata. This is equivalent to a separate ratio estimator using the estimated bird counts $\sum_j \sum_k c_{ijky'} t_{ijkyy'} N_{ij}/N_i n_{ij}$, as the stratum weight. Quenouille's estimator and jackknife variance are also used to obtain estimates for regions and the continent $(r_{yy'})$ over the strata by substituting

$$r'_{yy'} = \left[\sum_i (N_i/N)\left(\sum_j \sum_k c_{ijky} t_{ijkyy'} N_{ij}/N_i n_{ij}\right)\right] \Big/ \left[\sum_i (N_i/N)\left(\sum_j \sum_k c_{ijky'} t_{ijkyy'} N_{ij}/N_i n_{ij}\right)\right] \qquad (15)$$

for p' in equations 12 and 13.

Geometric Mean of Ratios of Counts in Successive Years

This quantity estimates the average annual rate of change in the size of the bird population. The ratio of the counts in successive years is estimated and their geometric mean calculated. The geometric mean $[(c_2/c_1)(c_3/c_2) \ . \ . \ . \ (c_p/c_{p-1})]^{1/(p-1)}$

reduces to $(c_p/c_1)^{1/(p-1)}$ if all the routes were run each year. In this situation the geometric mean depends only on the first and last count and would be highly variable. Because $r_{iy(y+1)}$ and $r_{iy'(y'+1)}$ are not independent, the variance cannot be calculated as the variance of a linear combination without including their covariances. However the variance can be estimated by expressing the geometric mean as a function of the c_{ijky}'s and jackknifing it. Here

$$a'_i = \left[\prod_{y}^{p-1} r'_{iy(y+1)} \right]^{1/(p-1)} \quad (16)$$

is substituted for p' in equations 12 and 13 to obtain the strata estimates and

$$a' = \left[\prod_{y}^{p-1} r'_{y(y+1)} \right]^{1/(p-1)} \quad (17)$$

is substituted to obtain the estimates for the regions and the continent; where $r_{iy(y+1)}$ and $r_{y(y+1)}$ are defined in equations 14 and 15, respectively.

Slope on Logarithmic Scale

Another estimator of the rate of change in the size of the bird population is the slope on the logarithmic scale, obtained by fitting the model

$$c_{ijky} = b_{ijko} b^{y}_{ijk} \epsilon_{ijky} \quad (18)$$

where c_{ijky} = the count in year y on route k in State or Province j within stratum i

b_{ijko} = the intercept on route k in State or Province j within stratum i

b_{ijk} = the population trend on route k in State or Province j within stratum i

ϵ_{ijk} = random error term associated with the predicted count. The error terms are assumed to be lognormally distributed with mean = 0 and variance = 1.

A multiplicative rather than an additive model is used because: (1) it is likely that population changes affect a proportion of the population (multiplicative model) rather than a specific number of individuals (additive model); (2) observers probably see or hear a proportion of the birds present; and (3) a multiplicative model (logarithmic transformation) has the advantage of stabilizing the variance for those data sets examined. Taking logarithms, the model becomes

$$c^*_{ijky} = b^*_{ijko} + b^*_{ijk} y + \epsilon^*_{ijky} \quad (19)$$

where the asterisk indicates the natural logarithms of the quantities and $c^*_{ijky} = \ln(c_{ijky} + 0.5)$. Because the logarithm cannot be taken of a zero count an arbitrary positive constant is added to c_{ijky}. The value 0.5 is used because it is half way between the smallest observable count and zero.

We wish to estimate the rate of change of the total bird population. Note that this is a different parameter than a "per area" rate of change which would give equal weight to each route. For example if half the routes doubled their counts from 50 to 100 birds and the others halved their counts from 10 to 5 in a year with equal probability sampling, the geometric mean rate of change would be 1 (no change). But the rate of change in the bird population would be 105/60 = 1.75.

To develop a justification for the estimate of the rate of change of the bird population, consider

$$b'_i = \left(\sum_j \sum_k b_{ijk} \bar{\bar{c}}_{ijk} N_{ij}/N_i n_{ij} \right) \Big/ \left(\sum_j \sum_k \bar{\bar{c}}_{ijk} N_{ij}/N_i n_{ij} \right) \quad (20)$$

where

$b_{ijk} = \exp[b^*_{ijk}]$ (estimated trend on route k)

$$b^*_{ijk} = \sum_{y=1}^{n_{ijk}} (c^*_{ijky} - \bar{c}^*_{ijk})(y - \bar{y}) / \sum_{y=1}^{n_{ijk}} (y - \bar{y})^2$$

$$\bar{c}^*_{ijk} = \frac{1}{n_{ijk}} \sum_{y=1}^{n_{ijk}} \ln(c_{ijky} + 0.5)$$

$\bar{\bar{c}}_{ijk} = (c_{ijk1} c_{ijk2} \ldots c_{ijkp})^{1/p}$ is the geometric mean of the counts on the kth route in the jth State or Province within the ith stratum.

Representing $\bar{\bar{c}}_{ijk}$ and b_{ijk} by functions of the predicted values from (18),

$$\bar{\bar{c}}_{ijk} \doteq \hat{b}_{ijko} (\hat{b}^1_{ijk} \hat{b}^2_{ijk} \ldots \hat{b}^p_{ijk})^{1/p} = \hat{b}_{ijko} \hat{b}^{(p+1)/2}_{ijk} = \hat{c}_{ijkq}$$

and

$$\hat{b}_{ijk} = \hat{c}_{ijk(q+1)} / \hat{c}_{ijkq}$$

where $\hat{c}_{ijkq}$ is the predicted count in year $q = (p + 1)/2$ where there are p annual counts. Substituting these values in (20)

$$b'_i \doteq \left(\sum_j \sum_k \hat{c}_{ijk(q+1)} N_{ij}/N_i n_{ij} \right) \Big/ \left(\sum_j \sum_k \hat{c}_{ijkq} N_{ij}/N_i n_{ij} \right). \quad (21)$$

This is the estimated ratio of counts in successive years, the quantity we wish to estimate. If the counts are proportional to the bird population along the route, this estimate is also the ratio of the bird populations in successive years.

The jackknife estimate is used to reduce bias, substituting

$$b'_i = \left(\sum_j \sum_k b_{ijk}\bar{\bar{c}}_{ijk} w_{ijk}/N_{ij}/N_i n_{ij}\right) \Big/ \left(\sum_j \sum_k \bar{\bar{c}}_{ijk} w_{ijk} N_{ij}/N_i n_{ij}\right) \quad (22)$$

for p' in equations 12 and 13 where

$\bar{\bar{c}}_{ijk} = \left[\prod_y^p (c_{ijky} + 0.5)\right]^{1/p}$ (0.5 added to avoid multiplying by a zero count)

n_{ij} = number of routes in jth State or Province within the ith stratum with two or more counts

w_{ijk} = 1 (will be redefined later).

The estimates for regions or the continent over strata are obtained by substituting

$$b' = \left[\sum_i (N_i/N)\left(\sum_j \sum_k b_{ijk}\bar{\bar{c}}_{ijk} w_{ijk} N_{ij}/N_i n_{ij}\right)\right] \Big/ \left[\sum_i (N_i/N)\left(\sum_j \sum_k \bar{\bar{c}}_{ijk} w_{ijk} N_{ij}/N_i n_{ij}\right)\right] \quad (23)$$

for p' in equations 12 and 13.

Slope on Logarithmic Scale, Weighted to Reduce Variance

Weighting the counts on individual routes by the number and dispersion of sampled years will reduce the variance of the trend estimate. However, if the decision to run or not run a route is related to the population trend on that route, a bias will be introduced. BBS routes are run by unpaid volunteers, and whether or not a route is run depends on the availability of volunteers. All routes are scheduled to be run each year but many routes are not run for reasons that appear unrelated to the bird populations or their trends. Routes are often added evenly across a State or Province as more observers volunteer. Therefore we feel that weighting BBS routes based on the years they were run will substantially reduce the variance of area estimates, but will introduce little bias into these estimates.

To develop the weighting factor consider the estimate of variance of the trend, which is

$$v(b^*_{ijk}) = \sum_y (c^*_{ijky} - \hat{c}^*_{ijky})^2 \Big/ \left[(n_{ijk} - 2) \sum_{y=1}^{n_{ijk}} (y - \bar{y})^2\right].$$

Because this variance is proportional to

$$\left[(n_{ijk} - 2) \sum_y^{n_{ijk}} (y - \bar{y})^2\right]^{-1},$$

the route estimate was weighted by

$$w_{ijk} = \left[(n_{ijk} - 1) \sum_y^{n_{ijk}} (y - \bar{y})^2\right]^{0.5} \quad (24)$$

to stabilize the variance. This gives less weight to routes sampled only a few years which would be expected to have a much greater variance than routes sampled many years. Here $(n_{ijk}-1)$ is used instead of $(n_{ijk}-2)$ to avoid giving zero weight to a route with two annual observations. Estimates of the weighted parameters are obtained by substituting their weight (w_{ijk}) into equations 22 and 23 prior to their substitution into equations 12 and 13.

Theil's Nonparametric Slope Statistics

This estimate of the rate of change of the bird population is less affected by extreme counts than are the parametric slope estimates. Individual slope estimates for each pair of years for a route are formed according to

$$d_{ijkyy'} = (c^*_{ijky'} - c^*_{ijky})/(y' - y),\ y < y'$$

and let

$$d_{ijk} = \exp[\text{median}\ (d_{ijkyy'})] \quad (25)$$

(see Hollander and Wolfe 1973:205–206). Estimates are obtained by replacing b_{ijk} with d_{ijk} in equations 22 and 23 before substituting them into equations 12 and 13.

Theil's Nonparametric Slope Statistic, Weighted to Reduce Variance

The variance of a median is approximately proportional to $p/(p + 1)^2$ (Gibbons 1971:36 eq. 6.6) where p is the number of data points. Because there are $p_{ijk} = n_{ijk}(n_{ijk} - 1)/2$ pairs of points on a route which are used to calculate the $d_{ijkyy'}$'s, the variance of d_{ijk} is proportional to $p_{ijk}/(p_{ijk} + 1)^2$. Thus the route estimates are weighted by

$$w_{ijk} = (p_{ijk} + 1)/(p_{ijk})^{0.5} \quad (26)$$

to stabilize the variance. Estimates are obtained by replacing b_{ijk} with d_{ijk} and substituting the above weight w_{ijk} in equations 22 and 23 prior to substitution into equations 12 and 13.

RESULTS AND DISCUSSION

It is extremely difficult to select among available models the one that best reflects the true dynamics of the population of interest. To make an unambiguous selection requires valid, up-to-date information on a species' population status from one or more independent sources. In the

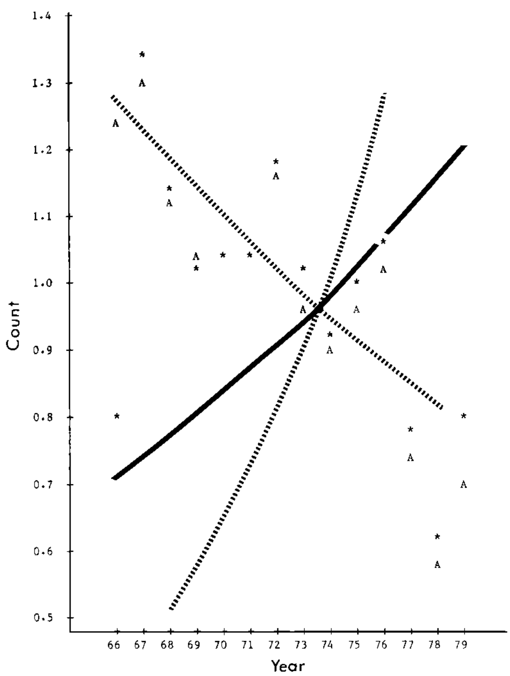

FIGURE 2. Continental population trend (solid line) and its 95% confidence limits (interrupted lines) of the Eastern Bluebird as estimated by a parametric slope (equation 23). The mean count on the routes that were run each year (*) and the adjusted mean counts (A) (when they differ from the mean counts) are also indicated. Data are from 1227 Breeding Bird Survey routes.

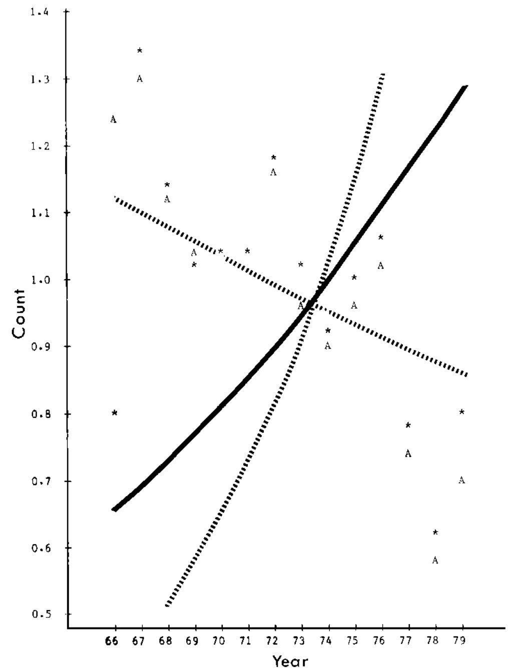

FIGURE 3. Continental population trend (and its 95% confidence limits) of the Eastern Bluebird as estimated by a nonparametric slope (equation 25). Mean (*) and adjusted mean counts (A) as in Fig. 2.

absence of such information other criteria are used. For the analysis of population trends considered here we have used both statistical and biological criteria. Estimates of the slope of the population growth curve on the logarithmic scale were weighted by the estimated species' population on that route. This weighting results in an estimate of the ratio of the total bird population in one year to the population in the previous year, the ratio desired. In addition, we expect routes with higher counts to be more centrally located with respect to the species' distribution pattern. As a result, these routes should have more weight than routes on the periphery of the species' range which are more prone to random fluctuations and which represent a smaller fraction of the species' population. Estimates that were weighted to reduce the variance consistently appear to have narrower confidence intervals on their slope estimates and importantly, for those cases examined, also showed very little bias as judged by the annual means (Geissler, unpublished analysis).

Biologically we looked for independent sources of corroboration for our trend estimates. Our search, restricted to the ornithological literature, particularly state field journals, supplied only anecdotal information. The lack of independent sources of avian trend estimates is not surprising. The BBS data are unique in that they represent the only data set that indexes the status of many species' populations over a large geographical area for a long period of time.

Proportional base year adjustment methods have been used to estimate population change. However, when we examined the performance of this method for random series of artificial mean counts we noted that realistic looking trends appear even when no trend exists in the original data (Fig. 1). The magnitude of these trends is even greater for species we examined with larger coefficients of variation in their annual mean counts.

Another approach to model selection is to compare the performance of the models with known artificial populations using computer simulation. We have not done any simulations, although we hope to in the future.

To make a tentative selection among the models developed we have examined in detail

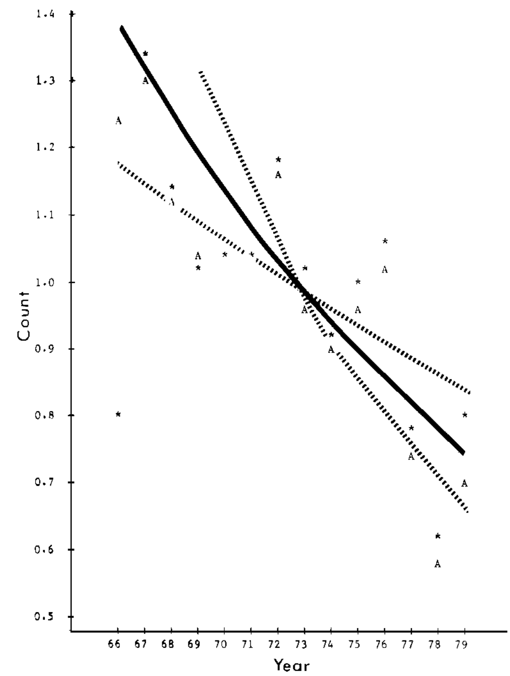

FIGURE 4. Continental population trend (and its 95% confidence limits) of the Eastern Bluebird as estimated by a parametric slope scale weighted to reduce the variance (equation 24). Mean (*) and adjusted mean counts (A) as in Fig. 2.

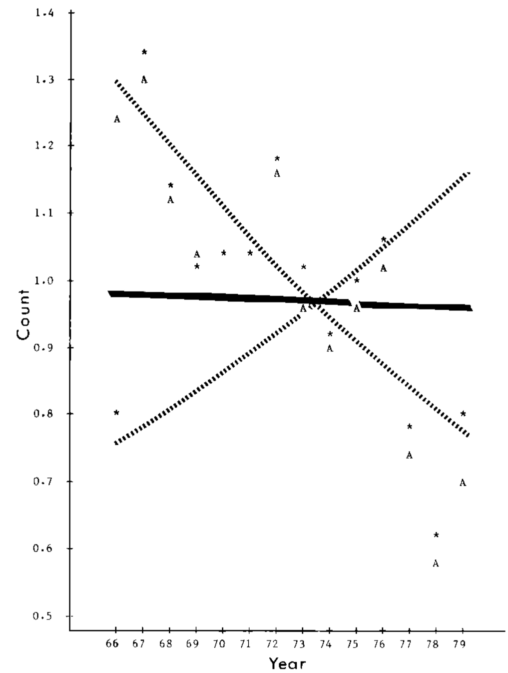

FIGURE 5. Continental population trend (and its 95% confidence limits) of the Eastern Bluebird as estimated by a nonparametric slope on the logarithmic scale weighted to reduce the variance (equations 25 and 26). Mean (*) and adjusted mean counts (A) as in Fig. 2.

the population trends for two species, the Eastern Bluebird (*Sialia sialis*) and the Loggerhead Shrike (*Lanius ludovicianus*). These species were selected for several reasons: (1) both species are well sampled by the BBS methods; (2) both species are well represented in the data set; (3) they have extensive geographic distributions; and (4) considerable anecdotal information indicates that these species have undergone substantial declines in population over the past 10 years. Anecdotal information on regional population declines is perhaps best summarized by the Blue List published since 1971 in *American Birds*. During this nine year interval the Loggerhead Shrike has been listed every year and the Eastern Bluebird, four of the nine years, most recently in the 1980 Blue List (also see Monroe 1978, Zimmerman 1979).

We present a comparison of the continental (Canada and U.S.A.) trend estimates for the Eastern Bluebird (Figs. 2–6). Figure 2 illustrates the unweighted, parametric slope estimate on the logarithmic scale (from equation 23); Figure 3, the unweighted, non-parametric slope on the logarithmic scale (equation 25 substituted into equation 23); Figure 4, the weighted, parametric slope on the logarithmic scale (equation 23 with weighting factor from equation 24); Figure 5, the weighted, non-parametric slope on the logarithmic scale (equations 25 and 26 substituted into equation 23); and Figure 6, the geometric mean model (equation 17).

In all figures both actual (equation 7) and adjusted mean counts (equation 11) are presented. Adjusted mean counts have the advantage of not being directly influenced by which routes were run in a particular year. If routes on the periphery of a species' range are added in later years of the survey it is possible for mean counts to show a decrease even if counts are increasing on most routes. However, adjusted mean counts will show this increase because predicted values are substituted whenever a count is missing. We make note of the fact that the difference between adjusted and actual mean counts for 1966–67 (e.g., Fig. 2) are a result of the algorithm used to calculate regional mean counts coupled with the poor coverage for the BBS in these years. These differences do not affect the trend estimates.

The difference in the trend estimates among the models is extensive. Both the parametric and

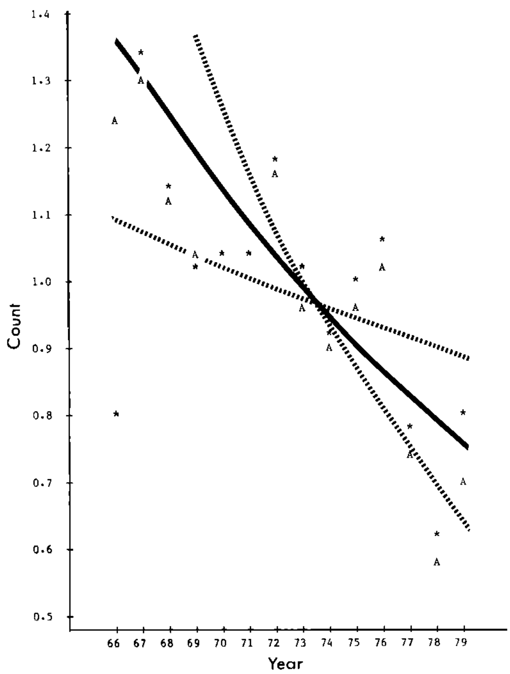

FIGURE 6. Continental population trend (and its 95% confidence limits) of the Eastern Bluebird as estimated by the geometric mean of the annual ratios of the counts in successive years (equation 17). Mean (*) and adjusted mean counts (A) as in Fig. 2.

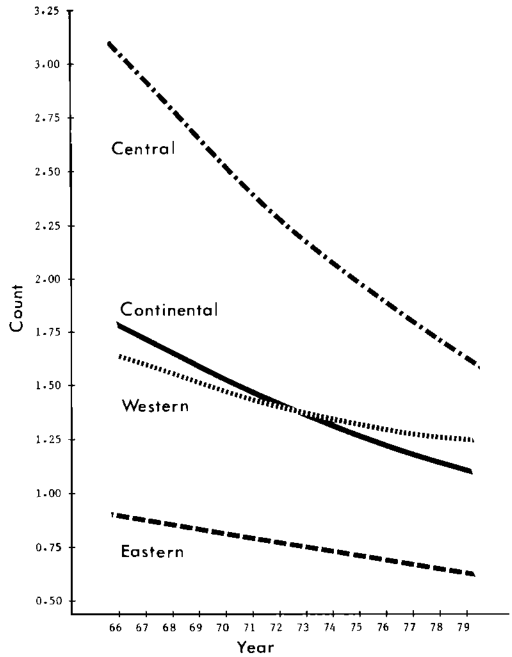

FIGURE 7. Continental (solid line) and regional population trends for the Loggerhead Shrike as estimated by a parametric slope weighted to reduce the variance (equation 24). Data are from 1021 Breeding Bird Survey routes.

non-parametric, unweighted models (Figs. 2 and 3) differ from the others in that they: (1) show an increasing population trend; (2) have large variances associated with the slope estimate; (3) fail to follow the adjusted and unadjusted mean counts; and (4) fail to corroborate the anecdotal evidence which indicates that the Eastern Bluebird is declining. The weighted nonparametric and geometric mean trend estimates are quite similar and closely follow the annual means. However, note that the confidence interval around the slope of the weighted parametric model is substantially smaller than for the other models (cf. Fig. 4 with Figs. 2, 3, 5, and 6). An identical pattern, with the weighted parametric model performing best, was noted on close examination of trends for the Loggerhead Shrike.

Judging by the performance of the weighted parametric model, we feel that it may accurately reflect the population trend of the Eastern Bluebird. It also seems intuitively reasonable to weight each route by the number and spread of years sampled. Routes sampled many years would be expected to give a much better index of the local population stability of a species. In addition, routes sampled many years would be expected to have a lower variance than routes sampled only a few years.

Weighting the route by the number of years sampled has the potential of introducing a bias if the decision to survey a route is based on some a priori concept of a species' trend along that route. To investigate this potential bias we calculated the correlation between the weighted parametric and weighted non-parametric route slope estimates and their weights. For the Eastern Bluebirds the correlations were significant ($P < .001$) but so low ($r = -0.14$) that we are confident that the weighting introduced little bias.

Continental and regional population trends for the Loggerhead Shrike, as estimated by the parametric slope on the logarithmic scale weighted to reduce the variance, are presented in Figure 7. Note that the trends for the three regions are quite different. All slope estimates, except for the Western Region, are different from zero ($P < .01$).

Partitioning of the continental estimate into regional estimates represents only a first-level breakdown. In addition, our analyses breakdown each regional estimate into strata estimates (see Bystrak 1981) and each stratum estimate into individual route estimates. As a result, we are able to look at very specific areas within a species' range to investigate any local effects that may be contributing to the species' changing population status. The power of the analysis as an investigative tool rests on the use of individual routes as the basic unit of analysis.

CONCLUSIONS

Three different approaches are used to estimate the annual rate of change in the bird populations c_{y+1}/c_y. The geometric mean has an intuitive appeal because of its simplicity, being the average of the annual ratios. It does not require weighting because the routes automatically contribute their proportional share to the numerator and denominator of the ratio. However it does not use all of the available data because ratios of successive years are restricted to routes that were run both years. In the extreme case where all routes were run every year, only the first and last years of data are used. In spite of this, the geometric mean performs surprisingly well.

Another approach to estimating the annual rate of change is to estimate the slope of the population growth curve on the logarithmic scale. Both parametric and nonparametric slope estimators are used. In either case, the route slope estimate must be weighted by the estimated bird population on that route to obtain an estimate of the change in the total bird population. Weighting according to the years a route was run was effective in increasing the precision of the estimates, but has the potential of introducing bias. To investigate the effect of the weighting on the slope estimate, we calculated the correlation between the weighted parametric and weighted non-parametric route slope estimates and their weights. For the Eastern Bluebird the slope estimate was significantly correlated with the weight but was so small that there was little opportunity to introduce a bias. In addition, the fitted trends do not show any obvious bias as judged by the adjusted annual means.

Nonparametric slope estimates have both the advantage and disadvantage of being less influenced by extreme points than the parametric slope estimates. This is an advantage if the extreme points are mistakes resulting from recording error, mistaken identification, etc. However, the lack of sensitivity to extreme points means that the nonparametric slope estimate will not be as sensitive as the parametric slope estimate to sharp changes in the bird population.

Some may argue that it is not logical to fit an average rate of change to a population for which the rate of change is fluctuating. This is certainly true in some situations. These situations can be identified by observing the fluctuations of the annual mean counts and the adjusted annual mean counts, and their failure to conform.

Based on our limited experience, the parametric slope, weighted to increase the precision, appears to be the best estimator. It has the smallest confidence intervals and is more sensitive to sharp population changes than the nonparametric estimates. However, more work is needed to investigate the properties of these estimators. Both an examination of their performance on several sets of data and a Monte Carlo study are planned. Early results of these studies indicate that the parametric slope estimates are positively biased but that the bias can be easily corrected.

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