J. Field Ornithol., 51(3): 244–247

EFFECT OF DELAYED REPORTING OF BAND RECOVERIES ON SURVIVAL ESTIMATES

By David R. Anderson and Kenneth P. Burnham

Brownie et al. (U.S. Fish and Wildl. Serv., Resource Publ. 131, 1978) presented 14 models based on an array of explicit assumptions for the study of survival in avian populations. These methods are replacing the life table methods previously used to estimate survival rates (e.g., Burnham and Anderson, *J. Wildl. Manage.*, **43:** 356–366, 1979). The new methods allow survival or recovery rates, or both, to be constant, time-specific, or time- and age-specific.

In studies to estimate survival rates for birds the data are often from recoveries of birds shot or found dead during the hunting season and reported to the Bird Banding Laboratory by sportsmen, conservation agency employees, or the general public. This note examines the bias in estimating annual survival due to a proportion of the recoveries being incorrectly reported a year late. Specifically, a few recoveries each year of, for example, adult male American Widgeon (*Anas americana*) banded in California are reported as being recovered in year i + 1 when in fact they were actually recovered the previous year i. Delayed reporting might typically be caused by people finding a band in their heavy clothing in the fall of the year and, being embarrassed about their failure to report the band when it was taken, report it a year late not mentioning the actual year of recovery. Heuristically, delayed reporting should bias estimated annual survival rates upwards because it appears from the data that the birds corresponding to the "delayed" recoveries actually lived an additional year.

METHODS

Results here are based on Seber's (*Biometrika,* **57:** 313–318, 1970) model (see Model 1 in Brownie et al., op. cit.) but with allowance for delayed reporting of a proportion q of the recoveries each year.

Let p = the probability that a band is reported in year i given that the bird also was shot in year i

q = 1 − p = the probability that report of the band is delayed one year.

We assume all recoveries are either reported in year i (as all the models of Brownie et al., op. cit., assume) or one year later. That is, we assume people do not wait 2, 3, . . . , ℓ years before reporting a band recovered in year 1. In this study we allow p to have the values 0.95, 0.98, and 0.99 because these seem to represent realistic values (5%, 2%, and 1% rate of delayed reporting). Of course, if p = 1.0 no delayed reporting exists.

The magnitude of the bias will be influenced by the true survival rates and possibly, the true recovery rates. Therefore, we computed the the-

TABLE 1.

Symbolic representation of band recovery data assuming (a) no delayed reporting and (b) proportion (1 − p) of the bands are reported to the Bird Banding Laboratory one year late.

(a) No delayed reporting, p = 1.0

Year banded	Number banded	Number of recoveries by year				
		1	2	3	...	ℓ
1	N_1	R_{11}	R_{12}	R_{13}	...	$R_{1\ell}$
2	N_2		R_{22}	R_{23}	...	$R_{2\ell}$
3	N_3			R_{33}	...	$R_{3\ell}$
•	•				•	•
•	•				•	•
•	•				•	•
k	N_k					$R_{k\ell}$

(b) Delayed reporting of one year, p < 1.0 (q = 1 − p)

Year banded	Number banded	Number of recoveries by year				
		1	2	3	...	ℓ
1	N_1	$R_{11}p$	$R_{12}p + R_{11}q$	$R_{13}p + R_{12}q$	...	$R_{1\ell}p + R_{1\ell-1}q$
2	N_2		$R_{22}p$	$R_{23}p + R_{22}q$	...	$R_{2\ell}p + R_{2\ell-1}q$
3	N_3			$R_{33}p$	...	$R_{3\ell}p + R_{3\ell-1}q$
•	•				•	•
•	•				•	•
•	•				•	•
k	N_k					$R_{k\ell}p + R_{k\ell-1}q$

oretical bias for three values of annual survival rate (S_i = 0.35, 0.60, and 0.85) and four values of recovery rate (0.01, 0.03, 0.06, 0.10). We examined the bias assuming banding was done over a 10-year period. In all, we examined 36 sets of expected recoveries generated from Table 1b: three survival rate values × four recovery rate values × three rates of delayed reporting = 36.

We computed the expected value of the estimator $\hat{S}_i$, $E(\hat{S}_i)$, for each of the 36 "data" sets using the adjusted maximum likelihood estimator for Model 1 (see Brownie et al., op. cit., p. 16). Because the estimator of S_i under Model 1 is unbiased assuming no delayed reporting, we can assess the bias of the estimator due to delayed reporting by generating data under the model structure shown in Table 1b. In addition, we made analyses under Models 0, 2 and 3 and intend to present these results qualitatively (see Brownie et al., op. cit., for details on these models). Two definitions are required for clarity:

$$\text{Bias} = E(\hat{S}_i) - S_i$$

$$\text{Percent relative bias (PRB)} = \frac{E(\hat{S}_i) - S_i}{S_i} \times 100.$$

TABLE 2.
Percent relative bias in the estimator of annual survival due to delayed reporting.

	Survival rate		
	35%	60%	85%
1%	7.31[1]	1.85	0.74
	2.91[2]	0.88	0.06
	2.40[3]	0.33	−0.21
3%	7.17	2.38	0.74
	3.06	0.83	0.35
	1.71	0.42	0.09
6%	6.60	2.30	1.04
	2.37	0.85	0.38
	0.94	0.38	0.17
10%	7.11	2.38	1.07
	2.91	0.92	0.41
	1.40	0.95	0.19

[1] p = 0.95 (5% delay)
[2] p = 0.98 (2% delay)
[3] p = 0.99 (1% delay)

RESULTS

We found, as might be expected, that the bias in the estimator of annual survival rate is independent of the number of birds banded. Furthermore, bias is not strongly affected by variation in recovery rates. Therefore, our results are much more general than the specific examples reported.

The percent relative bias (PRB) of the estimated average annual survival rate, $\hat{S}$ for each of the 36 cases is presented in Table 2. The bias is little affected by differing recovery rates. For survival rates of 60 and 85 percent, the PRB is less than 2.5 percent (e.g., if S = 0.60, then 2.5 PRB corresponds to $E(\hat{S}) = 0.615$) and is essentially negligible compared to the magnitude of the standard error commonly found in analyzing real data. The PRB was substantial only for survival rates of 35 percent where p = 0.95 (hence for low values of S and high values of q) ranging from 6.60 to 7.31 percent. Still, the size of the standard error is generally larger than this in most banding studies.

The PRB varied somewhat for the individual annual survival rates. Typically, the first and last estimates of annual survival were slightly more biased (e.g., years 1 and 9 in this study) than the estimates in the middle years of the study (e.g., years 3–7). This variation was slight and the estimates of PRB shown in Table 2 are indicative of what to expect for PRB on individual years.

The goodness of fit test for Model 1 (or Models 2 or 3) presented by Brownie et al. (op. cit.) will detect delayed reporting if it is substantial or if the sample size is large, or both. Of special interest is the fact that the tests of Model 1 vs. Model 0 (see Brownie et al., op. cit.) are quite sensitive to delayed reporting. This is indeed fortunate. If delayed reporting of recoveries is serious, the tests should indicate that Model 0 is appropriate and this model is less biased with respect to delayed reporting. The PRB for Model 0 ranged from −1.51 to 1.25 percent with most of the 36 cases studied having a slight negative bias. Of course, it is important to recall the fact that Model 1 is little biased by delayed reporting. In addition, we found Models 2 and 3 were also robust to delayed reporting.

A final remark concerns the direction of the bias. Except for Model 0 which is nearly unbiased, the other models have estimators that are slightly positively biased because of delayed reporting. In contrast, Nelson et al. (*J. Field Ornithol.,* **51:** 30–38, 1980) show that these same estimators were slightly negatively biased due to band loss. In nearly all sets of banding data we can expect some band loss and some delayed reporting of recoveries. Although we certainly cannot claim the two biases will cancel each other, it is at least satisfying that they do not magnify the overall bias.

CONCLUSION

The estimators of annual survival under Models 0, 1, 2 and 3 (Brownie et al., op. cit.) are generally robust to delayed reporting of band recoveries. If real data were analyzed under one of these models, the bias due to delayed reporting could probably be expected to be nearly negligible, especially considering the magnitude of the standard error of the estimates of annual or average annual survival. If banded samples are large and the proportion of recoveries reported a year late is large, then the tests should indicate that Model 0 is appropriate. This model is nearly unbiased with respect to problems in delayed reporting of recoveries. Finally, the direction of the bias in annual survival rate estimates is positive for most models due to delayed reporting and negative due to band loss.

Utah Cooperative Wildlife Research Unit, Utah State University, UMC 52, Logan UT 84322, and U.S. Fish and Wildlife Service, WELUT, Drake Creekside Bldg., 2625 Redwing Road, Ft. Collins, CO 80526. Received 8 November 1979, accepted 10 March 1980.