Management and Conservation Article

A Hierarchical Model for Estimating Change in American Woodcock Populations

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ABSTRACT The Singing-Ground Survey (SGS) is a primary source of information on population change for American woodcock (*Scolopax minor*). We analyzed the SGS using a hierarchical log-linear model and compared the estimates of change and annual indices of abundance to a route regression analysis of SGS data. We also grouped SGS routes into Bird Conservation Regions (BCRs) and estimated population change and annual indices using BCRs within states and provinces as strata. Based on the hierarchical model–based estimates, we concluded that woodcock populations were declining in North America between 1968 and 2006 (trend = −0.9%/yr, 95% credible interval: −1.2, −0.5). Singing-Ground Survey results are generally similar between analytical approaches, but the hierarchical model has several important advantages over the route regression. Hierarchical models better accommodate changes in survey efficiency over time and space by treating strata, years, and observers as random effects in the context of a log-linear model, providing trend estimates that are derived directly from the annual indices. We also conducted a hierarchical model analysis of woodcock data from the Christmas Bird Count and the North American Breeding Bird Survey. All surveys showed general consistency in patterns of population change, but the SGS had the shortest credible intervals. We suggest that population management and conservation planning for woodcock involving interpretation of the SGS use estimates provided by the hierarchical model. (JOURNAL OF WILDLIFE MANAGEMENT 72(1):204–214; 2008)

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Population status of the American woodcock (*Scolopax minor*) is monitored by the Singing-Ground Survey (SGS), a roadside survey coordinated by the United States Fish and Wildlife Service and the Canadian Wildlife Service. The SGS is one of several major roadside, count-based surveys that index change of bird populations in North America. Other count-based surveys include the Call-Count Survey (Sauer et al. 1994) for mourning doves (*Zenaida macroura*) and the North American Breeding Bird Survey (BBS; Sauer et al. 2003). These surveys share a common design: counts of birds are collected along roadsides without any attempt to estimate the proportion of animals missed during counts; a variety of studies have indicated that it is likely that the assumption of consistent proportion of birds counted is at least sometimes invalid (e.g., Dwyer et al. 1988).

To minimize the consequences of design deficiencies, analyses of SGS data have tended to be model based, using covariates in analyses to model factors that influence detectability of birds. Observers often differ in their ability to count woodcock, hence covariates to accommodate observer-associated differences in counts have been included in most analyses of SGS data. Analysis methods have evolved from base-year methods that estimate change from ratios of counts from comparable routes (Tautin et al. 1983), to route regression methods in which observers are treated as covariates and change is estimated by averages of route-specific regressions (Sauer and Bortner 1991), to a modified route regression in which Poisson regression with log links is used to estimate change on individual routes (Link and Sauer 1994, Kelley and Rau 2006). The route regression approach, although cumbersome, appears to provide reasonable estimates of population change (Thomas 1996, Link and Sauer 1998) and has the great advantage that it can be fit to almost any data set, no matter how unbalanced the data in terms of changes in survey locations and missing data. Criticisms of the route regression method generally attack the ad hoc nature of the weighted average used to estimate change (ter Braak et al. 1994), the lack of goodness-of-fit methods to assess when it is inappropriate, and the limited view of the population dynamics provided by a trend estimate (James et al. 1990). Methods now exist that provide a more coherent view of population change and provide new opportunities for controlling for detection of animals (e.g., Link and Sauer 2002).

Link and Sauer (2002) suggested the use of hierarchical models to estimate regional population change from count data. These models incorporate the complex structure of the data provided by count surveys, allowing analysts to explicitly incorporate model-based assumptions regarding the distribution of observer effects, stratum effects, effort, and other features over space and time. These methods have been applied to both BBS (Link and Sauer 2002) and Christmas Bird Count (CBC; Link et al. 2006) analyses and provide new opportunities for estimation of population change for species with limited data. The hierarchical model also can include spatial associations and covariates for abundance and change (Thogmartin et al. 2004) to better meet regional conservation needs.

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We applied the Link and Sauer (2002) model to estimate regional population change from SGS data, compared the results to the estimating equation-based route regression estimation methods used in earlier analyses, and extended the analysis by conducting an analysis of woodcock population change for Bird Conservation Regions (BCRs; Sauer et al. 2003). Bird Conservation Regions have become a primary geographic unit for regional bird conservation planning in the North American Bird Conservation Initiative. Summary of the survey results by BCRs is needed for regional prioritization activities, including development of the American Woodcock Conservation Plan, and for development of models that associate woodcock populations with environmental features that influence population change. Sauer et al. (2003) implemented an analysis of the BBS within BCRs by using the intersection of states or provinces and BCRs as the strata for analysis. Results of these stratum-level analyses can be aggregated for inference about either BCRs or states and provinces. We implemented a similar analysis for the SGS and documented the consequences of implementing the hierarchical analysis using state or provinces and strata relative to using BCRs within states or provinces as strata.

The CBC (Link et al. 2006) and the BBS (Sauer et al. 2003) collect woodcock data, but analyses of woodcock data from these surveys has been controversial (Straw et al. 1994) due to limitations imposed by survey protocols and timing. However, it is of interest to determine whether patterns of population change are similar among surveys. Comparisons of survey results do not provide insights into which (if any) survey is providing unbiased estimates when results differ among surveys (Sauer et al. 1994), but systematic differences between roadside and nonroadside results would be reflected in consistent differences between CBC and SGS or BBS results. We compared the results of the SGS at the survey-wide scale with continent-scale population changes estimated from the CBC (Link et al. 2006) and the BBS (Link and Sauer 2002) using hierarchical models similar to those applied to the SGS.

STUDY AREA

The SGS and BBS provided information from most of the breeding range of the American woodcock. The SGS was conducted in 25 states and provinces, grouped into Eastern and Central Management Units that were coincident with administrative Flyways. The BBS provided information for a similar region, although we noted that neither the SGS nor the BBS provided information from the northern portions of Quebec and Ontario, Canada. The CBC survey area included the wintering range of woodcock in the central and southern United States.

METHODS

The Singing-Ground Survey

The SGS is based on roadside surveys conducted once each year during early spring, timed to permit counting after woodcock migration has occurred but while courtship is still occurring. Routes contain 10 counting stops along a 5.4-km segment of secondary roads, at which an observer records all woodcock heard during a 2-minute count period during twilight. The SGS was begun in its present form in 1968, although surveys have not been conducted in all years in some of the states and provinces. To maximize efficiency, not all routes are run each year, and some routes are only occasionally surveyed (Sauer and Bortner 1991).

Analysis Methods

Estimating equation trend analysis and residual indices.—In the analysis of SGS data presently used for setting harvest regulations, Poisson regressions with log links are used to estimate rates of change for individual survey routes (Kelley and Rau 2006). Observer effects are included, allowing a different intercept for each observer in the analysis (Link and Sauer 1994). Change for a region is estimated as an average of the route slopes, in which the route-specific slopes are weighted by mean abundance of woodcock on the route and by a route-specific measure of survey consistency (a variance wt; Link and Sauer 1994). For management unit estimates, an additional area weight is included to accommodate regional differences in sampling. Variances of these trend estimates are estimated by bootstrapping. See Geissler and Sauer (1990) and Link and Sauer (1994) for additional information about the route regression method and the weights.

Residual indices are an approach for displaying year-to-year variation around an estimated regional trend. We estimated observer effects on each route after subtracting the effect of the regional trend from the yearly count. We then estimated the residual distance from the yearly counts and the trend and observer-adjusted predicted counts and averaged these residuals by year for all routes in the region. We then added these yearly average residuals to a regional predicted trajectory for the year, which we estimated by projecting the estimated regional yearly trend from the regional mean count for the midyear of the survey. For a complete method description, see Sauer and Geissler (1990).

To assess continuity with historical analysis methods, we conducted an estimating equations analysis of trends and annual indices by state or province and management units for the period 1968–2006 and present these results for comparison with hierarchical model results.

Hierarchical log-linear model.—Hierarchical models provide a means for directly estimating regional population change from the SGS. In hierarchical models, factors are not governed by fixed parameters. Instead, distributions of attributes such as year, stratum, and observer effects at the level of states (or other strata) are conditional on parameters that are also random variables. This hierarchical formulation permits us to specify how attributes such as population change are distributed over large regions that are divided into strata and allows us to make statements about the regional collections of population attributes such as trends and abundances that are based on the underlying regional parameters, not on the region-specific estimates. We modeled the influence of regions, observers, and other factors on the distributions of the parameters influencing counts, rather than on the counts themselves. This eliminates the need for ad hoc procedures for accommodating regional differences in precision of counts in summary analyses. This approach to modeling, and its value for analysis of bird populations, is discussed in Link and Sauer (2002).

Hierarchical models are generally fit using Bayesian methods, in which inference is based on the distributions of parameters conditional on the data (the posterior distributions). A Bayesian analysis requires that both the prior distributions of parameters and the sampling distribution of the data conditional on the parameters be specified. From these distributions, the posterior distribution can be found through integration (a difficult computation for most problems of interest), or through a simulation approach known as the Markov chain Monte Carlo method (MCMC; Gilks et al. 1996). The MCMC methods use first-order Markov chains simulated based on partially specified versions of the posterior distributions, allowing approximation of the distribution; sample mean, variance, and percentiles, when appropriately drawn from the simulations, approximate the true mean, variance, and percentiles.

The hierarchical model is an overdispersed Poisson regression with fixed and random effects. Counts $Y_{i,j,t}$ (i indexes stratum, j for unique combinations of route and observer, and t for yr) are independent Poisson random variables with means $\lambda_{i,j,t}$ that are described by log-linear functions of explanatory variables,

$$\log(\lambda_{i,j,t}) = S_i + \beta_i(t - t^*) + \omega_j + \gamma_{i,t} + \eta I(j,t) + \varepsilon_{i,j,t} \tag{1}$$

stratum-specific intercepts (S), slopes (β), and effects for observer–route combinations (ω), year (γ), start-up [η; $I(j,t)$ is an indicator for first year of survey for an observer], and overdispersion (ε). t^* is a baseline year (set to 19) from which change is measured. See Link and Sauer (2002) for discussion of the role of parameters and hyperparameters in Bayesian analyses. Hyperparameters S_i and β_i are given diffuse (essentially flat) normal distributions. Other effects had mean zero normal distributions, but observer-route effects were identically distributed, all having the same variance σ^2_ω; overdispersion effects (ε) were identically distributed with common variance σ^2_ε; and we allowed variance of the year effects (γ) to vary among strata ($\sigma^2_{\gamma,i}$). We assumed all these variances to have flat inverse gamma distributions.

Combining information among regions.—Stratum-specific annual indices of abundance are the year effects, scaled by the stratum and trend effects:

$$n_{i,t} = \exp[S_i + \beta_i(t - t^*) + \gamma_{i,t} + 0.5\sigma^2_\omega + 0.5\sigma^2_\varepsilon] \tag{2}$$

$n_{i,t}$ is an index to the number of birds per route in stratum i at year t (Link and Sauer 2002). Variance components are added to accommodate asymmetries in the log-normal distribution. Stratum indexes are $N_{i,t} = A_i n_{i,t}$, where A_i is the area of the stratum, and we defined composite indices for collections of strata as sums of $N_{i,t}$ divided by the total areas. Because the n are not area-specific population estimates, we did not present the $N_{i,t}$ as population totals; they are simply a weighted total of the route indexes. We defined trend as an interval-specific geometric mean of proportional changes in population size, expressed as a percentage (cf., Link and Sauer 1998). Thus the trend from year t_a to year t_b for stratum i is $100(B_i - 1)\%$, where

$$B_i = \left(\frac{n_{i,t_b}}{n_{i,t_a}}\right)^{\frac{1}{t_b - t_a}} \tag{3}$$

The composite trend $\overline{B}$ is calculated analogously as $100(\overline{B} - 1)\%$, using the composite indices $N_t = \sum_i N_{i,t}$, to calculate

$$\overline{B} = \left(\frac{N_{t_b}}{N_{t_a}}\right)^{\frac{1}{t_b - t_a}} \tag{4}$$

For presentation and comparison with residual index year effects, we scaled the composite indices N_t by the total area, obtaining a summary on the scale of birds per route.

Logistics of Analyses

Fitting the hierarchical model.—We used the program WinBUGS (Spiegelhalter et al. 1995) to fit this model for states and strata. WinBUGS is a user-friendly program for analysis of hierarchical models and contains a variety of model diagnostics to assess stability of the estimates (Link and Sauer 2002). The program conducts the MCMC analysis, presents summary statistics to allow users to determine when the Markov chains become stationary, and summarizes results based on the MCMC replicates. It also allows users to define and estimate derived parameters (such as the composite indices) and their variances and output the MCMC replicates for additional summaries. From the replicates, both estimates and credible intervals can be calculated.

Scales of summary.—Historically, SGS trend and annual indices were estimated at the scale of states or provinces, flyway-based Eastern and Central regions, and survey-wide. Consequently, we first conducted the hierarchical model analysis using states and provinces as the fundamental strata for comparison with historical results (the hierarchical state or province analysis).

We also used SGS data to estimate woodcock population change at the scale of BCRs. Because SGS routes have historically been administered and stratified within states and provinces, we retained the political units as a component of the stratification but redefined "strata" in the second analysis as the 55 regions formed by the intersection of BCRs and states or provinces (i.e., the strata are the BCRs within each state and province). Results from these strata can be aggregated within states or provinces and also can be aggregated within BCRs or larger regions. Hereafter, we call this analysis the hierarchical-BCR analysis.

Summary data for the survey.—The SGS differs greatly in consistency of information over its range, and these differences affect the quality of the estimates of population change. To summarize survey consistency for states, provinces, and BCRs, we calculated total number of routes, mean number of routes surveyed each year, the mean number of years routes were surveyed, and the mean duration (span of yr) of routes in each region. Duration of routes indicates the portion of the interval covered by an average route.

Christmas Bird Count Analysis

The CBC is coordinated by the National Audubon Society. Bird observations are collected by variable numbers of volunteer observers on a selected day in mid-late December within predefined 24.13-km (15-mile) diameter circles. See Link et al. (2006) for information regarding the design and analysis of the CBC. To apply a hierarchical log-linear model used for the SGS to the CBC, model components must be added to accommodate variation in participation (no. of counters) and the methods of data collection among circles and through time. Consequently, the CBC model includes an additional component, a stratum-specific effect of effort $B_i\ (\xi_{i,j,t}{}^{p_i} - 1)/p_i$ (Link et al. 2006; B_i is the coeff. relating transformed effort to counts, $\xi_{i,j,t}$ is the scaled effort for circle j in stratum i at time t, and p_i is the exponent that defines the shape of the effort relationship). Effort values are scaled to an overall mean. If the effort expended in producing count $Y_{i,j,t}$ is equal to the overall mean, then $\xi_{i,j,t} = 1$, and the effort effect is zero. Effort parameters p_i and B_i are normally distributed with means μ_p and μ_B and variances τ_p and τ_B; the means and variances are fixed effects. We used standard noninformative priors; for μ_p, we used a uniform prior on the interval $[-4, 4]$ (Link et al. 2006). As our goal in this analysis was to provide a comparative time series from CBC data, we do not present regional summaries or evaluation of effects of effort in this report. We used all CBC data for woodcock collected between the 1965 CBC (the 66th yr of the count) and the 2003 count (the 104th count) and conducted the analysis using BCRs within states as strata, compositing results as described in Link et al. (2006) to form survey-wide results.

North American Breeding Bird Survey Analysis

The BBS is an extensive roadside survey of breeding birds, conducted in June along 4,000 roadside survey routes. Unfortunately, the 50 3-minute counts are collected early in the morning along the routes, and few woodcock are encountered on the survey. Although observed on 572 routes over the survey interval, the mean abundance on routes in the analysis is 0.03 woodcock per route within the woodcock's range, indicating that the species is only observed occasionally. The formal description of the hierarchical model for BBS data is given in Link and Sauer (2002). We applied the hierarchical model to estimate population change for the species, using BCRs within states and provinces as strata. We only present regional estimates for comparison with other survey results.

RESULTS

Singing-Ground Survey Analysis

We estimated population trajectories for 25 states and provinces, for 12 BCRs, for Eastern and Central Management Units, and for the entire surveyed area. The number of survey routes varied greatly among states (Table 1), ranging from 3 (DE and RI) to 153 (MI). Overall, we used data from 1,232 routes in the analysis. For the hierarchical model analyses, results were based on 10,000 simulations after a burn-in (initial iterations to allow simulations to stabilize) of 40,000–90,000 iterations. We assessed stability of results from observation of graphs of results and autocorrelations. Comparison of Markov chain error with standard deviations suggested that convergence had occurred (i.e., the Markov chain error estimated from binned estimates of the replicates is generally $<5\%$ of the SDs [Spiegelhalter et al. 1995]; for the trend estimates of states and provinces the Markov chain errors were 2.8% of the SDs). The hierarchical analysis was based on 28,754 counts conducted by 7,290 observers in 55 BCR-state or BCR-province units within the 25 states and provinces.

Regions vary greatly in the consistency of information (Table 1). In Manitoba, Canada, the survey was initiated in 1992, hence the number of years of survey and duration of survey are much lower than other regions; thus estimates of long-term change from Manitoba have low credibility. Of the states and provinces providing data from the entire survey interval (1968–2006), Illinois, USA, and Quebec, Canada, both had mean number of years <10 surveyed per route, and Quebec also had mean range of <20 years covered for the survey interval (Table 1). Many regions also experienced a large amount of turnover of observers of survey routes, with Delaware having 8 observers surveying an average route over the interval. We summarize attributes of some early surveys in North Carolina, USA ($N = 16$), which we did not include in the analysis.

In conducting summary analyses for BCRs, it was evident that few data exist at the northern edge of the survey region. In particular, only the southern edge of the Boreal Softwood Shield was sampled in either province, and only 21 routes were surveyed in this BCR (Table 1). Because the historical analysis only covered the areas actually surveyed in the provincial-level summary of the SGS, this Boreal Softwood Shield cannot be considered a part of the area sampled by the SGS. Although we present estimates for the region, we follow the historic precedent and do not include it from our regional summaries in the hierarchical-BCR analyses. We also note that 5 routes in the Boreal Taiga Plains in Manitoba were also surveyed.

Trend estimates.—Trends (yearly % changes) for states and the Eastern, Central, and survey-wide summary regions estimated over 1968–2006 (Table 2) were very consistent between the 2 hierarchical modeling approaches. Estimating equation trends tended to be larger in magnitude (21/25 states and provinces, based on state or province strata) and more variable (CI width larger in 20/25 states and provinces) than trends based on hierarchical models.

Table 1. Summary by Bird Conservation Region (BCR), state, and provinces of Singing-Ground Survey data used in the hierarchical model analysis, 1968–2006. Sample sizes, mean number of years of survey on each route, mean number of observers that surveyed each route, and mean range of years of coverage for routes are presented for each region.

BCR, state, or province	No. routes	No. yr	SE	No. observers	SE	Mean of range	SE
Boreal Taiga Plains	5	7.2	0.92	2.4	0.24	13.6	0.51
Boreal Softwood Shield	21	10.6	1.23	4.3	0.54	17.1	1.49
Prairie Potholes	16	10.8	1.59	4.3	0.69	22.4	3.20
Boreal Hardwood Transition	292	24.9	0.61	5.5	0.16	31.1	0.59
Lower Great Lakes–St. Lawrence Plain	161	20.6	0.78	5.4	0.22	30.7	0.79
Atlantic Northern Forest	290	24.2	0.60	5.3	0.14	32.4	0.49
Eastern Tallgrass Prairie	95	11.7	0.62	4.5	0.18	28.6	0.93
Prairie Hardwood Transition	165	21.9	0.76	6.3	0.19	34.5	0.50
Central Hardwoods	35	12.7	0.76	5.5	0.31	32.1	1.12
Southeastern Coastal Plain	13	11.8	1.77	3.9	0.42	29.8	3.20
Appalachian Mountains	200	17.2	0.54	4.3	0.12	32.9	0.51
Piedmont	41	13.3	1.01	4.2	0.35	30.4	1.54
New England–Mid-Atlantic Coast	72	19.8	0.96	5.4	0.29	32.6	0.87
CT	10	20.6	3.34	6.1	0.71	35.0	1.06
DE	3	19.3	6.36	8.0	2.08	32.3	4.41
IL	42	9.3	0.49	4.9	0.26	25.3	1.31
IN	56	14.2	0.80	5.3	0.23	32.9	0.92
ME	67	28.6	1.02	5.4	0.25	36.0	0.76
MB	25	7.8	0.62	2.1	0.15	11.4	0.59
MD	25	16.6	1.45	6.2	0.41	32.2	2.01
MA	24	21.8	1.73	4.7	0.50	30.2	2.02
MI	153	27.4	0.78	6.2	0.21	33.5	0.73
MN	119	20.6	0.91	5.3	0.26	31.3	0.77
NB	66	26.8	1.22	6.0	0.33	32.0	1.06
NH	18	29.1	1.66	6.3	0.50	37.3	0.32
NJ	18	18.4	1.88	3.9	0.37	28.6	2.31
NY	117	21.8	0.86	4.9	0.19	32.6	0.88
NC	16	4.2	0.23	2.4	0.26	4.3	0.24
NS	68	19.0	1.26	4.4	0.28	28.7	1.29
OH	72	17.0	0.98	4.5	0.20	33.1	0.77
ON	146	19.3	0.82	5.7	0.27	26.6	0.86
PA	75	15.3	0.86	4.0	0.21	30.8	1.25
PE	13	25.5	2.50	5.5	0.51	30.5	2.56
PQ	60	8.6	0.69	2.9	0.24	17.3	1.41
RI	3	14.3	3.48	3.0	1.00	37.0	0.58
VT	22	29.5	1.57	6.3	0.46	36.8	0.40
VA	72	13.2	0.70	4.1	0.19	32.2	0.90
WV	54	17.4	1.12	4.1	0.23	32.4	0.94
WI	116	23.9	0.93	6.0	0.20	35.5	0.58

Estimates from states or provinces with small sample sizes (CT, DE, RI) tended to be quite different between hierarchical and route regression methods, but with large confidence and credible intervals, reflecting the low quality of the estimates. However, several other states were also poorly estimated (NJ, MA, IL, OH) in the estimating equation results. Note that hierarchical structure, by assuming that trend parameters are random effects varying among strata, results in fewer extreme estimates, a clear benefit of a hierarchical analysis (Link and Sauer 2002). At the regional scale, precision does not consistently vary among analyses, although the hierarchical model estimates from the state–province analysis are always most precise.

Aside from differences in magnitude of trend and size of confidence (or credible) intervals among analyses, patterns of population change from the hierarchical models were similar to historical analyses. Woodcock populations are declining range-wide; a primary distinction between analyses is the consequence of partitioning Quebec and Ontario into BCR units, leading to changes in size of credible intervals in both the provinces and the regional results. Bird Conservation Regions results (Table 3) suggested declining populations in the eastern portions of the range and imprecisely estimated trends in the northern and southwestern parts of the woodcock range. We present results for the Boreal Softwood Shield, although we caution (as noted above) that coverage only extends to the southern portion of the BCR.

Population annual indices.—We present population annual indices for selected states and provinces in the Eastern (Fig. 1) and Central (Fig. 2) Regions, as well as in the larger regions (Fig. 3). Precision of indices can only be estimated for the hierarchical model–based estimates and are reflected by the credible intervals around the hierarchical analyses. Because trends were defined as the ratios of the population indices in the hierarchical models, description of change and its precision was simple to calculate for any interval.

Because the relative abundance scaling (i.e., the level of the time series) is based on slightly different values (the residual index value is scaled to the relative abundance in the midyear

Table 2. Estimated population trends (% change/yr) for 1968–2006 for 3 analyses of American woodcock population data from the Singing-Ground Survey. A hierarchical Bird Conservation Region (BCR) analysis, a hierarchical BCR state or province analysis, and an Estimating Equations analysis are presented. We present estimated trends, credible intervals (2.5 and 97.5 percentile) for the hierarchical model analyses, and confidence intervals for the estimating equations analysis.

	Hierarchical model								
	State or provincial scale			BCR within state or province scale			Estimating equations		
		Credible interval			Credible interval			CI	
Region	**Trend**	**2.5%**	**97.5%**	**Trend**	**2.5%**	**97.5%**	**Trend**	**2.5%**	**97.5%**
CT	−4.4	−6.7	−2.1	−5.0	−7.1	−2.6	−10.4	−18.4	−2.5
DE	−1.0	−7.4	5.2	−0.5	−6.8	5.6	2.9	−10.7	16.4
ME	−1.3	−2.0	−0.6	−1.2	−1.9	−0.6	−1.9	−2.9	−1.0
MD	−4.0	−5.7	−2.3	−4.3	−6.1	−2.4	−9.7	−18.2	−1.2
MA	−2.4	−3.5	−1.1	−2.1	−3.6	−0.4	−4.6	−9.5	0.2
NB	−0.9	−1.9	0.2	−0.9	−2.0	0.2	−0.5	−1.8	0.8
NH	0.0	−1.2	1.3	−0.2	−1.5	1.1	1.2	−1.3	3.7
NJ	−6.2	−7.9	−4.3	−5.8	−7.5	−3.5	−8.9	−11.2	−6.6
NY	−1.4	−2.0	−0.9	−1.5	−2.0	−0.9	−2.5	−3.7	−1.2
NS	−1.1	−2.1	−0.2	−1.1	−2.1	−0.2	−0.2	−2.0	1.6
PA	−1.7	−2.6	−0.8	−1.2	−2.2	−0.1	−3.4	−5.7	−1.1
PE	−1.4	−3.1	0.3	−1.5	−3.1	0.3	−1.6	−3.7	0.4
PQ	0.3	−1.2	1.7	0.3	−2.6	3.7	−1.3	−5.0	2.3
RI	−11.6	−17.8	−6.1	−11.6	−17.7	−5.8	−16.3	−25.4	−7.2
VT	−0.3	−1.6	1.0	−1.0	−2.2	0.3	−0.7	−2.7	1.2
VA	−5.3	−6.5	−4.1	−4.4	−5.8	−2.9	−11.1	−15.6	−6.6
WV	−2.8	−3.8	−1.9	−2.9	−3.9	−1.9	−2.7	−4.4	−0.9
Eastern	−0.9	−1.4	−0.4	−0.8	−1.5	0.3	−1.9	−2.5	−1.3
IL	3.1	0.1	6.4	2.6	−0.4	6.1	24.5	−13.2	62.3
IN	−4.2	−5.9	−2.7	−4.0	−5.6	−2.4	−7.1	−13.1	−1.0
MB	−3.5	−6.6	−0.4	−6.1	−12.7	5.6	−2.4	−6.1	1.4
MI	−1.1	−1.5	−0.6	−0.9	−1.7	0.0	−1.7	−2.6	−0.7
MN	0.0	−0.7	0.7	0.1	−0.7	1.0	−1.0	−2.0	0.0
OH	−2.0	−2.9	−1.1	−2.0	−2.9	−1.1	−6.2	−9.6	−2.8
ON	−0.8	−1.4	0.0	1.0	−0.6	2.8	−1.9	−2.8	−1.0
WI	−0.8	−1.4	−0.2	−0.9	−1.5	−0.3	−1.9	−2.7	−1.1
Central	−0.9	−1.3	−0.6	−0.7	−1.1	−0.3	−1.8	−2.3	−1.3
Survey	−0.9	−1.2	−0.5	−0.7	−1.1	−0.2	−1.9	−2.3	−1.5

of the survey; the hierarchical model yr effects are scaled by estimated stratum effects in the context of the model), time series tended to be scaled to different levels. We note that, generally, the pattern of population change as estimated by hierarchical models and estimating equations were very similar (e.g., NB, Fig. 1; MI, Fig. 2). Regions with inconsistent coverage or small samples (e.g., CT, PQ, Fig. 1; IL, Fig. 2) tended to show larger differences in magnitude of year-to-year changes between the residual indices and the hierarchical model–based indices. Hierarchical model indices were similar except in Ontario and Quebec, where the large areas associated with each BCR influenced the overall level of the composite index. State and regional indices reflected the slightly higher magnitudes of declines from the route regression trend indices; extreme yet imprecise trend estimates in the route regression method tended to have residual indices that suggested large population changes. In contrast, hierarchical model indices suggested more moderate population change.

Table 3. Estimated population trends (yearly % change) of American woodcock for 1968–2006, based on the hierarchical Bird Conservation Region state or province analysis. We present trend and credible intervals.

			Credible interval	
BCR	**No.**	**Trend**	**2.50%**	**97.50%**
Boreal Softwood Shield	8	−5.0	−7.1	−2.6
Prairie Potholes	11	−0.5	−6.8	5.6
Boreal Hardwood Transition	12	−1.2	−1.9	−0.6
Lower Great Lakes–St. Lawrence Plain	13	−4.3	−6.1	−2.4
Atlantic Northern Forest	14	−2.1	−3.6	−0.4
Eastern Tallgrass Prairie	22	−0.9	−2.0	0.2
Prairie Hardwood Transition	23	−0.2	−1.5	1.1
Central Hardwoods	24	−5.8	−7.5	−3.5
Southeastern Coastal Plain	27	−1.5	−2.0	−0.9
Appalachian Mountains	28	−1.1	−2.1	−0.1
Piedmont	29	−1.2	−2.2	−0.1
New England–Mid-Atlantic Coast	30	−1.5	−3.1	0.34

Population annual indices and credible intervals from each BCR documented regional variation in precision of indices (as shown by width of band formed by the CIs) and also showed the regional patterns in population change (Fig. 4). Boreal Softwood Shield results were based on one route (in ON) prior to 1973, and small numbers of routes were added incrementally until 1995 when the maximum number (21) was attained. Consequently, credible intervals are very large

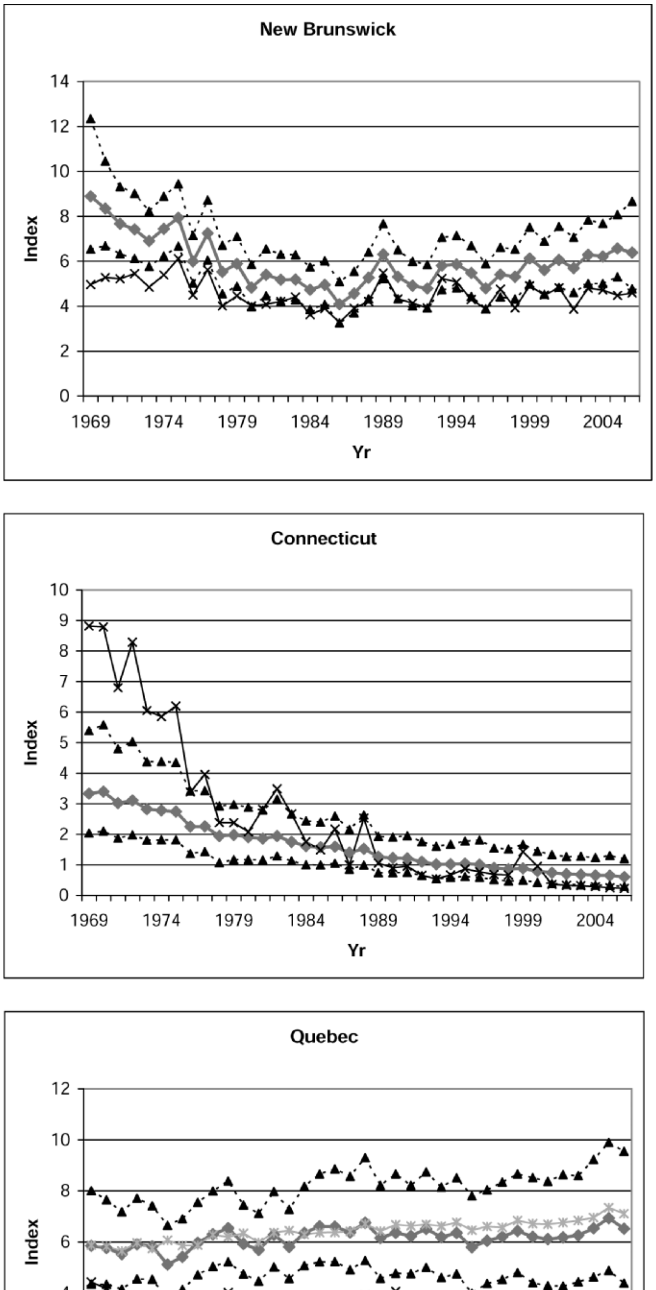


Figure 1. Annual indices of American woodcock populations in New Brunswick, Canada; Connecticut, USA; and Quebec, Canada, based on data from the Singing-Ground Survey, 1968–2006. Results are presented for a hierarchical model analyses, conducted using state-provincial strata (⧫), (with 95% credible intervals ▲); a hierarchical model analysis using Bird Conservation Regions as strata (*, Quebec only), and for a residual index analyses using state-provincial strata (x).

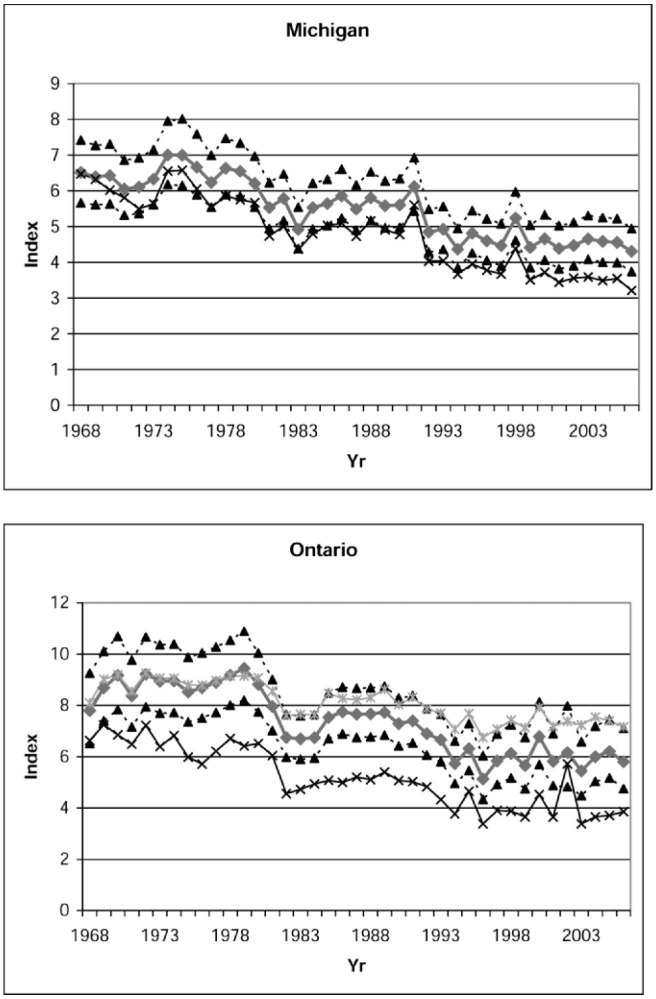


Figure 2. Annual indices of American woodcock populations in Michigan, USA, and Ontario, Canada, from a hierarchical analysis of Singing-Ground Survey data, 1968–2006, using state-provincial strata (⧫), their 95% credible intervals (▲), from a hierarchical analysis using Bird Conservation Regions as strata (*), and for a residual index analysis using state-provincial strata (x).

in the early years and are not displayed in Figure 4. The Prairie Pothole BCR also has imprecise estimates in early years. It is largely peripheral to the survey, and is only represented prior to 1992 by 10 routes in Minnesota, USA, that were initiated between 1969 and 1980. Other BCR estimates portray more precise views of population change, consistent with the increased precision of the estimated trends (Table 3).

Comparative Survey Analysis

Although year-to-year changes were often inconsistent between SGS (state or province), CBC, and BBS continental-scale analyses of woodcock population changes, overall patterns of population change were quite consistent among surveys (Fig. 5). Estimated population change over the intervals for the CBC (interval: 1965–2003; trend: –1.8%/yr; 95% CI: –2.8, –0.9) and the BBS (interval: 1966–2005; trend: –1.5%/yr, 95% CI: –2.8, –0.2) show declining populations but have larger credible intervals than the SGS estimates (interval: 1968–2006; trend: –0.9%/yr, 95% CI: –1.2, –0.5). Note that the scaled indices were large for both the CBC and the BBS in 1965–1966 (Fig. 5).

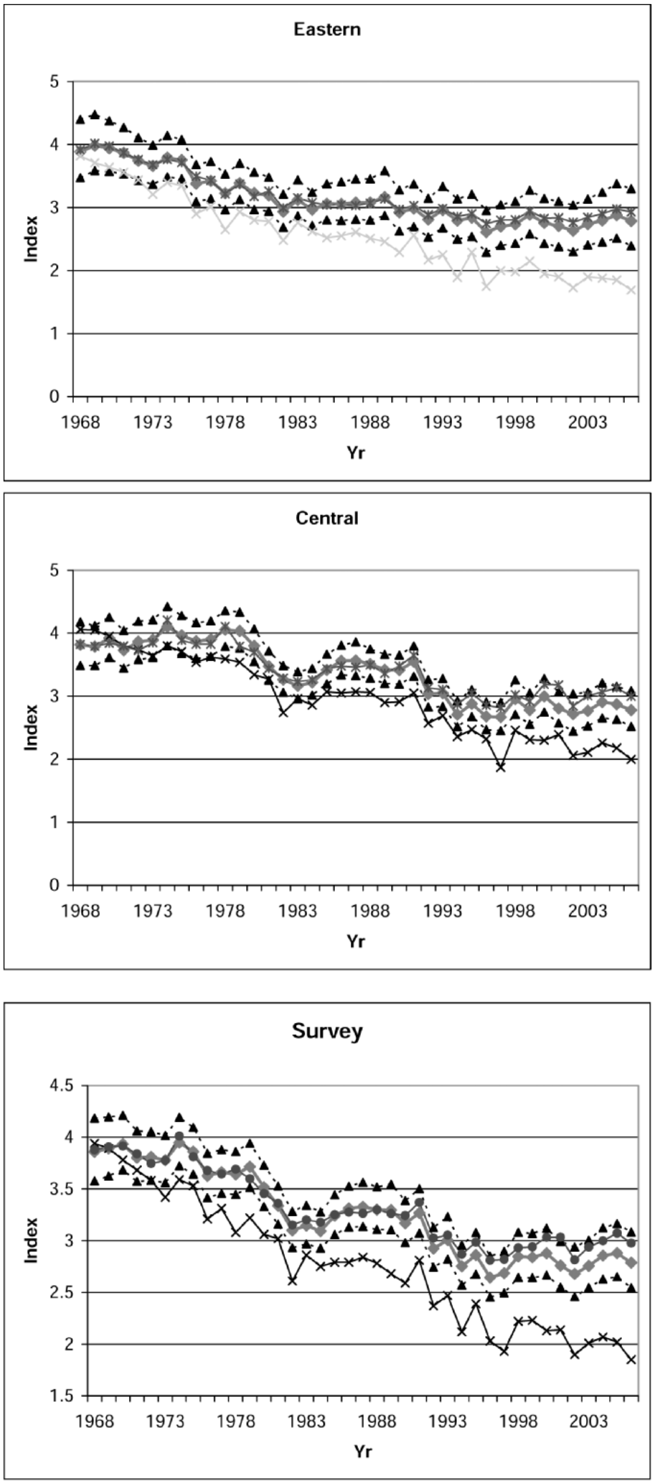


Figure 3. Composite annual indices of American woodcock for the Eastern and Central Management Units and the entire survey area based on Singing-Ground Survey data, 1968–2006, from a hierarchical state-provincial analysis (♦) with 95% credible intervals (▲), from a hierarchical-BCR analysis (*), and from residual indices (x).

DISCUSSION

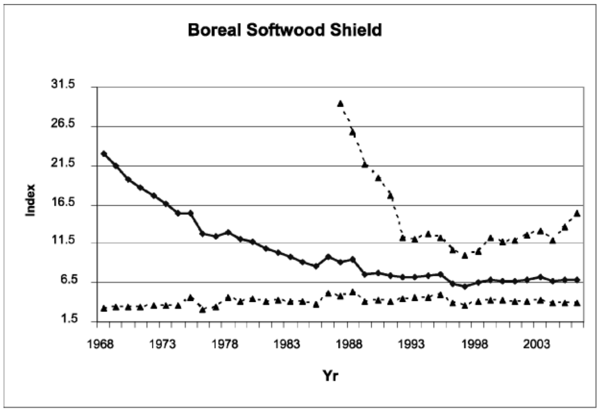
American woodcock populations are declining in North America, and SGS results are consistent with other survey results in documenting this decline. Our analysis does not justify speculation about causes of regional declines; we refer readers to the American Woodcock Conservation Plan (J. R. Kelley, United States Fish and Wildlife Service, unpublished document) for information regarding possible causal factors influencing the declines, particularly changes in amounts of successional habitats.

Using Hierarchical Log-Linear Models for SGS Analyses

Our analysis of SGS data using historical methods and the hierarchical log-linear model indicates several benefits associated with the hierarchical models. First, estimation is generally more efficient, providing smaller credible intervals for estimates of trend in most states and provinces. The quality of information varies greatly among strata, and the hierarchical model permits information from the collection of regions to inform the estimation both for each region and for the composite estimates. This use of information from the ensemble to improve individual estimates is a well-known phenomenon (Efron and Morris 1977). Second, the model allows direct estimation of population trend (interval-specific change) from composite annual indices, unlike the 2-step process used in earlier analyses of SGS data. Third, credible intervals can be estimated directly for the annual indices as part of the analysis. Although extremely computer-intensive, computer programs are now readily available for estimation of hierarchical models using MCMC methods (e.g. Speigelhalter et al. 1995 and other programs cited therein).

A referee suggested that a negative binomial distribution would be an alternative to the Poisson log-normal mixture distribution to model counts in the analysis (e.g., White and Bennetts 1996). In our view, there is no compelling statistical reason for preferring one over the other. The marginal distribution of the Poisson-gamma model (i.e., negative binomial) can be written down in closed form, which is useful if one chooses to use maximum likelihood as a means for model fitting. However, when using Bayesian methods for model fitting, the Poisson log-normal model is easier to use, as it has both a natural hierarchical structure and natural hyperprior distributions. Aside from these operational considerations, we also note that the models are extremely similar. Both are overdispersed relative to the Poisson, with the overdispersion induced by a random mean governed by a 2-parameter distribution. In many cases, the log-normal and gamma distributions are virtually indistinguishable, hence the Poisson mixed versions will be even less distinguishable. It is quite unlikely that inference will be affected by the choice. To illustrate this, we fit an overdispersed Poisson log-normal distribution with mean $= 5$ and variance $= 25$, along with the closest approximating negative binomial. The Kullback–Leibler distance (Burnham and Anderson 1998) is very small (approx. 0.01). Consequently, it would be difficult to distinguish the 2 distributions without a very large sample size.

Use of hierarchical models to estimate population change from count surveys avoids many of the ad hoc aspects of the route regression analysis. The route regression method has


Boreal Softwood Shield
31.5
26.5
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Index
1968
1973
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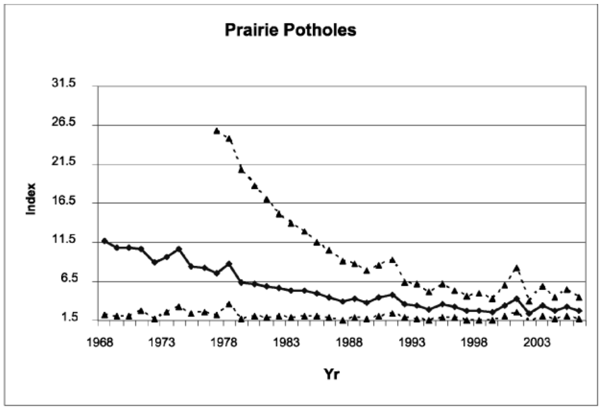
Prairie Potholes
31.5
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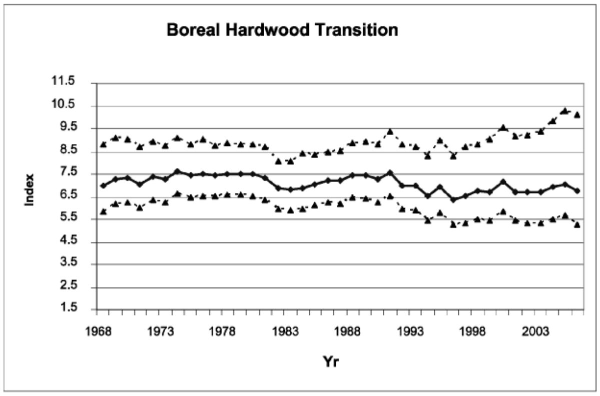
Boreal Hardwood Transition
11.5
10.5
9.5
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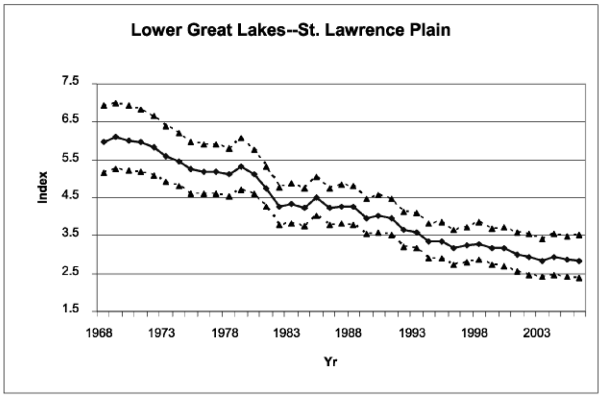
Lower Great Lakes--St. Lawrence Plain
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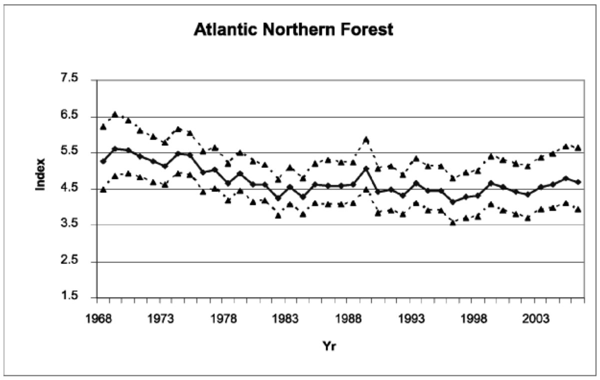
Atlantic Northern Forest
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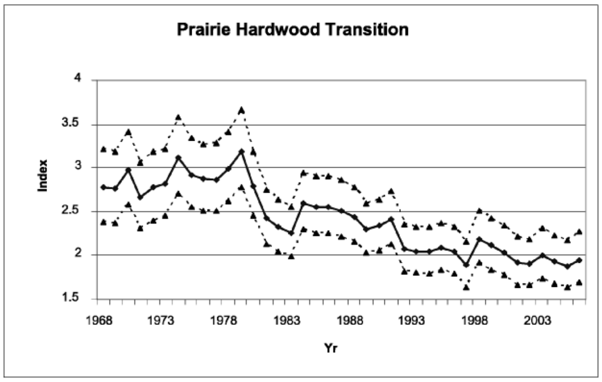
Prairie Hardwood Transition
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Index
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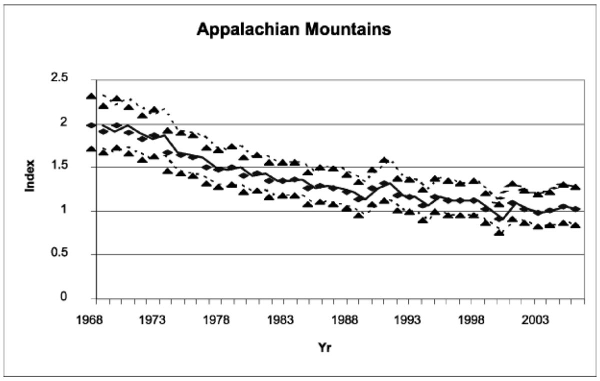
Appalachian Mountains
2.5
2
1.5
1
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Index
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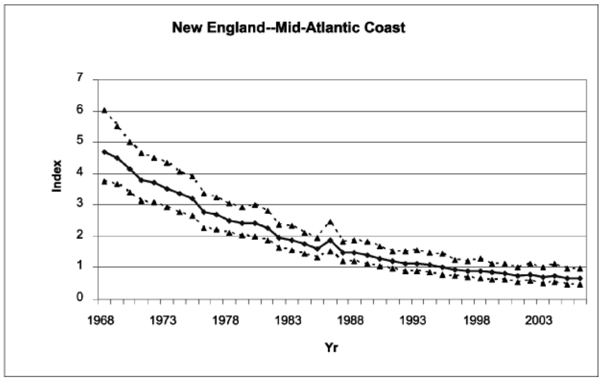
New England--Mid-Atlantic Coast
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Index
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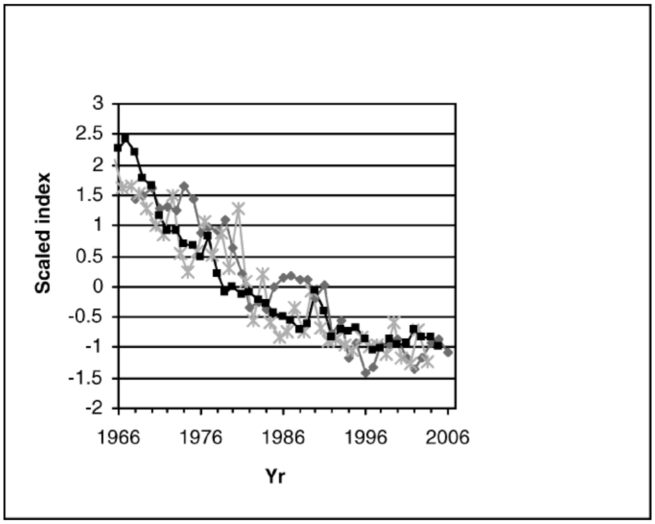

Figure 5. Comparative analysis of population change in continental American woodcock populations as surveyed by the Singing-Ground Survey (♦), Christmas Bird Count (*), and North American Breeding Bird Survey (■). Indices have been standardized by subtracting the mean of the time series from each observation and dividing the difference by the standard deviation of the time series.

been widely used because it provides a means for estimating trend for complicated data sets that are often missing years and require covariates. The route estimates can be easily calculated then combined using abundance, relative precision, and area weights to form aggregate estimates at any geographic scale. Unfortunately, this flexibility has a cost, in that it is often unclear how data within the interval of interest is used in the aggregation. Abundance and precision quantities used in the procedure are also controversial, as they are only proportional to the actual quantities of interest, and estimation of variances require use of bootstrapping procedures (ter Braak et al. 1994, see Sauer et al. 2003 for a discussion of route-weighting). In the hierarchical model analysis, the state or provincial year effects are estimated at the stratum level, and trend and regional estimates are summarized from these year effect models. This approach simplifies the overall analysis, eliminates possible inconsistencies associated with distinct trend and annual index estimation procedures, and provides a better theoretical basis for estimation of regional population change.

For the SGS analysis, hierarchical model–based year effects are similar in pattern to the residual method estimates. Consequently, the results provided by earlier management summaries of SGS data (e.g., Kelley and Rau 2006) are consistent with results from new methods. However, hierarchical model approaches have several important advantages relative to the residual index method. Specification of a model that incorporates overdispersion and other random effects allows estimation of variances and covariances for the year effects. These estimates can be displayed around the time series, allowing users to ascertain the significance of population fluctuations. From these estimates, reduced models such as trend can be directly estimated from the year effects for any subinterval, eliminating the possibility of inconsistencies between trend estimates and patterns in the annual indices. The models also can be extended to incorporate covariates at the scale of survey routes, allowing for modeling of effects of habitats and other environmental features on SGS counts, and these more complex models can be compared to the basic model presented here. Due to limited availability of covariate information across the range of the SGS, we did not construct more complicated models to compare with the basic model.

Unfortunately, uncertainties remain with regard to the value of information collected in the SGS. We cannot directly address the question of biased estimation associated with roadside sampling, and the possibility exists that other factors (such as traffic noise) have had differential effects on observers' ability to hear birds over time. The hierarchical models described here permit several opportunities for modeling and controlling for these factors. Covariate analyses, although model-based, can increase our understanding of roadside habitat changes, if habitat information are associated with routes and introduced as explanatory variables in the analyses. Thogmartin et al. (2007) have used SGS data in spatial hierarchical models, and these approaches allow us to partially address some of the concerns about roadside surveys. However, collection of direct data on factors influencing counting (e.g., Dwyer et al. 1988) in combination with modeling exercises is likely the most effective way of increasing our understanding of how best to sample and model bird populations (Sauer et al. 2003).

Analysis for Bird Conservation Regions

Analysis of the SGS data for BCRs highlights the limited information from the northern edge of the survey range. In earlier analyses, estimates have been provided for Ontario and Quebec, and integrated into overall survey results without a clear documentation of the coverage of the survey. However, the area weights used in the analysis clearly indicate that the biologists who designed the survey did not include the Boreal Softwood Shield. Our analysis of BCRs has clarified the northern edge of the survey, and documented the limited information associated with the Boreal Softwood Shield and other peripheral BCRs such as the Prairie Potholes. Within the survey area, however, woodcock appear to be well-surveyed in several BCRs.

←

Figure 4. Composite annual indices 1968–2006 of American woodcock populations from a hierarchical analysis of Singing-Ground Survey data (♦) and their 95% credible intervals (▲) in Boreal Softwood Shield, Prairie Potholes, Boreal Hardwood Transition, Lower Great Lakes–St. Lawrence Plain, Atlantic Northern Forest, Prairie Hardwood Transition, Appalachian Mountains, and New England–Mid-Atlantic Coast Bird Conservation Regions. Upper credible intervals were omitted for some regions and years.

Comparisons with Other Surveys

Although anecdotal, it is useful to document general consistency in results of continent-scale surveys. All of the surveys have deficiencies, and a primary concern among biologists is that estimates based on the surveys contain directional biases that lead to flawed views of population change. For example, roadside sampling in the SGS and BBS may lead to declines in populations if roadsides are developed faster than surrounding countryside or vehicle traffic increases over time; CBC counts might indicate unwarranted population increases if observer effort is not appropriately accommodated in the analysis. Consistency among estimates provides weak evidence that these possible sources of bias in estimation are not influencing long-term change estimates.

MANAGEMENT IMPLICATIONS

We recommend that the hierarchical model be used to analyze Woodcock SGS data. Although estimation at the scale of BCRs within states and provinces is possible, we suggest that, unless BCR information is of explicit interest, the present state and province strata be retained for yearly analyses. Bird Conservation Regions are not part of the SGS design, and little benefit accrues from subdividing the strata unless future studies require the BCR-level results. However, we recommend that survey organizers formally define the northern edge of the survey range, which we have operationally defined as the northern boundary of the Boreal Hardwood Transition BCR. Establishing new survey routes and ensuring consistent coverage of existing routes should be a priority of survey coordinators, with particular emphasis on the northern edge of the survey region. As with any survey, evaluation and improvement of the SGS should be viewed as an ongoing process, requiring periodic review of both analysis and survey methods.

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