The Auk 125(2):434–444, 2008
© The American Ornithologists' Union, 2008.
Printed in USA.

ESTIMATING THE RESPONSE OF RING-NECKED PHEASANTS (*PHASIANUS COLCHICUS*) TO THE CONSERVATION RESERVE PROGRAM

Ryan M. Nielson,[1,8] Lyman L. McDonald,[1] Joseph P. Sullivan,[2] Colleen Burgess,[3]
Devin S. Johnson,[4] Douglas H. Johnson,[5] Shawn Bucholtz,[6] Skip Hyberg,[7]
and Shay Howlin[1]

[1]*Western EcoSystems Technology, 2003 Central Avenue, Cheyenne, Wyoming 82001, USA;* [2]*Ardea Consulting, 10 First Street, Woodland, California 95695, USA;* [3]*MathEcology, 3120 W. Carefree Highway, Suite 1-642, Phoenix, Arizona 85086, USA;* [4]*National Oceanic and Atmospheric Administration, National Marine Mammal Laboratory, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, Washington 98115, USA;* [5]*U.S. Geological Survey, Northern Prairie Wildlife Research Center, 204 Hodson Hall, 1980 Folwell Avenue, Saint Paul, Minnesota 55108, USA;* [6]*U.S. Department of Agriculture, Economic Research Service, 1800 M Street NW, Washington, D.C. 20036, USA; and* [7]*U.S. Department of Agriculture, Farm Service Agency, South Agricultural Building, 1400 Independence Avenue SW, Stop 0519, Room 2745, Washington, D.C. 20250, USA*

Abstract.—We evaluated associations between the Conservation Reserve Program (CRP) and Ring-necked Pheasant (*Phasianus colchicus*) populations by modeling Breeding Bird Survey (BBS) counts of Ring-necked Pheasants during 1987–2005 along 388 routes in nine states. Ring-necked Pheasant counts were analyzed as overdispersed Poisson counts in a Bayesian hierarchical model estimated with Markov-chain Monte Carlo methods. This approach allowed for simultaneous estimation of the relationships between BBS counts and various habitat types, including CRP habitat types, for multiple regions and across the entire study area. The predictor variables included a time trend and percentages of major National Land Cover Dataset 1992 and CRP habitat types within a 1,000-m buffer around each route, along with other patch metrics. The deviance information criterion was used as a guide to help identify the most parsimonious model. We estimated that, on average, there was a positive association of Ring-necked Pheasant counts with the amount of CRP herbaceous vegetation within a 1,000-m buffer around a route. The analysis can be repeated periodically to model changes in Ring-necked Pheasant populations associated with new CRP enrollments and expiration of existing CRP contracts on a large scale. Our methodology can also be extended to other species and to other states and regions. *Received 4 January 2007, accepted 5 August 2007.*

Key words: Breeding Bird Survey, Conservation Reserve Program, hierarchical model, Markov-chain Monte Carlo, *Phasianus colchicus*, Poisson regression, Ring-necked Pheasant.

Estimación de la Respuesta de *Phasianus colchicus* al Programa de Conservación de Reservas

Resumen.—Evaluamos las asociaciones entre el Programa de Conservación de Reservas (PCR) y las poblaciones de *Phasianus colchicus* mediante modelos utilizando los conteos de *P. colchicus* realizados por el Muestreo de Aves Reproductivas (BBS, por sus siglas en inglés) entre 1987 y 2005 a lo largo de 388 rutas en nueve estados. Los conteos de *P. colchicus* fueron analizados como conteos de Poisson con sobredispersión en un modelo jerárquico Bayesiano estimado con métodos de Monte Carlo y cadenas de Markov. Este enfoque permitió la estimación simultánea de la relación entre los conteos del BBS y varios tipos de hábitat, incluyendo los tipos de hábitat del PCR, para múltiples regiones y a través de toda el área de estudio. Las variables de predicción incluyeron una tendencia temporal y los porcentajes de los principales tipos de la Base de Datos de Cobertura Terrestre Nacional de 1992 y los tipos de hábitat del PCR dentro de un área de amortiguamiento de 1000 m alrededor de cada ruta, junto con otras medidas de los parches. El criterio de información de desvío fue usado como una guía para ayudar a identificar el modelo más parsimonioso. Estimamos que, en promedio, hubo una asociación positiva entre los conteos de *P. colchicus* y la cantidad de vegetación herbácea del PCR dentro de un área de amortiguamiento de 1000 m alrededor de una ruta. El análisis pude ser repetido periódicamente para modelar cambios en las poblaciones de *P. colchicus* asociados a la incorporación de nuevos PCR y la expiración de contratos existentes de PCR a gran escala. Nuestra metodología puede también ser extendida a otras especies y a otros estados y regiones.

---

[8]E-mail: rnielson@west-inc.com

The Auk, Vol. 125, Number 2, pages 434–444. ISSN 0004-8038, electronic ISSN 1938-4254. © 2008 by The American Ornithologists' Union. All rights reserved. Please direct all requests for permission to photocopy or reproduce article content through the University of California Press's Rights and Permissions website, http://www.ucpressjournals.com/reprintInfo.asp DOI: 10.1525/auk.2008.07002

The Conservation Reserve Program (CRP) makes annual lease payments from the Farm Service Agency (FSA) available to landowners for establishing resource-conserving cover on eligible farmland. The FSA's June 2004 CRP overview (Barbarika et al. 2004:1) states that "over 34.7 million acres of environmentally sensitive and fragile lands have been placed into grass and trees that improve the soil, water, air, and wildlife resources of the Nation." Some CRP practices may indirectly benefit wildlife by improving soil and water quality, whereas others may provide increased wildlife habitat by restoring native vegetation and wetlands or supplying wildlife food plots. Barbarika et al. (2004) list 29 CRP practices that may benefit wildlife species.

In the present study, we focus on the effects of CRP on Ring-necked Pheasants (*Phasianus colchicus*). Although the Ring-necked Pheasant is an exotic species, they are often associated with agricultural lands (Giudice and Ratti 2001) and have ecological characteristics that make them good indicators of agricultural landscapes and the successional habitat created by CRP. Ring-necked Pheasants use a variety of habitats throughout the year. They use wetlands and shrublands—as opposed to croplands, developed lands, grasslands, or forests—heavily during winter (Smith et al. 1999). They use dense vegetation such as warm-season grasses, cattail (*Typha* spp.), and canary grass (*Phalaris* spp.) during harsh winter weather (Gabbert et al. 1999). They often roost in trees or dense shrubs (Stokes 1956) but also use Alfalfa (*Medicago alfalfa*) and residual grass cover and nest in tall vegetation consisting of grasses, weeds, or shrubs (Olsen 1977). Therefore, at different times of the year, Ring-necked Pheasants would be expected to benefit from many of the CRP practices.

Some attempts have already been made to assess the effects of CRP on Ring-necked Pheasants. Generally, these smaller studies have shown positive associations between Ring-necked Pheasant numbers and CRP. In Brookings County, South Dakota, Larsen et al. (1994) found greater numbers of Ring-necked Pheasants in food plots in or near CRP fields of Switchgrass (*Panicum virgatum*) that provided adequate winter cover during high snow depth. Patterson and Best (1996) reported nearly a threefold increase in Ring-necked Pheasant densities in CRP versus row-crop fields in Marshall County, Iowa. A study by Clark et al. (1999) in two northern counties of Iowa suggested that adding blocks of CRP of ≥15 ha to intensively farmed landscapes could improve nest success. Best et al. (2001) evaluated relationships between landscape composition and plot counts of various bird species conducted from mid-May to late July in row-crop fields within six counties of Iowa with moderate to large areas of CRP; however, results for Ring-necked Pheasants were inconclusive. In a study of 42 CRP fields in eastern South Dakota, Eggebo et al. (2003) found that increases in Ring-necked Pheasant abundance and productivity were associated with CRP field age and cover type, which largely reflected differences in vegetation structure. They found that 10- to 13-year-old cool-season-grass CRP fields provided the best habitat for Ring-necked Pheasants. Haroldson et al. (2006) found a positive association between Ring-necked Pheasant counts and CRP grasslands in south-central Minnesota. Until now, Nusser et al. (2004) provided what was the largest and most quantitative analysis of the effects of CRP on Ring-necked Pheasants. These authors combined land-use data from the National Resources Inventory and the annual Iowa state pheasant population survey to model the effects of CRP on Ring-necked Pheasants in Iowa. They found that benefits were greatest when CRP replaced cropland where the initial perennial habitat base was lower.

To quantitatively evaluate the benefits to wildlife populations when considering CRP offers, and to comply with the Government Performance and Results Act (GPRA), the FSA needs accurate estimates of the responses of wildlife populations to land-use changes and habitat development related to CRP practices throughout the United States and the ability to link population changes to changes in CRP enrollments. We related indices of Ring-necked Pheasant populations based on the Breeding Bird Survey (BBS) to CRP practices using a Bayesian hierarchical modeling approach that treated BBS counts as resulting from a multilevel probability structure (Link and Sauer 2002; Thogmartin et al. 2004b, 2006). At the highest level, the study area, we postulated that BBS counts were related to habitat covariates in a very general sense (e.g., positive association versus negative association). However, regional differences in these relationships likely existed (e.g., strong, mild, or weak positive association), resulting in a hierarchical structure. Our hierarchical model had the ability to accommodate the complex nature of the BBS survey design and residual spatial autocorrelation in the BBS counts, provide predictions of Ring-necked Pheasant counts for individual routes, and simultaneously estimate relationships between BBS counts and habitat types for specific regions and across the study area.

Methods

Model data.—The BBS is an annual survey administered by the U.S. Geological Survey (USGS). The surveys are conducted along secondary roads during the peak of the nesting season, primarily in June. Survey routes are located using a stratified random process within states to sample habitats that are representative of large regions. The standard route is 39.4 km long, with a total of 50 stops located at 805-m intervals along the route. A 3-min count is conducted at each stop, during which the observer records all birds heard or seen within 402 m (Sauer et al. 2001; for a link to more details about the BBS program, see Acknowledgments). We used the sum of Ring-necked Pheasant counts along a route within a year as an index of abundance.

The BBS produces an index of abundance rather than a complete count or density of breeding bird populations. Analyses of BBS counts assume that fluctuations in these indices of abundance are representative of changes in the population as a whole (Sauer et al. 2001). The BBS is biased toward species that are detectable from roadsides. It is most likely to be sensitive to population changes of species likely to be observed along roads where the roadside habitat is representative of the larger area and the factors affecting the bird population are present along the road. Bystrak (1981) discussed the utility of the BBS and stated that it has demonstrated its usefulness as an effective index of bird population levels, both temporally and spatially.

Geographic-information-system (GIS) data for the locations of the BBS's digitized routes in North America are available from the Bird Conservation Node of the National Biological Information Infrastructure (see Acknowledgments). Bird count data are available from the USGS Patuxent Wildlife Research Center's website (see Acknowledgments). Only those routes and years identified as acceptable by the BBS for inclusion in analyses were used. To model the relative abundance of Ring-necked Pheasants along BBS routes, the routes were buffered at three levels—extending radially outward from the route at distances of 400 m, 700 m, and 1,000 m—and the percentages of CRP lands and other major habitat types within each buffer were calculated and used as predictor variables. If BBS routes were straight lines, these buffer sizes would correspond to 3,154 ha, 5,520 ha, and 7,886 ha, respectively. These three buffer sizes were chosen on the basis of the BBS survey protocol (i.e., birds are counted if seen or heard within 402 m) and the potential home-range sizes and daily movements of Ring-necked Pheasants (Giudice and Ratti 2001).

The CRP data were provided by the FSA and processed by the U.S. Department of Agriculture Economic Research Service (ERS). As of November 2005, spatially explicit county-level data for nine states in the range of Ring-necked Pheasants—Idaho, Kansas, Minnesota, Missouri, Nebraska, North Dakota, Oregon, South Dakota, and Utah—were available for analysis (Fig. 1). Unfortunately, digitized maps of CRP lands were not complete or available at the time of the present study for much of the eastern cornbelt (Feed Grain and Livestock Land Resource Region, especially Iowa and Illinois) and for areas of the Rockies (Colorado, Wyoming, and Montana). We understand the importance of these limitations and suggest rerunning the analysis when the complete data become available. Data from the BBS website (Sauer et al. 2007) suggest moderate to high average counts (10–30) in 1994–2003 for large areas of four states in these regions not included in our analysis: Washington, Montana, Iowa, and Illinois. However, we were able to include the four states with the largest contiguous areas of BBS routes with average counts >30: North Dakota, South Dakota, Nebraska, and Kansas.

We combined CRP practices into five categories (Table 1). This was necessary because of the small areas of rare CRP enrollment types across the landscape (data available from the FSA website; see Acknowledgments). In addition, it is believed that any effect of CRP enrollment types and ages on Ring-necked Pheasant abundance is largely attributable to differences in vegetation structure (Eggebo et al. 2003), and our five CRP categories represent a range of vegetation structures.

It was possible for a CRP contract to have multiple practices and for there to be no further information in the available data on how those practices were distributed within the contract parcel. Our solution for when a buffer edge intersected CRP contract parcels was to assign proportions of the parcels to specific CRP practices within the buffer. In some instances, the number of acres for a practice and the size of a parcel matched; we assumed that the practice was restricted to a single parcel for that contract.

In other instances, a single parcel contained multiple CRP practices. In those instances, two approaches were necessary. To most accurately assign the proportion of area for a specific CRP practice within the buffer, the different practices were randomly spread across the parcel(s) of the contract on the basis of known shares. Although this method was useful for achieving correct proportions, it would have artificially inflated the amount of edge and number of patches within the parcels, thereby biasing estimates of edge density and interspersion–juxtaposition as measured by FRAGSTATS (see below). Therefore, for these variables, each parcel was assigned the dominant practice for the contract.

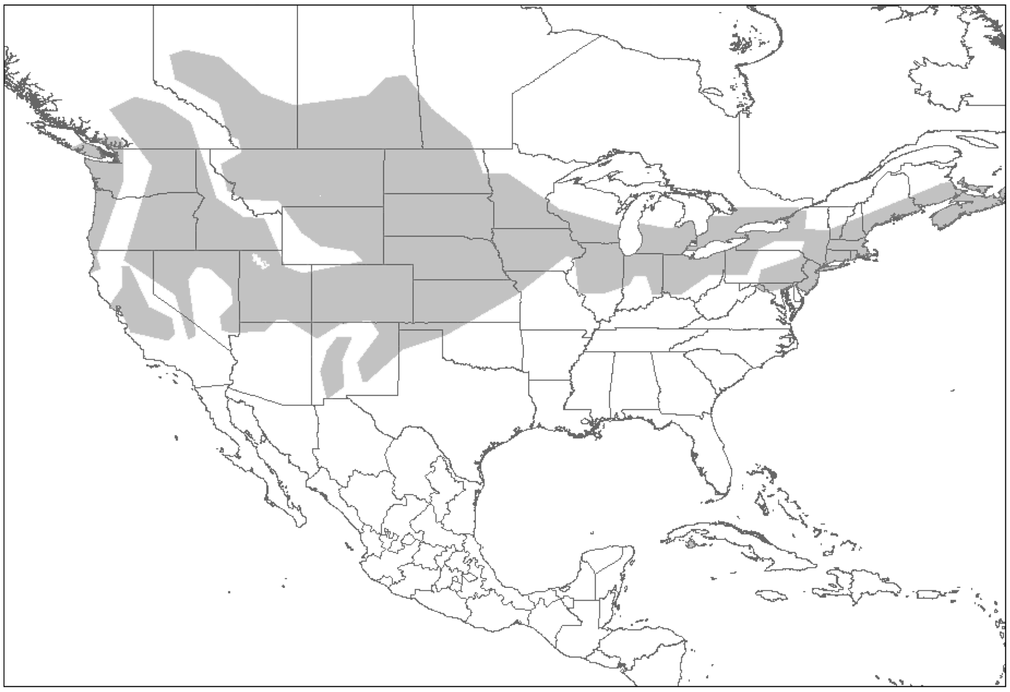


FIG. 1. Range map for Ring-necked Pheasants (Ridgely et al. 2003).

TABLE 1. Conservation Reserve Program enrollment types and assigned categories for analysis.

Enrollment	Name	Category
CP7	Erosion control structures	Developed
CP6	Diversions	Developed
CP12	Wildlife food plot	Herbaceous vegetation
CP33	Upland bird-habitat buffer	Herbaceous vegetation
CP18	Salinity-reducing vegetation	Herbaceous vegetation
CP25	Rare and declining habitat	Herbaceous vegetation
CP2	Native grasses	Herbaceous vegetation
CP29	Marginal pasture–wildlife habitat buffer	Herbaceous vegetation
CP30	Marginal pasture–wetland buffer	Herbaceous vegetation
CP1	Introduced grasses	Herbaceous vegetation
CP8	Grass waterways	Herbaceous vegetation
CP21	Filter strips	Herbaceous vegetation
CP13 (A and C)	Filter strips	Herbaceous vegetation
CP10	Established grasses	Herbaceous vegetation
CP24	Crosswind trap strips	Herbaceous vegetation
CP15	Contour grass strips	Herbaceous vegetation
CP14	Wetland trees	Trees
CP3	Tree planting	Trees
CP13 (B and D)	Filter strips	Trees
CP16	Shelterbelts	Trees
CP22	Riparian buffers	Trees
CP17	Living snow fences	Trees
CP3A	Hardwood tree planting	Trees
CP5	Field windbreaks	Trees
CP11	Established trees	Trees
CP31	Bottomland hardwood trees	Trees
CP19	Alley-cropping	Trees
CP9	Wildlife water	Wetland–water
CP23	Wetland restoration	Wetland–water
CP27	Farmable wetland program–wetland	Wetland–water
CP28	Farmable wetland program–upland buffer	Wetland–water
CP4 (A, B or C)	Wildlife habitat corridor	Woody vegetation
CP4	Wildlife habitat	Woody vegetation
CP20	Alternative perennials	Woody vegetation

TABLE 2. National Land Cover Dataset (NLCD) 1992 classifications and assigned categories for analysis.

NLCD 92 classification (grid code)	Category
Low-intensity residential (21)	Developed (or barren)
High-intensity residential (22)	Developed (or barren)
Commercial–industrial–transport (23)	Developed (or barren)
Bare rock (31)	Developed (or barren)
Quarries–mines (32)	Developed (or barren)
Urban–recreational grasses (85)	Developed (or barren)
Deciduous forest (41)	Forested
Evergreen forest (32)	Forested
Mixed forest (43)	Forested
Shrubland (51)	Woody vegetation
Orchard–vineyard (61)	Woody vegetation
Grasslands–herbaceous (71)	Herbaceous vegetation
Pasture–hay (81)	Herbaceous vegetation
Row crops (82)	Agricultural field
Small grains (83)	Agricultural field
Fallow (84)	Agricultural field
Woody wetlands (91)	Wetland
Emergent–herbaceous wetlands (92)	Wetland

We also included National Land Cover Dataset (NLCD) 1992 habitat types in our analysis of Ring-necked Pheasant counts by overlapping and aggregating the image with the CRP data. The 1992 NLCD was the most recent and complete NLCD available at the time of the present study, and this image corresponds to the peak of CRP enrollment in many regions. The NLCD classifications were grouped into six categories (Table 2). Grouping of NLCD classifications was largely done to reduce the effect of known errors and inconsistencies in the data attributable to the effects of imagery timing, classification ambiguity, and interpreter management (Thogmartin et al. 2004a). Thogmartin et al. (2004a) proposed that aggregating classes is an acceptable compensatory method for alleviating some of the NLCD 1992 classification errors. Land-cover categories from the NLCD 1992 considered in this analysis were chosen *a priori* on the basis of a review of relevant literature (Thogmartin et al. 2004a, 2006) and expert opinion. Although category names of NLCD and CRP types are similar (Tables 1 and 2), these habitats are known to be qualitatively distinct. For example, NLCD herbaceous vegetation is often mowed, sprayed, burned, and grazed, whereas CRP herbaceous vegetation is mostly unmanaged to mimic natural habitats.

The program FRAGSTATS was used to calculate an index of interspersion–juxtaposition (McGarigal and Marks 1995; see Acknowledgments) of land-use categories and edge density. This was accomplished by identifying unique patches of NLCD and CRP categories. Patches were identified as groups of 30 × 30 m cells falling into one of the 11 NLCD or CRP categories.

Land resource regions (LRR) were defined as strata in the analysis. The LRR information was downloaded as ArcInfo coverage from the Natural Resource Conservation Service website (see Acknowledgments). We assigned each BBS route to an LRR. For routes crossing LRR boundaries, each route was assigned to the LRR that contained the majority of the route.

Statistical modeling.—In many instances, the available CRP data did not contain information that would allow estimation of the age of a contract. Another major limitation was that the data did not contain information about expired CRP contracts. Given these restrictions, it was not possible to obtain a snapshot of CRP for any period before 2004. Therefore, it was not possible to develop a longitudinal data set of CRP. We analyzed, across several years (1987–2005), the relationship of Ring-necked Pheasant counts along BBS routes to snapshots of the landscape based on the available NLCD (1992) and CRP (2004) data.

To accommodate the spatial heterogeneity of NLCD and CRP cover types and the multilevel sampling design of the BBS, we took a Bayesian hierarchical modeling approach similar to the methodology described in Thogmartin et al. (2004b, 2006). A Bayesian hierarchical model was fitted using Markov-chain Monte Carlo (MCMC) methods (Link et al. 2002) to model BBS counts of Ring-necked Pheasants as overdispersed Poisson counts (i.e., the variance is larger than in the standard Poisson distribution). Using counts of Ring-necked Pheasants since the beginning of the CRP (1987–2005) along routes where at least one Ring-necked Pheasant had been observed during this period, we modeled the expected value λ_{ijt} of count Y_{ijt} in LRR i at route j in year t as

$$\log[\lambda_{ijt}] = LRR_i + \gamma_i(t - t^*) + \sum_{k=1}^{p} \beta_{ik} x_{ijk} + \alpha_t + \omega_{ij} + \varepsilon_{ijt}$$

where t^* was the median year (1996) from which change was measured, γ_i was the trend over time (change per year) in LRR i, β_{ik} were environmental (fixed) effects of covariates x_{ijk} in LRR i, k indexes the number of environmental effects, α_t were random year effects, ω_{ij} were random route-specific effects, and ε_{ijt} were overdispersed Poisson errors. Year 1987 was chosen as the first year for data in the analysis because CRP enrollments began in 1986. We standardized each environmental covariate (subtraction of the mean and division by the SD) to increase the efficiency of the MCMC process (Gilks and Roberts 1996). The model was fitted using WinBUGS, version 1.4.1 (Spiegelhalter et al. 2003; see Acknowledgments). The code for estimating parameters of this model can be obtained from R.M.N.

As mentioned above, we limited our inferences to those areas where there was potential for increase in Ring-necked Pheasant abundance by including only routes where at least one pheasant was recorded on the BBS during the period 1987–2005. If we had included routes where CRP parcels may or may not be present but where no Ring-necked Pheasants were recorded during that period, that might have negatively biased the estimates of the contribution of CRP lands where there is potential for an increase in numbers of Ring-necked Pheasants.

The spatial structure considered for the random route-specific effect (ω_{ij} in the above equation) is used to control for any spatial correlation in the BBS counts not accounted for by the environmental variables. Using BBS count data from the year during 1987–2005 in our data with the largest number of routes surveyed (2003), we calculated Moran's I (Moran 1948) for multiple distances and estimated the spatial autocorrelation function using a supersmoother (Friedman 1984) fit by the "supsmu" function in R (R Development Core Team 2005; see Acknowledgments). We defined the Gaussian conditional autoregressive (CAR) model to allow for spatial relatedness out to a distance where the estimated autocorrelation function was close to 0.

We used vague prior distributions (Link et al. 2002) to begin the MCMC sampling. Parameters for environmental variables and time trend at the study-area level were assigned relatively flat normal distributions with mean of 0.0 and variance of 100. Parameters at the LRR level were assigned means equal to study-area parameters and SDs ~ uniform(0, 100). Random year effects and overdispersed Poisson errors were assigned mean zero normal distributions with SD ~ uniform(0, 100). Under the assumption of no residual spatial correlation in the BBS counts, random route effects were also assigned relatively flat normal prior distributions with zero mean and SD ~ uniform(0, 100).

We determined the appropriate burn-in and chain length (Link et al. 2002) on the basis of the Raftery and Lewis (1992) diagnostic and by visual inspection of trace plots from the MCMC process fitting a spatial model with all environmental variables (full model accounting for spatial autocorrelation). All models were fitted using one chain containing 30,000 iterations following a 10,000-iteration burn-in.

Model selection.—During model selection, we considered the effects of covariates listed in Tables 1 and 2, including quadratic effects, provided that these habitats constituted >5% of the total area in buffers around all BBS routes. We also considered the average patch size within a buffer, and an index of interspersion–juxtaposition. A correlation analysis of all environmental variables revealed that edge density was negatively correlated with average patch size ($|r| > 0.62$ for all buffer sizes); thus, edge density was dropped from the analysis.

Our objective was to identify the most parsimonious model, and we used the deviance information criterion (DIC; Spiegelhalter et al. 2002) as a guide to that end. The DIC is a measure of goodness of fit and model complexity—essentially, the Bayesian equivalent of Akaike's information criterion (AIC; Burnham and Anderson 2002). A better model corresponds to a lower DIC. Final models were obtained by backwards variable removal from the full model using the DIC (Thogmartin et al. 2004b). The full model contained a time trend, random year and route effects, the environmental variables listed above, and quadratic forms for the percent NLCD agricultural field and percent CRP wetland. Model selection was performed for each of the three buffer sizes.

Following model selection, the need for the CAR spatial structure was evaluated using the DIC criterion. Provided that the final model had the appropriate structure (i.e., overdispersed Poisson with appropriate random and fixed effects), the CAR spatial structure might not be needed if the spatial correlation was adequately accounted for by the model covariates (both nuisance and fixed effects; Thogmartin et al. 2004b). If the DIC was lowered with the CAR component in the model, then the CAR component was included; otherwise, random route effects were treated as independent.

Model evaluation.—We measured model goodness-of-fit by the posterior predictive P value (Gelman and Meng 1996). Information-theoretic statistics like DIC are used to compare candidate models (Burnham and Anderson 2002). The goodness-of-fit assessment is not a comparison of models, but an evaluation of how well the data fit the final model. A P value close to 0.0 or 1.0 indicates that the data do not agree with the proposed model, whereas a value near 0.5 suggests that the model adequately fits the data. We also excluded all BBS counts in 2005 and refitted the final model using the same number of MCMC iterations. We then compared predictions of BBS counts for 2005 based on the re-estimated model to the actual counts. Pearson's correlation coefficient (Neter et al. 1996) was used to assess the agreement between the model and observed counts. We assumed that using 2005 for this comparison would provide the most precise evaluation of the final model, because the CRP information in the data represented enrollment in 2004.

The models fitted using MCMC were compared with similar non-Bayesian models (i.e., overdispersed Poisson models containing only environmental covariates). These simpler models were estimated using PROC GENMOD (SAS Institute 2000). This type of comparison has been used with other data to evaluate support for the objective Bayesian models fitted using MCMC (e.g., Thogmartin et al. 2004b).

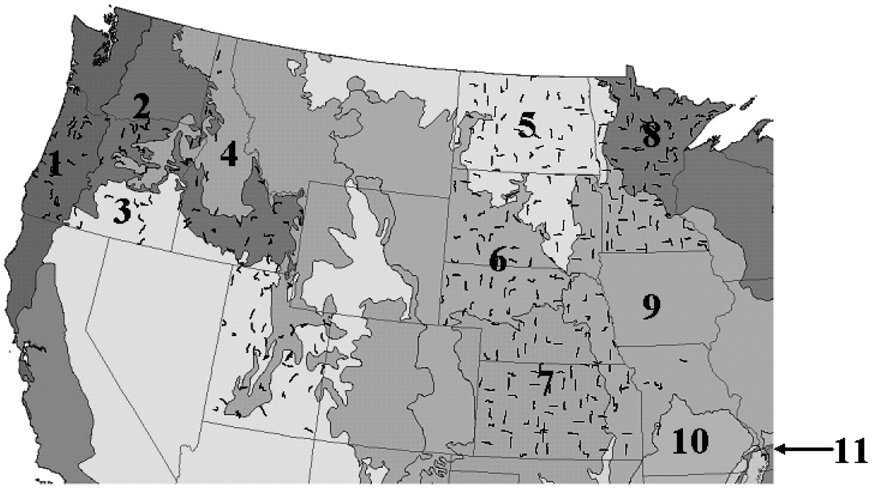
To aid interpretation of the modeled effect of a CRP covariate in the final model, we predicted the average BBS count along a hypothetical route within each LRR with average conditions for that region. Then we computed the predicted count following an increase in CRP along the hypothetical route.

RESULTS

There were 388 BBS routes surveyed during 1987–2005 within the range of Ring-necked Pheasants in counties with CRP enrollment information available in a GIS (Fig. 2). These routes contributed a total of 4,615 counts (zeros included) of Ring-necked Pheasants for model development. Total area of CRP enrollment types within each of the 11 LRRs represented in our data, and the amounts captured in the 1,000-m buffers around the 388 BBS routes, are provided in Table 3. Most of CRP enrollment falling within 1,000 m of the BBS routes was herbaceous vegetation (84%), followed by signups of wetlands–water (14%). Much of the CRP enrollments of woody vegetation and trees occurred well away from the 388 BBS routes used in the analysis. Approximately 91% of the CRP enrollments in the herbaceous-vegetation category were classified as grass.

Model selection resulted in similar models across buffer sizes (DIC: 400 m = 20,674.5; 700 m = 20,674.2; 1,000 m = 20,671.2), and these models were not substantially different according to DIC differences (Burnham and Anderson 2002). The 1,000-m buffer model had the lowest DIC and the fewest variables, leading to a simpler model. The coefficients of percent CRP wetland–water and (percent CRP wetland–water)^2 in all three models were not significantly different from 0.0 at the study-area level or within any of the LRRs, according to 90% credible intervals. The coefficients for other covariates in the 1,000-m model were significant by this criterion in at least one of the LRRs. Thus, we dropped these two covariates from the 1,000-m buffer model to obtain a more parsimonious model. The DIC for this model was 20,674.5.

The final step in model selection was to evaluate whether there was substantial spatial correlation in Ring-necked Pheasant counts not accounted for by the model. Observed Ring-necked Pheasant numbers along BBS routes in 2003, the year with the largest number of routes surveyed (289), showed evidence of significant autocorrelation between routes at distances ≤350 km, and the estimated autocorrelation function was approximately zero at 450 km (Fig. 3). Judging from these distances and the fact that one of the most isolated routes in our data was 429 km away from the next route, we considered Ring-necked Pheasant counts for routes <430 km apart potentially correlated. However, the model's predictor variables accounted for much of the spatial correlation in BBS counts, and inclusion of the CAR spatial structure for the random route effects did not improve model fit (DIC = 21,552.6). Thus, the final model (Tables 4 and 5) assumed uncorrelated random route effects. The SD of the



ID	#BBS routes	Name	ID	#BBS routes	Name
1	24	NW Forest, Forage, and Specialty Crop	7	60	Central Great Plains Winter Wheat and Range
2	34	NW Wheat and Range	8	42	Northern Lake States Forest and Forage
3	45	Western Range and Irrigated	9	61	Central Feed Grains and Livestock
4	16	Rocky Mountain Raneg and Forest	10	2	East and Central Farming and Forest
5	61	Northern Great Plains Spring Wheat	11	1	Mississippi Delta Cotton and Feed Grains
6	42	Western Great Plains Range and Irrigated			

FIG. 2. Land resource regions and Breeding Bird Survey routes in the nine states covered by analysis data.

TABLE 3. Hectares of Conservation Reserve Program (CRP) categories enrolled in 2004 within the 11 land resource regions (LRRs) represented by 388 Breeding Bird Survey routes in the analysis, along with the amount found within 1,000 m of the survey routes.

LRR	Developed	Herbaceous vegetation	Trees	Wetland–water	Woody vegetation	Total CRP
1	0	715	1,792	40	50	2,598
2	0	334,135	9,332	609	35,138	379,214
3	0	76,550	707	0	2,083	79,340
4	0	19,842	1,660	8	1,118	22,628
5	4	1,039,523	14,667	473,474	289,793	1,817,460
6	4	269,303	10,821	8,649	15,034	303,810
7	7	1,023,624	6,160	3,152	11,497	1,044,439
8	0	55,004	23,435	29,623	57,426	165,488
9	81	816,115	33,591	102,091	37,485	989,364
10	21	22,672	2,634	266	181	25,773
11	0	1,879	1,007	66	7	2,959
Total hectares	117	3,659,360	105,807	617,978	449,811	4,833,073
Percent	<0.01%	75.71%	2.19%	12.79%	9.31%	100.00%
1,000-m buffer						
Total hectares	1	32,847	95	5,594	410	38,947
Percent	<0.01%	84.34%	0.24%	14.36%	1.05%	100.00%

estimated overdispersion for this model was 0.76; a value of 0.0 would indicate no overdispersion.

The posterior predictive P value for the final model was 0.664, which indicates reasonable fit of the model to the observed data. Model predictions for 2005 based on 1987–2004 habitat data were highly correlated with observed counts ($r = 0.827$; Fig. 4). In addition, a fixed-effects model with the same covariates estimated using SAS PROC GENMOD (SAS Institute 2000) had coefficients similar to those of the Bayesian hierarchical model, and 90% credible intervals for hierarchical model coefficients for the time trend and environmental effects were not significantly different ($\alpha = 0.10$) from their corresponding estimates in the fixed-effects model.

The final model for the entire study area (Table 4) estimated a positive relationship between Ring-necked Pheasant counts and routes with higher percent CRP herbaceous vegetation within a 1,000-m buffer. Across the study area, there was an estimated (Table 5) average 22% increase (exp(0.1991) = 1.22-fold) in Ring-necked Pheasant counts along a BBS route associated with a 1 SD increase (4.05%; 319 ha) in percent CRP herbaceous vegetation

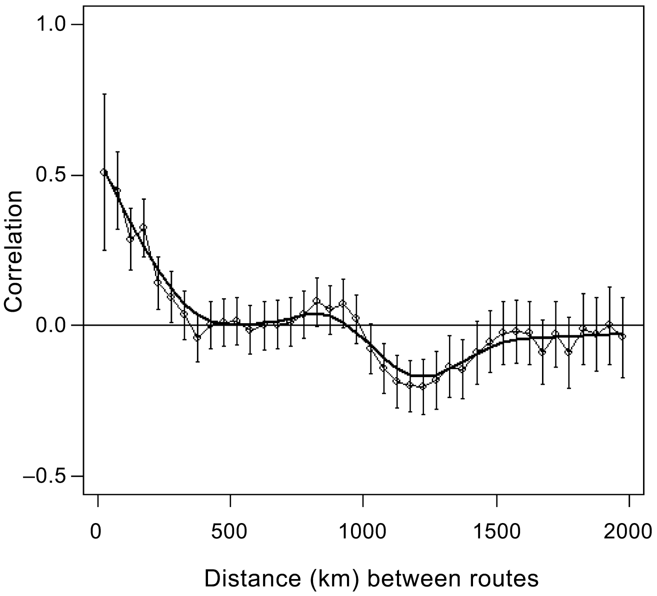


FIG. 3. Moran's *I* statistics and estimated autocorrelation function for total number of Ring-necked Pheasants observed on a Breeding Bird Survey route in 2003. Vertical bars are Bonferroni-corrected 95% confidence intervals on Moran's *I*. The darker line is the smoothed autocorrelation function.

TABLE 4. Means of posterior distributions (coefficients) of standardized model parameters, with 90% credibile intervals for the entire study area. Distributions were calculated using one chain of length 30,000 after discarding the first 10,000 values.

Parameter	Mean	5%	95%
Intercept	1.5451	0.972	2.097
Trend	–0.0059	–0.045	0.030
Percent NLCD woody vegetation	0.2748	–1.070	1.636
Percent NLCD herbaceous vegetation	0.7040	–0.835	2.143
Percent NLCD agricultural field	1.4919	0.732	2.212
(Percent NLCD agricultural field)^2	–0.6584	–0.961	–0.371
Percent CRP herbaceous vegetation	0.1991	0.004	0.414
Average patch size (ha)	–0.0526	–0.958	2.021
Index of interspersion and juxtaposition	–0.1702	–0.455	0.670

Abbreviations: NLCD = National Land Cover Dataset, CRP = Conservation Reserve Program.

Table 5. Predicted counts of Ring-necked Pheasants along a Breeding Bird Survey (BBS) route with average conditions for the land resource region (LRR), and the predicted count following an increase of 1 SD in percent Conservation Reserve Program (CRP) herbaceous vegetation. First, we predicted the Ring-necked Pheasant count along a BBS route with average conditions for each LRR and in the study area. Using the estimated "coefficient" of percent CRP herbaceous vegetation in the final model, a new prediction was made given an increase of 1 SD (4%; 319-ha; 788-acre) in percent CRP herbaceous vegetation in a buffer. A similar-sized decrease can be expected for a 319-ha reduction in CRP herbaceous vegetation.

LRR	Coefficient for percent CRP herbaceous vegetation	Predicted count along average route	Hectares of CRP herbaceous vegetation along average route	Predicted count following 319-ha increase in CRP
1	0.178	1.1	1.1	1.4
2	0.214	3.9	201.7	4.6
3	0.188	3.0	82.1	3.7
4	0.203	1.3	4.9	1.5
5	0.195	0.8	333.4	0.9
6	0.206	28.7	144.8	34.8
7	0.227[a]	32.6	366.8	40.1
8	0.203	1.1	50.8	1.4
9	0.173	6.2	321.7	7.6
10	0.199	0.8	164.0	1.0
11	0.202	50.9	0.0	62.1
Study area	0.199[a]	4.7	194.1	5.7

[a] Statistically significant at the $\alpha = 0.1$ level.

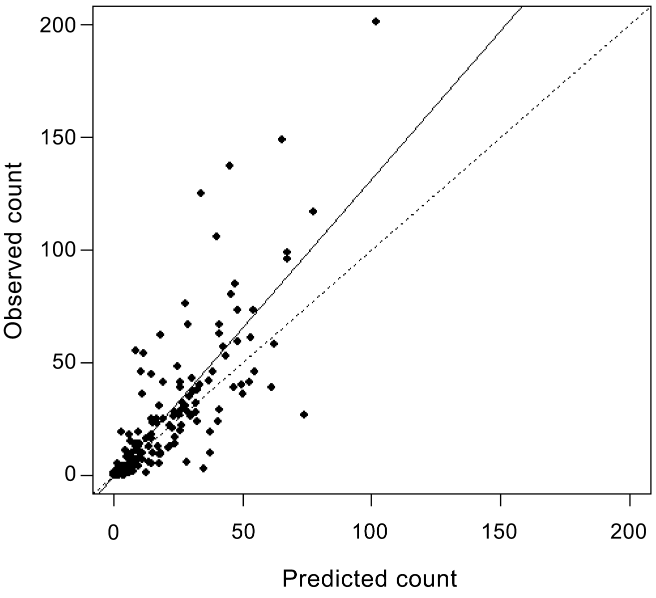


Fig. 4. Ring-necked Pheasant counts along 200 routes surveyed in 2005 versus counts predicted by the final model re-estimated using 1987–2004 data. The dotted line represents a one-to-one relationship. The solid line represents the linear relationship estimated by least-squares regression.

within a 1,000-m buffer, holding other variables constant. A similar-sized decrease (–22%) could be expected for a 319-ha reduction in CRP herbaceous vegetation. Predictions based on this relationship are more robust for common values of percent CRP herbaceous vegetation (Table 5).

Discussion

Interpretation of the final model.—In general, one can expect several different sets of covariates to do equally well in fitting the available data, and so we caution the reader from putting too much importance on which covariates ended up in our final model. For example, a model with "total percent CRP," which includes wetlands, trees, and woody and herbaceous vegetation, was found to predict BBS counts nearly as well as the final model containing only "CRP herbaceous vegetation." Thus, we cannot conclude that relatively higher numbers of Ring-necked Pheasants are not associated with other CRP practices besides those falling in the herbaceous-vegetation class. More importantly, models (sets of covariates) that do not include some measure of CRP extent will likely be inferior to models that do. Our finding that Ring-necked Pheasant indices were positively associated with percent CRP herbaceous vegetation is consistent with widely held expectations (i.e., *a priori* hypotheses) of managers and biologists that this species would respond positively to increases in CRP. Here, we tried to focus on predicting the responses of Ring-necked Pheasant to CRP while striking a balance with description and explanation.

There is an indication of a slight decline in Ring-necked Pheasant numbers across the entire study area since 1987 (trend over years is slightly negative but not significant; Tables 4 and 5). Small, negative trends in Ring-necked Pheasant counts were statistically significant in the following LRRs: 1, northwestern forest, forage, and specialty crop; 2, northwestern wheat and range; and 3, western range and irrigated. However, there has been a small but significant increase in counts in LRR 5, northern Great Plains spring wheat. Sauer et al. (2001) reported similar trends in these regions. Increases in Ring-necked Pheasant populations from 1982 to 1995 at some locations in Iowa (Nusser at al. 2004) have been

TABLE 6. Means of posterior distributions (coefficients) of standardized model parameters for each land resource region (LRR) and the entire study area. Distributions were calculated using one chain of length 30,000 after discarding the first 10,000 values.

			% NLCD						
Region	Intercept	Yearly trend	Woody vegetation	Herbaceous vegetation	Agricultural field	Agricultural field^2	% CRP herbaceous vegetation	Mean patch size (ha)	Index of interspersion-juxtaposition
LRR 1	1.678[a]	−0.063[a]	0.034	1.144[a]	0.859	−0.606	0.178	−0.273	−0.174
LRR 2	1.393	−0.025[a]	0.929	−0.218	1.529[a]	−0.590[a]	0.214	0.569	−0.141
LRR 3	1.419	−0.028[a]	0.326	0.323	0.671	−0.677[a]	0.188	−1.171	−0.056
LRR 4	1.502	−0.013	0.574	0.537	1.590[a]	−0.670	0.203	0.014	−0.163
LRR 5	1.586	0.043[a]	1.306[a]	1.970[a]	2.112[a]	−0.657[a]	0.195	0.346[a]	−0.314[a]
LRR 6	1.633	0.005	−1.134	0.801[a]	1.635[a]	−0.654[a]	0.206	−0.078	−0.086
LRR 7	1.775[a]	−0.006	−0.476	0.374[a]	1.661	−0.644[a]	0.227[a]	−0.219	−0.177
LRR 8	1.536[a]	0.029	−0.004	3.806[a]	2.018[a]	−0.636	0.203	−0.524	−0.235
LRR 9	1.703[a]	0.007	−0.890	−1.046[a]	1.264[a]	−0.722[a]	0.173	0.297	−0.147
LRR 10	1.307	−0.006	1.572	−2.077	2.057	−0.680	0.199	0.460	−0.200
LRR 11	1.465	−0.010	0.766	2.176	1.026	−0.703[a]	0.202	0.023	−0.186
Study area	1.545[a]	−0.006	0.275	0.704	1.492[a]	−0.658[a]	0.199[a]	−0.053	−0.170

Abbreviations: NLCD = National Land Cover Dataset, CRP = Conservation Reserve Program.

[a] Statistically significant at the $\alpha = 0.1$ level.

attributed to CRP enrollments. Negative trends in abundance have been tied to habitat losses (Rodgers 1999) and decreased chick survival (Warner et al. 1999), despite increasing CRP enrollments. In addition, the final model shows that there is (1) a positive relationship for Ring-necked Pheasant counts along BBS routes associated with larger amounts of NLCD 1992 agricultural land, woody and herbaceous vegetation, and CRP herbaceous vegetation; (2) an estimated decrease in Ring-necked Pheasant counts along BBS routes in areas with large patches of habitat as defined by our NLCD and CRP cover types; and (3) an estimated decrease associated with increases in the index of interspersion–juxtaposition.

The effects for percent CRP herbaceous vegetation and percent NLCD agricultural land were the only statistically significant environmental effects at the study-area level (Table 4), and both were very consistent across LRRs (Table 6). Predicted increases in Ring-necked Pheasant counts along BBS routes associated with a 1 SD increase (4.05%; 319 ha) in percent CRP herbaceous vegetation varied from 18% to 25% across the LRRs (Table 5). The effect for percent CRP herbaceous vegetation was also statistically significantly in LRR 7, central Great Plains winter wheat and range.

A nonlinear effect for percent CRP herbaceous vegetation could be estimated with more data that better estimate the relationship for routes with extremely large or small amounts of CRP. A polynomial relationship could show a smaller increase in the number of Ring-necked Pheasants after a critical mass of CRP herbaceous vegetation has been reached within a buffer around a BBS route. Although an increase in percent CRP herbaceous vegetation would require an equivalent decrease in percent NLCD 1992 agricultural field, the final model contained a nonlinear effect of percent NLCD 1992 agricultural field, so the estimated effect on Ring-necked Pheasants of turning cropland into CRP herbaceous vegetation depends on the amount of remaining cropland within a 1,000-m buffer around the BBS route.

Estimates of effects of percent NLCD 1992 woody and herbaceous vegetation and mean patch size exhibited higher-than-expected variation across LRRs (Table 6), possibly indicating that separate models should be determined for each region (i.e., allowing different model parameters), provided that more data were available for each region. Woody vegetation was rare in the NLCD 1992 data, with the exception of routes within LRRs 1, 2, 3, and 4, Rocky Mountain range and forest. Variation in the estimated effects of percent NLCD woody and herbaceous vegetation could be attributable to differences in specific types of herbaceous and woody vegetation across LRRs. Because of the inherent problems with the NLCD 1992 image discussed above, our modeling approach was not able to explain these differences.

The Bayesian hierarchical model simultaneously provided estimates for the entire study area and for each LRR. The number of routes in two of the LRRs—10, the east and central farming and forest region, and 11, the Mississippi Delta cotton and feed grains region—were very small: two and one, respectively. As of November 2005, all LRRs currently have some areas lacking CRP data in GIS format. The LRRs with smaller sample sizes provide less information for study-area parameter estimates than other regions, and their specific posterior distributions are closer to the study-area-level parameters because they essentially borrow information from regions with more observations. This modeling effect is also known as "shrinkage" (Verbeke and Molenberghs 2000). Because of small sample sizes, use of parameter estimates for LRRs 10 and 11 would be inappropriate until reanalyzed with additional data.

As previously mentioned, it was not possible to develop a snapshot of CRP for any period prior to the first release of the CRP data on the Common Land Unit level (in 2004) and, therefore, it was not possible to develop a longitudinal data set of CRP. This imposed a limitation on the data analysis, because the preferred analysis would take a longitudinal approach to modeling CRP practice types, amounts, and age (e.g., CRP enrollments along a route would mature through time). As shown by Eggebo et al. (2003) and Larsen et al. (1994), CRP enrollment age and vegetation structure can be correlated, and vegetation structure is an important characteristic of Ring-necked Pheasant habitat.

Use of the DIC for model selection.—Little is known about the ability of the DIC to select the most parsimonious model, and our experience and that of others (e.g., Swanepoel and De Beer 1992, Shibata 1997) is that its frequentist equivalent, AIC, tends to overfit the available data. Overfitting a statistical model tends to result in a model that fits extreme values in the data and, hence, may not accurately fit the general trend of other or future data. This potential for overfitting led us to select a parsimonious final model guided by DIC rather than a strict adherence to the DIC.

In some regions, and particularly for winter, dense wetland vegetation is important roosting habitat during harsh weather (Smith et al. 1999), but percent CRP wetland was dropped from the final model selected by DIC because estimates of the effects of wetlands were not significantly different from zero within any individual LRR or across the study area as a whole. However, CRP wetland enrollment types CP23 and CP27 (Table 1) were not available until 1997, so wetland habitats enrolled prior to 1997 were likely enrolled as grasses (CP1, CP2, CP10). This may have obscured any effect of CRP wetlands in our analysis.

Availability of data and refitting models.—Data available for this analysis represent a substantial, but incomplete, selection from the range of Ring-necked Pheasants in the United States. The methods described above, including selection of covariates, can be reapplied when data on CRP enrollments are available from additional counties and states. The distribution of CRP enrollment by type varies spatially, so we would expect that modeling counts along BBS routes in other areas of the country might require inclusion of CRP trees, CRP woody vegetation, or CRP wetland classes.

The NLCD 1992 covers the entire contiguous 48 states with a consistent approach and definitions. This coverage is becoming outdated, given that it is based on Landsat or aerial images from 1992. At the time we conducted this analysis, the NLCD was being updated on the basis of 2001 images. We recommend rerunning the analysis, including variable selection, using the NLCD 2001 image and updated CRP data once they become available.

Recommendations for future research.—Although using 2004 CRP and NLCD 1992 data to model BBS counts from 1987 to 2005 is reasonable, some effort should be made to determine how CRP enrollment locations, types, and amounts have changed since the program began. In addition, alternative definitions of unique patches of habitat types could be more meaningful with regard to Ring-necked Pheasants and, thus, provide more appropriate measures of mean patch size and interspersion–juxtaposition.

Future modeling could allow for variables represented at various buffer sizes to enter the same model (i.e., a model may contain predictor variables measured in a 400-m buffer, others measured in a 700-m buffer, and so on). Justification for this "multiscale" model is that Ring-necked Pheasants may select for different habitat characteristics at different scales (Best et al. 2001). For example, Ring-necked Pheasants may prefer to have a high percentage of CRP herbaceous vegetation within a 1,000-m buffer, surrounded by a high percentage of farmland within a 3,000-m buffer. Continuing this effort, more than one parsimonious model could be fitted to the data, using the DIC criterion as a guide. Model-averaging may then be used to estimate changes in counts on BBS routes. This method would de-emphasize the importance of one predictor variable (e.g., percent CRP herbaceous vegetation in a 1,000-m buffer) at the expense of other variables (e.g., percent total CRP enrollment in a 700-m buffer). This method may be informative; however, fitting Bayesian hierarchical models is computer intensive and the increase in computing time may be prohibitive.

Conservation and management implications.—Our analysis indicates a positive association of Ring-necked Pheasant counts along BBS routes with larger amounts of CRP enrollment. This positive association is consistent across broad regions and, thus, is a reliable predictor variable of Ring-necked Pheasant abundance. As mentioned above, other, smaller-scale studies (Larsen et al. 1994, Patterson and Best 1996, Clark et al. 1999, Eggebo et al. 2003, Haroldson et al. 2006) have also seen a positive correlation between Ring-necked Pheasant numbers and CRP practices. Although the Ring-necked Pheasant is an exotic species, it has characteristics that make it a good indicator of agricultural landscapes and the successional habitat created by CRP. The methods presented here offer insight into the effect of CRP on Ring-necked Pheasants on a large geographic scale and can be a valuable tool for further evaluation of the CRP in other regions and for other species.

ACKNOWLEDGMENTS

We thank R. Iovanna, U.S. Department of Agriculture Farm Service Agency (FSA), for his ideas and helpful reviews of early versions of our report. We thank J. Sauer of the U.S. Geological Survey (USGS) Patuxent Wildlife Research Center and W. Thogmartin of the USGS Upper Midwest Environmental Sciences Center for helpful advice during the planning stages of this study. We also thank the associate editor and two anonymous referees for their many helpful comments and suggestions, which greatly improved our manuscript. The USGS Patuxent Wildlife Research Center's website is www.pwrc.usgs.gov. For information on the Breeding Bird Survery, see www.mbr-pwrc.usgs.gov/bbs/bbs.html. Information on the CRP is available from the FSA website: www.fsa.usda.gov/. For the Bird Conservation Node of the National Biological Information Infrastructure, go to mbirdims.fws.gov/nbii/. ArcInfo coverage from the Natural Resource Conservation Service website was accessed at www.nrcs.usda.gov/technical/NRI/maps/aboutmaps/us48mlra.html. FRAGSTATS is available at www.umass.edu/landeco/research/fragstats/fragstats.html. WinBUGS is available at www.mrc-bsu.cam.ac.uk/bugs/. The R statistical and graphing environment is available at www.r-project.org/.

LITERATURE CITED

BARBARIKA, A., S. HYBERG, J. WILLIAMS, AND J. AGAPOFF. 2004. Conservation Reserve Program Overview. CRP: Planting for the Future. U.S. Department of Agriculture, Farm Service Agency, Washington, D.C.

BEST, L. B., T. M. BERGIN, AND K. E. FREEMARK. 2001. Influence of landscape composition on bird use of rowcrop fields. Journal of Wildlife Management 65:442–449.

BURNHAM, K. P., AND D. R. ANDERSON. 2002. Model Selection and Multimodel Inference: A Practical Information-theoretic Approach, 2nd ed. Springer–Verlag, New York.

BYSTRAK, D. 1981. The North American Breeding Bird Survey. Pages 34–41 *in* Estimating Numbers of Terrestrial Birds (C. J. Ralph and J. M. Scott, Eds.). Studies in Avian Biology, no. 6.

Clark, W. R., R. A. Schmitz, and T. R. Bogenschutz. 1999. Site selection and nest success of Ring-necked Pheasants as a function of location in Iowa landscapes. Journal of Wildlife Management 63:976–989.

Eggebo, S. L., K. F. Higgins, D. E. Naugle, and F. R. Quamen. 2003. Effects of CRP field age and cover type on Ring-necked Pheasants in eastern South Dakota. Wildlife Society Bulletin 31:779–785.

Friedman, J. H. 1984. SMART User's Guide. Laboratory for Computational Statistics, Stanford University Technical Report no. 1.

Gabbert, A. E., A. P. Leif, J. R. Purvis, and L. D. Flake. 1999. Survival and habitat use by Ring-necked Pheasants during two disparate winters in South Dakota. Journal of Wildlife Management 63:711–722.

Gelman, A., and X.-L. Meng. 1996. Model checking and model improvement. Pages 189–201 *in* Markov Chain Monte Carlo in Practice: Interdisciplinary Statistics (W. R. Gilks, S. Richardson, and D. J. Spiegelhalter, Eds.). Chapman and Hall/CRC Press, New York.

Gilks, W. R., and G. O. Roberts. 1996. Strategies for improving MCMC. Pages 89–114 *in* Markov Chain Monte Carlo in Practice: Interdisciplinary Statistics (W. R. Gilks, S. Richardson, and D. J. Spiegelhalter, Eds.). Chapman and Hall/CRC Press, New York.

Giudice, J. H., and J. T. Ratti. 2001. Ring-necked Pheasant (*Phasianus colchicus*). *In* The Birds of North America, no. 572 (A. Poole and F. Gill, Eds.). Birds of North America, Philadelphia.

Haroldson, K. J., R. O. Kimmel, M. R. Riggs, and A. H. Berner. 2006. Association of Ring-necked Pheasant, Gray Partridge, and Meadowlark abundance to Conservation Reserve Program grasslands. Journal of Wildlife Management 70:1276–1284.

Larsen, D. T., P. L. Crookston, and L. D. Flake. 1994. Factors associated with Ring-necked Pheasant use of winter food plots. Wildlife Society Bulletin 22:620–626.

Link, W. A., E. Cam, J. D. Nichols, and E. G. Cooch. 2002. Of *BUGS* and birds: Markov chain Monte Carlo for hierarchical modeling in wildlife research. Journal of Wildlife Management 66:277–291.

Link, W. A., and J. R. Sauer. 2002. A hierarchical analysis of population change with application to Cerulean Warblers. Ecology 83:2832–2840.

McGarigal, K., and B. J. Marks. 1995. FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure. U.S. Department of Agriculture, Forest Service General Technical Report PNW-GTR-351.

Moran, P. A. P. 1948. The interpretation of statistical maps. Journal of the Royal Statistical Society, Series B 10:243–251.

Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. 1996. Applied Linear Statistical Models, 4th ed. McGraw-Hill, Boston.

Nusser, S. M., W. R. Clark, J. Wang, and T. R. Bogenschutz. 2004. Combining data from state and national monitoring surveys to assess large-scale impacts of agricultural policy. Journal of Agricultural, Biological, and Environmental Statistics 9:1–17.

Olsen, D. W. 1977. A literature review of pheasant habitat requirements and improvement methods. Utah State Department of Natural Resources Publication no. 77-7.

Patterson, M. P., and L. B. Best. 1996. Bird abundance and nesting success in Iowa CRP fields: The importance of vegetation structure and composition. American Midland Naturalist 135:153–167.

R Development Core Team. 2005. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna.

Raftery, A. E., and S. M. Lewis. 1992. One long run with diagnostics: Implementation strategies for Markov chain Monte Carlo. Statistical Science 7:493–497.

Ridgely, R. S., T. F. Allnutt, T. Brooks, D. K. McNicol, D. W. Mehlman, B. E. Young, and J. R. Zook. 2003. Digital Distribution Maps of the Birds of the Western Hemisphere, version 1.0. NatureServe, Arlington, Virginia.

Rodgers, R. D. 1999. Why haven't pheasant populations in western Kansas increased with CRP? Wildlife Society Bulletin 27:654–665.

SAS Institute. 2000. SAS/STAT User's Guide. SAS Institute, Cary, North Carolina.

Sauer, J. R., J. E. Hines, and J. Fallon. 2001. The North American Breeding Bird Survey, Results and Analysis 1966–2000, version 2001.2. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland.

Sauer, J. R., J. E. Hines, and J. Fallon. 2007. The North American Breeding Bird Survey, Results and Analysis 1966–2006, version 10.13.2007. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland.

Shibata, R. 1997. Bootstrap estimate of Kullback-Leibler information for model selection. Statistica Sinica 7:375–394.

Smith, S. A., N. J. Stewart, and J. E. Gates. 1999. Home ranges, habitat selection and mortality of Ring-necked Pheasants (*Phasianus colchicus*) in north-central Maryland. American Midland Naturalist 141:185–197.

Spiegelhalter, D. J., N. G. Best, B. P. Carlin, and A. van der Linde. 2002. Bayesian measures of model complexity and fit. Journal of the Royal Statistical Society, Series B 64:583–639.

Spiegelhalter, D. J., A. Thomas, N. G. Best, and D. Lunn. 2003. WinBUGS, Version 1.4 Users Manual. MRC Biostatistics Unit, Cambridge, United Kingdom.

Stokes, A. W. 1956. Pelee Island pheasants. Pages 357–386 *in* Pheasants in North America (D. L. Allen, Ed.). Stackpole, Harrisburg, Pennsylvania, and Wildlife Management Institute, Washington, D.C.

Swanepoel, J. W. H., and C. F. De Beer. 1992. Some new model selection criteria in simple regression. Journal of Statistical Computation and Simulation 42:137–149.

Thogmartin, W. E., A. L. Gallant, M. G. Knutson, T. J. Fox, and M. J. Suárez. 2004a. A cautionary tale regarding use of the National Land Cover Dataset 1992. Wildlife Society Bulletin 32:970–978.

Thogmartin, W. E., M. G. Knutson, and J. R. Sauer. 2006. Predicting regional abundance of rare grassland birds with a hierarchical spatial count model. Condor 108:25–46.

Thogmartin, W. E., J. R. Sauer, and M. G. Knutson. 2004b. A hierarchical spatial model of avian abundance with application to Cerulean Warblers. Ecological Applications 14:1766–1779.

Verbeke, G., and G. Molenberghs. 2000. Linear Mixed Models for Longitudinal Data. Springer, New York.

Warner, R. E., P. C. Mankin, L. M. David, and S. L. Etter. 1999. Declining survival of Ring-necked Pheasant chicks in Illinois during the late 1900s. Journal of Wildlife Management 63:705–710.

Associate Editor: T. L. Shaffer