Developing Spatially Explicit Habitat Models for Grassland Bird Conservation Planning in the Prairie Pothole Region of North Dakota[1]

Neal D. Niemuth[2], Michael E. Estey[2], and Charles R. Loesch[2]

Abstract

Conservation planning for birds is increasingly focused on landscapes. However, little spatially explicit information is available to guide landscape-level conservation planning for many species of birds. We used georeferenced 1995 Breeding Bird Survey (BBS) data in conjunction with land-cover information to develop a spatially explicit habitat model predicting the occurrence of Northern Harrier (*Circus cyaneus*) in the Prairie Pothole Region of North Dakota, USA. Presence of Northern Harriers was positively associated with the amount of grassland in the landscape and presence of Northern Harriers at adjacent stops, and negatively associated with forest cover and an eastern geographic gradient. The resulting spatially explicit map showing predicted presence of Northern Harrier corresponded well with results of a conceptual grassland bird habitat model applied to the same landscape. Detections of Northern Harrier in 1997 BBS data used for validation were strongly correlated with model predictions. Our findings indicate that empirical models using BBS data and conceptual models can be used in conjunction with landcover data to develop spatially explicit models predicting general suitability of landscapes for some species of birds.

Key Words: conservation planning, GIS, grassland bird, Northern Harrier, spatially explicit habitat model.

Introduction

Concern over decreasing bird populations has stimulated a variety of bird conservation plans, many of which (e.g., North American Waterfowl Management Plan, Partners in Flight, The Nature Conservancy's Migratory Bird Program) explicitly promote a landscape approach to bird conservation. Landscape characteristics are an important consideration in bird conservation planning for a variety of biological reasons. Bird habitat selection is hierarchical, with birds first selecting habitat at broad scales, then making fine-grained selections such as nest and foraging sites (Wiens 1973, Johnson 1980). Landscape-level conservation thus provides a broad habitat foundation within which birds can select habitat at a fine-grained scale. In addition, landscape characteristics can influence avian demographics through nest predation and brood parasitism (Porneluzi and Faaborg 1999, Young and Hutto 1999).

Landscape characteristics also are important from logistical and management standpoints. If habitat is purchased or otherwise selected for management based on landscape characteristics, local characteristics (e.g., vegetation composition and structure) within a patch can be modified relatively easily. But it is difficult to modify the landscape around a patch with suitable local characteristics if landscape characteristics are not suitable. Conceptual models have been developed to guide landscape-level conservation planning (e.g., Fitzgerald et al. 1999), but specific landscape-level habitat relationships are not known for most species of birds (Flather and Sauer 1996, Haig et al. 1998, Scott et al. 1993).

Much of the information regarding North American bird populations comes from the Breeding Bird Survey (BBS), an annual, continent-wide survey (Sauer et al. 2000). The BBS is used primarily to monitor bird populations but is rarely viewed in context of surrounding habitat (Flather and Sauer 1996). We used georeferenced BBS data in conjunction with land-cover information to determine landscape-level habitat relationships for the Northern Harrier in North Dakota. The Northern harrier is typically considered area sensitive, requiring large blocks of suitable habitat to be present (Herkert et al. 1996, Niemuth and Boyce 2000, Robinson 1991). However, size of habitat patch may not be as important as the total amount of grass in the landscape, as Northern Harriers will nest in relatively small (8 ha) patches of grass in proximity to extensive grassland areas (Herkert et al. 1999).

Our analysis had three primary objectives: (1) develop a model identifying landscape characteristics associated with the presence of Northern Harrier; (2) link the model to a geographic information system (GIS) to create a map showing predicted probability of Northern Harrier presence across the Prairie Pothole Region of

[1]A version of this paper was presented at the **Third International Partners in Flight Conference, March 20-24, 2002, Asilomar Conference Grounds, California**.

[2]Habitat and Population Evaluation Team, Region 6, U.S. Fish and Wildlife Service, 3425 Miriam Avenue, Bismarck, ND 58501-7926 USA. E-mail: Neal_Niemuth@fws.gov.

North Dakota; and (3) compare the resulting probability map with a map created by a GIS-based conceptual model identifying Grassland Bird Conservation Areas (GBCAs) in the study area. GBCAs identify large blocks of grassland potentially suitable for area-sensitive grassland bird species.

Methods

Study Area

The study area was that portion of North Dakota east and north of the Missouri River, approximating the Prairie Pothole Region of the state (*fig. 1*). The landscape surface was formed by glacial action and is characterized by numerous depressional wetlands and prairie flora (Bluemle 1991). The climate is cool and dry, and soils are typically heavy (Winter 1989). Agriculture is the primary land use with cropland dominating in the eastern portion of the study area, and the amount of grassland generally increasing farther west.

BBS Data

We obtained BBS data for 1995 and 1997 for 30 routes within our study area (*Fig. 1*) from the United States Geological Survey Patuxent Wildlife Research Center, Laurel, Maryland. Each 40-km route contained 50 stops, or survey points, 0.8 km apart; details of route placement and sampling were described by Bystrak (1981). Because changes in land use such as enrollment of cropland in the U.S. Department of Agriculture Conservation Reserve Program (CRP) can impact populations of grassland birds (Reynolds et al. 1994), BBS data and satellite imagery were acquired for approximately the same time period. We acquired digitized survey routes from the National Atlas of the United States (http://nationalatlas.gov) as an ArcView shapefile (Environmental Systems Research Institute, Redlands, California). Most analyses of BBS data use 40-km survey routes as the observational unit; samples at this scale are coarse, and land cover and avian communities can vary considerably within each route. We calculated locations for each of the 50 stops on each BBS route by creating a point at the start of each digitized route and every 0.807 km thereafter to the end of the route. Stop locations were verified using BBS route maps (Keith Pardieck, USGS, pers. comm.). Accuracy of stop points was visually verified by comparing points to intersections on public road layers, which in our study region typically follow public land survey lines at 1.61-km intervals.

Landcover Data

Landcover data were derived from a mosaic of Thematic Mapper satellite images (30-m resolution) acquired from May 1992 through September 1996. Individual images were classified, resampled to 2.02-ha minimum mapping unit, and mosaicked into a single grid. User accuracy for all images exceeded 80 percent[3]. Wetland information was obtained from the National Wetlands Inventory (NWI) digital database and integrated into the landcover grid as basins identified by the most permanent wetland type within each basin (Cowardin et al. 1995). Predictor variables (*table 1*) were estimated using a GIS.

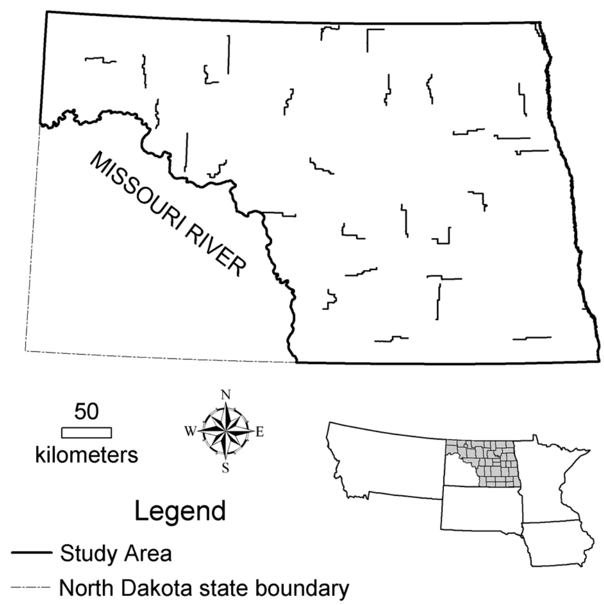

Figure 1— Location of 30 BBS routes North Dakota that were sampled in 1995 or 1997 and included in analysis. Bird-landscape relationships were only modeled east of the Missouri River.

Our study area covered a large geographic region, so we included easting and northing Universal Transverse Mercator (UTM) coordinates as linear and quadratic terms to model possible gradients in factors such as climate, regional landscape characteristics, resource availability, and species range. Because the spatial scale of sampling may influence results (Porter and Church 1987, Wiens 1989a), we sampled landscape data at three scales using circular moving window analysis, which summarizes data within a "window" of a selected size around each cell in a GIS data layer. Landscape data were in raster format and circle radii were irregular, so the area within each moving window was 48, 191, and 452 ha, respectively, for circles with radii of about 400, 800, and 1200 m. Spatial analyses were performed using the ARC/INFO Grid module (Environmental Systems Research Institute, Redlands, California, USA).

[3]unpublished data, U.S. Fish and Wildlife Service and Ducks Unlimited, Bismarck, North Dakota

Table 1— *Candidate predictor variables used to determine associations between presence of Northern Harriers and landscape characteristics at 1350 BBS stops in North Dakota.*

Landscape Variable	Description
Undisturbed Grass (%)	Predominant mix of cool-season grasses and forbs planted on previously cropped land. This land cover is generally undisturbed but may be hayed or grazed intermittently. Examples include CRP plantings and dense nesting cover on U.S. Fish and Wildlife Service waterfowl production areas.
Grassland (%)	Predominant mix of native grasses, forbs, or scattered low shrubs on unbroken prairie. This land cover is typically grazed or hayed annually.
Hayland (%)	Predominant mix of alfalfa and cool-season grasses hayed once or twice annually.
Cropland (%)	Tilled and planted with small grains or row crops that are harvested annually; includes fallow fields.
Forest (%)	Areas of mature trees.
Patches (*n*)	Number of disjunct patches identified by GIS for all land-use categories. Cells of the same habitat type were considered as belonging to the same patch only if they had at least one edge in common.
Wetlands (*n*)	Number of disjunct NWI[1] wetland basins within each buffer, regardless of basin type.
Temporary (%)	Area of temporary wetland basins derived from NWI data.
Seasonal (%)	Area of seasonal wetland basins derived from NWI data.
Semipermanent (%)	Area of semipermanent wetland basins derived from NWI data.
Northing	UTM[2]coordinate indicating north-south position.
Easting	UTM coordinate indicating east-west position.
Harrier Presence	Presence or absence of Northern Harrier at adjacent BBS stop.

[1]National Wetlands Inventory
[2]Universal Transverse Mercator

Model Development

We used the presence of Northern Harrier at BBS stops to develop a resource selection function (RSF; Manly et al. 1993), assuming that the relative probability of encountering a species could be predicted by landscape-level characteristics, x_i, according to the model

$$w(x) = \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_k x_k)$$

where β_i were estimated using logistic regression.

We developed candidate models at each of three scales and then used Akaike's Information Criterion (AIC) to select models that best fit the data at each scale (Burnham and Anderson 1998). Development of models was exploratory, but based on other research we predicted that presence of Northern Harriers would be positively associated with grasslands, temporary wetlands, and seasonal wetlands and negatively associated with forests, agriculture, landscape fragmentation, and large bodies of open water (reviewed in MacWhirter and Bildstein 1996). We calculated AIC differences (Δ_i) to allow comparison of models within and among scales, and considered models with $\Delta_i < 2$ in selection of the final model (Burnham and Anderson 1998). We examined differences in Northern Harrier response to grass type (i.e., grassland and undisturbed grass) by comparing AIC values for models with grass types combined to AIC values for models with each grass type included separately. If the Northern Harrier responded differently to grass types, AIC scores for models with separate grass types should have improved more than the penalty for including an additional variable(s). Selection of the final model was based on parsimony, species biology, and interpretability. Statistical analyses were performed using Number Cruncher Statistical System (NCSS, Kayesville, Utah, USA).

Individual stops within each route were 0.807 km apart and likely exhibited positive spatial autocorrelation (i.e., stops close to each other were more likely to be similar than stops farther apart). Spatial autocorrelation can cause apparent statistical significance when none exists (Legendre 1993) and obscure ecological patterns (Carroll and Pearson 2000). We addressed spatial structure of the data set by explicitly incorporating spatial location into our analysis as a trend surface variable (Haining 1990, Legendre 1993) using linear and quadratic terms and by including an autologistic term that incorporated presence of Northern Harriers at adjacent stops (Augustin et al. 1996).

Model Evaluation

Evaluating models based on BBS data is complicated because a site where the bird was not detected might actually be used. Traditional model assessments (e.g., classification success, Cohen's Kappa, Receiver Operating Characteristics) assume that use or nonuse is known (Fielding and Bell 1997). Because nonuse was not known for certain, we evaluated RSF models using a variant of the correlation approach used by Boyce et al. (2002). RSF scores for landscapes surrounding BBS stops in a validation data set were ranked and sorted into 27 groups of 50 and Spearman's rank correlation was calculated for the rank of each group and the number of Northern Harrier detections in each group. Models that perform well show a strong correlation between RSF rank and number of detections (Boyce et al. 2002). Model performance was assessed using BBS data from 1997. This was primarily a same-place, different-time validation, as 27 routes in our study area were sampled in each of the two years. However, three of the routes sampled in 1997 were different from those surveyed in 1995, so 150 of the validation points were from a different time and place.

We created a spatially explicit map showing the relative probability of detecting Northern Harriers throughout the landscape by using the final RSF in conjunction with corresponding GIS layers. The resulting map was then compared to the GBCA map, which was refined from a conceptual model (Fitzgerald et al. 1999) in cooperation with Partners in Flight, the North American Bird Conservation Initiative, and the Prairie Pothole Joint Venture.[4] The GBCA model identified potential grassland bird habitat consisting of a core and matrix. Cores were comprised of a minimum of 95 percent compatible habitat (e.g., grassland, temporary and seasonal wetlands, up to 30 percent permanent and semipermanent wetlands) with minimum dimensions of 1.6 km x 1.6 km and < 5 percent hostile habitat (e.g., forest, urban areas). Matrices encompassed a 1.6-km buffer area around the outer boundary of cores. A GBCA has a minimum area of 23 km^2 (4.8 km x 4.8 km) with > 40 percent of the area consisting of compatible habitat[4].

Results

Twenty-seven routes and 1,350 stops were sampled with Northern Harriers detected at 39 and 40 stops in 1995 and 1997, respectively. Landscapes surrounding BBS stops varied considerably in type and distribution of landcover (*table 2*), and some landscape characteristics were strongly correlated. At the 800-m scale, area of grassland and agriculture were negatively correlated (r = -0.85), and number of habitat patches and number of wetlands were positively correlated (r = 0.78). Correlation among variables at 400-m and 1200-m scales was similar. Consequently, the relative fit of candidate models was similar among scales, with AIC scores generally lowest with landcover data from the 800-m sampling window.

Variables in competing models were similar (*table 3*). We selected a final model where relative probability of detecting a Northern Harrier, w(x), was predicted by

$$w(x) = \exp(-3.13 - (0.0000018 * \text{Easting}) + (0.013 * (\text{Grassland} + \text{Undisturbed Grass})) - (0.13 * \text{Forest}) + (0.8 * \text{Harrier Presence}))$$

In the model evaluation, the number of stops with Northern Harriers detected in ranked RSF groups was positively correlated (r = 0.56, 25 df, P = 0.002) with RSF values. The map showing relative probability of detecting Northern Harrier (*fig. 2a*) was similar to that created by the conceptual GBCA model (*figs. 2b* and *2c*).

[4] Unpublished data, M. E. Estey, U.S. Fish and Wildlife Service, Bismarck, North Dakota

Table 2— *Mean, range, and standard deviation of landcover variables used in development of landscape-level habitat models for the Northern Harrier.*[1]

Landscape Variable	Mean	Minimum	Maximum	sd
Undisturbed Grass (%)	4.9	0	91	9.9
Grassland (%)	20.0	0	99	23.6
Hayland (%)	0.9	0	24	2.6
Cropland (%)	61.8	0	100	31.2
Forest (%)	1.7	0	55	6.5
Patches (*n*)	39.3	1	163	24.3
Wetlands (*n*)	19.3	0	81	13.8
Temporary (%)	0.7	0	14	1.5
Seasonal (%)	2.5	0	25	3.4
Semipermanent (%)	2.0	0	44	4.5

[1]Values shown are for landcover within 800 m of BBS stops.

Table 3—*Variables, Akaike differences (Δ_i), and Akaike weights (w_i) for candidate models predicting presence of Northern Harriers in the Prairie Pothole Region of North Dakota, USA.*

Model	Δ_i	w_i
Easting, Undisturbed Grass + Grassland, Harrier Presence, (Forest) [1, 2]	0.0	0.26
Undisturbed Grass + Grassland, Harrier Presence, (Forest)	0.2	0.24
Easting, Undisturbed Grass + Grassland, (Forest)	0.6	0.19
Undisturbed Grass + Grassland, Harrier Presence, (Forest), (Hay)	1.8	0.11
Easting, Undisturbed Grass, Grassland, Harrier Presence, (Forest)	1.8	0.10
Easting, Undisturbed Grass + Grassland, Harrier Presence, (Forest), (Hay)	1.9	0.10

[1]Parentheses indicate negative relationship. Variable codes defined in Table 1.
Δi indicates the difference between the AIC score for each model and the lowest AIC score of the candidate models for each species.
+ indicates grassland and undisturbed grass cover classes were combined in the model.
[2]Selected as final model.

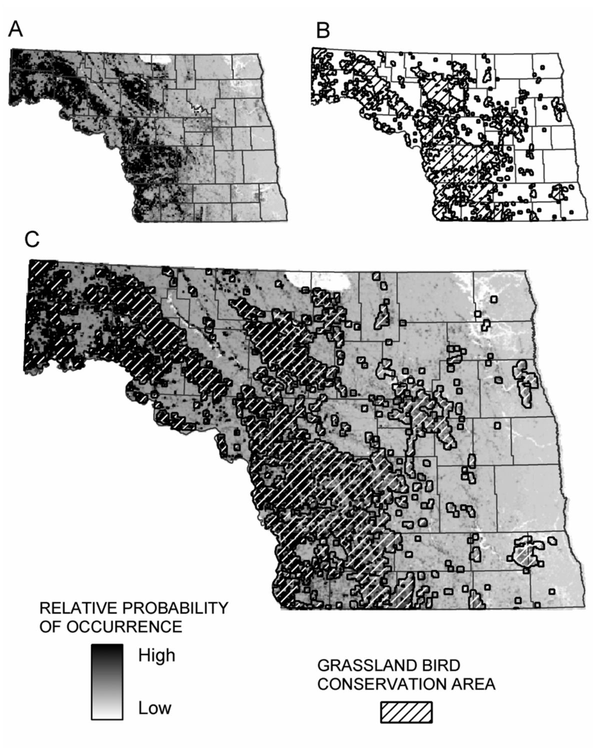

Figure 2— Conservation planning models for the Prairie Pothole Region of North Dakota including A) relative probability of detecting Northern Harrier; B) Grassland Bird Conservation Areas; and C) Grassland Bird Conservation Areas overlain on Northern Harrier probability map.

Discussion

Northern Harrier Habitat Associations

The models predicting presence of Northern Harriers as a function of landscape characteristics in our analysis agree well with findings of previous studies. Harriers were positively associated with grassland and undisturbed grassland, and negatively associated with forest, as would be expected from a grassland specialist. Northern harriers often select dense cover for nesting (Evrard and Bacon 1998, Kantrud and Higgins 1992), but our analysis was based on harrier detection, which was most likely when birds were foraging or perched, rather than at nests. Our data indicated no strong selection for undisturbed grassland (typically Conservation Reserve Program plantings or dense nesting cover at Waterfowl Production Areas) over grassland (*table 3*), although in the model with both grass types considered separately, regression coefficients were nominally greater for undisturbed grassland (0.02) than grassland (0.01). Two competing habitat models showed a negative relationship with increasing area of annually harvested hay fields in the sample window, which is consistent with previous findings of low use of annually hayed or burned grasslands by Northern Harrier (Hecht 1951, Duebbert and Lokemoen 1977).

We found little evidence of selection for wetlands. This agrees with previous findings that Northern Harriers in western North America are more upland oriented than those in eastern North America (summarized in MacWhirter and Bildstein 1996), although Northern Harriers certainly use wetlands in North Dakota for foraging and nesting (Stewart 1975). Presence of Northern Harriers did not appear to be influenced by habitat patchiness, although the small number of harrier observations likely reduced the power of the analysis to detect additional, but less pronounced, relationships with other characteristics such as wetland area and patchiness. Presence of Northern Harriers also may be influenced by habitat characteristics at scales other than those sampled.

The negative relationship with the easting trend surface variable may reflect broad-scale patterns of land use, as eastern North Dakota typically has more cropland and less grass than western North Dakota (Cowardin et al. 1995). Lower numbers of Northern Harrier in eastern North Dakota are evident in BBS general distribution and relative abundance maps (e.g., Sauer et al. 2000), which are based on inverse distancing of route data and do not incorporate habitat relationships. In addition to reflecting possible broad-scale patterns in land use, trend surface variables may incorporate gradients in precipitation, population distribution, vegetation characteristics, and other unmodeled landscape characteristics that influence occurrence of Northern Harrier. A similar geographic trend was found in duck nest success in the study area (Reynolds et al. 2001). Inclusion of trend surface variables in spatially explicit models improves model fit and reduces spatial autocorrelation in model residuals.[5] Significant correlation between ranked and grouped RSF values and bird detection in the validation data set indicate that the model performed well and was robust from 1995 to 1997.

Correspondence with GBCA Model

The spatially explicit probability map developed from the BBS data corresponded strongly with the map produced using the conceptual GBCA model (*Fig. 2*). This is not surprising, given that the GBCA model identified large blocks of grass without trees, which, with the exception of the easting trend surface variable and proximity of other Northern Harriers, is similar to the habitat relationships identified in the empirically derived Northern Harrier habitat model. The Northern Harrier is a widely distributed species that uses many types of grass; empirical probability maps developed for other species of grassland birds in the region do not match the GBCA map as well, with differences between GBCA maps and empirical models differing among species. For instance, Baird's Sparrow (*Ammodramus bairdii*) has a more restricted distribution than Northern Harrier and probability maps showed it more likely to be found in western North Dakota than in the eastern part of the state.[5] LeConte's Sparrow (*A. leconteii*) selected for dense cover and wetlands relative to upland grasses.[5]

Even with differences among species, both modeling approaches provided useful information that aids managers and conservation planners in identifying potential habitat at the landscape level, which is a primary step in effective conservation planning. Conceptual or expert-based habitat models can be an important step in identifying wildlife habitat (Marcot 1987), and results of conceptual models can agree well with empirical models as is the case with the Northern Harrier in North Dakota and other species elsewhere (Clevenger et al. 2002).

[5] unpublished data, U.S. Fish and Wildlife Service, Bismarck, North Dakota

Using BBS Data to Develop Bird/Habitat Models

Using BBS data in conjunction with RSFs and landcover information produced a biologically plausible model for the Northern Harrier, although number of detections was low. Using BBS data to develop useful habitat models will work best when birds and predictor variables are adequately sampled. The number of used sites as well as model generality may be increased by summing presence data for multiple years, although this approach must consider species biology and changes in landcover, precipitation, and food/prey availability among years.

The 400-m radius of the BBS stop sample area and the high visibility of the Northern Harrier likely reduced potential roadside bias of BBS data, although roadside bias is minimal for many grassland and shrubland bird species (Rotenberry and Knick 1995). Also, use of habitat likely was higher than indicated by BBS data, as not all individuals present are detected during the single, short sample period at each point. Regardless of detectability, the habitat model provides a relative probability of detecting a species, but relative probabilities will vary among species due to differences in detectability. As the BBS is an index of populations (Bystrak 1981), the maps produced by our analysis should be considered an index of the probability of encountering a species based on the landscape characteristics included in each model. Finally, data from BBS stops are not statistically independent, and spatial autocorrelation must be considered when developing and interpreting spatial models.

Role of Habitat Modeling in Conservation Planning

Habitat models such as those presented in this paper, whether based on empirical data or expert opinion, are tools for identifying areas where target species are likely to occur. The models we have presented do not include demographic parameters, which, although difficult to assess, are important considerations in conservation planning. Similarly, landscape-level models do not incorporate fine-grained habitat characteristics, such as vegetation composition and structure, which also influence habitat selection (Madden et al. 2000). Species occurrence and statistical modeling also may be influenced by other factors such as land use (e.g., cultivated vs. grazed wetlands), local correlation among variables, combinations of variables not encountered in the model-building data set, errors in classification of landcover data, soil quality, vegetation, vegetation succession, local conditions, and interactions between predictor variables.

Presence of target species in an area of habitat is influenced by a variety of other, non-habitat factors, including weather, annual variation in distribution, prey availability, competition, and predation (George et al. 1992, Igl and Johnson 1999, Niemuth and Solberg 2003, Wiens 1989b). Bird response to landscape characteristics likely will change in areas with different resource availabilities, and application of the models should be limited to interpolation within the range of geographic and habitat variables used to develop the models. Like all models, landscape-level habitat models are imperfect for a variety of reasons. However, such models provide an objective, quantitative method of evaluating landscapes for conservation. Ideally, habitat models for conservation planning should be based on many years of data and incorporate annual variation as well as demographic parameters. But in the absence of better information, these models provide some basis for making conservation decisions.

Our results suggest that broad landscape characteristics influence occurrence of Northern Harrier, and likely other species of grassland birds in the Prairie Pothole Region of North Dakota. We believe the coarse-grained approach to conservation planning is appropriate in our region given the hierarchical nature of habitat selection. We reiterate the advantages of managing habitat within an appropriate landscape as opposed to altering a landscape surrounding a point with desired features. Similar models have been developed and used effectively for planning waterfowl management activities in the region (Cowardin et al. 1988, Reynolds et al. 1996). Development of habitat models for non-waterfowl species will aid integration of conservation efforts for all bird species.

Unfortunately, the level of biological data available for waterfowl is lacking for most other species of migratory birds, especially that information needed for landscape-level modeling. In the absence of detailed autecological studies explaining resource selection and reproductive success, the combination of landscape information, geo-referenced BBS data, and RSF analysis provides a powerful tool for developing coarse-grained models that present an indication of avian distribution and landscape-level habitat selection. This information can be used to provide direction for future sampling and analysis, or the models can be incorporated into plans for integrated landscape-level conservation planning (e.g., Freemark et al. 1993, Scott et al. 1993, Askins 2000). Given the importance of landscape characteristics to avian habitat selection and demography, landscape-level habitat models are an important consideration in conservation planning for birds.

Acknowledgments

We thank the many volunteers who annually collect BBS data, especially R. E. Martin, G. B. Berkey, R. K. Murphy, E. Freeberg, and R. L. Rytter. We thank B. C. Dale, D. A. Granfors, B. McCready, R. E. Reynolds, and T. D. Rich for helpful comments on an earlier draft of this paper. B. C. Dale, S. K. Davis, D. H. Johnson, R. E. Reynolds, and C. A. Ribic provided valuable observations and discussion. We also thank K. L. Pardieck of USGS Patuxent Wildlife Research Center for providing BBS stop data and route information, K. Van Cleave of Northern Prairie Wildlife Research Center for providing literature, M. S. Rosenberg for providing software and assistance, and the Great Plains Regional Office of Ducks Unlimited, Inc., for helping develop landcover information.

Literature Cited

Askins, R. A. 2000. **Restoring North America's birds: Lessons from landscape ecology.** New Haven, CN: Yale University Press; 320 p.

Augustin, N. H., M. A. Mugglestone, and S. T. Buckland. 1996. **An autologistic model for the spatial distribution of wildlife.** Journal of Applied Ecology 33: 339–347.

Bluemle, J. P. 1991. **The face of North Dakota.** Revised edition. Bismarck, ND: North Dakota Geological Survey, Educational Series 21; 187 p.

Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. **Evaluating resource selection functions.** Ecological Modeling 157: 281-300.

Burnham, K. P. and D. R. Anderson. 1998. **Model selection and inference: a practical information-theoretic approach.** New York: Springer-Verlag, 320 p.

Bystrak, D. 1981. **The North American Breeding Bird Survey**. Studies in Avian Biology 6: 34-41.

Carroll, S. S., and D. L. Pearson. 2000. **Detecting and modeling spatial and temporal dependence in conservation biology.** Conservation Biology 14: 1893-1897.

Clevenger, A. P., J. Wierzchowski, B. Chruszcz, and K. Gunson. 2002. **GIS-generated, expert-based models for identifying habitat linkages and planning mitigation passages.** Conservation Biology 16: 503-514.

Cowardin, L. M., D. H. Johnson, T. L. Shaffer, and D. W. Sparling. 1988. **Applications of a simulation model to decisions in mallard management.** Technical Report Number 17. Fish and Wildlife Service, U.S. Department of the Interior; 28 p.

Cowardin, L. M., T. L. Shaffer, and P. M. Arnold. 1995. **Evaluation of duck habitat and estimation of duck population sizes with a remote-sensing-based system.** Biological Science Report 2. National Biological Service U.S. Department of the Interior; 26 p.

Duebbert, H. F. and J. T. Lokemoen. 1977. **Upland nesting of American bitterns, marsh hawks, and short-eared owls**. Prairie Naturalist 9: 33-40.

Evrard, J. O. and B. R. Bacon. 1998. **Northern harrier nest site characteristics in northwest Wisconsin.** Passenger Pigeon 60: 307-312.

Fielding, A. H., and J. F. Bell. 1997. **A review of methods for the assessment of prediction errors in conservation presence/absence models.** Environmental Conservation 24: 38-49.

Fitzgerald, J. A., D. N. Pashley, and B. Pardo. 1999. **Partners in Flight bird conservation plan for the northern mixed-grass prairie, version 1.0.** The Plains, VA: American Bird Conservancy; 65 p.

Flather, C. H., and J. R. Sauer. 1996. **Using landscape ecology to test hypotheses about large-scale abundance patterns in migratory birds.** Ecology 77: 28-35.

Freemark, K. E., J. R. Probst, J. B. Dunning, and S. J. Hejl. 1993. **Adding a landscape ecology perspective to conservation and management planning.** In: D. M. Finch and P. W. Stangel, editors. Status and management of Neotropical migratory birds. Gen. Tech. Rep. RM-229. Fort Collins, CO: USDA Forest Service; 346-352.

George, T. L., A. C. Fowler, R. L. Knight, and L. C. McEwen. 1992. **Impacts of a severe drought on grassland birds in North Dakota.** Ecological Applications 2: 275-284.

Haig, S. M., D. W. Mehlman, and L. W. Oring. 1998. **Avian movements and wetland connectivity in landscape conservation.** Conservation Biology 12: 749-758.

Haining, R. P. 1990. **Spatial data analysis in the social and environmental sciences.** Cambridge: Cambridge University Press; 409 p.

Hecht, W. R. 1951. **Nesting of the marsh hawk at Delta, Manitoba.** Wilson Bulletin 63: 167-176.

Herkert, J. R., S. A. Simpson, R. L. Westemeier, T. L. Esker, and J. W. Walk. 1999. **Response of northern harriers and short-eared owls to grassland management in Illinois.** Journal of Wildlife Management 63: 517-523.

Johnson, D. H. 1980. **The comparison of usage and availability measurements for evaluating resource preference.** Ecology 61: 65-71.

Igl, L. D., and D. H. Johnson. 1999. **Le Conte's sparrows breeding in conservation reserve program fields: Precipitation and patterns of population change.** Studies in Avian Biology 19: 178-186.

Kantrud, H. A., and K. F. Higgins. 1992. **Nest and nest site characteristics of some ground-nesting, non-passerine birds of northern grasslands.** Prairie Naturalist 24: 67-84.

Legendre, P. 1993. **Spatial autocorrelation: Trouble or new paradigm?** Ecology 74: 1659-1673.

MacWhirter, R. B. and K. L. Bildstein. 1996. **Northern Harrier (*Circus cyaneus*).** In: A. Poole and F. Gill, editors. The Birds of North America. Philadelphia, PA and Washington, DC: The Academy of Natural Sciences and The American Ornithologists' Union; No. 210.

Madden, E. M., R. K. Murphy, A. J. Hansen, and L. Murray. 2000. **Models for guiding management of prairie bird habitat in northwestern North Dakota.** American Midland Naturalist 144: 377-392.

Manly, B. F. J., L. L. McDonald, and D. L. Thomas. 1993. **Resource selection by animals: Statistical design and analysis of field studies.** London: Chapman and Hall; 177 p.

Marcot, B. G. 1986. **Use of expert systems in wildlife-habitat modeling.** In: J. Verner, M. L. Morrison, and C. J. Ralph, editors. Wildlife 2000: Modeling habitat relationships of terrestrial vertebrates. Madison, WI: University of Wisconsin Press; 145-150.

Niemuth, N. D., and M. S. Boyce. 2000. **Enhanced avian diversity in Wisconsin pine barrens through aggregated timber harvest: A simulation.** Transactions of the North American Wildlife and Natural Resources Conference 65: 184-199.

Niemuth, N. D., and J. W. Solberg. 2003. **Response of waterbirds to number of wetlands in the prairie pothole region of North Dakota.** Waterbirds 26: 233-238.

Porneluzi, P. A., and J. Faaborg. 1999. **Season-long fecundity, survival, and viability of ovenbirds in fragmented and unfragmented landscapes.** Conservation Biology 13: 1151-1161.

Porter, W. F., and K. E. Church. 1987. **Effects of environmental pattern on habitat preference analysis.** Journal of Wildlife Management 51: 681-685.

Reynolds, R. E., D. R. Cohan, and M. A. Johnson. 1996. **Using landscape information approaches to increase duck recruitment in the prairie pothole region.** Transactions of the North American Wildlife and Natural Resources Conference 61: 86-93.

Reynolds, R. E., T. L. Shaffer, J. R. Sauer, and B. G. Peterjohn. 1994. **Conservation Reserve Program: Benefit for grassland birds in the Northern Plains.** Transactions of the North American Wildlife and Natural Resources Conference 59: 328-336.

Reynolds, R. E., T. L. Shaffer, R. W. Renner, W. E. Newton, and B. D. J. Batt. 2001. **Impact of the conservation reserve program on duck recruitment in the U.S. prairie pothole region.** Journal of Wildlife Management 65: 765-780.

Robinson, S. K. 1991. **Effects of habitat fragmentation on midwestern raptors.** In: B. G. Pendleton, D. L. Krahe, M. N. LeFranc, Jr., K. Titus, J. C. Bednarz, D. E. Anderson, and B. A. Millsap, editors. Proceedings of the midwest raptor management symposium and workshop. Scientific and technical series No. 15. Washington, DC: National Wildlife Federation; 195-202.

Rotenberry, J. T., and S. T. Knick. 1995. **Evaluation of bias in roadside point count surveys of passerines in shrub-steppe and grassland habitats in southwestern Idaho.** In: C. J. Ralph, J. R. Sauer, and S. Droege, editors. Monitoring bird populations by point counts. Gen. Tech. Rep. PSW-GTR-149. Albany, CA: Pacific Southwest Research Station, USDA Forest Service; 99-101.

Sauer, J. R., J. E. Hines, I. Thomas, J. Fallon, and G. Gough. 2000. **The North American Breeding Bird Survey, results and analysis 1966-1991.** Version 98.1. Laurel, MD: Patuxent Wildlife Research Center, Geologic Survey, U.S. Department of Interior.

Scott, J. M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T. C. Edwards, Jr., J. Ulliman, and R. G. Wright. 1993. **Gap analysis: A geographic approach to protection of biological diversity.** Wildlife Monographs 123.

Stewart, R. E. 1975. **Breeding birds of North Dakota.** Fargo, ND: Tri-College Center for Environmental Studies; 295 p.

Wiens, J.A. 1973. **Pattern and process in grassland bird communities.** Ecological Monographs 43: 237-270.

Wiens, J. A. 1989a. **Spatial scaling in ecology.** Functional Ecology 3: 385-397.

Wiens, J. A. 1989b. **The ecology of bird communities: Volume 1, Foundations and patterns.** Cambridge: Cambridge University Press; 539 p.

Winter, Thomas C. 1989. **Hydrologic studies of wetlands in the northern prairie.** In: A. van der Valk, editor. Northern prairie wetlands. Ames, IA: Iowa State University Press; 16-54.

Young, J. S., and R. L. Hutto. 1999. **Habitat and landscape factors affecting cowbird distribution in the northern Rockies.** Studies in Avian Biology 18: 41-51.