CHAPTER

Landscape-Level Planning for Conservation of Wetland Birds in the U.S. Prairie Pothole Region

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There are many ongoing, extensive, and well-defined wildlife conservation issues in the Prairie Pothole Region (PPR) of North America. Substantial programs have been developed to address these conservation issues in the United States portion of the PPR. These programs require biologically sound and scientifically rigorous tools to provide programmatic accountability as well as guidance for conservation actions. Consequently, conservation scientists have developed an integrated process of model development and application that encompasses biology, social issues, ecological threats, program delivery, landscape management, and public policy. We describe a portion of that process as it is applied to conservation of wetland-dependent birds such as waterfowl, waterbirds, and shorebirds, and we have illustrated the process using examples of spatial models for five species of upland-nesting ducks (*Anas* spp.), sora (*Porzana carolina*), and marbled godwit (*Limosa fedoa*). Our emphasis is on conservation as a process, and we have included considerable background information that we feel is necessary to convey the importance of context and program delivery to developing effective models for conservation at broad spatial scales.

THE PRAIRIE POTHOLE REGION

The PPR is located in the north central part of North America where areas of high wetland density intersect with grasslands of the northern Great Plains (Fig. 20-1). "Pothole" basins in the PPR are of glacial origin and contain a variety of wetland types ranging from wet meadows and shallow-water ponds to saline lakes, marshes, and fens (Cowardin et al. 1979, Kantrud et al. 1989). Most wetlands in

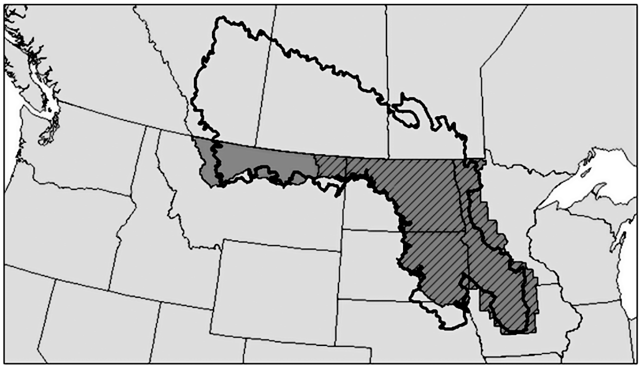

FIG. 20-1

Location of the Prairie Potholes Bird Conservation Region (black outline), which approximates the Prairie Pothole Region of North America. The U.S. Prairie Pothole Joint Venture is shown in dark gray; cross-hatching identifies the primary working area within the PPJV.

the PPR are < 0.5 ha in size, and wetland density exceeds 40 per km^2 in some areas (Kantrud et al. 1989). The numerous wetlands of the PPR help make it the most productive area for waterfowl in North America, hosting >50% of the continent's surveyed populations for 8 of 12 waterfowl species found in the region (Batt et al. 1989). The North American Waterfowl Management Plan (NAWMP; North American Waterfowl Management Plan Committee 1986) identified the PPR as the continent's top priority for waterfowl conservation and emphasized the need for innovative, landscape-level conservation strategies.

The myriad wetlands also make the PPR valuable to a host of other wetland-dependent species, especially waterbirds. Although population data for waterbirds are imperfect, the PPR appears to harbor ~70% of the continental population of Franklin's gull (*Larus pipixcan*); >50% of the continental population of pied-billed grebe (*Podilymbus podiceps*), American bittern (*Botaurus lentiginosus*), sora, American coot (*Fulica americana*), and black tern (*Chlidonia niger*); and ~30% of the continental population of American white pelican (*Pelecanus erythrorhynchos*) and California gull (*Larus californicus*; Beyersbergen et al. 2004). Grasslands in the PPR complement wetlands, as many species of wetland birds nest in surrounding grasslands, and nesting success of many species of grassland-nesting birds increases with amount of grass in the landscape (Greenwood et al. 1995, Reynolds et al. 2001, Herkert et al. 2003, Stephens et al. 2005).

CONSERVATION EFFORTS

Loss and degradation of wetland and upland habitats are the primary conservation issues affecting wetland birds in the PPR (Beyersbergen et al. 2004). Settlement by Europeans greatly transformed the PPR, largely through conversion of native grasslands and wetlands to agricultural fields. As a consequence, populations of most species of wetland birds have declined from historic levels, and habitat is considered the limiting factor for populations of most wetland bird species in the region. Accordingly, primary conservation treatments in the PPR are protection of existing wetlands and grasslands through purchase of conservation easements and restoration of degraded or converted wetlands and grasslands.

Conservation efforts in the PPR began in earnest in 1934, with passage of the Migratory Bird Hunting Stamp ("Duck Stamp") Act. Money from Duck Stamps went into the Migratory Bird Conservation Fund (MBCF), which was used to buy National Wildlife Refuges, and, since 1958, Waterfowl Production Areas in the form of fee-title acquisitions and purchase of wetland and grassland easements. Since 1989, when Congress passed the North American Wetlands Conservation Act (NAWCA) to provide funding to implement the NAWMP, the bulk of conservation efforts for permanent habitat in the PPR have been funded by the MBCF, NAWCA, and nonfederal match for NAWCA funds. Presently, approximately $13 million is spent annually on waterfowl conservation in the U.S. PPR, with about $11 million coming from the MBCF and the remainder from NAWCA. Ducks Unlimited and state wildlife agencies are the primary providers of matching funds for NAWCA grants.

Identification of priority conservation areas within the PPR is important given limited conservation funds and the large area, diversity of landcover, and variation in bird distribution and density within the region. Early conservation efforts in the PPR were largely opportunistic and focused on waterfowl. Following establishment of the NAWMP, the Prairie Pothole Joint Venture (PPJV) was formed as a regional, cooperative entity to coordinate waterfowl management by member groups and agencies in the U.S. PPR. Two Habitat and Population Evaluation Team (HAPET) offices were created in 1989 to provide strategic guidance for conservation in the PPJV; the modeling and conservation planning process we describe is the approach taken by these offices.

APPROACH TO CONSERVATION PLANNING

Realities of Conservation

Landscape-level conservation planning for wetland birds is complicated by a variety of social, ecological, and programmatic issues. The PPR landscape and economy are dominated by agriculture, which greatly influences conservation needs, opportunities, and implementation. Wetlands are viewed by some landowners as an impediment to farming, and these individuals may have little appreciation for, or even an active dislike of, some wildlife, wetlands, and conservation programs (Leitch 1989). On the other hand, grasslands and wetlands provide forage and water for cattle, and many ranchers in the region are supportive of efforts to maintain these habitats and are willing cooperators in conservation programs. Therefore, maintaining grasslands in the landscape has direct benefits for wetland conservation as well as the ranching community. However, government subsidies create financial incentives to raise commodity crops (i.e., corn, soybeans) instead of cattle, which have led to plowing of grasslands and draining or degradation of wetlands.

Land use and conservation issues vary across the PPR. Some physiographic regions such as the Agassiz Lake Plain along the Minnesota/North Dakota border are heavily cultivated and have virtually no wetlands or grasslands remaining. Landscapes such as these require extensive habitat restoration, although high land prices and competing land uses limit what can be accomplished. Other parts of the PPR have considerable areas of intact wetlands and/or grasslands that are used for cattle ranching or operations that include both cattle and crop agriculture. These landscapes are more conducive to conservation of existing habitat, which is invariably cheaper than habitat restoration; however, some conservation programs have funding dedicated to habitat restoration. Therefore, all landscapes and treatments are considered when planning for conservation action. The HAPET approach is to identify the best conservation treatment for every location based on landscape characteristics and the best location for every appropriate conservation treatment.

Water conditions in the PPR vary greatly over time and space (Fig. 20-2), which influences density and distribution of waterfowl (Stewart and Kantrud 1973, Brewster et al. 1976) and other waterbirds (Alisauskas and Arnold 1994, Peterjohn and Sauer 1997, Niemuth and Solberg 2003; Fig. 20-2). Consequently, areas that may experience high use by wetland birds one year may be completely unsuitable a few years later simply because of lack of water. Finally, limited funding also constrains conservation efforts in the PPR. Even though the PPJV's efforts have been expanded to include all priority migratory bird species that routinely inhabit the region, expanded commitments have not been met with corresponding new funding and the vast majority of funding historically and presently comes from and is directed toward waterfowl.

Model Development and Integration

Most conservation efforts in the PPR focus on protection and restoration of grasslands and wetlands, and there is great potential for providing benefits for multiple species. We developed standalone, single-species models because of the targeted nature of funding and because diversity metrics are often inappropriate as a response variable in models for conservation planning (Conroy and Noon 1996, Villard et al. 1998, Goldstein 1999). This approach allows targeting of locations and treatments to address different needs (e.g., preservation, restoration, or enhancement of wildlife habitat) for any focal species, combination of species, or program. This approach also allows for rapid response to requests for specific decision support (see Johnson et al., this volume), is conducive to adaptive changes in models as new information becomes available, and maximizes ability

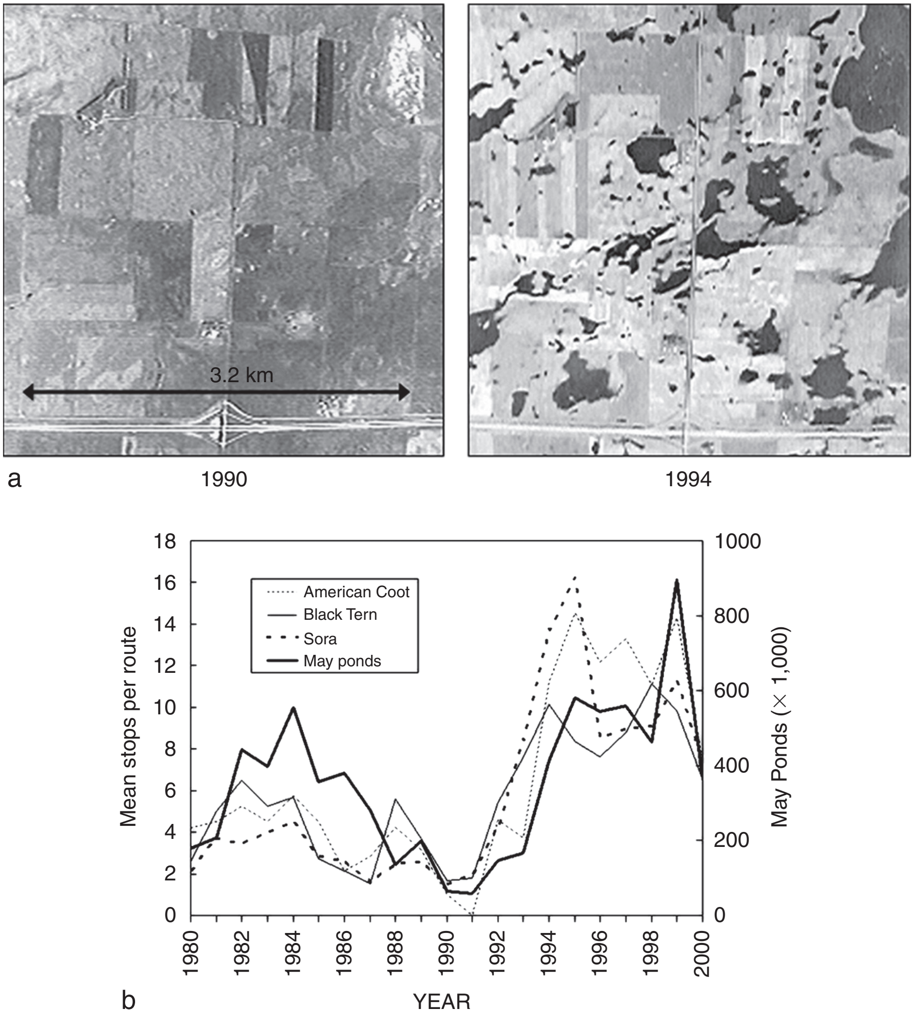

FIG. 20-2

(A) Aerial videograph of Four-Square-Mile Survey Plot 182 in central North Dakota, USA, in 1990 and 1994; note highway interchange at bottom of videographs. (B) Variation in estimated number of May ponds and number of Breeding Bird Survey stops on which waterbirds were detected in north-central North Dakota, 1980–2000 (Niemuth and Solberg 2003).

to integrate programs and species while maintaining biological integrity of models used as conservation planning tools. Spatial tools may vary depending on location and are developed to meet specific needs of partners and programs. We believe the philosophy of separate planning and integrated action allows maximum flexibility while maintaining biological integrity of models. This approach also preserves the unique priorities and objectives of conservation partners, as opposed to an approach where partners may be pressured to work only in areas of overlap identified for multiple species. Promoting conservation actions only in areas of maximum species overlap (i.e., a local species richness approach) can lead to "conservation mediocrity" and is often inconsistent with the greater need to conserve biodiversity at the continental and ecosystem scales.

Spatial models developed for conservation planning in the PPR incorporate different types of biological responses; unfortunately, costs of acquiring data used to parameterize models typically increase with the usefulness or completeness of the response (Fig. 20-3A). The type of model developed for conservation

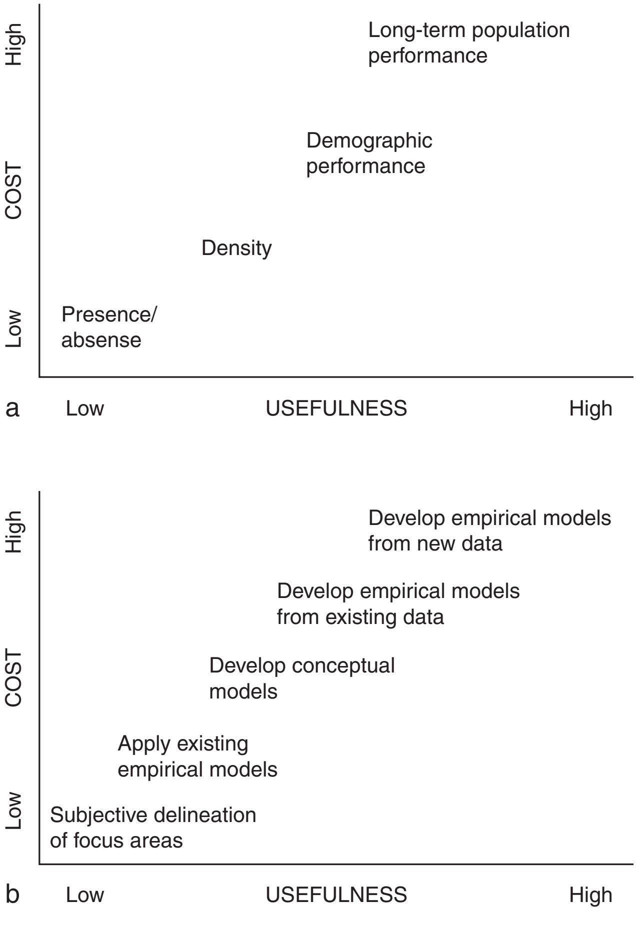

FIG. 20-3

General relationships between usefulness and cost for (A) various levels of biological response used in spatial models and (B) methods of developing spatial models.

planning in the PPR depends primarily on the question being asked and resources available for data collection and model development (Fig. 20-3B). We use presence-absence data and logistic regression for identifying potential habitat when species occur in low numbers or when more comprehensive data are not available. When count data are available, we use linear or Poisson regression to model densities of birds across the landscape with the understanding that high density does not necessarily indicate habitat quality. However, if habitat quality is defined as the product of density, survival, and reproduction vital rates (Van Horne 1983), models predicting density are valuable as a component of that definition, particularly when used in combination with additional information that provides some indication of population response such as survival or nesting success. In addition, models of bird abundance help ensure that assessments of risk or expenditure of limited conservation resources consider many, rather than few, birds. Our goal is to create biologically and scientifically sound empirical models, developed at appropriate scales and meeting specific purposes. Finally, we ensure that our models are of sufficiently fine spatial and temporal resolution that they can provide guidance at the scale at which conservation actions take place, and we acknowledge the assumptions and limitations inherent to modeling (see Johnson et al., this volume). In the absence of data suitable for developing empirical models, we have found considerable value in using conceptual models to assess landscapes (Niemuth et al. 2005) and aid in the identification of assumptions and knowledge gaps (also see Dijak and Rittenhouse, this volume; and Fitzgerald et al., this volume for applications of habitat suitability models). In this chapter, we illustrate the development of empirical models for waterfowl and marbled godwit using field data collected through our offices; the development of empirical models for sora using Breeding Bird Survey (BBS) data; and the development of a conceptual model for marbled godwit. These models follow a generalized hierarchy of usefulness and cost (Fig. 20-3B).

Data Availability and Quality

Reliable wetland and landcover data are the foundation of all these modeling efforts. We used the National Wetlands Inventory (NWI) digital database, which is based on the Cowardin et al. (1979) wetland classification system, and provided finer thematic and spatial resolution for wetlands than was possible using available satellite imagery. National Wetlands Inventory data for our study region are based on aerial photographs collected in the late 1970s and early 1980s; a 2005 evaluation of wetland loss in North Dakota and South Dakota indicates that <3% of wetland basins identified by NWI showed indications of new surface drainage since aerial photography was collected (C. R. Loesch, U.S. Fish and Wildlife Service, unpublished data). Aerial photography used by the NWI was collected during periods of average precipitation. Some very small wetlands identified by the NWI were delineated by a single point on a map, to which we assigned a buffer of 7.6 m, creating a polygon with an area of 0.015 ha. The NWI delineated different water regime and vegetation zones, when present, within large wetlands. In these cases we created wetland basin polygons identified by the most permanent water regime within each basin (Cowardin et al. 1995, Johnson and Higgins 1997). Our final classes were temporary, seasonal, semipermanent, permanent, and riverine wetland basin polygons, which we used in the models. National Wetland Inventory data were not available for all of Montana, which is why our primary working area did not include all of the PPR in Montana.

For the sora and marbled godwit models, we used landcover data derived from Thematic Mapper satellite images (30 m resolution) acquired from May 1992 through September 1996. Individual images were classified, upland landcover classes were resampled to 2.02 ha minimum mapping unit, and NWI basin data were integrated into the grid with a 0.09 ha minimum size of individual wetland basins (Table 20-1). User accuracy for all images exceeded 80% (U.S. Fish and Wildlife Service, unpublished data). Biological response (i.e., bird) data were collected at scales and times appropriate to the questions being addressed in models and are discussed in the following sections.

Conservation Planning for Ducks

An early priority of the PPJV was development of tools to identify priority areas for waterfowl conservation efforts. In this chapter, we summarize the waterfowl modeling work of Reynolds et al. (2006) and compare their results to models developed for sora and marbled godwit. Modeling efforts focused on five species of upland-nesting ducks because of their high numbers in the PPR and importance to continental harvest: blue-winged teal (*Anas discors*), gadwall (*A. strepera*), mallard (*A. platyrhynchos*), Northern pintail (*A. acuta*), and Northern shoveler (*A. clypeata*). For a complete description of field methodology and model development as it was applied in North Dakota, South Dakota, and northeastern Montana, see Cowardin et al. (1995), Reynolds et al. (1996), and Reynolds et al. (2006); data collection and model development were similar in the U.S. Fish and Wildlife Service (USFWS) Region 3 (Minnesota and Iowa) portion of the PPR (R. R. Johnson, unpublished data).

Conservation Planning for Waterbirds and Shorebirds

Relatively little information exists regarding relationships between nonwaterfowl birds and landscapes (Scott et al. 1993, Flather and Sauer 1996), and development of spatial planning tools for nonwaterfowl birds in the PPR lags behind development of spatial planning tools for ducks. Breeding biology, species status, and available data strongly influence the approach taken for model

Table 20-1 Candidate Predictor Variables Used to Model Number of Soras Detected at Breeding Bird Survey Stops in North Dakota, USA. All Landcover Variables were Calculated from Variably Sized Buffers Around BBS Stops

Landscape Variable	Description
Temporary (%)	Percent of wetland area within the buffer composed of temporary wetland basins derived from NWI data.
Seasonal (%)	Percent of wetland area within the buffer composed of seasonal wetland basins derived from NWI data.
Semipermanent (%)	Percent of wetland area within the buffer composed of semipermanent wetland basins derived from NWI data.
Wetland variety (n)	Number of different wetland water regimes (temporary, seasonal, etc.) within moving window.
Wetland number (n)	Number of wetland basins within moving window.
Wetness (%)	Percent of area of seasonal and semipermanent wetland basins containing water, interpolated from >23,000 basins videographed during 1995 waterfowl surveys (see Reynolds et al. 2006) in North Dakota, South Dakota, and eastern Montana.
Undisturbed Grass (%)	Percent of buffer composed of mix of cool-season grass and forb species planted on previously cropped land; generally undisturbed but may be hayed or grazed intermittently. Includes CRP plantings and dense nesting cover on waterfowl production areas.
Forest (%)	Percent of buffer composed of forest cover within each buffer.
Northing	Universal Transverse Mercator coordinate indicating north-south position. Also included as quadratic term.
Easting	Universal Transverse Mercator coordinate indicating east-west position. Also included as quadratic term.
Observer	Identifier for each observer, coded as 0/1 binary variable.
Stop Number	Number (1–50) of stop within each route.

development and conservation of traditional waterbird species in the PPR. For example, American white pelican and Franklin's gull are highly colonial and typically nest in the same few locations each year. Conservation of habitat for these species is simplified, as their nesting sites are generally known and, in most cases, already protected. Species such as sora and black tern are more broadly distributed across the landscape, and their distribution and density can vary greatly among years. Therefore, we have adopted a landscape approach to modeling and conservation of species such as these. Because population size of most waterbird species in the PPR is poorly known, conservation scientists have not set numeric population goals but instead strive for "no net loss" of populations through conservation of existing habitat (Beyersbergen et al. 2004). Populations and ranges of several species of shorebirds breeding in the PPR also are shrinking as wetland and grassland habitats are lost; for marbled godwit, planners have set a tentative population target of a 35% increase (commensurate with past habitat loss) over a present estimate of 168,000 in the Great Plains subpopulation (Brown et al. 2000).

We used stop-level BBS data in conjunction with landcover information to model correlates of the number of soras detected at BBS stops in the PPR portion of North Dakota in 1995; we did not model soras in South Dakota due to limited BBS coverage in that state. Because seasonal timing of the BBS (Bystrak 1981) was suspected of being suboptimal for detecting species such as marbled godwit, we used data from a regional survey of breeding shorebirds instituted by the Bismarck HAPET office to develop a similar landscape-level model predicting presence of marbled godwits. Empirical models presented in this chapter that predict density and distribution of sora and marbled godwit are examples based on one year of data; in practice, models from multiple years are used to reduce variation caused by changes in moisture and wetland conditions among years. Spatial and temporal variation in bird numbers reinforces the importance of long-term data sets collected over broad spatial extents to effective conservation planning in the PPJV.

MODELING SPECIES ABUNDANCE AND DISTRIBUTION

Waterfowl Models

Following methodology detailed in Reynolds et al. (2006), we sampled waterfowl annually from 1987–1998 on 626 10.4 km^2 primary sampling blocks that were stratified based on the area of land that the USFWS owned or had under easement in the surrounding 93.2 km^2 township (Cowardin et al. 1995). We randomly selected approximately 4,435 wetland basins from within the primary sampling blocks that we visited twice each year, once from 1 May–15 May and again from 20 May–5 June; we matched data with peak occurrence of each species (Reynolds et al. 2006; R. R. Johnson et al., unpublished data). Surveyors estimated the percentage of surface area of each wetland basin covered by water by comparing the extent of water observed in wetland basins to mapped NWI wetland boundaries overlaid on aerial photographs. We used these ground data to develop models that incorporated both temporal and spatial variation in wetland condition. We did not include riverine wetlands, which composed <0.03% of wetlands in the study area, in the survey design, but modeled waterfowl presence on riverine wetlands using pair-ratio models from surveys conducted 1983–1986 (Reynolds et al. 2006).

Statistical analysis.—Given the number and distribution of waterfowl observed on wetland basins during surveys, we used linear regression in Montana and the Dakotas (Reynolds et al. 2006) and Poisson regression in Minnesota and Iowa (R. R. Johnson, unpublished data) to relate numbers of duck pairs to wetland and spatial variables. Because models were developed to be applied to approximately 3.3 million wetland basins in the PPJV area, we only considered predictor variables in model development that had been measured remotely for all wetlands. We developed models for each of the five priority species based on the nonlinear relationship identified by Cowardin et al. (1988) between duck pairs and wetland size for the four classes of wetland basins (temporary, seasonal, semipermanent, permanent) considered in analysis. We included Universal Transverse Mercator (UTM) coordinates in analysis because ducks were not distributed evenly throughout the PPR (Stewart and Kantrud 1973). We used backward stepwise procedures to fit each model, deleting terms with $P > 0.05$ in each step (Reynolds et al. 2006).

Model application.—Because ducks use nesting cover away from core wetlands used for feeding and resting (Duebbert et al. 1983), we used published home range characteristics to model potential accessibility of land units surrounding wetlands to female ducks on a species-specific basis (Reynolds et al. 2006). We derived potential accessibility to breeding hens in the region by summing the number of breeding pairs predicted to have access to 390 × 390 m (15.2 ha) land units for the five target species using the ArcInfo GRID module (Environmental Systems Research Institute, Redlands, California). Relationships between ducks and wetlands were described for individual wetland basins, which varied in size, so that portion of the waterfowl model did not have an explicit measure of scale. However, proximity zones used to determine accessibility of land units to breeding hens varied among species and ranged from 1.2 to 4.0 km (Reynolds et al. 2006).

Sora Models

We obtained 1995 data for 27 BBS routes within the PPR portion of North Dakota from the U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. Each 40 km BBS route contained 50 stops, or survey points, 0.81 km apart; details of route placement and sampling were described by Bystrak (1981). 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). We calculated locations for 50 stops on each BBS route by creating a point at the start node of each digitized route and every 0.81 km thereafter to the end of the route.

Because many bird species are influenced by the landscape beyond the area included by traditional bird survey methods (e.g., point-count circles; Howell et al. 2000), we sampled habitat at three scales using circular moving window analysis, which summarizes data within a “window” of a selected size around each 30 × 30 m cell in a raster GIS data layer. The area within each moving window was 48, 191, and 452 ha, respectively, for circles with radii approximating 400, 800, and 1,200 m.

Analyzing BBS data at the stop level allows inferences to be made at a much finer spatial resolution than using BBS data at the route level. However, developing predictive models from stop-level BBS data is complicated by the presence of spatial autocorrelation, which can lead to overestimation of the precision of parameter estimates (Legendre 1993) and obscure ecological patterns (Carroll and Pearson 2000). We addressed several forms of spatial structure and nuisance factors in stop-level BBS data. First, BBS stops are nested within routes, and varying ability of observers (see Sauer et al. 1994) on different routes may result in spatial patterns in detection. Therefore, we included observer identity as a dummy variable (Table 20-1) to incorporate differences in observer ability in our models. Second, detection of some species of birds varies substantially during the daily survey period (Robbins 1981), which begins 0.5 hour before sunrise and typically lasts 4 to 4.5 hours (Bystrak 1981). Thus, birds that are most vocal early in the day are more likely to be found on stops at the beginning of a route than at stops toward the end of a route. We included stop numbers to provide an index to time relative to sunrise (Table 20-1), which enabled incorporation of time-related differences in detection in predictive models. Third, bird distribution across large geographic extents may follow gradients as a consequence of trends in climate and landcover (see O'Connor et al. 1999). Consequently, adjacent stops were more likely to have similar landcover and avifauna than stops farther apart. We included easting and northing UTM coordinates as linear and quadratic terms (Table 20-1) to model broad-scale gradients in bird distribution as trend surface variables (Legendre 1993).

Statistical analysis.—We found that the number and distribution of soras detected on BBS stops in North Dakota in 1995 followed a Poisson distribution, so we used Poisson regression to model the number of soras detected at BBS stops as a function of predictor variables (Table 20-1). We developed a set of candidate models at each of the three scales and then used information-theoretic methods to evaluate how well models were supported by the data at each scale (Burnham and Anderson 1998). Based on previous studies, we assumed that soras would be positively associated with annual precipitation and local water availability; complexes of temporary, seasonal, and semipermanent wetlands; and dense grasslands surrounding wetlands (Kantrud and Stewart 1984, Fairbairn and Dinsmore 2001, Naugle et al. 2001, Niemuth and Solberg 2003). In an attempt to develop a parsimonious model and avoid spurious correlations, we only evaluated main effects of linear relationships, with the exception of the trend surface variables described previously. We assessed models for overdispersion based on goodness-of-fit of the global model, using Akaike's Information Criterion corrected for overdispersion and small sample size (QAIC_c) for model selection and adjusting variance estimates as appropriate (Burnham and Anderson 1998). We considered all models with AIC differences

(Burnham and Anderson 1998) ≤ 4.0; for purposes of this example, we did not average models but used the model that was best supported by the data. We used 80% of the data for model building and 20% for validation. We used Number Cruncher Statistical System (Hintze 2004) for statistical analysis and program PASSAGE (Rosenberg 2003) to assess autocorrelation.

We evaluated spatial dependencies in the data and the ability of models to account for spatial dependencies by creating Moran's *I* correlograms, which evaluate spatial dependence at increasing distances between points (Moran 1950, Legendre and Legendre 1998). Values of Moran's *I* range from –1 to 1 indicating greater levels of negative and positive spatial autocorrelation, respectively. We created correlograms for the amount of seasonal and semipermanent wetland in the landscape, number of soras detected at BBS stops, and residuals from models that incorporated observer effect, stop number, and stop location.

Model application.—We created maps showing predicted number of birds throughout the study region by incorporating GIS layers for habitat and location into the Poisson regression equation for the final model. Because the maximum number of soras detected at any BBS stop in the study area in 1995 was six, we capped predicted values at six individuals. Model output consisted of GIS cells representing the number of individuals predicted to be present at a BBS stop, which we reclassified into 60 categories ranging from 0 to 6 at intervals of 0.1. We then resampled resolution of GIS cells to an area equaling the 125 m effective detection distance assumed by Rosenberg and Blancher (2005).

Marbled Godwit Statistical Models

Prior to instituting the breeding shorebird survey, the Bismarck HAPET office spent two years assessing roadside bias, daily timing of surveys, and seasonal timing of surveys; based on these evaluations, roadside surveys were adopted. Survey routes were 40 km long and were randomly located within physiographic strata. Surveys were similar to the BBS in that stops were 0.8 km apart, were surveyed for three minutes, and included birds within a 400 m radius, but differed from the BBS in that surveys started at sunrise, routes were sampled once in early May and once in early June, and only breeding shorebirds were recorded.

Statistical analysis.—Methodology and landscape data were similar to that used to develop the sora model except that observer effects, stop number, and annual wetness were not included in models, as marbled godwit numbers do not appear to fluctuate with water conditions and we did not expect marbled godwit detection to be strongly influenced by time of day or observer ability. Given the low numbers of stops on which marbled godwits were detected and the low numbers of marbled godwits detected, we modeled probability of detecting marbled godwit using logistic regression, which models a binary response (detection/nondetection per stop, in this case); we developed models separately for North Dakota and South Dakota. We evaluated goodness of fit (Hosmer and Lemeshow 2000) of the global model and receiver operating characteristics (ROC) plots to indicate how models performed on data with which they were built, with the caveat that absolute use or nonuse at stops was not known. Receiver operating characteristics scores range from 0 to 1 and indicate the ability of a model to discriminate between two groups; a score of 0.5 indicates random performance and higher values indicate better discrimination (Hosmer and Lemeshow 2000).

Model application and comparison of models.—We applied the marbled godwit model using techniques similar to those described for soras. Model output consisted of GIS cells representing the relative probability of a marbled godwit being detected at a shorebird survey stop. Finally, we examined similarity in areas identified as high priority/density by the marbled godwit, sora, and waterfowl models. We calculated the correlation between GIS grid layers of the North Dakota portion of the PPR for all pair-wise combinations of the three models.

Marbled Godwit Conceptual Model

In the absence of data suitable for developing statistical models, conceptual models can provide guidance for conservation efforts (Fig. 20-3B). To identify important breeding sites for marbled godwits in Minnesota, the USFWS Region 3 HAPET met with marbled godwit experts from state and federal agencies in Minnesota. By leading the group on a tour of habitats ranging from suitable to unsuitable, essential elements of breeding godwit habitat patches and landscapes were identified. We formalized these concepts into rules (Table 20-2), and applied the rules to elevation, NWI, and classified landcover data.

Table 20-2 Parameters Used in a Conceptual Model to Predict Marbled Godwit Habitat Quality in Minnesota, USA

Scale	Characteristic	Criteria
Patch	Size	$\geq$ 130 ha: $\geq$ 400 m wide – required $\geq$ 800 m wide – better
	Wetlands	$\geq$ 1.6 ha of temporary or saturated wetlands per 130 ha patch; predicted quality did not increase with additional wetlands
	Trees	>100 m between patch and trees
Landscape	Percent grass (3.2 km radius)	10–30% – required >30% – better
	Topography (535 m radius)	$\geq$4% average slope – poor $\leq$3% average slope – better

RESULTS AND CHARACTERISTICS OF MODELS

Waterfowl Models

Waterfowl response to wetland basins varied both spatially and temporally among species and water regimes as described in Reynolds et al. (2006) with similar responses in Minnesota and Iowa (R. R. Johnson, unpublished data). In general, the number of duck pairs per unit of wet area increased from south to north and from east to west for all wetland classes; number of pairs increased nonlinearly, with higher densities on smaller wetlands (Reynolds et al. 2006). Cross-validation indicated that these models performed substantially better than models that did not account for spatial variation or nonlinearity. Models predicting the number of pairs on individual wetlands had R^2 values of approximately 0.30; this value increased to 0.88 when predicting total number of pairs occupying wetlands on landscapes of 41.6 km^2 (Reynolds et al. 2006). When we applied regression coefficients to the corresponding GIS layers, summed accessibility, and displayed results, the model resembled a radar image of a thunderstorm weather system crossing the region and was called the "Thunderstorm Map" (Fig. 20-4).

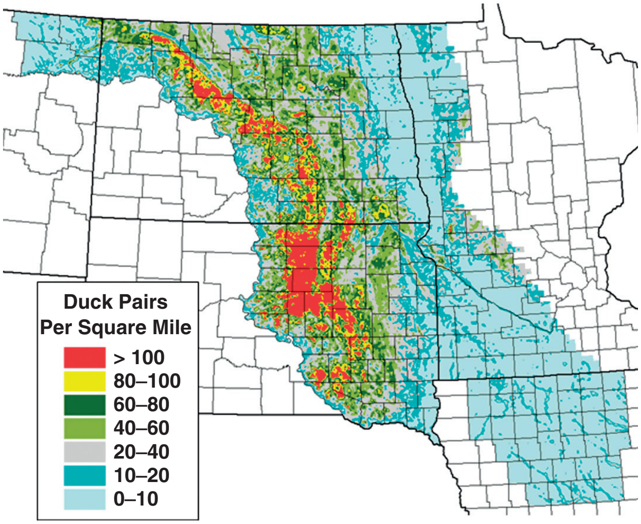

FIG. 20-4

Results of applying duck pair-wetland regression models to wetland basins, pair ratio models to riverine wetlands, and accessibility models to 390 × 390 m (15.2 ha) land units to the primary working area within the Prairie Pothole Region of the United States. This figure (referred to as the "Thunderstorm Map") shows which land units would be accessible to different densities of nesting hens and, thus, where grassland conservation efforts would provide the greatest benefits. Results are presented as pairs per km^2 for proximity zones around each land unit, where the area of proximity for each of five upland-nesting duck species was the approximate distance hens have been known to travel from core wetlands to nesting cover (derived from Reynolds et al. 2006; and R. R. Johnson, unpublished data).

Even though the model was developed using wetland data, the results (potential number of duck pairs in a community of wetlands with access to land units) are used to target uplands with potential for access by high numbers of nesting hens.

Sora Model

The area of seasonal and semipermanent wetlands within 800 m of BBS stops showed strong positive spatial autocorrelation (Fig. 20-5A), as did the number of soras (Fig. 20-5B). The number of birds detected per stop ranged from 0 to 6, with 365 soras detected at 238 of the 1,080 stops in the model-building data set. In addition to being influenced by observer ability, time of day, and location, the number of individuals detected was positively associated with amount of water in wetland basins; area of temporary, seasonal, and semipermanent

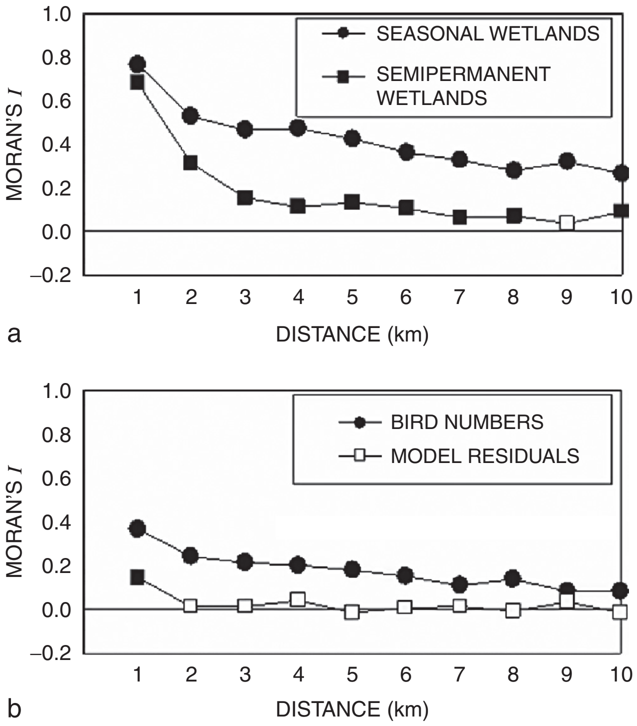

FIG. 20-5

(A) Moran's *I* correlograms for amount of seasonal and semipermanent wetlands within 800 m of 1,350 North Dakota Breeding Bird Survey stops. (B) Moran's *I* correlograms for number of soras detected at Breeding Bird Survey stops in 1995 (circles) and residuals from model including habitat, trend surface, observer, and time of day variables (squares). Filled symbols denote statistically significant ($P < 0.05$) positive spatial autocorrelation.

wetlands; area of undisturbed grass; number of wetland basins; and variety of water regimes in the surrounding landscape (Equation 1; nuisance factors such as observer effect and time of day not presented). There was little model uncertainty, as the best model had an AIC weight of 0.85, and the only other competing model with an AIC difference ≤ 4.0 had an AIC weight of 0.15. The rank of candidate models was similar but with consistent differences in AIC values, among scales, with lowest AIC values at the 800 m scale.

$$\begin{aligned}\text{Soras} = \text{Exp}(&-38.18 - (5.76\text{E-}6 * \text{East}) + (5.78\text{E-}6 * \text{North})\\ &+(0.1 * \text{Temporary}) + (0.09 * \text{Seasonal}) + (0.05 * \text{Semipermanent})\\ &+(0.17 * \text{Wetland variety}) + (0.013 * \text{Wetland number}) + (0.11 * \text{Wetness})\\ &+(0.008 * \text{Undisturbed Grass}) - (0.007 * \text{Forest}))\end{aligned} \quad (20\text{-}1)$$

The final model fit moderately well ($R^2 = 0.33$); as expected, predicted numbers were significantly ($P < 0.0001$) correlated with actual number of birds detected in the validation portion of the data, although the correlation coefficient was low (0.37). Inclusion of trend surface, observer effect, moisture, and time-of-day terms substantially improved model fit and reduced positive spatial autocorrelation in residuals (Fig. 20-5B). Spatial patterns in density are readily discernible on the map showing estimated number of individuals (Fig. 20-6).

Marbled Godwit Models and Comparison of Statistical Models

Participants observed marbled godwits at 144 (11.5%) of 1,250 stops along 25 survey routes in North Dakota and 32 (3.8%) of 850 stops along 19 survey routes in South Dakota. Some model uncertainty existed, particularly in South

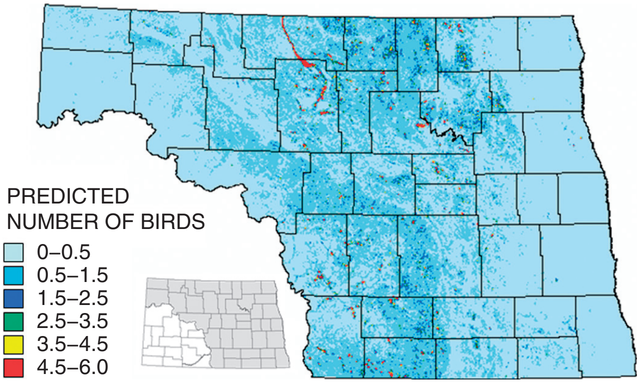

FIG. 20-6

Number of soras predicted to be present per 5-ha unit in the Prairie Potholes Bird Conservation Region portion of North Dakota, USA, in 1995 as a function of landscape-level spatial model. Low numbers relative to waterfowl model (Fig. 20-4) are due in part to different spatial scales used in model output.

Dakota, although competing models within states were similar (Table 20-3). Even though marbled godwits were more frequently observed in North Dakota, parameter estimates from final models indicated that marbled godwits showed similar responses to landscape characteristics in analyses for both states (Table 20-4); the lack of discontinuities along the North Dakota/South Dakota state line (Fig. 20-7A) reinforces the similarity in results. Final models performed well, with ROC scores of 0.74 and 0.82, for North Dakota and South Dakota, indicating acceptable and excellent discrimination, respectively (Hosmer and Lemeshow 2000). Models performed best using variables sampled with an 800-m window.

Areas of high predicted occurrence of marbled godwits in the PPR of North Dakota and South Dakota generally coincided with areas identified as having high potential waterfowl density (Fig. 20-7). Predicted presence of marbled godwits was positively correlated with predicted waterfowl accessibility (r = 0.55)

Table 20-3 State, AIC differences (Δ_i), variables included in model, number of parameters (K), and AIC weights (w_i) for logistic regression models predicting detection of marbled godwits in North Dakota and South Dakota

State	(Δ_i)	Variables in model	K	(w_i)
ND	0.0	East, north, grassland, temporary, seasonal, semipermanent	7	0.58
ND	2.0	East, north, grassland, temporary, seasonal, semipermanent, forest	8	0.21
ND	2.0	East, north, grassland, temporary, seasonal, semipermanent, number of wetlands	8	0.21
SD	0.0	East, north, grassland, temporary, seasonal, semipermanent, forest	8	0.44
SD	1.0	East, north, grassland, temporary, seasonal, semipermanent, forest, variety of wetlands	9	0.27
SD	2.0	East, north, grassland, temporary, seasonal, semipermanent, forest, number of wetlands	9	0.16
SD	2.5	East, north, grassland, temporary, seasonal, semipermanent	7	0.13

Table 20-4 Parameter Estimates for Landscape-Level Logistic Regression Models Predicting Detection of Marbled Godwits in North Dakota and South Dakota. Variable Labels Follow those of Table 20-1

State	Intercept	East	North	Grassland	Temporary	Seasonal	Semiperm.	Forest
ND	41.3	-8.6E-6	-7.3E-6	0.006	0.23	0.09	0.07	
SD	-14.1	-1.1E-5	3.7E-6	0.007	0.08	0.09	0.07	-4.3

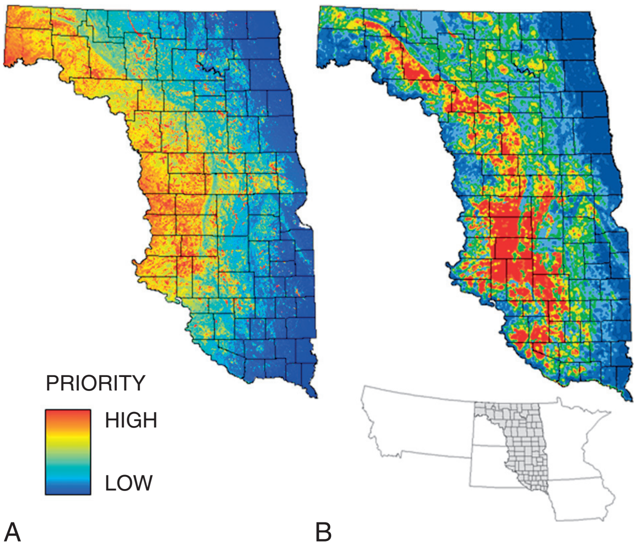

FIG. 20-7

(A) Predicted distribution of marbled godwit in the Prairie Pothole Region of North Dakota and South Dakota, USA, in 2004, where landscapes with high probability of detecting marbled godwits are given high priority. (B) Breeding duck "Thunderstorm Map" from Fig. 20-5 for the same geographic region and using same color scheme as (A); priority in this example was defined by number of five species of waterfowl predicted to have access to 390 × 390 m land units. Southern South Dakota is outside the range of marbled godwit; hence, predicted marbled godwit presence is low even though predicted duck numbers are high.

and modeled sora density in North Dakota ($r = 0.40$); predicted densities of sora and waterfowl also were positively correlated ($r = 0.42$; $P < 0.001$ in all cases).

The conceptual model developed for marbled godwit conservation in Minnesota identified areas most likely to support breeding marbled godwits and areas with varying potential for habitat restoration (Fig. 20-8A). Although the model was knowledge (versus data) driven, independent surveys and ancillary data correlated well with the model output (Fig. 20-8B).

APPLICATIONS TO CONSERVATION

The models we have described, particularly the waterfowl model and its derivatives, are the primary tools used to guide the annual expenditure of millions of dollars for acquisition of conservation easements within the PPJV. The primary criterion for acquiring a grassland easement in the PPJV is that the property to be acquired falls within a zone having ≥25 pairs of waterfowl per square mile (2.6 km^2) as identified by the Thunderstorm Map. In addition, the Thunderstorm Map is used to identify areas with high potential to attract nesting pairs but little

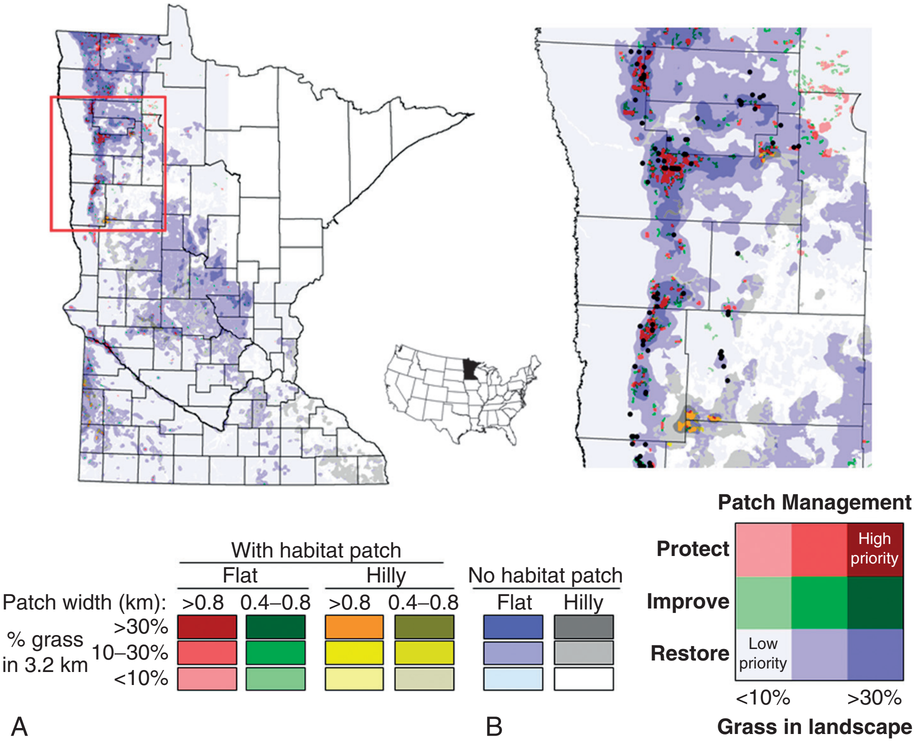

FIG. 20-8

(A) Conceptual model for marbled godwit habitat quality in Minnesota, USA, driven by expert knowledge. Dark red areas indicate the full complement of requirements are met and should be protected; purple areas would require restorations to meet species needs (i.e., patch development: increase grass patch size, wetland restoration within patch, etc.). Yellow and colorless areas should not be targeted for godwit management because of the godwit's preference for low-relief areas. (B) Portion of conceptual marbled godwit model in northwestern Minnesota showing location (◉) of marbled godwits observed along *ad hoc* roadside survey.

grassland cover to target for upland treatments such as grassland restoration. Finally, the Thunderstorm Map has been used by the U.S. Government Accountability Office (GAO; 2007) to evaluate the cost effectiveness of easements acquired by the U.S. Fish and Wildlife Service. As mentioned previously, models predicting density are particularly valuable when used in combination with additional information that provides an indication of population response such as survival or nesting success. Because waterfowl nesting success increases with the amount of grass in the landscape (Greenwood et al. 1995, Reynolds et al. 2001, Stephens et al. 2005), typical conservation treatments include acquisition of easements on grasslands in areas with high potential waterfowl accessibility or restoration of grasslands in areas with high potential duck numbers but little grassland.

Conservation models such as those we have described are not only useful for identifying areas for conservation action, but also allow assessment of how past conservation actions have benefited other species, identification of areas of overlapping priority, assessment of past and ongoing habitat loss, and estimating the relative impacts of wetland versus upland habitat change. As Fig. 20-7 and the correlations demonstrate, priority landscapes for waterfowl, sora, and marbled godwit in our region are similar, and it is likely that sora and marbled godwit have benefited substantially from waterfowl conservation efforts. Waterfowl production areas and conservation easements protect >2.7 million acres of wetlands and grasslands in the PPJV (Beyersbergen et al. 2004). These wetland and grassland complexes, protected primarily through waterfowl conservation dollars, have conserved substantial amounts of habitat for many species of nonwaterfowl birds (Fig. 20-9; Naugle et al. 2001). Of course, species vary in their

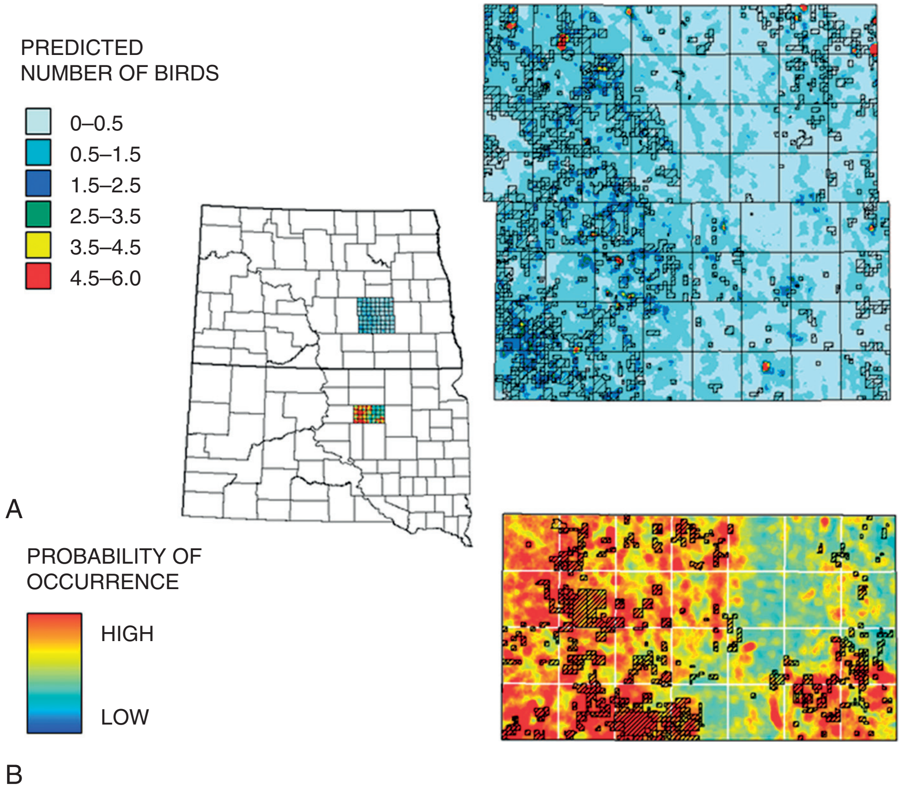

FIG. 20-9

(A) Waterfowl Production Areas and wetland easements (black hatching) overlaid on map of predicted number of soras in Stutsman County, North Dakota. (B) Waterfowl Production Areas and grassland easements (black hatching) overlaid on map of predicted probability of occurrence of marbled godwit in Faulk County, South Dakota. Gridlines in both maps indicate civil townships at 10 km intervals.

habitat requirements and not all species will show as much overlap as the species we have presented here. For the most part, conservation needs in the PPR are simple: Preserve and enhance wetlands and grassland where they exist and restore wetlands and grasslands where they have been converted to other uses. But that simplicity quickly disappears when multiple management treatment types (e.g., wetland protection, riparian restoration, etc.) with varying costs and opportunities are considered for multiple species over a broad geographic region. Spatial models enable conservation scientists to assess these factors and identify gaps in coverage as well as areas of overlap, with the goal of maximizing the benefits of conservation programs in the PPR. Spatially and biologically explicit models also allow critical examination of costs and benefits of proposed policies and programs.

Policy and Management Implications

Despite the relative simplicity of conservation needs in the PPR, current conservation efforts appear insufficient to maintain present levels of habitat. Spatial models such as we have described are useful in that they help prioritize and target areas for conservation, thus increasing efficiency of conservation efforts. But conservation in the PPR is not limited by lack of planning tools such as the spatial models we have described or the innumerable planning documents that are the devil's spawn of various conservation initiatives. Conservation is limited by funding to conserve and restore habitat. Wetland-dependent birds in the PPR have benefited greatly from agricultural programs such as the Conservation Reserve Program (CRP) and the "Swampbuster" provision of the 1985 U.S. Food Security Act (Johnson et al. 1996, Reynolds et al. 2001, Beyersbergen et al. 2004, Niemuth et al. 2006). In the absence of substantial increases in conservation funding, continuation and expansion of wildlife-friendly agricultural policy count as the single factor that can provide the greatest benefit to wetland bird populations in the PPR. Limited resources and competing demands for land will require strategic application of such programs to increase benefits to wildlife. Spatial models are ideal for such applications (Reynolds et al. 2006) and are being used to target enrollment of lands in the CRP across the PPR (Farm Service Agency 2006) and the Wetland Reserve Program in Minnesota (R. R. Johnson, personal observation). Spatial models also will be useful for strategic targeting of landscapes for wildlife benefits in other programs, such as enrollment of wetlands and grasslands in future carbon sequestration programs.

Wildlife management in the PPR is complicated by several factors. First, because the majority of the land in the PPR is privately owned and used for agricultural production, cooperation with private landowners will be essential to continued conservation efforts in the region. Second, many wetland bird species in the region respond to wetland and grassland complexes at a landscape scale (Naugle et al. 2001, Reynolds et al. 2001, Niemuth et al. 2006). Conservation treatment and management actions need to consider landscape context and may involve many landowners, as well as a variety of governmental and nongovernmental agriculture and conservation programs. Finally, even though waterfowl conservation efforts have conserved substantial amounts of habitat used by nongame species, the value of waterfowl conservation to nongame species is sometimes questioned. Additional, nonwaterfowl funding will be necessary to meet the conservation needs of all priority species in the region. These considerations, and others, further emphasize the need for a cooperative approach to conservation in the PPR.

FUTURE DIRECTIONS

Considerable uncertainty exists regarding future directions for wetland bird conservation in the PPR, as several factors indicate that avian distribution, land use, and conservation issues are likely to change in the future. Potential effects of global climate change in the PPR are poorly understood, but likely will influence water conditions and wetland distribution by altering precipitation and evapotranspiration levels (Johnson et al. 2005). Agricultural land use in the region likely will intensify as native prairie continues to be converted to cropland and genetically modified crops are planted to help meet increasing demands for food commodities and biofuels (Higgins et al. 2002, Krapu et al. 2004). The extent and degree of these changes may be shaped by federal farm programs, which greatly influence conservation in the region (Johnson and Igl 1995, Johnson et al. 1996, Reynolds et al. 2001), and are in turn influenced by a host of political and economic factors. Spatial models will be necessary to assess and address the effects of these, and other, changes as they influence conservation delivery in the PPR.

Several factors could substantially improve future modeling efforts and our ability to increase efficiency of conservation planning in the PPJV. High priority should be given to the acquisition of more and better bird data to be used as a response variable in model development. This need is particularly important for nonwaterfowl species, of which many priority species are infrequently detected on existing surveys. Presently, most of the models we use for conservation planning in the PPJV focus on species presence or density; acquiring survival and productivity data would enable better consideration of aspects of avian conservation that presently are poorly addressed, particularly for nongame species. Better understanding of existing data and models is also a priority. For example, the effect of roadside bias on parameter estimates in spatial models developed from BBS data is unknown. Similarly, detection probabilities have not been assessed for any of the data sets we presently use in development of spatial models. Finally, inclusion of upland habitat variables in waterfowl models may be a valuable next step, especially as models are used to make decisions regarding placement of upland treatments such as CRP grasslands.

Expanded species coverage also will be needed. Current planning efforts emphasize focal species and conservation of areas that provide benefits for multiple species (see Johnson et al., this volume). As models for additional species are developed and planning efforts become more refined, planning will better incorporate species whose habitats show little or no overlap with other species. Evaluation and adoption of new modeling techniques (e.g., Elith et al. 2006) may help improve modeling efforts and enable development of useful models for species for which little data are available. However, it is imperative that pursuit of improvements in statistical methodology does not overshadow species biology and the development and use of models for specific applications and treatments. Acquiring finer-grained remotely sensed data would enable incorporation of additional information (e.g., vegetation species composition and structure, distribution of small clumps of trees and shrubs, amount and configuration of emergent vegetation in wetland basins) into models. However, some fine-grained features are ephemeral and influenced by annual precipitation levels, and are therefore of little value for long-term planning. Finally, all of our models are based on assumptions that landcover data are accurate, bird-habitat relationships are adequately modeled, and that conservation treatments adequately address factors presently limiting populations of species of concern. All these assumptions must be assessed and models refined in an adaptive manner, especially as human pressures on wildlife continue to increase.

Given increasing demands on resources, future conservation efforts will require even greater collaboration among federal and state agencies, nongovernmental organizations, and other partners. However, collaboration must go beyond the formation of partnerships and plans. The solution to conservation needs in the PPR lies not with better planning and modeling, but with increased on-the-ground actions that benefit wetland birds.

SUMMARY

The millions of wetlands that define the Prairie Pothole Region (PPR) make it the most productive area for waterfowl in North America. These wetlands are equally important to many other wetland-dependent bird species, particularly shorebirds and waterbirds. In response to ongoing loss of wetlands and grasslands, extensive conservation initiatives, particularly acquisition of conservation easements, have been undertaken to conserve wetland bird habitat in the United States portion of the PPR. In recent years, these conservation efforts have been guided largely by the results from spatial models that evaluate landscapes relative to their accessibility to breeding waterfowl and their potential for waterfowl production. We presented a philosophy of conservation planning and illustrated that philosophy with examples of spatial models that predict density and distribution of sora and marbled godwit, in addition to upland-nesting

waterfowl. Given the targeted nature of conservation funds and that diversity metrics are inappropriate as a response variable in models used for conservation planning, we developed species-specific models that can stand alone or be integrated with results of other models. This allows targeting of locations and treatments to address different needs (e.g., preservation, restoration, or enhancement of wildlife habitat) for any focal species, combination of species, or program while maintaining biological integrity of information used in conservation planning tools. We developed models by using National Wetlands Inventory data, landcover data, and estimates of water conditions as predictor variables for species presence-absence or count data. We determined that target bird species in the region were influenced by landscape composition and configuration, wetland class, and amount of water in wetland basins. Priority areas for several wetland-dependent bird species in the region overlap considerably, and many nonwaterfowl species have benefited substantially from waterfowl conservation efforts in the PPR.

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