PRIORITIZING GRASSLAND CONSERVATION ON THE MISSOURI COTEAU OF SOUTH DAKOTA

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INTRODUCTION

Temperate grasslands are one of the most threatened and least well-protected biomes worldwide (Hoekstra et al. 2005). The greatest threat to these grasslands is conversion to annual crop production. Biodiversity is drastically reduced and population dynamics of remaining native plant and animal species are often fundamentally changed when grasslands are converted to croplands (Samson et al. 2004, Brennan and Kuvlesky 2005, Stephens et al. 2005). Thus, protection of grassland is a critical objective for wildlife managers.

Breeding populations of many grassland bird species in the Great Plains of North America have declined since the advent of mechanized farming (McCracken 2005). These population declines have coincided with large-scale conversion of native prairie grasslands and wetlands to cropland. Loss of grassland to agriculture and fragmentation of remaining grassland is thought to have resulted in reduced reproductive success for these species and reduced abundance (McCracken 2005). Negative relationships between reproductive success and fragmentation of grassland have been documented for grassland-nesting ducks, shorebirds and raptors (Stephens et al. 2005, Stephens 2006).

The glaciated portion of eastern South Dakota, commonly known as the Prairie Pothole Region (PPR) is an important nesting area for a diverse group of waterfowl, shorebirds, songbirds, and raptors (Batt et al. 1989, Skagen and Thompson 2000). Native mixed-grass prairie in this region has undergone extensive conversion to cropland but remains the most abundant type of grassland nesting habitat available to breeding birds in the Prairie Pothole Region. Conversion continues across the PPR today and has recently increased noticeably in some areas such as the Missouri Coteau. The Coteau is a sub-region of the PPR that contains most of the remaining native grasslands within the PPR

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(Johnson et al. 1994). The Coteau is very important to many species of ground-nesting birds (Batt et al. 1989, Skagen and Thompson 2000, Kushlan et al. 2002, Rich et al. 2004), thus it is a high- priority area for conservation efforts.

Identifying and protecting tracts of grassland that sustain populations of desired species and have high biodiversity value is a primary objective of public and private wildlife conservation groups in the Missouri Coteau. This has proven to be a useful planning strategy. However, current demand by private landowners for protection of native grasslands via purchased conservation easements exceeds available funding. When demand is high and resources for protection are limited, integrated conservation planning strategies based on biological value, risk of conversion and cost of protection can have great utility (Newburn et al. 2005). Models of biological value have been the focus of conservation planning efforts in the Missouri Coteau to date, but consideration of risk and cost factors will increase the efficiency of these protection efforts. For example, a manager might need to choose to protect only one of two parcels of grassland with equivalent biological value. The choice can be made less subjective if a rigorous prediction of their relative probabilities of conversion and costs of protection is available.

We combined models of nest survival of shorebirds and raptors with models of the probability of grassland conversion and the cost of purchased easements to develop a decision-support utility for managers seeking to prioritize conservation efforts in the Missouri Coteau of South Dakota. Our specific objectives were to 1) Estimate recent rates of conversion of native grassland to cropland in South Dakota, 2) use observed recent conversions to construct and validate predictive models of the probability of conversion, 3) develop predictive models of the cost of protection for native grassland, and 4) combine these probability models in a GIS.

METHODS

Nest Survival of Shorebirds and Raptors

We studied nest survival of ground-nesting shorebirds and raptors on 50, 4-square-mile sites across the Missouri Coteau region of North and South Dakota during 2000-2006. Sites were selected according to a random design stratified by amount of perennial grass cover and number of wetland basins.

Nest-searching began in early-May each year. We located nests using ATVs and a 50-meter chain-drag (Klett et al.1986). When a nest was found we recorded its UTM coordinates and marked it with a fiberglass rod placed 5m north of the nest. We recorded the species, number of eggs, and date of the visit. We revisited nests periodically until ≥1 egg hatched or the nest was abandoned or destroyed. When we could not relocate a nest, or determine the fate of a nest, or when a nest was abandoned before the first revisit, the nest was not included in analyses.

We used generalized linear models (McCullaugh and Nelder 1989) and information-theoretic methods (Burnham and Anderson 1998) to estimate daily nest survival probability and evaluate competing hypotheses about nest survival. Candidate models described nest survival as a function of species; habitat type at the nest site; vegetation structure at the nest site (nest robel); and the landscape variables proportion grassland, amount of edge between grassland and cropland, total length of roads, number

of wetland basins, and area encompassed by the wetland basins. Nest survival was modeled separately for shorebirds and raptors using the same predictors. Landscape variables were measured at the study site (4-mi^2) scale. We used SAS Proc NLMIXED (SAS Institute 1999) to estimate parameters of candidate models (Stephens et al 2005).

Probability of Grassland Conversion

We estimated the probability of grassland conversion across the Missouri Coteau by classifying a series of four Landsat (4, 5, and 7) scene footprints in 1989 and 2003 (Figure 1). All pixels within each scene were classified into one of three classes: 1) native vegetation, 2) wetland/open water, and 3) all other features (cropland, urban etc). A separate classification model was developed for each of the 8 scenes using CART 5.0 (Breiman et al 1984; Salford Systems 2002).

We used the public land survey grid to divide the study area into 0.16km^2 (i.e., 16ha or 40acre) sample plots. We used all of the plots where at least 35% of the upland (non-water) area was classified as native grassland in the first image. A plot was classified as converted if the proportion of its area in grassland was less than 35% in the second image. The 35% threshold was selected because of the important negative correlation between grassland fragmentation measures and reproductive success for ground-nesting birds. For example, when two-thirds of a tract of grassland is converted, the habitat value for nesting waterfowl is functionally lost (Stephens et al. 2005). We used a post-classification approach to change detection to categorize the fate of selected plots over the interval between satellite images (Lunetta and Elvidge 1999).

We calculated predictor variables to characterize variation in climate (e.g., precipitation), land ownership (e. g., percent public land) and landscape characteristics (e. g., amount of grassland in surrounding landscape) among the 0.16km^2 plots. All predictors were calculated in ArcGIS 9.1 using zonal functions.

We used SAS Proc LOGISTIC (SAS Institute 1999) to construct logistic regression models (Hosmer and Lemeshow 2000) of grassland conversion. Fate of the sample plot (0, not converted; 1, converted) during the study period was the response variable. We used stepwise selection with entry and retention probabilities set at 0.95 to reduce the number of potential models while still allowing all of the predictors to enter the model set (Shtatland et al. 2004).

We used a generalized measure of R^2 (Nagelkerke 1991) and 2 model selection criteria: Schwarz's criterion (SC; Schwarz 1978) and Akaike's information criterion (AIC; Burnham and Anderson 1998) to select a best-approximating model from the subset of reasonable approximating models and evaluated the goodness-of-fit and prediction accuracy of the best-approximating model using standard methods. The Hosmer and Lemeshow goodness-of-fit test (Hosmer and Lemeshow 2000) allowed us to assess whether the logistic model adequately fit the data. We evaluated predictive accuracy using the area under the receiver operating characteristic (ROC) curve (Fawcett 2006) and 10-fold cross-validation (Shao 1993, Kohavi 1995).

Cost of Grassland Protection

We modeled cost of protection using data from perpetual grassland easements bought by the USFWS in the Missouri Coteau during 1992-2002. We estimated inflation from a linear model of easement cost through time and adjusted easement costs to 2002 dollars. We used five predictor variables (latitude, longitude, elevation, slope, and soil capability class) in a linear regression with cost in 2002 dollars per acre as the response variable. We used the R-language (Ihaka and Gentleman 1996) to generate parameter estimates for several competing models, and we selected the model with the highest R^2 value for prediction of cost across the Coteau. The regression results were compared to surfaces resulting from direct spatial interpolation of the cost data. The regression model allowed us to minimize the effect of considerable fine scale spatial variation in cost in order to isolate more general characteristics useful for prediction.

Grassland Conservation GIS

Spatial layers representing each variable were created for the final GIS analysis by applying the models to attributes associated with quarter-quarter section (16ha.) polygons on the Missouri Coteau in eastern South Dakota. Values assigned to each polygon included classified land cover (US Fish and Wildlife Service, unpublished data), predicted nest survival, probability of conversion, and cost of protection. These attributes were then used as input to estimate the back-transformed, polygon-specific conversion probabilities using the estimated coefficients from the best-approximating models. Polygon values were calculated using ArcGIS 9.1 with the Spatial Analyst extension (Environmental Systems Research 2005) using estimated model coefficients from SAS and R. Combinations of attributes revealing the intersection of relatively high predicted nest survival, high predicted probability of conversion, and low cost of protection were used to identify the highest priority areas for land protection.

The continuous distribution of each key characteristic in the final model (cost, risk and nest success) was assigned to a categorical class (High, Medium, and Low) in order to facilitate production of a final map representing the intersections of these critical characteristics. Class boundaries were developed using an algorithm designed to identify natural breaks in the distributions of each data set (Environmental Systems Research 2005). Finally we mapped the extent of the optimal classes representing the areas of high nest survival for raptors and shorebirds ranked by cost and risk of conversion.

RESULTS

Nest Survival of Shorebirds and Raptors

We found nests for four species of shorebirds (marbled godwit [*Limosa fedoa*], upland sandpiper [*Bartramia longicauda*], willet [*Tringa semipalmata*], and Wilson's phalarope [*Phalaropus tricolor*]) during this study (Table 1). Across all years and sites, fate was determined for 645 nests: of these, 330 hatched and 315 failed. Of the failed nests, 291 were destroyed by unidentified predators, 22 were abandoned, and 2 did not hatch because of non-viable eggs.

The best model with landscape variables for shorebirds contained the variables Year, Species, Percent Grassland 4-mi^2 scale, Cropland Edge 4-mi^2 scale, Total Road Length 4-mi^2 scale and Wetland Area 4-mi^2 scale. This model was substantially better than the habitat type only model. Landscapes that yielded the highest nest survival for shorebirds were those with higher amounts of grassland, lower levels of edge between cropland and grassland, greater road length, and a greater amount of wetland area.

We located and monitored 229 nests of short eared owls (*Asio flammeus*) and northern harriers (*Circus cyaneus* ;Table 2). Across years and sites, fate was determined for 210 nests: of these, 117 hatched and 93 failed. Of the failed nests, 68 were destroyed by unidentified predators, and 25 were abandoned.

The best model for raptors contained the variables Habitat Type, Nest Robel and Wetland Area. Northern harriers and short-eared owls had similar nest survival rates which did not warrant consideration of each species separately.

Probability of Grassland Conversion

During 1989-2003 we monitored the fates of 33,938 plots which encompassed 450,714 ha of native grassland; of these 2,443 were converted to cropland. The analysis area lost 28,634ha, or approximately 6.4%, of its native grassland during the 15-year period of observation. The best-approximating model was the best model of grassland conversion. This model had 17 parameters (Table 3). The Hosmer and Lemeshow goodness-of-fit test indicated that this model fit the data (H&L $X^2 = 8.74$, df = 8, p = 0.38). The area under the receiver operating characteristic curve was 0.77. At the cut-off probability that maximized the sum of sensitivity and specificity (0.08), the model accuracy estimated by 10-fold cross-validation was 0.68, and it correctly predicted 71% of observed conversions.

Cost of Grassland Protection

The cost of protection model was developed from 634 easements. Payments ranged from $38.58/acre to $294.60/acre. The best model had an R^2 value of 0.37 and predicted cost in dollars per acre from this equation: 1101-0.0001877*Latitude-0.1342*Elevation-1.992*Soil Class. Thus, cost of easements increased from north to south, from higher to lower elevations, and from poorer- to higher-quality soils (Figure 2).

Grassland Conservation GIS

When combined, the nest survival, probability of conversion, and cost of protection layers revealed areas of convergence among these variables. There were approximately 18,058 acres for raptors and 9,148 acres for shorebirds where high nest survival probability intersected high risk of conversion and low cost of protection (Table 4). The intersection of high nest survival for shorebirds and high nest survival for raptors comprised 23,275 acres. The northern portion of the Missouri Coteau in South Dakota contained considerable acreage with low and moderate cost of protection for raptors (Figure 3) and shorebirds (Figure 4).

DISCUSSION

The combination of information about biological value, probability of landscape change, and cost of protection can provide a powerful utility for conservation planning. All of these dimensions have been considered informally by most land managers and conservation planners in the past. Nevertheless, a formalized integration of all three of these components has been lacking from most conservation plans. Even a simple approach like ours can provide useful focus for planning efforts. This approach allows quantitative evaluation of the potential consequences of assumption violations and system changes within a region. Furthermore, it identifies weaknesses in the understanding of how the landscape might change and its potential to affect populations.

The 23,275-acre overlap between the area of high biological value for raptors and shorebirds illustrates some important points about the value of our approach for conserving biodiversity. The ability to identify areas that are important to a variety of wildlife species is especially useful to management entities with multi-species conservation mandates. Cooperation between conservation interests can be fostered and resources can be combined when there is reasonable expectation of success for all stakeholders. This kind of concentrated conservation is particularly valuable in landscapes and regions where habitats of high biological value are under threat of conversion and funding is limited.

Multiple conservation planning strategies can be derived from a diversified approach like the one we used. This system can be used to investigate the costs and benefits of prioritizing one criterion over another. For example, prioritizing low-cost will result in conservation of the largest area while prioritizing high-risk might result in land-use change pressures being shifted to other areas and habitats.

This approach was useful and productive but it could benefit from introduction of predictor variables that describe local and regional economics, more sophisticated analysis, and external validation. For example, land-use choices might be influenced by macro- and micro-economic factors in subtle ways. Recently-developed analysis approaches also show promise for conservation planning. For example, optimization routines (Williams et al. 2002) could help identify the best strategies for a given set of objectives. Bayesian methods would allow more realistic component models to be developed. Moreover, a conservation planning utility like this one can and should be updated and re-parameterized as new information comes to light. External validation and updating of cost of protection models will be particularly important in the highly-dynamic economic environment of the Great Plains.

Conservation planning guided by models derived from data will tend to be more efficient and effective than planning based on more subjective criteria. Integrating information about the probability of land-use change and cost of protection provides planners and managers with a cohesive conceptual framework for allocating limited conservation resources. Areas of high biological value that are at high risk of conversion and are relatively inexpensive to protect can be prioritized. This strategy will maximize the area that can be protected for a given amount of funding. Approaches like ours will become even more relevant and useful as the component models become more sophisticated and realistic.

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Table 1. Shorebird nests by species 2000-2006.

Year	MAGO	UPSA	WILL	WIPH	Total
2000	4	59	21	13	97
2001	5	60	20	16	101
2002	2	18	19	15	54
2003	3	77	18	34	132
2004	0	38	11	16	65
2005	0	53	22	38	113
2006	7	80	14	26	127
Total	21	385	125	158	689

Table 2. Sample Sizes of Raptor Nests 2000-2006.

Year	NOHA	SEOW	Total
2000	30	16	46
2001	20	0	20
2002	8	1	9
2003	29	1	30
2004	39	16	55
2005	25	7	32
2006	37	0	37
Total	188	41	229

Table 3. Logit-scale parameter estimates and standard errors for the best-approximating predictive model of probability of grassland conversion in the southern Missouri Coteau during 1989-2003.

Predictor (spatial scale)	Estimate	SE
Intercept	-3.107	0.033
Percent grass cover (0.65km^2)	-0.274	0.041
Mean slope (0.16km^2)	-0.533	0.059
Cropland/grassland edge (0.65km^2)	0.260	0.028
County annual precipitation	0.418	0.056
Percent school trust land (41.40km^2)	-0.355	0.046
Cropland/grassland edge (0.16km^2)	0.180	0.027
Mean slope (5.18km^2)	-0.417	0.069
Temporary/seasonal wetland count (0.16km^2)	-0.123	0.024
Semi-permanent/permanent wetland count (41.40km^2)	0.099	0.025
Percent grass cover (5.18km^2)	-0.190	0.042
Percent public ownership (41.40km^2)	-0.172	0.034
County frost free days	-0.300	0.059
Percent public ownership (5.18km^2)	0.094	0.027
Slope standard deviation (41.40km^2)	0.158	0.045
Soil capability class (0.16km^2)	-0.091	0.034
County cropland value	0.075	0.032

Table 4. Number of acres of the Missouri Coteau in South Dakota where predicted nest survival of ground-nesting raptors (A.) and shorebirds (B.) was highest. Categories were listed by increasing predicted cost of protection and decreasing predicted probability of conversion.

A.

Cost of Protection	Risk of Conversion	Acres
Low	High	18,058
Low	Moderate	56,937
Low	Low	72,541
Moderate	High	35,166
Moderate	Moderate	81,959
Moderate	Low	142,958
High	High	17,247
High	Moderate	32,984
High	Low	17,247

B.

Cost of Protection	Risk of Conversion	Acres
Low	High	9,148
Low	Moderate	21,728
Low	Low	29,192
Moderate	High	40,828
Moderate	Moderate	100,401
Moderate	Low	135,481
High	High	7,343
High	Moderate	10,850
High	Low	7,343

Figure 1. Location and extent of the Missouri Coteau region in the United States.

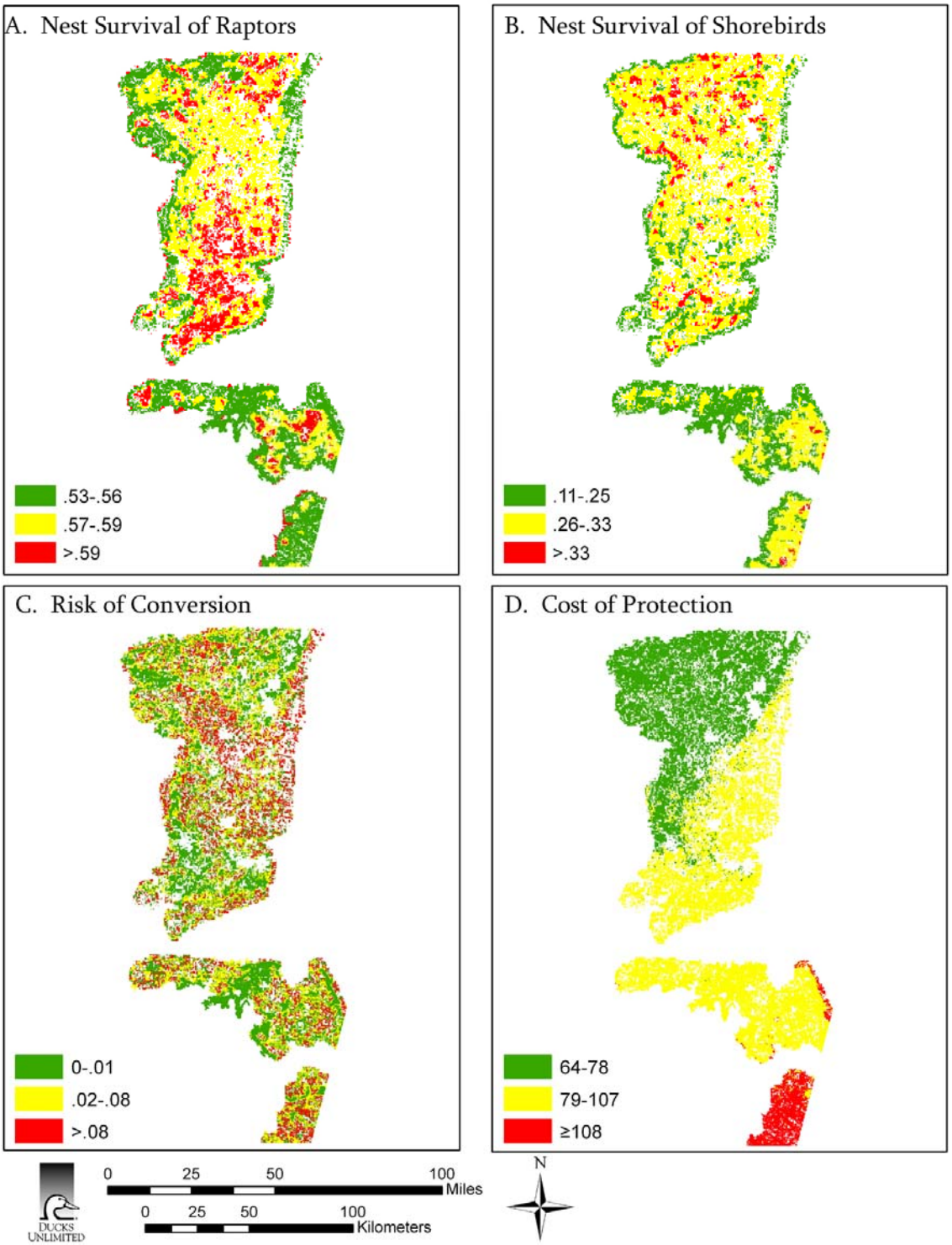

Figure 2. Spatial representations of A. nest survival probability of raptors, B. nest survival probability of shorebirds, C. probability of conversion to cropland, and D. cost of protection of grassland (in $/per acre) predicted for the Missouri Coteau region of South Dakota.

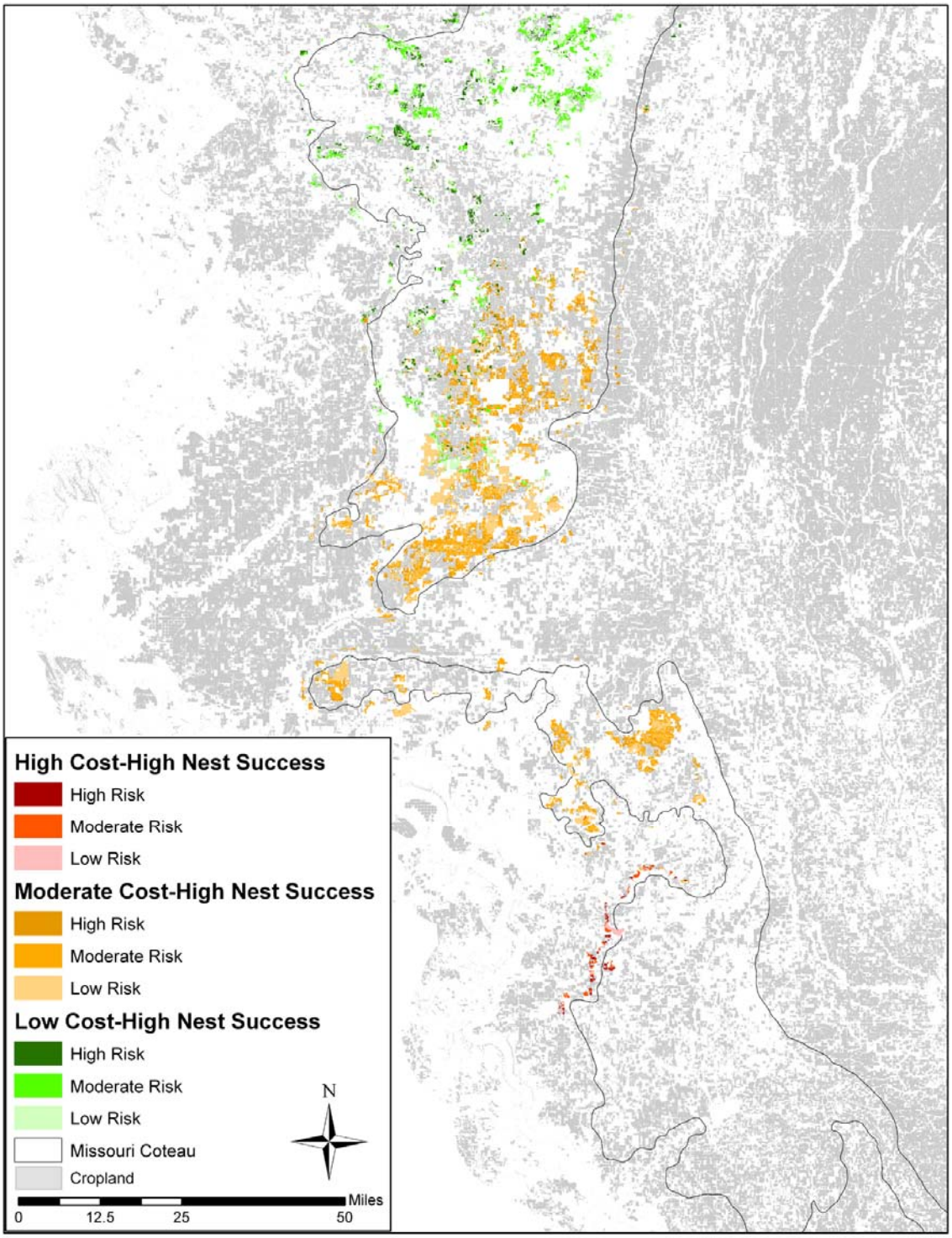

Figure 3. Areas with high predicted nest survival of raptors ($\hat{p}$ >0.59) ranked by cost of protection and probability of conversion.

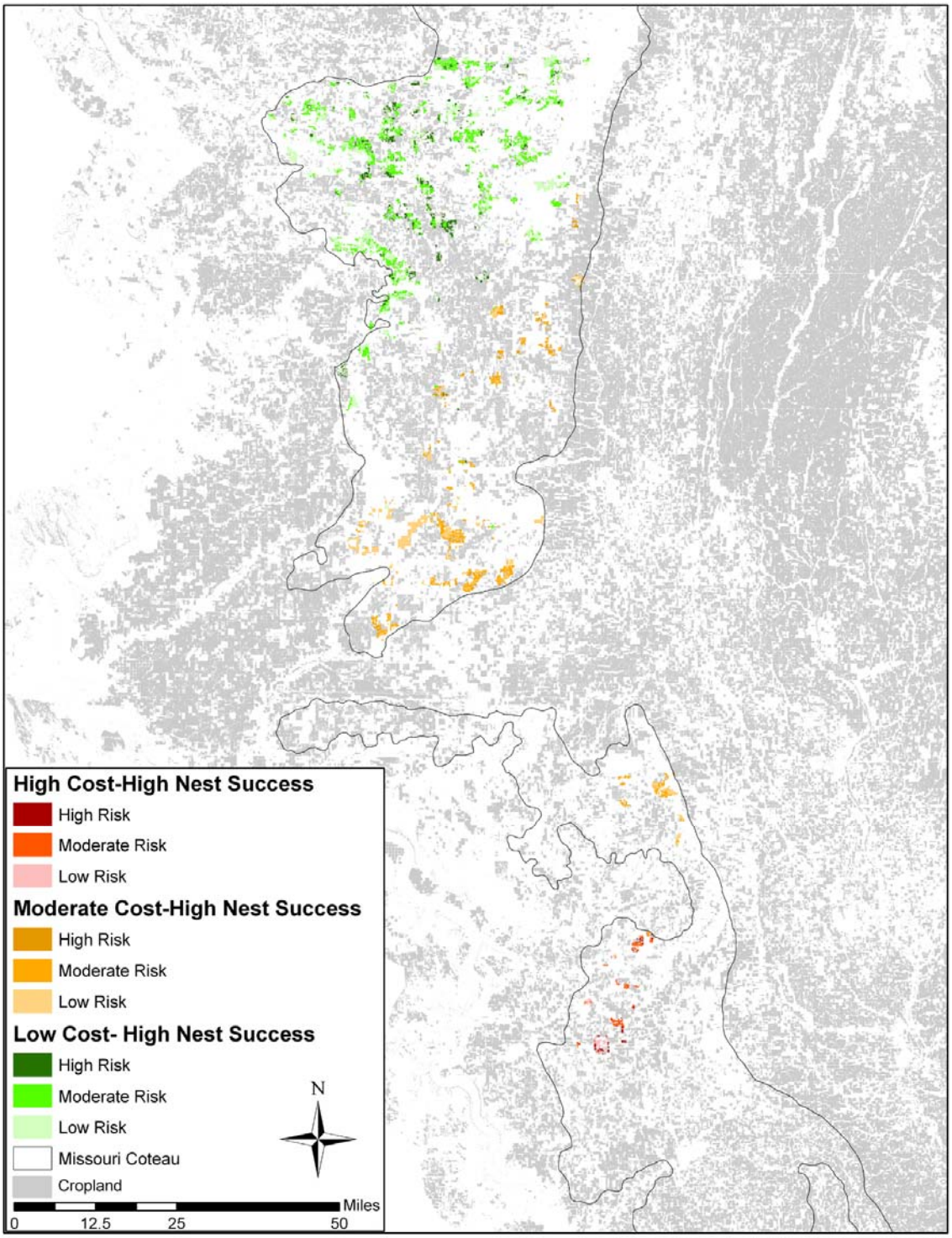

Figure 4. Areas with high predicted nest survival of shorebirds ($\hat{p} > 0.33$) ranked by cost of protection and probability of conversion.