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Contributed Paper

Predicting and Mapping Potential Whooping Crane Stopover Habitat to Guide Site Selection for Wind Energy Projects

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Abstract: *Migratory stopover habitats are often not part of planning for conservation or new development projects. We identified potential stopover habitats within an avian migratory flyway and demonstrated how this information can guide the site-selection process for new development. We used the random forests modeling approach to map the distribution of predicted stopover habitat for the Whooping Crane (*Grus americana*), an endangered species whose migratory flyway overlaps with an area where wind energy development is expected to become increasingly important. We then used this information to identify areas for potential wind power development in a U.S. state within the flyway (Nebraska) that minimize conflicts between Whooping Crane stopover habitat and the development of clean, renewable energy sources. Up to 54% of our study area was predicted to be unsuitable as Whooping Crane stopover habitat and could be considered relatively low risk for conflicts between Whooping Cranes and wind energy development. We suggest that this type of analysis be incorporated into the habitat conservation planning process in areas where incidental take permits are being considered for Whooping Cranes or other species of concern. Field surveys should always be conducted prior to construction to verify model predictions and understand baseline conditions.*

Keywords: avian migration, en route bird conservation, random forests, site selection, stopover, Whooping Crane (*Grus americana*), wind farm

Predicción y Mapeo del Hábitat Potencial de Descanso de la Grulla Americana para Guiar la Selección de Sitios para Proyectos de Energía Eólica

Resumen: *Los hábitats de descanso migratorio frecuentemente no son parte de la planeación de la conservación o proyectos de desarrollo nuevos. Identificamos hábitats de descanso potenciales dentro de una vía de aves migratorias y demostramos cómo esta información puede guiar en la selección de sitios para nuevos desarrollos. Usamos el acercamiento del modelo de bosques aleatorios para mapear la distribución del hábitat de descanso predicho de la grulla americana (*Grus americana*), una especie en peligro cuya vía migratoria se traslapa con un área donde se espera que el desarrollo de energía eólica se vuelva cada vez más importante. Usamos esta información para identificar áreas para el desarrollo potencial de poder eólico en un estado de los E.U.A. dentro de la vía de vuelo (Nebraska) que minimicen los conflictos entre el hábitat de descanso de la grulla y el desarrollo de fuentes de energía limpias y renovables. Hasta el 54% de nuestra área de estudio fue predicha como inapropiada como un hábitat de descanso para la grulla y podría considerarse como de bajo riesgo para conflictos entre las grullas y el desarrollo de energía eólica. Sugerimos que este tipo de análisis sea incorporado al proceso de planeación de conservación de hábitat en áreas donde permisos*

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de toma incidentales están siendo considerados para grullas americanas u otras especies de preocupación. El muestreo en campo deberá ser hecho siempre antes de la construcción para verificar las predicciones del modelo y entender las condiciones basales.

Palabras Clave: Bosques aleatorios, conservación de aves en ruta, descanso, granja de viento, Grulla Americana (*Grus americana*), migración de aves, selección de sitio

Introduction

Migration events are likely the most dangerous parts of a bird's life, strewn with unpredictable challenges and hazards that have a disproportionate effect on populations (Sillett & Holmes 2002; Carlisle et al. 2009). Although an estimated 6 billion birds migrate annually in North America, migration is one of the most poorly understood components of the avian life cycle (Faaborg et al. 2010). Conservation plans that address only breeding or wintering habitat are incomplete (and likely inadequate) without an explicit consideration of habitats used for stopover during migration (Moore et al. 1995). Directing conservation efforts toward understanding and protecting stopover habitat is critical, especially in light of ongoing landscape changes within migratory flyways.

Here, we focus on conservation planning within the migratory flyway of the Whooping Crane (*Grus americana*), a U.S. federally listed endangered bird. Currently, the only wild, self-sustaining population of Whooping Cranes contains fewer than 300 individuals. Migration is perilous for Whooping Cranes. Previous research suggests that 60–80% of mortality of fledged Whooping Cranes occurs during migration (Lewis et al. 1992). Identification and protection of habitat along the migratory route is a key conservation need for the recovery of the species (CWS & USFWS 2007). The rapid development of wind energy in the United States—including within the Whooping Crane migratory flyway—gives a new sense of urgency to understanding this species' stopover ecology. Several general local-scale characteristics seem common among stopover sites (e.g., palustrine wetlands for roosting, nearby crops for feeding sites; Howe 1989; Austin & Richert 2001), and Whooping Cranes may recognize suitable large-scale features in the landscape, such as wetland complexes (Richert 1999). However, little is known about the relative importance of these and other environmental characteristics to migrating Whooping Cranes or the distribution of potential stopover habitats within the flyway.

The Whooping Crane flyway overlaps with a part of the United States that has recently received much attention for its wind energy potential. Wind energy is rapidly gaining traction in the United States and could supply up to 20% of the nation's electricity needs by 2030 (USDOE 2008). A growing wind power presence in the United States could have substantial benefits like reduced greenhouse gas emissions and stabilized electricity prices, but it may also directly or indirectly affect wildlife (Drewitt & Langston 2006; Kuvlesky et al. 2007). Up to 25% of proposed wind farms are never built or are substantially delayed because of concerns about their environmental impacts (USDOE 2008). The recent withdrawal of plans for a major wind farm project in North Dakota, for instance, cited costs of threatened and endangered species mitigation (including for the Whooping Crane) as the primary reason for abandoning the proposed project (e.g., Minneapolis Star Tribune, 4 April 2011, "Xcel cancels North Dakota wind energy project"). These delays and costs emphasize the need for careful evaluation of potential development locations prior to making siting decisions.

Infrastructure associated with wind farms poses a risk to migrating cranes (USFWS 2009) because collisions with turbines and associated infrastructure, avoidance of habitat, and alteration of migratory flight paths in response to wind farms have been demonstrated for other birds (e.g., Erickson et al. 2004; Masden et al. 2009; Pruett et al. 2009). Although no collisions with wind turbines have yet been reported for Whooping Cranes, collisions with power lines are a substantial source of mortality for migrating Whooping Cranes (especially when lines are near stopover sites) (Brown et al. 1987; Lewis et al. 1992). Collision with power lines is the leading source of mortality for fledged Whooping Cranes (Stehn & Wassenich 2008). Another substantial risk is that Whooping Cranes may avoid stopover habitat altogether and extend flight distances to find suitable stopover sites when wind farm areas are present (USFWS 2009). This could negatively affect the physical condition of migrating cranes and potentially increase their mortality (USFWS 2009). Any of these direct or indirect effects of wind farm areas could constitute take under the U.S. Endangered Species Act (ESA). For example, if Whooping Cranes avoid stopover habitat near wind farms, this is considered harm from habitat modification (as defined in 50 CFR 17.3) and thus could result in take (USFWS 2009). Any potential wind energy project in the Whooping Crane migration corridor therefore must be in compliance with the ESA; this would likely include applying for an incidental take permit and developing a habitat conservation plan to minimize and mitigate impacts.

We sought to contribute to comprehensive conservation planning within the migratory flyway of the Whooping Crane. First, we wanted to increase understanding of the stopover ecology of this species. We used citizen

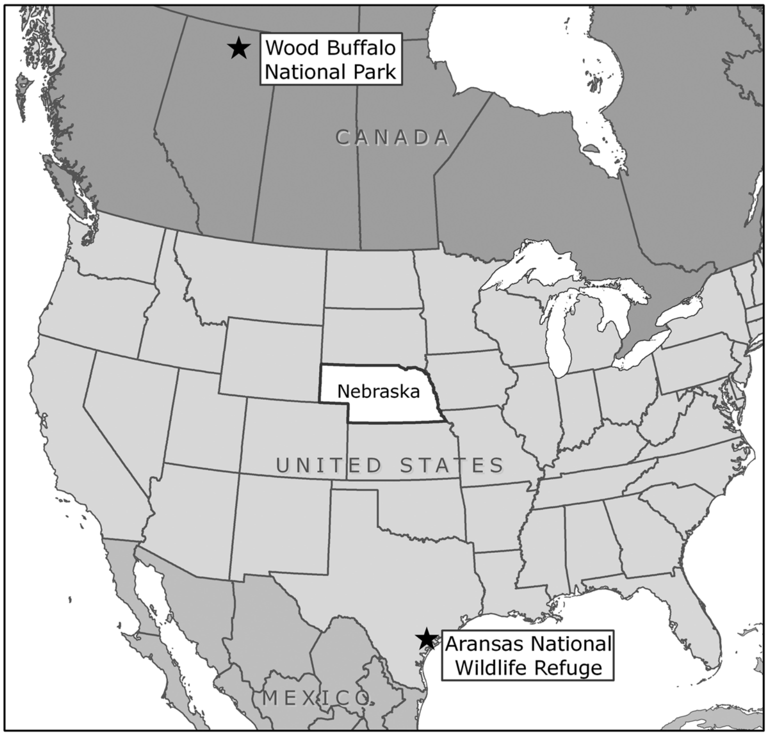

Figure 1. Locations of Whooping Crane breeding habitat in Wood Buffalo National Park and wintering habitat in Aransas National Wildlife Refuge.

science data in a random forests model (Breiman 2001) to identify the relative importance of environmental factors and find areas predicted to be suitable for stopover during migration. Second, we compared our model results with maps depicting wind resource potential. We looked for areas with both adequate wind potential and low suitability for Whooping Crane stopover sites, illustrating an approach to minimize potential conflicts between new wind energy projects and the Whooping Crane. Although general nation-wide guidelines for selecting sites have been suggested to reduce negative effects of wind farms on wildlife (e.g., Kiesecker et al. 2011; USFWS 2012), we refined the focus to demonstrate an approach that could be incorporated into local, species-specific decisions. This work is particularly timely in light of the incidental take permit being considered for wind energy development within the entire Whooping Crane migratory corridor (USFWS 2011).

Methods

Study Area

The only self-sustaining wild population of Whooping Cranes migrates twice yearly between its breeding location in Canada and its wintering grounds in South Texas, U.S.A. The species has been documented in 11 U.S. states between those locations during annual migrations. However, we limited the scope of the analysis to the 180-mile migratory corridor containing 95% of confirmed Whooping Crane sightings (USFWS 2007) within the state of Nebraska. We selected Nebraska because of its central location within the flyway and the large number of Whooping Crane stopovers there (Fig. 1).

Data

We used a database of Whooping Crane sightings compiled by the U.S. Fish & Wildlife Service (USFWS, Nebraska Field Office, unpublished data). The database contains incidental observations reported by the public and verified by biologists. Only the first observation of a particular crane is included in the database, even if it was observed in multiple locations. The sightings in the database are classified into 6 categories of locational precision. We used all points in the 2 most-precise categories—Global Positioning System and public land survey system cadastral quarter sections (grid cells of 0.6 km^2, with sightings placed in the center)—to develop binary maps of detection and nondetection for each 1 km^2 cell in the study area. We included only sightings reported since 1990 to minimize the changes in land cover between time of sighting and date of land-cover analysis (e.g., from 1992 to 2001, the land cover remained unchanged for 88.6% of cells within our study area, according to Fry et al. 2009; 99.0% of cells remained unchanged from 2001 to 2006). Because conservation efforts would likely focus on the full spectrum of habitats used by migrating cranes, we used all stopover sites in the database from spring and fall migrations, 1990 through 2009 (n = 151 in the 2 most-precise categories within

Table 1. Predictor variables included in random forests model of Whooping Crane stopover habitat, mean values of predictor variables for Whooping Crane occurrence and pseudo-absence points, and variable importance as calculated with the random forests model and indicated by mean decrease in model accuracy after data for each variable were permuted.

Predictor variable	*Description*	*Mean percent occurrence points (min, max)*	*Mean percent absence points (min, max)*	*Mean decrease in accuracy (SD)*
Agricultural land[a]	All crop-based land uses (% cover in 1 km^2)	38.9 (0.0–99.1)	31.8 (0.0–99.8)	8.48 (2.15)
Bearing[b]	Directional heading between the cell and Aransas National Wildlife Refuge in South Texas, U.S.A.	171.90 (166.41–178.59)	170.94 (164.47–179.17)	37.17 (2.07)
Ecotone[a]	Categorical variable that identifies combined Euclidean distance from nearest agricultural and nearest wetland area	Within 100 m of agriculture and 500 m of wetland[d]	Within 100 m of agriculture and 500 m of wetland[d]	10.54 (2.65)
Roads[c]	Primary and secondary roads (% cover in 1 km^2)	0.3 (0.0–6.0)	1.8 (0.0–11.4)	31.67 (2.32)
Urban area[a]	Urban land, defined as towns or cities with more than 100 people (% cover in 1 km^2)	0.05 (0.0–7.3)	6.8 (0.0–100)	8.21 (1.13)
Wetlands and water[a]	Wetlands and open water (% cover in 1 km^2)	10.4 (0.0–81.1)	7.5 (0.0–100)	13.03 (2.20)

[a] *Center for Advanced Land Management Information Technologies (CALMIT). 2007. 2005 Nebraska Land Use Patterns. Original resolution 28.5 m (http://calmit.unl.edu/2005landuse/statewide.shtml).*
[b] *Developed with the geosphere package in R (Hijmans et al. 2011).*
[c] *Census TIGER Database, 2009.*
[d] *Because ecotone is a categorical variable, this is a mode instead of mean.*

the migration corridor, with duplicates per 1 km^2 cell removed).

We measured 4 land use/land-cover types associated with Whooping Crane stopover sites (Austin & Richert 2001) to test as predictor variables (Table 1): agricultural land, roads, urban areas, and wetlands and water. A variable describing grass, pasture, and rangeland cover was originally included as a fifth land-cover variable but was removed prior to analysis because of high negative correlation with agricultural crop cover. We used ArcGIS 9.3 (ESRI 2008) to calculate percent cover within 1 km^2 cells for each variable. We selected 1 km^2 as the grain size for this study because preliminary analysis of multiple spatial scales (i.e., focal windows up to 50 km^2) suggested the 1 km^2 scale accurately captured environmental characteristics relevant to the Whooping Crane and broader spatial scales did not improve model performance. We also developed 2 additional predictor variables to explore the potential for fine- and broad-scaled evaluation of the landscape (Table 1). At the broad scale, bearing identified the directional heading between each pixel and the Whooping Crane wintering ground and was measured as compass degrees traveled from the centroid of the winter range to the stopover location in Nebraska. Bearing was transformed by subtracting 180 from each value to avoid a bimodal distribution due to the split between 0° and 360°. This layer was developed with the geosphere package in R (Hijmans et al. 2011). Bearing was included in the model to account for the apparent adherence of Whooping Cranes to a specific path during migration (Howe 1989; Austin & Richert 2001). At a finer scale, we developed a categorical ecotone variable to represent the interaction between agricultural areas and wetlands. For each point on the landscape, we measured distance from nearest agricultural area and distance from nearest wetland. Cells were then classified into 16 categories to indicate distance from both cover types (Supporting Information). For example, a cell within 100 m of wetlands but more than 1 km from agricultural land falls into a category separate from a cell near agricultural land but distant from wetlands. This layer was originally derived from a land-cover map with 28.5 m cells and resampled to a cell size of 1 km^2; each cell had the ecotone category that occurred most frequently within its boundaries. The ecotone layer was included in the model to explore the possibility that Whooping Cranes might select stopover sites that are near both land-cover types; they have often been observed walking between wetlands and agricultural fields to feed during a migratory stopover (Howe 1989). These ecotone areas may serve as a cue to migrating Whooping Cranes, possibly indicating diverse and abundant food resources when both land-cover types are nearby (Hutto 1985; Moore & Aborn 2000).

Species Distribution Model

We used a machine-learning approach (random forests, Breiman 2001) to estimate the relation between environmental characteristics and relative suitability for Whooping Crane stopover sites and generate a map of predicted suitability within the migratory corridor. Random forests builds many decision trees (generating a forest of independent tree models) by splitting branches into increasingly homogeneous groups as measured by the Gini index, and then combines the predictions over all trees into a single composite model (Cutler et al. 2007). We chose random forests because it is a powerful nonparametric method that is well-equipped to deal with the complex interactions and nonlinear relations typical of ecological data. Random forests consistently performs well against other ecological modeling approaches (Cutler et al. 2007) and can be used to map relative suitability or probability of occurrence for a species across a landscape (Magness et al. 2008).

Because the Whooping Crane occurrence points are likely spatially biased toward areas where birders frequently visit (Austin & Richert 2001), we selected other locations across Nebraska where birders are known to visit to use as pseudo absences (i.e., points that describe the environmental conditions in the modeled region). This set of known birding locations can be thought of as target-group absences (Mateo et al. 2010) because they represent locations where other species (but not Whooping Cranes) have been reported. We included as pseudo absences all observations reported via the eBird project (CLO & NAS 2012) during spring and fall migrations, 1990–2009, within the 180-mile Whooping Crane migration corridor in Nebraska ($n = 431$, with duplicates per 1 km^2 cell removed). The eBird points were distributed across all land-cover types in the 180-mile migration corridor in proportions that would be expected on the basis of the extent of each cover type (G-tests for frequencies of 7 land-cover categories for eBird points and 500 random points within the migration corridor showed no significant difference). These points were well-distributed spatially across the study area; 90.6% of all cells were within 25 km of an eBird point. However, both eBird points and Whooping Crane locations are more likely to be located on federal, state, or local protected areas than are randomly sampled points in the study area (15.3% of eBird points and 7.9% of Whooping Crane occurrences, compared with 1.7% of randomly sampled points), according to the Protected Areas Database (http://databasin.org/datasets/, accessed 5 March 2013). In this sense, the effects of sample selection bias are likely minimized because both occurrence points and pseudo-absence points are subject to the same type of bias (Phillips et al. 2009; Mateo et al. 2010).

We used the random forests method as implemented in R (R Core Team 2012) to estimate the importance of each variable and generate maps showing predicted suitability within the study area (Breiman 2001). Measures of variable importance are reported as the mean decrease in accuracy, which is the normalized difference of the prediction error when the variable is included as observed and the prediction error when the values of the variable have randomly been permuted (Liaw & Weiner 2002). Larger decreases in accuracy indicate greater importance. We randomly generated 25 training and test data sets, withholding 20% of the full data set each time for model evaluation, and ran random forests 25 times, averaging the results across all runs. Imbalanced data sets (e.g., when pseudo absences far outnumber presences) can cause problems for model performance (Chen et al. 2004), so we included an equal number of presences and pseudo absences in each training data set (Barbet-Massin et al. 2012). We used the area under receiver operating curve (AUC), 1 indicator of model accuracy, to evaluate model performance. Values for AUC range from 0 to 1; 0.5 indicates that the model is no better than random (Fielding & Bell 1997). We generated a final map of relative suitability by averaging the mapped predictions across the 25 runs.

To check and confirm our results, we used an alternate modeling approach (Maxent, Phillips et al. 2006) to calculate variable importance and generate maps of predicted suitability, although we do not present those results in detail here. For this step, we used the species-with-data mode in Maxent to include the same occurrence points and the full set of pseudo absences used in random forests. We retained all default settings and parameter values in Maxent and used 10-fold cross-validation to train and test the model (see Phillips et al. 2006 for more discussion on Maxent methods).

Wind Resources and Site Suitability Analysis

We used the random forest suitability map to guide site selection for wind energy projects. We used data from the National Renewable Energy Laboratory to find areas with adequate wind resource potential (http://www.nrel.gov/gis/data_wind.html, accessed December 2010). The original data were in polygon format, which we converted to a raster with 1 km^2 cells. Wind power classes range from 1 to 7; 1 is poor and 7 is superb. For this analysis, we assumed that sites ranked 3 (fair) or better were most likely to be explored for future wind development, in line with the wind power scenarios explored by USDOE (2008).

We integrated the maps of wind resource potential with the suitability map generated by random forests to find areas that minimize conflict between the 2. In the random forests map, each pixel was assigned a probability of suitability for stopover between 0 and 1. We used 2 thresholds with clear ecological interpretations to distinguish between suitable and unsuitable Whooping Crane stopover areas. The first threshold was set at the lowest predicted value where a known Whooping Crane stopover site occurred; thus, with this threshold, unsuitable sites were those that had a predicted suitability value lower than those where the species had been recorded (lowest presence threshold [LPT], as in Pearson et al. 2007). The second threshold corresponded to an omission error of 10% (i.e., 90% of known stopover sites were classified as suitable and 10% were incorrectly classified as unsuitable). We may have underestimated the area of stopover habitats with this threshold, but we wanted to present a more flexible option (from a wind energy development perspective) for comparison with the LPT. The 2 thresholds allowed us to generate 2 binary maps depicting Whooping Crane stopover sites.

We used model predictions to locate and prioritize sites for wind energy exploration and help guide the site selection process prior to major investment. We made the assumption that potential wind energy projects in the U.S. Great Plains generally seek to minimize conflicts with federally listed endangered species, so our approach identified sites where adequate wind resources overlap with areas predicted to be unsuitable for Whooping Crane stopovers. In other words, we focused on sites with fair or better wind resources and then prioritized them by the level of potential conflict with migrating cranes. We used these prioritization criteria to assign a site suitability ranking to each 1 km^2 cell in the study area (Table 2). The site suitability rankings prioritized sites for wind energy exploration ranging from high suitability for wind development with low risk for Whooping Crane conflict to good suitability for wind development but with higher risk of conflict with Whooping Cranes. We assigned a rank of 3 to areas where good wind potential overlapped with predicted stopover habitat, a combination that suggests a higher risk of conflict. Sites with poor or marginal potential for wind power were unranked.

Table 2. Site suitability rankings for wind energy development and land area within each ranking category in the Nebraska migration corridor.

Suitability rank	*Definition*	*Total land area in km^2 (% Nebraska migration corridor)*
1	Overlap of areas with fair or better wind potential with unsuitable stopover areas as designated by the lowest presence threshold; areas are lowest risk for conflict with Whooping Cranes	31,706 (28.7)
2	Overlap of areas with fair or better wind potential with unsuitable stopover areas as designated by the 10% omission error threshold; areas involve slightly higher risk for conflict with Whooping Cranes	28,118 (25.4)
3	Overlap of areas with fair or better wind potential with predicted stopover habitat for Whooping Cranes designated by the 10% omission error threshold; areas involve the greatest risk for conflict with Whooping Cranes	33,121 (30.0)
Unranked	Inadequate wind resource potential	17,558 (15.9)

Results

Environmental Characteristics of Whooping Crane Stopover Sites

Directional heading (bearing) ranked the highest for variable importance; percent cover of roads was a close second (Table 1). The remaining variables were all fair predictors of suitability (Table 1). Partial dependence plots (Supporting Information) showed that when other variables were held constant, relative suitability increased as bearing shifted to the center of the migratory corridor. These plots also indicated that areas of high agricultural cover, low coverage of roads and urban areas, and intermediate wetland cover had higher predicted relative suitability. Of the 16 ecotone categories, areas close to wetlands (<100 m) and simultaneously <1 km from agricultural land were most likely have the greatest predicted suitability. The AUC was fairly high (test AUC = 0.85, SD = 0.04) for the model, indicating a good fit.

The importance of bearing and percent road cover was confirmed by the Maxent model. In addition, the map of predicted suitability generated by the Maxent model was visually similar to that of random forests and had a Pearson's correlation of 0.9 ($p < 0.0001$).

Wind Resources and Site Suitability Analysis

Substantial parts of the migration corridor within Nebraska had low predicted suitability as Whooping Crane stopover sites, particularly in the western portion of the corridor and areas near major roads (Fig. 2).

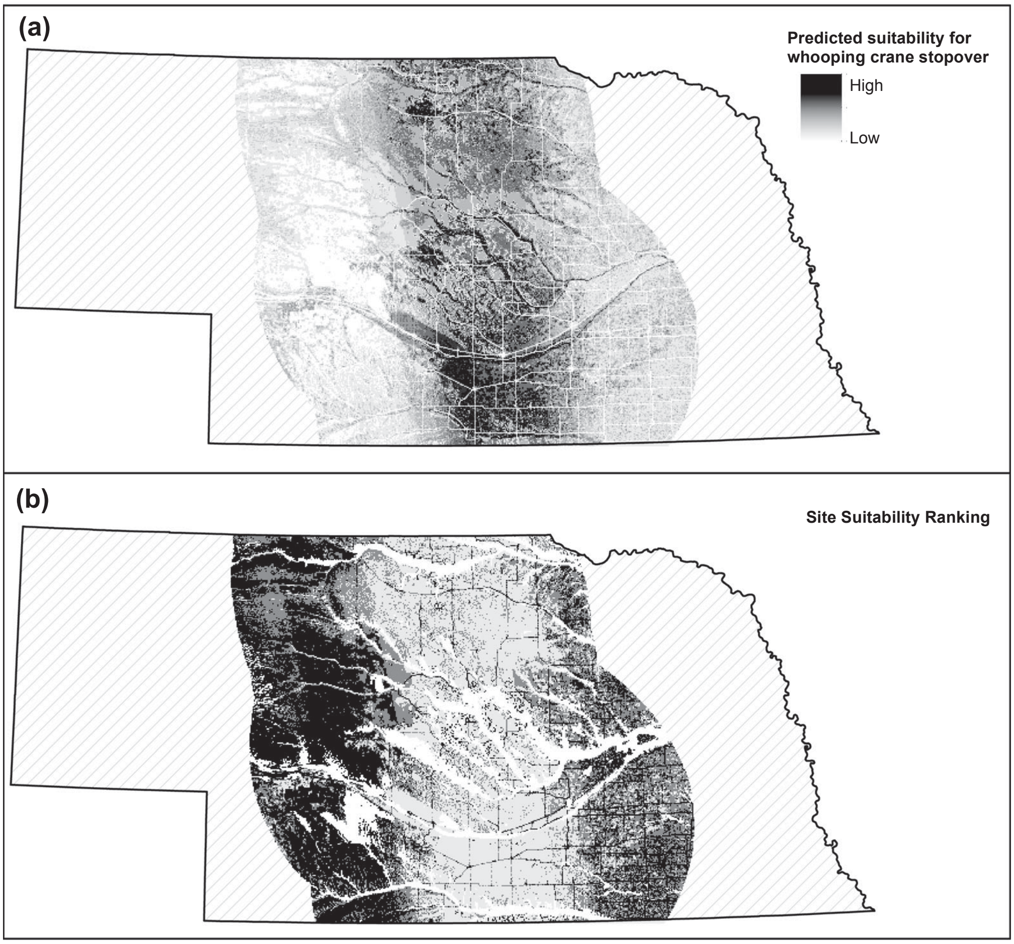

Figure 2. (a) Predicted suitability of stopover habitat within the Nebraska Whooping Crane migratory corridor and (b) ranking of areas for wind power development suitability (outermost line, Nebraska state boundary; hatching, areas outside the Whooping Crane migratory corridor). In (a) the shade of each pixel indicates suitability of area for Whooping Crane stopover habitat. In (b) wind-power site suitability rankings prioritize sites predicted to have adequate wind resources and reduced risk of conflict with migrating Whooping Cranes (darkest shade, rank 1, areas predicted to have good potential for wind power with lowest risk of conflict with Whooping Crane stopover habitat; moderate gray, rank 2, good potential for wind power with greater risk of conflict with stopover habitat; light gray, rank 3, good potential for wind power with greatest risk of conflict with stopover habitat; white, unranked areas with poor or marginal wind resource potential).

Approximately 31,700 km^2 within the Nebraska migration corridor (28.7% of the corridor) had a rank of 1 (adequate wind resources and a low predicted suitability value for Whooping Crane stopovers below our most stringent threshold, the LPT) (Table 2).

With the less-restrictive definition of unsuitable stopover habitat, the 10% omission error, even more area within the Nebraska migration corridor could be explored for wind energy development—an additional 28,100 km^2 had a rank of 2. The total area with ranks 1 and 2 (i.e., adequate wind energy potential and low predicted suitability for Whooping Crane stopover sites) covered approximately 59,800 km^2 (54.1% of the land area in the corridor).

Discussion

Our results indicated that substantial portions of the migratory corridor in Nebraska had low predicted suitability for Whooping Crane stopover sites. Depending on the stringency of the threshold selected, up to 59,800 km^2 within the Nebraska corridor could be explored for wind energy development with minimal expected conflict with Whooping Cranes.

Implications for Whooping Crane Stopover Ecology

At a very broad scale, Whooping Cranes appeared to adhere to a fairly narrow range of directional headings during migration, a finding that is supported by previous work as well (Howe 1989; Austin & Richert 2001). Within that band of suitable bearings, the environmental characteristics within 1 km^2 of a site affected the predicted probability of use as a stopover. This result reflects the potential for a hierarchical decision making process during migration (Hutto 1985; Moore & Aborn 2000), in which a series of environmental cues affect habitat selection at sequentially smaller scales. For example, starting with the broadest scale, the Whooping Crane appears to stick closely to a specific migratory route. Then, within that route, certain areas are preferred (e.g., areas closer to crops and wet natural habitats), whereas others are avoided (e.g., areas of high road cover). Although we examined wetland coverage and proximity variables, we did not explicitly include wetland quality in our analysis; this could be an important variable to consider in future research. Whooping Cranes may use stopover sites that meet certain criteria at different spatial scales.

At the broad scale, the importance of the bearing variable in our model supported what was expected in a small-front migration. Small-front migration, which is primarily found in diurnal migrants like the Whooping Crane, often implies a fairly narrow migration shadow, and stopover areas outside that shadow, however, suitable, are rarely used (Berthold 2001). In that sense, adhering to the appropriate orientation appears to be the strongest factor acting on Whooping Cranes during migration, which provides us a relatively narrow corridor within which to focus conservation efforts. Not all migratory pathways are so clear-cut, however, and many species may be much less predictable in directional heading during migration (e.g., Sandberg & Moore 1996).

The model we developed performed reasonably well (test AUC = 0.85), and we expect that it can be improved with time as more precise data become available (e.g., from radio-tracked Whooping Cranes).

Conservation Planning and Development in Migratory Bird Flyways

A robust understanding of en route ecology and distribution of stopover habitats will help us build comprehensive and effective conservation plans for migratory birds. It is admittedly difficult to untangle the factors that affect en route ecology, but we demonstrated that the best available data can make useful predictions about where suitable and unsuitable stopover areas are.

Habitat modeling in a migratory bird flyway can be a relatively straightforward process when citizen reports on bird sightings are available. Using citizen-reported data for pseudo-absence points, in addition to presence points, for the species of interest can improve the accuracy of species distribution models because both data sets are subject to the same types of bias (e.g., Phillips et al. 2009; Mateo et al. 2010). This approach provided a useful way to account for the biases in the Whooping Crane occurrence data set. Publicly available data on bird locations, such as the eBird project and Bird Banding Laboratory (e.g., Kreakie & Keitt 2012), may be helpful for expanding this approach to other regions or for other species. The potential biases and limitations of citizen science data such as these have been well documented (Austin & Richert 2001; Sullivan et al. 2009) and all our results should be interpreted cautiously. For highly endangered species like the Whooping Crane, additional rigorously collected data would help reveal any unexpected biases or concerns about the observations reported by citizens. For some species, such as birds with broad migratory fronts or species that are less visible during migration, additional field data might be needed to develop a useful model. Nonetheless, in many cases, citizen science data can be useful in addressing conservation questions at the landscape scale (Dickinson et al. 2010).

We focused on areas that could be explored for wind energy development with low risk of conflict with Whooping Crane stopover habitats, but this approach could also help locate areas of restoration potential (i.e., areas where habitat within the migratory corridor is currently lacking) and conservation potential (i.e., areas where large blocks of habitat currently exist). The 1 km^2 grain of our analysis allowed a landscape-wide evaluation of sites at a scale relevant for Whooping Cranes, but potential projects could look for aggregations of suitable cells that meet their land area needs. Small areas of land that had a rank of 1 may be fragmented and interspersed within areas of higher risk, so we suggest that developers examine the landscape context of potential sites with respect to the land area requirements for new projects. Although the approach we used here was tailored to aid wind energy site selection, other large-extent proposed projects (for instance, pipeline projects like the proposed Keystone XL) could revise this approach to evaluate sites that meet their own unique criteria.

Over 31,700 km^2 in the Nebraska migratory corridor had a site suitability rank of 1 for potential wind energy development, with adequate wind resources and lowest predicted suitability for Whooping Crane stopover habitat. This is more than enough land to meet and exceed the U.S. Department of Energy's vision for Nebraska wind power by 2030 (5–10 GW, USDOE 2008, p. 10), if we assume an average capacity density of 3.0 MW/km^2 (Denholm et al. 2009). Here, we assumed that developers of wind energy in the Great Plains will seek to minimize conflicts with ESA requirements early in the site selection process. We are not suggesting that Whooping Cranes take priority over wind energy development; rather, we are illustrating a process that can help avoid unnecessary conflicts between the 2. Future wind development projects across the United States could augment this site selection approach by incorporating multiple species of concern within the area of interest as well as other engineering or regulatory constraints on wind energy siting. Finally, we emphasize that our model provides insight into the suitability of stopover areas, but it does not necessarily account for birds in flight or indicate actual use by Whooping Cranes. Sites that appear suitable for Whooping Crane stopovers may not be used, particularly because their population size is so small. This highlights the importance of field surveys to verify model predictions and delineate baseline conditions prior to construction (e.g., Anderson et al. 1999). Our approach is meant to be used in the initial stages of project planning as the first step in avoiding potential negative effects through careful site selection.

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Supporting Information

Plots indicating the relation between environmental variables and predicted suitability for Whooping Crane stopover sites (Appendix S1) are available on-line. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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