FINAL REPORT: IDENTIFYING POTENTIAL LANDSCAPES FOR CONSERVATION ACROSS THE GRASSLANDS OF NORTH AMERICA: INTEGRATING KEYSTONE SPECIES, LAND USE PATTERNS, AND CLIMATE CHANGE TO ENHANCE CURRENT AND FUTURE GRASSLAND RESTORATION EFFORTS

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INTRODUCTION

Because prairie dogs (*Cynomys* spp.) function as ecosystem engineers and keystone species in North America's grasslands (Fig. 1), their conservation and management lies at the core of many conservation efforts[1,2]. However, prairie dog management is challenging because they are severely affected by epizootic plague outbreaks caused by the introduced bacterium *Yersinia pestis*[3,4], and highly threatened by drought and climate change in the southern portion of their range[5–7]. In fact, the formerly largest remaining colonies (in Janos, Chihuahua, Mexico; Conata Basin of South Dakota, USA; and Thunder Basin National Grassland, Wyoming, USA) have collapsed by 50 to over 90%, during the last two decades, largely due to plague, drought, and/or land use impacts[6,8–10]. This underscores the urgency for conserving prairie dog colonies, associated species, and mitigating plague and

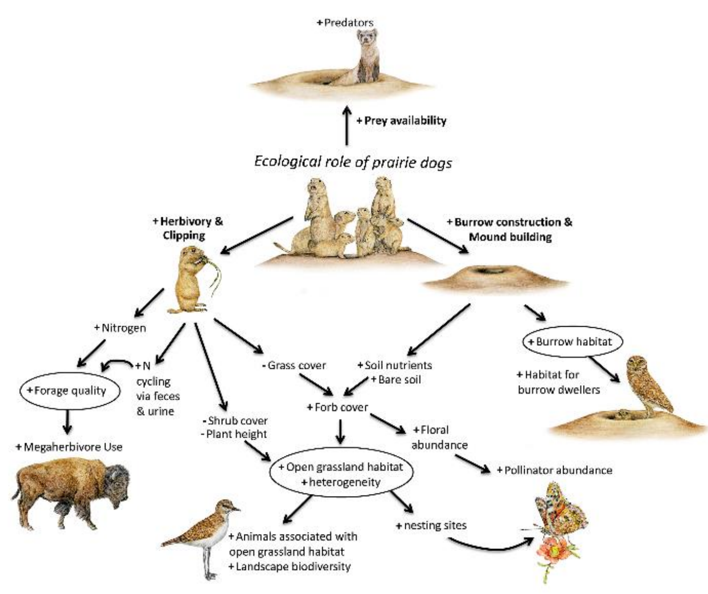

Fig. 1. Conceptual diagram illustrating how the ecological role of prairie dogs cascades throughout the prairie dog ecosystem. Plus signs indicate an increase in an ecosystem property as a result prairie dogs; minus signs indicate a decrease. (Modified version from Davidson et al. 2012 [1]*)*

impacts from climate and land use change by identifying potential landscapes for conservation action, both now and into the future. And,–critically–such areas need to be considered within the context of rangelands that are relied on for cattle production and have traditionally harbored complex social cultures resistant to prairie dog conservation[11,12].

The capacity for a landscape to support spatially extensive grassland conservation efforts depends on a complex suite of abiotic, ecological, social, and economic factors[13]. Mapping of landscape capacity to support such conservation efforts across North America's central grasslands provides a much-needed tool for optimizing use of scarce funds for grassland conservation and restoration efforts. This is especially valuable for contemporary management because of the social, environmental, and economic factors that influence where prairie dog complexes can be conserved and expanded across large blocks of continuous habitat – to support numerous, associated grassland species[1,10,13].

To address this need, we identified potential landscapes for conservation, through spatial modeling. Our work examines ecological, political, and social factors, along with changing climate and land use to maximize long-term conservation potential and co-existence with human activities. Our project involves two major components: Part I, developing a black-tailed prairie dog (*C. ludovicianus*) (BTPD) habitat suitability model (HSM) under both current climate and projected future climate scenarios and Part II, identifying suitable landscapes for black-tailed prairie dog (BTPD) ecosystem conservation using the conservation planning tool, Zonation.

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PART I: HABITAT SUITABILITY MODEL FOR THE BLACK-TAILED PRAIRIE DOG ECOSYSTEM

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INTRODUCTION

Here, we develop a habitat suitability model (HSM) for the black-tailed prairie dog (BTPD) ecosystem. Our HSM is based on presence and absence data for prairie dog occurrences across the geographic range of the BTPD within the United States, and how the prairie dog occurrences relate to climate, soils, topography, and land cover (Fig. 1). We also project the BTPD HSM under two future climate scenarios: 1) warm and wet and 2) hot and dry.

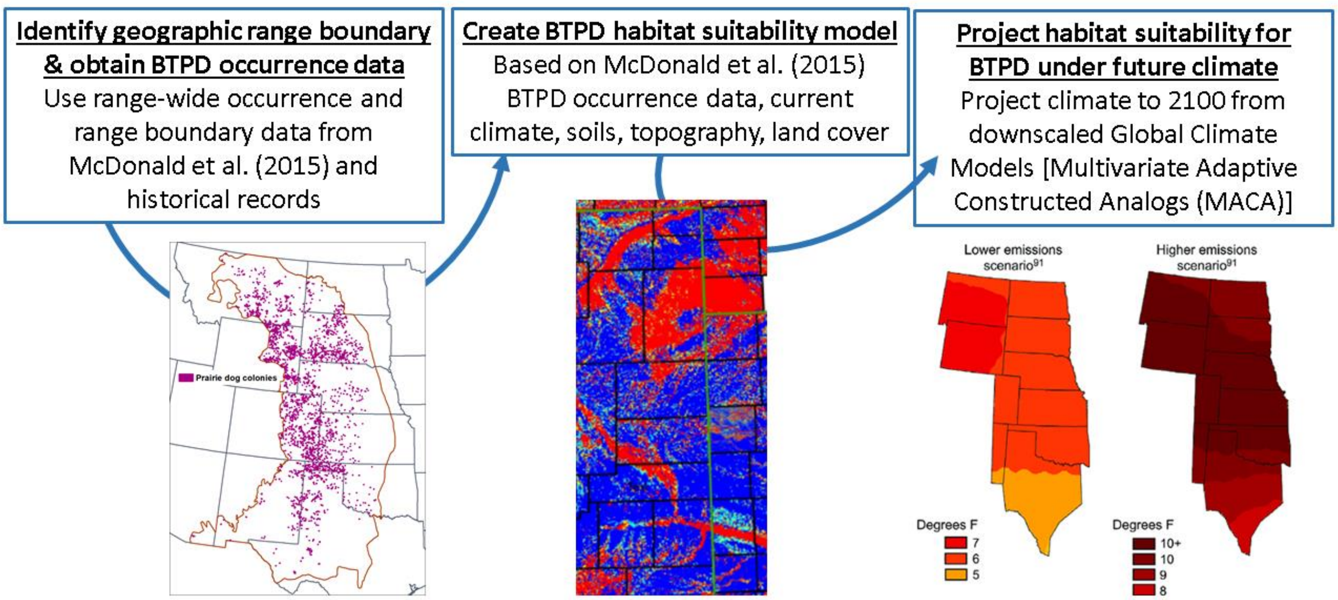

Fig. 1. *Methodological approach for developing the black-tailed prairie dog habitat suitability model (HSM).*

METHODS

To begin Part I of our analysis, we first obtained BTPD occurrence data and identified their geographic range boundary (Fig. 2). We obtained range-wide prairie dog occurrence data from Western EcoSystems Technology, Inc. (WEST, Inc.; Hereafter, "WEST data") to use for our primary HSM analysis because colony data was systematically collected across the BTPD range over the same time period[14]. The WEST data is based on prairie dog colonies identified using National Agriculture Imagery Program (NAIP) imagery from a stratified random sample of 2x2 mile grid cells extending across the BTPD range within the United States. (Table 1.).

Table 1. *Sample size of the WEST data[14]. The Table below is Table 1.1 from McDonald et al. (2015)[14], showing total number of 2 mi by 2 mi grid cells in each state or overlapping BLM managed land, number of grid cells sampled (sample size) and date of National Agriculture Imagery Program (NAIP) imagery.*

State	Sample size	Total number of cells	Date of NAIP Images
Arizona	477	2,361	2013
BLM	2,422	21,790	2012, 2013, 2014
Colorado	1,122	11,101	2013
Kansas	1,034	12,785	2014
Montana	1,318	16,302	2013
Nebraska	1,128	13,960	2014
New Mexico	1,362	16,852	2014
North Dakota	1,012	5,011	2014
Oklahoma	1,078	8,888	2013
South Dakota	1,230	12,165	2014
Texas	1,982	24,539	2014
Wyoming	1,722	8,790	2012

In order to transform the WEST data into a format suitable for data analyses, we generated presence and absence points for BTPD using the WEST data. For each colony polygon detected within a given grid cell, we assigned one presence point for each hectare within the colony and then randomly selected one absence point for every 15 ha within the remaining portion of the grid cell where no colonies were found. All points were at least 60 m (two 30 x 30 m raster cells) away from each other, and all absence points were at least 500 m from any presence point. This produced approximately 86,300 presence points and 315,000 absence points, from which we randomly selected the same number of absence points as presence points to use in our HSM analysis.

Our BTPD range boundary is based on current and historical distribution. To determine current range we largely followed the WEST[14] boundary and extended the range boundary where appropriate to reflect the historical range distribution based on museum specimens. Each states' Western Association of Fish and Wildlife Agencies (WAFWA) Prairie Dog Conservation Team (PDCT) member approved the Final BTPD boundary for their state, and GPS point locations for all museum specimens we used to create the boundary are stored in the project database along with detailed metadata for each.

The next step in our Part I modelling effort involved determining the best and most current spatial data layers available for soils, climate, topography, and land cover for the HSM (Tables 2 and 3 and Fig. 3). We downloaded and processed data for analyses (described below) and identified suitable land cover types and patch metrics. These efforts yielded a total of 25 environmental input datasets for the full study area, based on the data sources in Table 2 (see also Fig. 3).

Our research team used several valuable databases representing major improvements in the resolution and accuracy of the input variables. First, we used the 2016 National Land Cover Database (NLCD), which was released by USGS in May of 2019. This 2016 database represents a major improvement from 2011 NLCD that was previously available, as it incorporates new data derived from the USDA's Cropland Data Layers for 2011 – 2016, and implemented new algorithms for identifying developed and paved surfaces. Second, rather than using the National Soil Survey's SSURGO database to map soil types across the BTPD range, we used a new digital soil map of the US (POLARIS [15,16]) that builds upon SSURRGO but includes improved interpolation of soil texture and other attributes down to a 30-m pixel resolution. One limitation is that this improved soil model did not include depth to bedrock, which is an important factor influencing BTPD burrowing. We attempted to use the latest SSURGO soils data[17] for the depth to bedrock metric, compiling depth to bedrock values from individual statewide datasets and averaged over map unit components. Many map units had no bedrock depth measure in SSURGO, so we estimated missing data using a component-weighted average of maximum horizon depth. Polaris soils data[16] are available as individual 1-degree tiles per metric per depth, so we downloaded, depth-weighted, and merged the Polaris data by soil metric over the study area. The most recent National Elevation Data (NED)[18] was likewise downloaded as individual 1-degree tiles and merged over the study area. We then corrected the NED by identifying and removing as many sink artifacts as possible, while preserving true sinks such as playas and perennial water bodies. Next, we used the software TauDEM[19] to calculate a Topographic Wetness Index as well as slope for the entire BTPD range. The NED was also used to create a Terrain Ruggedness Index as well as information on aspect as a function of 'northness' and 'eastness'. We used the 2016 NLCD[20] as the basis of several land cover type metrics including patch size, distance to patch edge, and nearest edge type. Finally, current climate data metrics were calculated from raw daily gridded meteorological data[21] averaged over 1994 - 2014. All continuous datasets were normalized to be between 0 and 1 (-1 to +1 in the case of the northness and eastness measures) so that inputs had equivalent scales. Categorical data (primarily land cover) were converted to one-hot 'dummy' variables for use in modeling algorithms that cannot accept categorical inputs. The Python and R scripting code written for many of the above calculations is available at https://github.com/mmfink/HOTR_Code. TauDEM, which is written in C++, is available at http://hydrology.usu.edu/taudem/taudem5/. The remaining data processing was done in ESRI ArcGIS. During iterative modeling, we narrowed down environmental inputs based on covariate correlation, proportion of deviance explained, and effect on model performance (Table 3). We were forced to drop the SSURGO-derived depth to bedrock input due to the large amount of data coded as zeroes (indicating no real depth data available), which was biasing model output.

Table 2. *Spatial data layers and their sources used in the black-tailed prairie dog (BTPD) habitat suitability model.*

Variable	**Spatial data layer for Habitat Suitability Model**
BTPD colony occurrences	Prairie dog occurrences from WEST survey[14]
Land Cover	USGS National Land Cover Database 2016[20]
Soils	POLARIS 30-m resolution database[16] Metrics: bulk density to 100cm, Sand to 100cm, %Clay to 100cm, % organic matter to 100cm, pH to 100cm
Slope & elevation	National Elevation Dataset[18] Metrics: Topographic Wetness Index, Topographic Ruggedness Index, slope, aspect
Climate – current	Current climate (1994-2014), using gridMet[21] Metrics: Mean annual precipitation (mm), winter + spring & summer + fall precipitation, max summer temperature, potential evapotranspiration, growing degree days
Climate – future (used only for HSMs projected into the future)	Future Climate (2100), using MACAv2_METDATA[22,23] Metrics: Mean annual precipitation (mm), winter + spring & summer + fall precipitation, max summer temperature, potential evapotranspiration, growing degree days

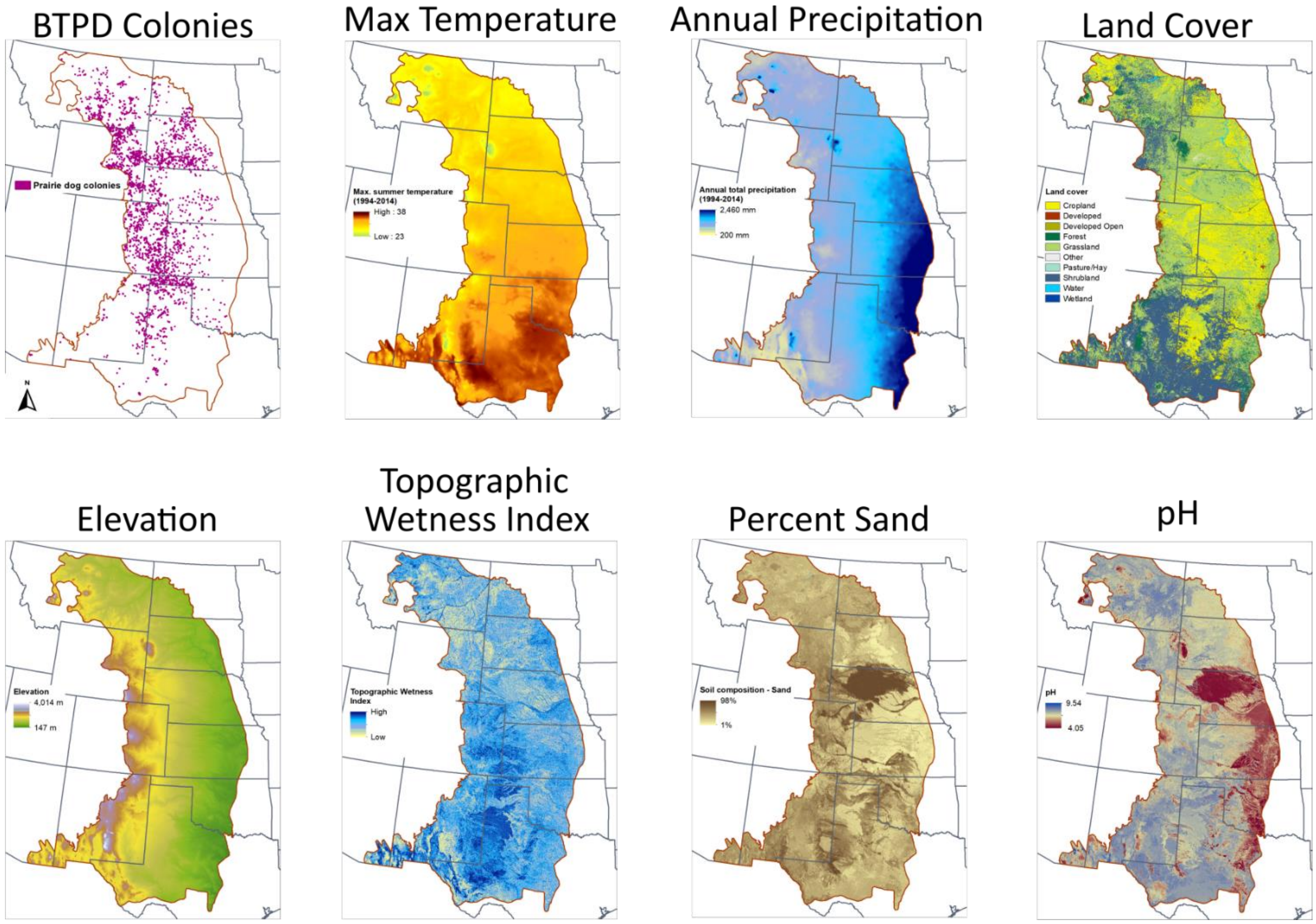

Fig. 3. *Some of the spatial layers created for the black-tailed prairie dog (BTPD) habitat suitability model, based on BTPD occurrence*[14], *climate*[21], *land cover*[24], *topography*[18], *and soils*[16].

To determine the best-fit habitat suitability model for our data, we evaluated the performance of several different independent models and an ensemble model[25,26]. Specifically, we created BTPD habitat suitability models using a: 1) Generalized Linear Mixed-Model (GLMM), 2) Random Forest model (RF), 3) Boosted Regression Trees model (BRT, also known as Generalized Boosted Models or GBM), and 4) an ensemble model that combined the outputs of the GLM, BRT, and RF HSMs. Models were created using the R packages *lme4*[27], *randomForest*[28], and *dismo*[29]. The GLMM used the identity of the sampling grid cell that each presence or absence point fell within as a random factor. All R code used for modeling is available at the previously mentioned GitHub repository.

Table 3. *All environmental inputs considered, with the final used in bold (in "Label" column).*

Label	**Description**	**Based On**
bd	soil bulk density to 1 m (g/cm3)	POLARIS
clay	percent clay to 1 m	POLARIS
DEM	elevation (m)	USGS NED
depth	depth to bedrock (cm)	SSURGO
distToNon	distance (from each pixel) to the nearest non-habitat (m)	NLCD 2016
eastness	east-west aspect index	USGS NED
GDD5	annual growing degree-days, base 5, averaged over 1994-2014	gridMET
hab_non	binary designation of grass/shrub habitat (1) or other land cover type (0)	NLCD 2016
hab_nonpch	patch size of contiguous habitat or non-habitat (m2)	NLCD 2016
nearType	land cover type of the nearest non-habitat (categorical)*	NLCD 2016
nlcd	land cover (categorical)*	NLCD 2016
nlcd_patch	patch size of each land cover type (m2)	NLCD 2016
northness	north-south aspect index	USGS NED
om	percent organic matter to 1 m	POLARIS
PET	annual potential evapotranspiration, grass reference (mm), averaged over 1994-2014	gridMET
ph	soil pH to 1 m (soil:water method)	POLARIS
ppt_sf	summer – fall (June-November) total precipitation (mm), averaged over 1994-2014	gridMET
ppt_ws	winter – spring (December-May) total precipitation (mm), averaged over 1994-2014	gridMET
ppt_yrly	annual total precipitation (mm), averaged over 1994-2014	gridMET
sand	percent sand to 1 m	POLARIS
slope	degrees slope	USGS NED
tmax	maximum summer (June-August) air temperature, averaged over 1994-2014	gridMET
TRI	Terrain Ruggedness Index	USGS NED
TWI	Topographic Wetness Index	USGS NED

*Categorical variables were converted into one-hot dummy variables (e.g., nlcd.Grassland, nlcd.Cropland, etc.) for the GLMM model.

Models were trained on a random 70% subset of the full dataset, maintaining relatively equal numbers of presence and absence points (Fig. S1). Half of the remaining data (15%) were used to evaluate RF and BRT model performance during tuning of the calling parameters (such as number of trees). The final 15% of withheld data ("Testing dataset") were then used to evaluate all three final models (Table S1, Fig. S1). All sampling of presence/absence points was done at the level of the grid cell (i.e., the cells were randomly sampled, not the points within them). We selected 95% Sensitivity because our primary goal was to correctly identify prairie dog habitat.

The ensemble model was created as a weighted average of the final GLMM, RF, and BRT models. Using the *mean* of Sensitivity=0.95, weights used were calculated by averaging 6 performance metrics (AUC, TSS, PCC, Kappa, Sensitivity, and Specificity), which were themselves averaged over a 10-fold cross-validation of the models built on the Training dataset. This gives the higher performing models more influence over the ensemble. For the cross-fold validation, each fold randomly sampled 10% of the sampling grid cells in the Training dataset, so that if a sampling grid cell was selected, all presence and absence points within that cell were assigned to that fold. The ensemble was evaluated against the Testing dataset as well (Table S1).

BTPD Habitat Suitability Model under Future Climate
Next, we projected our BTPD HSM into the future (2100) under two different (representing "best" and "worst case") climate scenarios: 1) warm and wet (IPSL-CM5A-LR_r1i1p1_rcp45); and 2) hot and dry (MIROC5_r1i1p1_rcp85). These models best represented the two scenarios for our study region. The future climate model scenarios were obtained from MACA v2-METDATA, and were averaged over 2076-2099 (Table 2). All other model inputs remained the same. From the MACA website, "Climate forcings in the MACAv2-METDATA were drawn from a statistical downscaling of global climate model (GCM) data from the Coupled Model Intercomparison Project 5 (CMIP5, Taylor et al. 2010) utilizing the Multivariate Adaptive Constructed Analogs (MACA[22]) method with the METDATA[30] observational dataset as training data."

Ensemble Model Review
During summer 2020, our team met with biologists from each state individually and with other experts on the prairie dog ecosystem to provide detailed state-level review of the ensemble habitat suitability map. After extensive review, our team worked to address each of the comments we received. The biggest challenge was modelling the desert grasslands of the American Southwest (AZ, southern NM, southwestern TX), where prairie dogs occurred historically, and considerable grassland remains. Throughout this region, prairie dogs were extensively exterminated over the last century and their populations have not recovered as in other parts of their range, likely due to the increasingly arid climate and grassland desertification[31–34]. Nevertheless, extensive grassland remains in the region and colonies do exist, just not in high enough abundance to be well-sampled by the WEST et al. effort. To help address this, we obtained additional, recent data (within the last ca. 10 years) for AZ, NM, and TX from within the desert grassland ecoregion[35] to add to the occurrence locations identified in the WEST data. This allowed us to better model habitat conditions where BTPDs occur across the desert grassland ecoregion. We randomly selected the same number of grid cells in the WEST et al. data and traded them out with the new grid cells covering the additional occurrence data. This way we were able to retain the same number of grid samples per state. To account for the higher level of sampling effort in Wyoming and Colorado in the WEST[14] study, we randomly sampled an equal density of grid cells in each state across the BTPD geographic range. We also removed errors in occurrence data identified during the reviews by biologists in each state, as some of the occurrences were false positives. In a few instances along the western edge of the BTPD range in New Mexico, we removed mapped colonies that were likely to be Gunnison's prairie dogs rather than BTPD, based on consultation with the state wildlife agency.

RESULTS

Among the three models used the build the ensemble HSM, the GLMM performed most poorly and was more restrictive in identifying suitable prairie dog habitat compared to the RF and BRT models (Table S1; Fig. S1). Yet, the GLMM performed better at modelling suitability relative to soils across the BTPD range compared to the RF and BRT, while RF and BRT modelled suitability relative to climate better than GLMM. Climate variables were important predictors across all models, followed by topography and landcover; soils were generally less important (Fig. S2). The variables of greatest importance for the GLMM were: topographic ruggedness, growing degree days, and soil organic matter; whereas variables of greatest importance for both the RF and BRT were: summer-fall precipitation, growing degree days, winter-spring precipitation, landcover, and topographic ruggedness (Fig. S2).

When we compared performance metrics of all four models (GLMM, RF, BRT, ensemble), the Random Forest model performed slightly better than the ensemble, followed by BRT and GLMM (Table S1; Fig. S1). However, we selected the ensemble model to build our HSM because not only did it perform similarly well to RF, but it also made ecologically most sense when we evaluated each of the models independently and the ensemble HSM appeared to reduce the impact of individual model biases. Indeed, ensemble HSMs often perform better than single HSMs because they can average out uncertainties and biases inherent in different model algorithms. Our final ensemble model exhibited high predictive accuracy, with an AUC of 0.96 and error rate of 13% at a Sensitivity (ability to correctly identify prairie dog habitat) of 95% (Figs. 4 and S3). We also evaluated the model when Sensitivity was equal to Specificity and when Specificity was 95% and found similar model performance (Table S3; Fig. S3).

The most suitable habitat for the BTPD ecosystem under the current climate extends largely from northern and eastern New Mexico and the panhandle of Texas and Oklahoma through eastern Colorado, eastern Wyoming, southern Montana, western south Dakota, and parts of western Kansas and Nebraska (Fig. 5, Table 4). Small patches of suitable habitat occur through the southwest in Arizona, southern New Mexico, and southwest Texas. The eastern part of the original prairie dog range is largely unsuitable due to the extensive conversion of grassland to cropland, and the southern portion of their geographic range is limited largely by climate suitability. Low suitability across most of Nebraska is due to excessively sandy soils.

Model	AUC	TSS	kappa	PCC	Sensitivity	Specificity	Error rate
Ensemble	0.96	0.75	0.75	0.87	0.95	0.80	0.13
		True Skill Statistic TSS = TPR + TNR − 1		Percent correctly classified	ability to correctly identify **prairie dog habitat** (true positive rate)	ability correctly identify **non-prairie dog habitat** (true negative rate)	

Fig. 4. *Performance metrics of the black-tailed prairie dog ensemble habitat suitability model. These performance metrics reflect when Sensitivity is set to 0.95.*

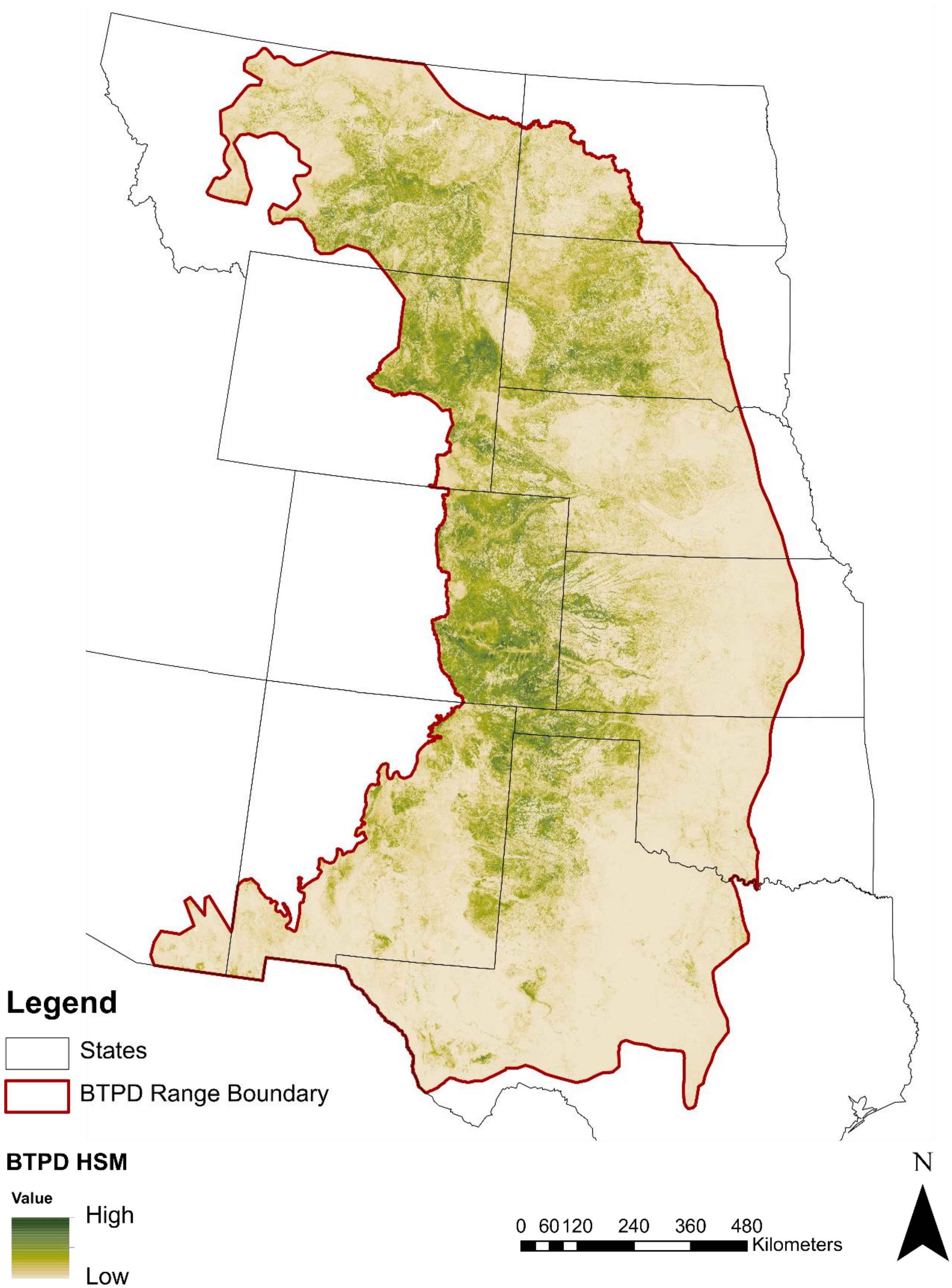

Fig. 5. *Black-tailed prairie dog (BTPD) ensemble habitat suitability model (HSM), under current climate. Dark green shows areas of highest habitat suitability for BTPDs, and beige shows areas of lowest suitability.*

Table 4. *Number of hectares of black-tailed prairie dog (BTPD) habitat that is of low, medium, and high suitability within each state and across the BTPD range.*

STATE NAME	Low	Medium	High
Montana	1,763,366	1,345,433	1,588,702
North Dakota	340,733	180,275	63,826
South Dakota	1,711,314	1,277,664	1,470,485
Wyoming	1,064,272	1,021,180	1,961,438
Nebraska	692,534	441,174	389,552
Colorado	1,338,636	1,558,562	4,216,600
Kansas	631,120	420,207	760,199
Arizona	13,750	5,789	108
Oklahoma	280,290	212,791	480,503
Texas	1,018,266	804,629	1,064,014
New Mexico	1,169,982	863,150	728,047
Entire US Range	10,024,502	8,130,936	12,723,491

Projecting suitable habitat into the future under both future scenarios (warm and wet; hot and dry) shows how the suitable habitat shifts northward (Fig. 6). Under the warm and wet scenario, eastern Colorado remains a stronghold, and suitable habitat expands across Wyoming, Montana, western North Dakota, South Dakota, western Nebraska, Kansas, and central Texas. Suitable habitat under this scenario retracts across the Southwest, with reductions especially in southern and eastern New Mexico with the northeastern part of New Mexico remaining as highly suitable habitat; it also declines somewhat across the Texas-Oklahoma panhandle region. Under the more extreme hot and dry future scenario, suitable habitat substantially declines across the Southwest through Texas, Oklahoma, and Kansas. Central and northeastern New Mexico and eastern Colorado remain favorable habitat but become the southern edge of suitable range, with the heart of suitable habitat projected to occur across Wyoming, Montana, and the Dakotas. We did not model the future scenarios beyond the known historical range within the United States, but it is likely suitable habitat could expand beyond the historical range in North Dakota, Montana, and Canada with the project northward range shift.

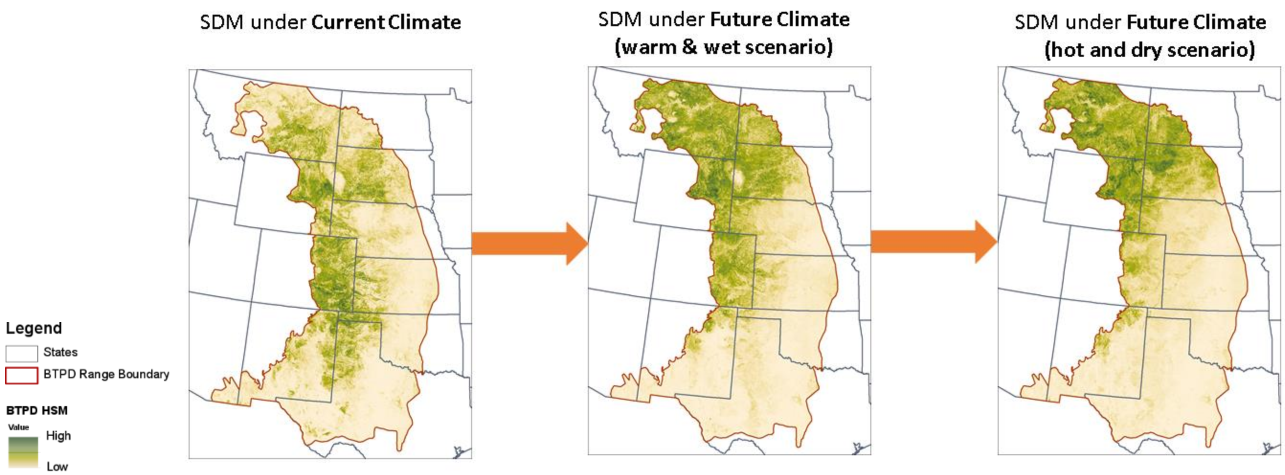

Fig. 6. *Black-tailed prairie dog (BTPD) habitat suitability models (HSM) under current climate and future climate scenarios. Dark green shows areas of highest habitat suitability for BTPDs, and beige shows areas of lowest suitability.*

FINAL PRODUCTS:

The final map products have been posted online through the Colorado Natural Heritage Program (CNHP) at Colorado State University, the Western Association of Fish and Wildlife Agency (WAFWA), and made available through an interactive web map [36] (Table 5). Within the interactive web map, users can view the output raster layers of the modeled priority areas and have the ability to query for additional information associated with each cell.

Table 5. *List of data products produced.*

Dataset product	type	format	resolution	access
BTPD Habitat Suitability Model (HSM) under current climate	raster	geo-TIF	90m	CNHP WAFWA
BTPD HSM under future climate (2100); warm & wet scenario	raster	geo-TIF	90m	CNHP WAFWA
BTPD HSM under future climate (2100); hot & dry scenario	raster	geo-TIF	90m	CNHP WAFWA

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We thank Imtiaz Rangwala, Climate Science Lead, North Central Climate Adaptation Science Center for guidance on modelling habitat suitability for BTPDs under future climate. The MACA website provides this data acknowledgement statement for the future climate projections, "The dataset MACAv2-METDATA was produced with funding from the Regional Approaches to Climate Change (REACCH) project. We acknowledge the World Climate Research Programme's Working Group on Coupled Modeling, which is responsible for CMIP5, and we thank the climate modeling groups for producing and making available their model output. For CMIP5, the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals."

We also thank the Western Association of Fish and Wildlife Agencies Prairie Dog Conservation Team, Rich Reading, Lauren McCain, Nicole Rosmarino, Kristy Bly, and Steve Forrest for their reviews and critical feedback of our models. Their expert knowledge and on-the-ground insights were integral to improving our final models and central to informing and co-producing this decision support tool. We also thank the Southern Plains Land Trust, Turner Endangered Species Fund, and the American Prairie for providing spatial layers of their properties to help inform our prioritization analysis. We are grateful to Matt Peek and the Kansas Department of Wildlife and Parks their support of this project and funds from the Pittman–Robertson Federal Aid in Wildlife Restoration Act.

SUPPLEMENTARY DOCS (PART I)

Table S1. *Mean 10-fold Cross-Validation Performance metrics on the Testing dataset for the Generalized Linear Mixed-Model (GLMM), Random Forest model (RF), and Boosted Regression Trees model (BRT) when sensitivity = 95%.*

Model	AUC	TSS	err_rate	kappa	PCC	Sensitivity	Specificity	Threshold
GLMM	0.891	0.552	0.224	0.552	0.776	0.95	0.602	0.035
RF	0.970	0.788	0.106	0.788	0.894	0.95	0.838	0.232
BRT	0.922	0.624	0.188	0.624	0.812	0.95	0.674	0.165
Ensemble	0.956	0.734	0.133	0.734	0.867	0.95	0.784	0.206

Table S2. *Ensemble model metrics (against the Testing dataset) for when sensitivity = specificity, sensitivity = 95%, and specificity = 95%. Sensitivity (True Positive Rate); Specificity (False Negative Rate).*

	AUC	TSS	err_rate	kappa	PCC	Sensitivity	Specificity	Threshold
Sensitivity = Specificity	0.96	0.781	0.109	0.781	0.891	0.893	0.888	0.321
Sensitivity 95%	0.96	0.746	0.127	0.746	0.873	0.950	0.796	0.217
Specificity 95%	0.96	0.756	0.122	0.756	0.878	0.806	0.950	0.435

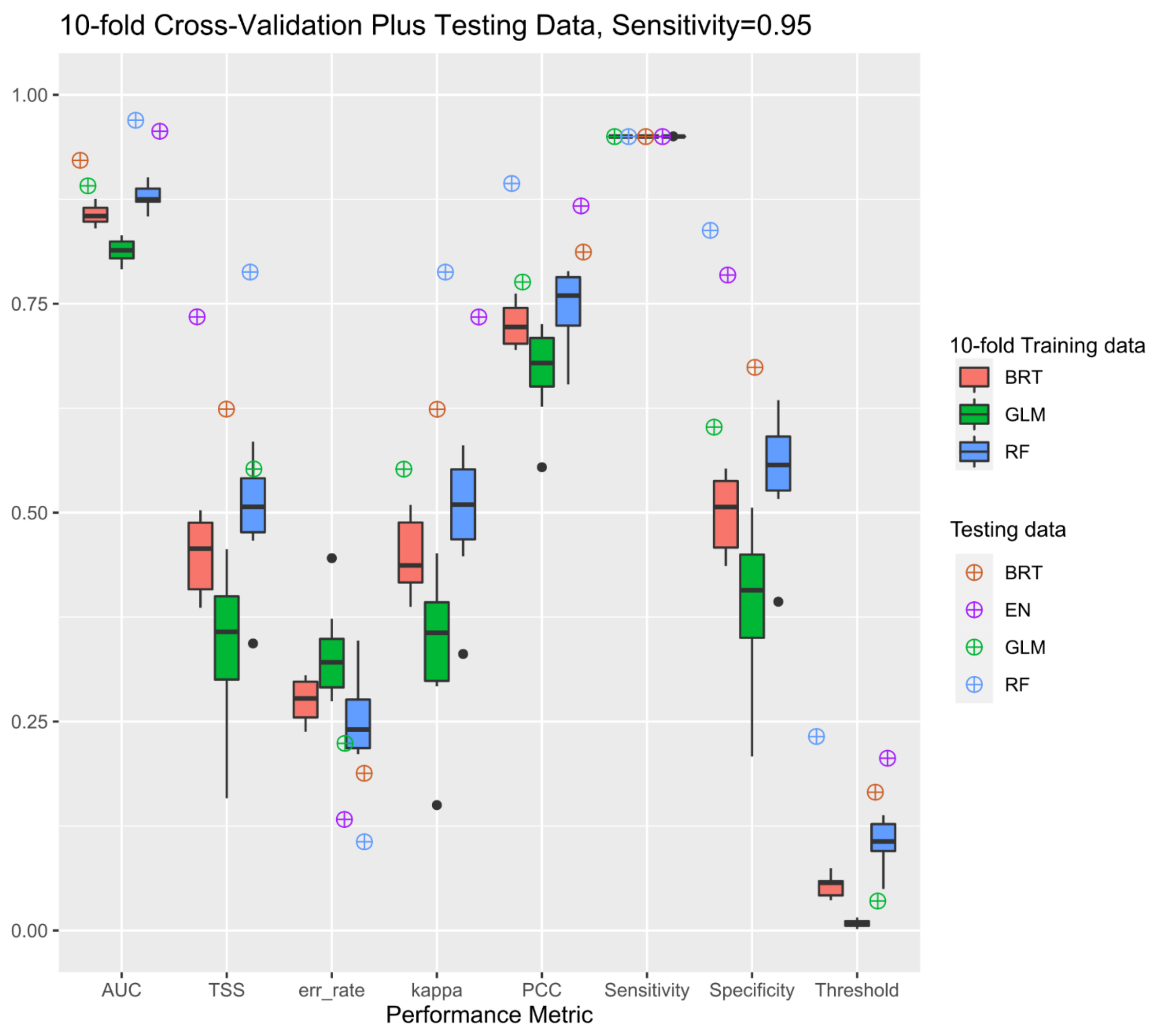

Fig. S1. *Performance metrics of the 10-fold cross validation and testing dataset for the Generalized Linear Mixed-Model (GLMM), Random Forest model (RF), Boosted Regression Trees model (BRT), and Ensemble (EN) when sensitivity = 95%.*

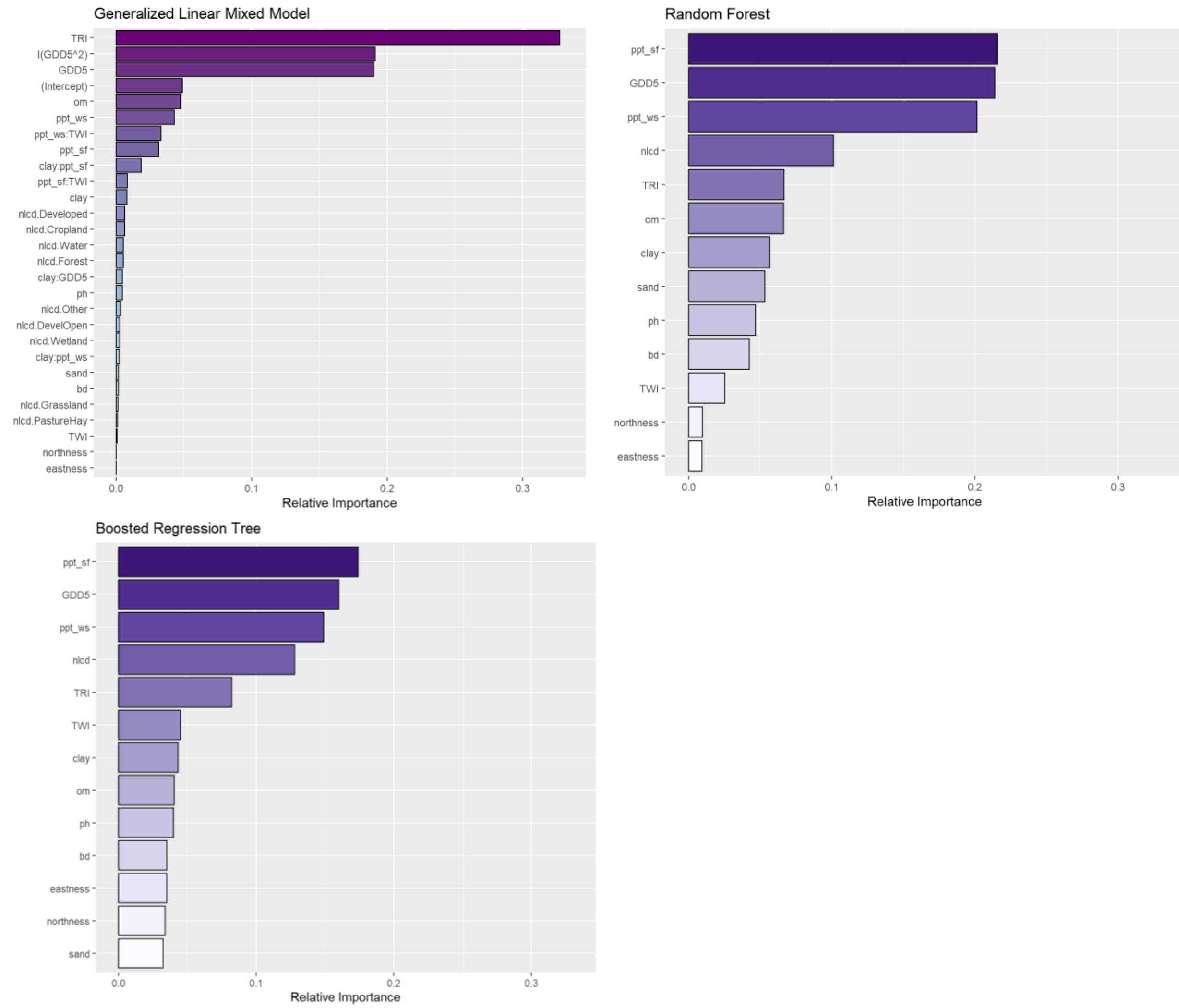

Fig. S2. Variable importance plots for the Generalized Linear Mixed Model, Random Forest, and Boosted Regression Tree. All values have been normalized so that the sum of all variable importance measures for a model = 1. See Table 3 for label and description of each variable.

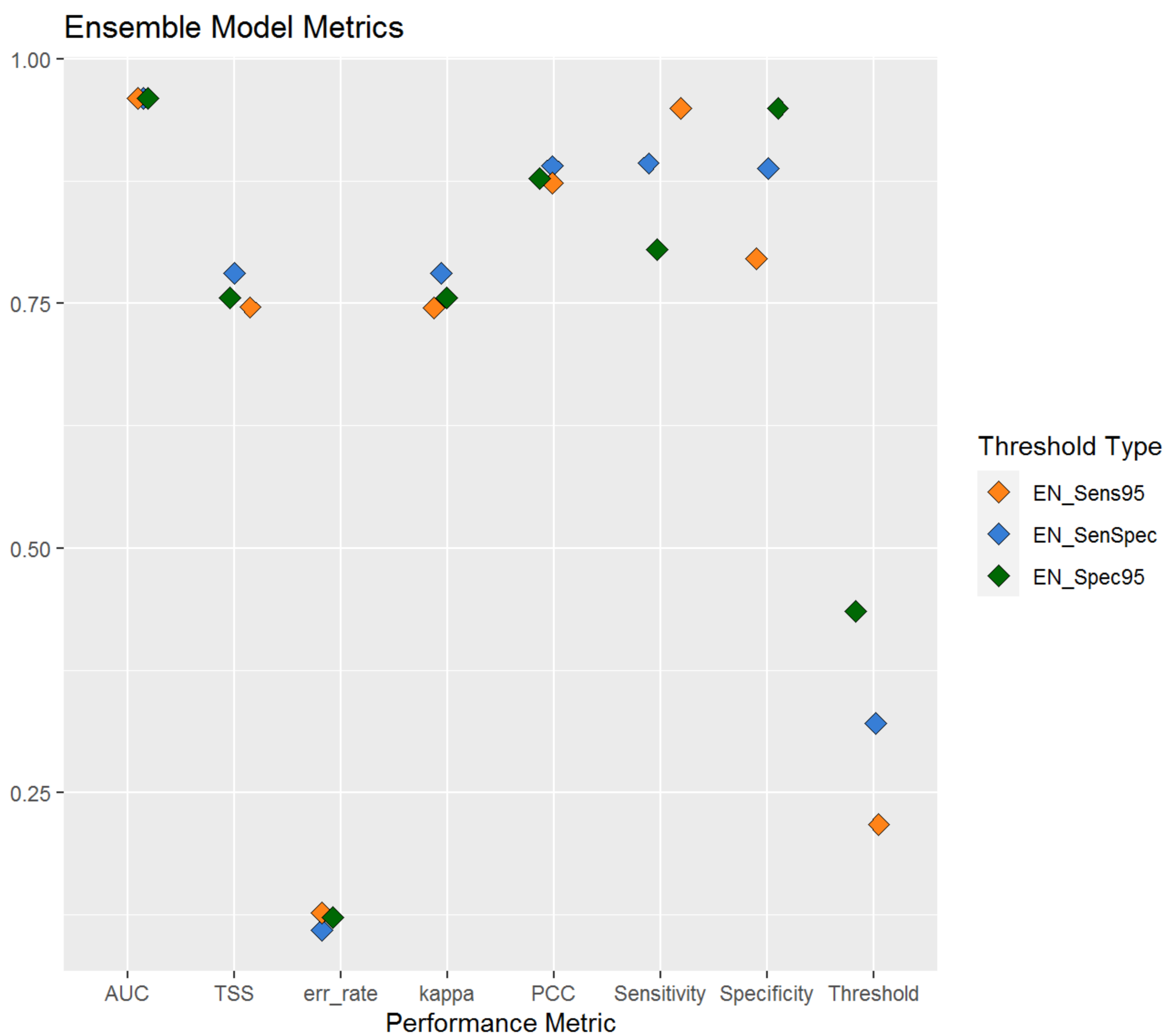

Fig. S3. *Ensemble (EN) model performance when sensitivity = specificity, sensitivity = 95%, and specificity = 95%. Sensitivity (Sen; True Positive Rate); Specificity (Spec; False Negative Rate).*

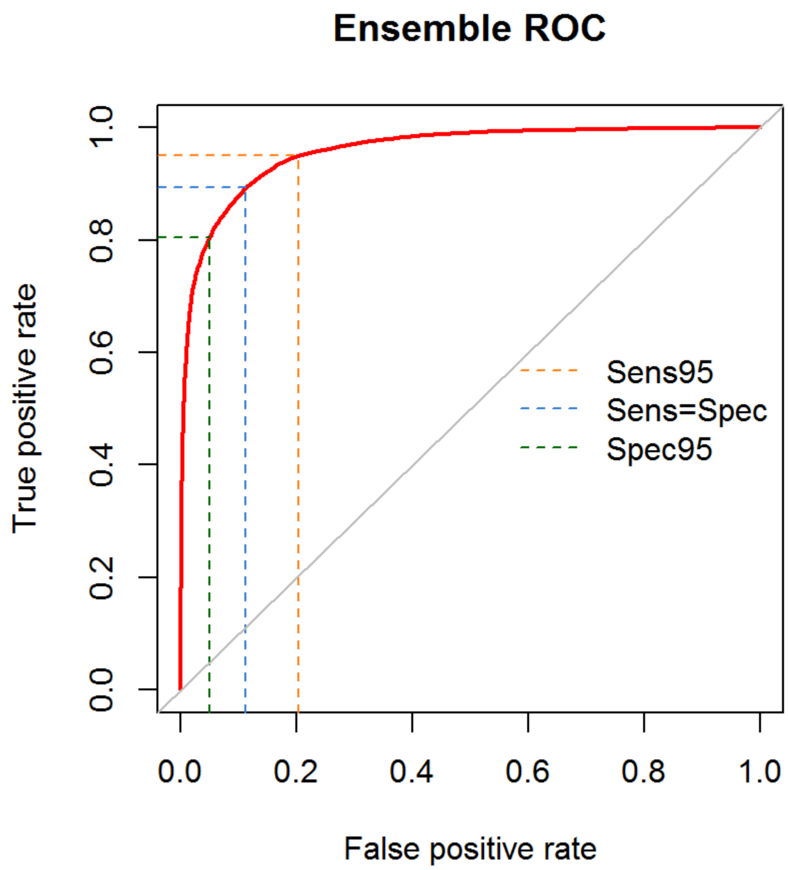

Fig. S4. *Ensemble model performance when sensitivity = specificity, sensitivity = 95%, and specificity = 95%. ROC curve shows relationship between sensitivity (true positive rate) and specificity (true negative rate). Gray solid line indicates random performance. Dashed lines show the values the axes measure for the thresholds at: Sensitivity (Sen) = 0.95 (0.217); Sensitivity = Specificity (0.321); Specificity (Spec) = 0.95 (0.435).*

PART II: POTENTIAL LANDSCAPES FOR CONSERVATION ACROSS THE CENTRAL GRASSLANDS OF NORTH AMERICA

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INTRODUCTION

Here, we use a conservation planning analysis to identify potential landscapes for conservation across North America's central grasslands, with a focus on the black-tailed prairie dog (BTPD) ecosystem within the United States. Our approach considers conservation potential based on our black-tailed prairie dog habitat suitability model, threats, land cover and projected landuse change, habitat connectivity, and climate (both present and future) (Fig. 1).

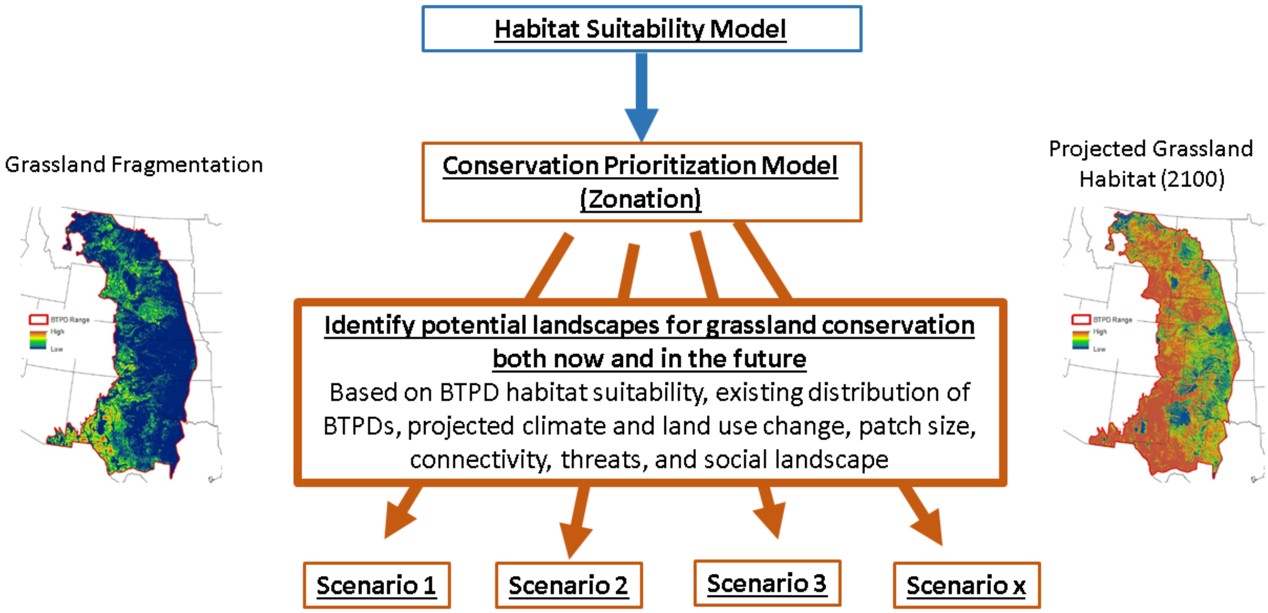

Fig. 1. *Methodological approach for identifying suitable landscapes for the black-tailed prairie dog (BTPD) ecosystem conservation.*

METHODS

Once the habitat suitability models were created (Part I), we gathered and created a suite of spatial layers that describe the social, political, ecological, and anthropogenic landscape within the current BTPD geographic range within the United States to include in a conservation prioritization analysis. The goal of this analysis was to not only assess the suitability of the habitat for the prairie dog ecosystem, but also how the social and political landscape, threats to prairie dog habitat (such as development), habitat connectivity, and general ecological landscape (e.g., percent cover of grass) collectively influence opportunities to conserve the BTPD ecosystem (Table 1).

Data Preparation

To prepare the underlying data for the conservation prioritization analysis using the program Zonation, the data layers were integrated into the nested hexagon framework (NHF). The NHF grid is based around a 1 km^2 hexagon unit that is aggregated up by units of 7 to generate coarser scale cells of 7 km^2 (cogs), 49 km^2 (wheels), and 343 km^2 (rings), allowing for cross-scale multidisciplinary analysis while obscuring precise sensitive location data (Fig. 2).

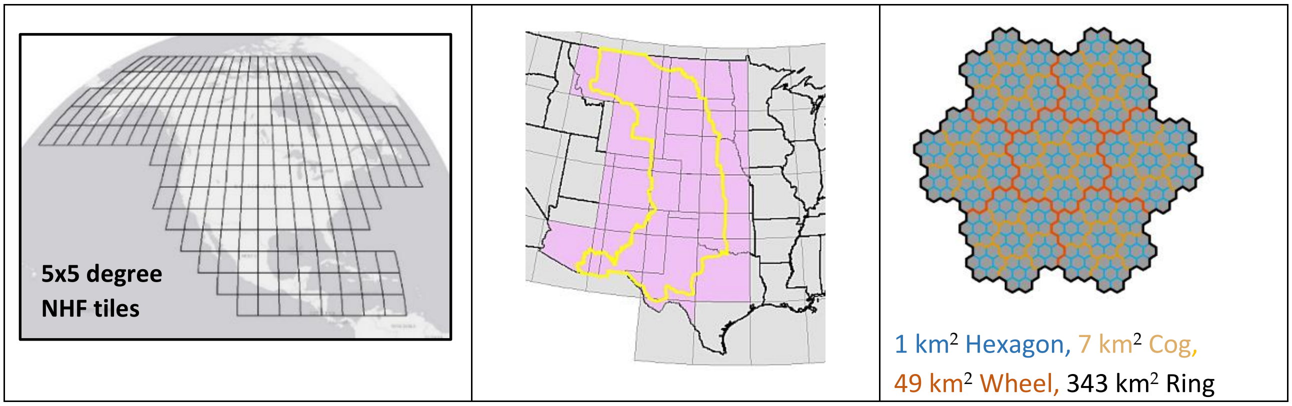

Fig. 2. *From left to right, views of the 5x5 degree latitude/longitude tiles showing the extent of the NHF grid, the NHF tiles covering the Great Plains used to summarize datasets for this project, and the cell structure of the nested hexagon framework.*

A total of 31 data layers representing point, polygon, and raster formats were processed and summarized into the NHF for consideration in the Zonation analysis (Table 1). While the exact process used to integrate the data layers into the NHF and subsequently into raster files for the Zonation analysis was slightly different for each data layer, the general process was the same. All GIS data processing was done using ESRI ArcMap 10.7 software. Input data layers were intersected with the NHF and the data layers were summarized per NHF hexagon cell using Zonal Statistics, Tabulate Area, or other similar geoprocessing tools to generate a summary of the source layer data per hexagon. Examples of the resulting tabular summaries conveyed the area of each landcover class per hexagon cell (later converted to a percent), the mean tillage risk, majority landscape condition, the sum of the meters of road or number of wells within a cell, or the presence of wind turbines within each 1 km^2 hexagon cell. The specific summary methods of each input layer integrated can be found within Table 1.

Table 1. *Summary of the data layers and the summary methods used to integrate datasets into the nested hexagon framework (NHF). The table also conveys the relationship between the layer data values and habitat suitability for the black-tailed prairie dog (BTPD) ecosystem, and which layers were incorporated into the final Zonation analysis.*

Data category	Source dataset	Summary method (per 1 km^2 hexagon)	Relationship to prairie dogs	Included in final Zonation analysis
% grass/shrub	2016 NLCD (52, 71, 81)[20]	% grass/shrub within hexagon	Positive	Yes
% emergent wetland	2016 NLCD (95)[20]	% emergent wetland within hexagon	Negative	Yes
% grass/shrub in 1 mile	Raster surface of % grass/shrub from NLCD[20] (52, 71, 81) within 1 mile	Mean value in hexagon	Positive	Yes

Percent tree cover	NLCD trees[20] + USFS % tree cover[37] + PLJV cedar and mesquite[38]	% of hexagon with tree cover	Negative	Yes
Tillage risk	Olimb tillage risk[39]	Mean % in hexagon	Negative	Yes
Oil/gas wells (well count)	Welldatabase[40]	# of active wells in hexagon	Negative	Yes
Oil/gas wells (well density)	Welldatabase[40]	# of all well records in hexagon	Negative	Yes
Wind power potential	NREL wind speed at 100 meters[41]	Mean windspeed in hexagon	Negative	Yes
Distance to Transmission lines	DHS transmission lines[42]	Distance from hexagon to nearest transmission line	Negative	Yes
Wind turbines	FAA obstruction database[43]	“Built or proposed” present in hexagon	Negative	Yes
Protected Area	PAD-US[44]	Acres of GAP 1 sites in hexagon	Neutral	Yes
Protected Area	PAD-US[44]	Acres of GAP 2 sites in hexagon	Neutral	Yes
Protected Area	PAD-US[44]	Acres of GAP 3 sites in hexagon	Neutral	No
Protected Area	PAD-US[44]	Acres of GAP 4 sites in hexagon	Neutral	No
Private Lands Conservation	NCED[45] + Turner[%] + SPLT[#] + APR[^] properties	Sum of conservation acres per hexagon (NCED + Turner + SPLT + APR)	Positive	Yes
% CRP	County level CRP[46]	% of county enrolled in CRP, % then assigned to all hexagon cells in county	Positive	Yes
Road density	US Census Tiger Roads[47]	Sum of road length per hexagon (road class = S1100, S1200)	Negative	Yes
Road density	US Census Tiger Roads[47]	Sum of road length per hexagon (road class = S1400, S1500)	Negative	Yes
Political support for the environment	League of Conservation Voters Conservation Scorecard[48]	Mean per hexagon of the median LCV scorecard value for US Representatives from 1973-2020.	Positive	Yes
Preference for prairie dog population increases	*Prairie dog survey**	Mean per hexagon of the proportion of population supporting prairie dog increases based on responses of 29,000 survey participants spatialized to the US Census tract	Positive	Yes
Preference for federal economic incentives for prairie dog conservation	*Prairie dog survey**	Mean per hexagon of the proportion of population supporting federal incentives for prairie dog conservation based on responses of 29,000 survey participants spatialized to the US Census tract	Positive	Yes
Preference for private economic incentives for prairie dog conservation	*Prairie dog survey**	Mean per hexagon of the proportion of population supporting private incentives for prairie dog conservation based on responses of 29,000 survey participants spatialized to the US Census tract	Positive	Yes
Institutional capacity to actualize conservation	Count of Land and Water Conservation Fund projects[49]	Count of LWCF projects per hexagon	Positive	Yes
Land cover change	USGS (projected 2100)[50]	Pct grass per hexagon (classes 11,12,14) in future climate scenario A2, 2050	Positive	Yes

Land cover change	USGS (projected 2100)[50]	Pct grass per hexagon (classes 11,12,14) in future climate scenario A2, 2100	Positive	Yes
Land cover change	USGS (projected 2100)[50]	Pct grass per hexagon (classes 11,12,14) in future climate scenario B2, 2050	Positive	Yes
Land cover change	USGS (projected 2100)[50]	Pct grass per hexagon (classes 11,12,14) in future climate scenario B2, 2100	Positive	Yes
Landscape fragmentation	Modified from Augustine et al. (2019)[13] **	mean distance to grassland fragmenting feature (cropland, woodland, urban, road)	Negative	Yes
Climate change	BTPD HSM under future climate (2100), warm and wet scenario	Mean of BTPD habitat probability values in hexagon	reference	Yes
Climate change	BTPD HSM under future climate (2100), hot and dry scenario	Mean of BTPD habitat probability values in hexagon	reference	Yes
BTPD Habitat Suitability Model (HSM)	Ensemble model of BTPD habitat potential (under current climate)	Mean of BTPD habitat probability values in hexagon	reference	Yes
BTPD non-habitat mask***	Mask layer of unsuitable habitat, based on the BTPD HSMs	Majority of 90m pixel was unsuitable habitat	reference	Yes

**Prairie dog survey (unpublished data by Williamson et al.):* The probability that a region would support increases in prairie dog populations or support federal incentives for prairie dog conservation was based on survey responses from over 29,000 North American residents. Census tract level estimates were generated using a Bayesian multi-level regression with post stratification wherein the demographics of survey respondents are used to map the probability to Census geographies based on the demographic composition of the Census tracts.
***Landscape Fragmentation layer:* We mapped the degree of rangeland fragmentation across the historic BTPD range following the methods of Augustine et al. (2019)[13], except that we used the 2016 NLCD as the source data layer, rather than a combination of the 2011 NLCD and USDA Cropland Data Layers. Briefly, every pixel was classified as (1) rangeland, which we defined as grassland, shrubland, and improved pasture/hay cover types, (2) a fragmenting land cover type, which we defined as forest, cropland, or developed lands, or (3) neutral land cover types which were not rangeland, but also did not fragment adjacent rangelands. In the final fragmentation map, we set all pixels mapped as either a fragmenting or a neutral land cover type to a value of zero, and then calculated the distance to the nearest fragmenting land cover type for each rangeland pixel (e.g., Figure 3 of Augustine et al. 2019).
**** BTPD non-habitat mask: We created a layer to mask out highly unsuitable habitat. We classified highly unsuitable habitat as those areas where suitability was in the 10th (lowest) percentile for each of the BTPD HSMs generated under the current and future climate scenarios, and where soils were comprised of 90% or greater of sand.*
[%] Ted Turner Properties
[#] Southern Plains Land Trust Properties
[^] American Prairie Reserve Properties

Within the attribute table of the hexagon feature class, a series of new attribute fields were created to convey the newly summarized data (e.g., % grassland, majority Landscape Condition, number of wells). Using the unique hexagon ID's, the data tables of the summarized information were joined with the feature class attribute table, and the summarized data was copied into the newly created hexagon attribute fields using the "calculate field" process. Due to the number of hexagons (over 2 million record rows) being calculated, this process often took several days so researchers later began using a python script to "update cursor" that proved much faster than join/calculate field process. The resulting attribute table of the NHF one-kilometer cells provided a summary of the datasets integrated, all pre-summarized to the same framework for compatibility and easy use (Table 2). Some source data layers like percent of CRP and the political voting data were originally in coarse (county/voting district) spatial resolutions. As a result of summarizing these datasets to the hexagons, the results display a false level of spatial precision regarding the data values conveyed. In cases where coarse data was summarized and displayed at a higher spatial resolution, many individual hexagons share the same value that originally represented the district/county as a whole, not a specific hexagon.

Table 2. *Subset of the NHF hexagon attribute table showing the information from the summarized datasets allowing a single cell to reveal information about a wide range of variables at once.*

hexagon_id	State	Pct_NLCD_Grass	Pct_NLCD_EmgWet	Pct_NLCD_range	Pct_NLCD_Forest	Pct_NLCD_Crop	Pct_NLCD_Urban	Tree_acres	Tree_pct
105W-40N-269-5-3-5	CO	20	11	31	1	68	0	2	0.81
105W-40N-269-5-4-1	CO	2	2	4	0	38	4	124	50.22
105W-40N-269-5-4-2	CO	0	0	0	0	96	4	0	0.09
105W-40N-269-5-4-3	CO	2	1	3	0	74	9	33	13.41
105W-40N-269-5-4-6	CO	15	9	24	1	38	7	78	31.59
105W-40N-269-5-4-7	CO	0	3	4	0	59	0	82	33.21

Mean_windspeed	Wind_turbine	Mtrs_to_Trans	PADUS_GAP1	PADUS_GAP2	PADUS_GAP3	PADUS_GAP4	NCED_ac	MeanDistToFrag	Maj_LSCond
6.59	0	4438	0	0	0	0	34	17	43
6.58	0	2596	0	0	78.285542	49.847519	126	1	0
6.58	0	3524	0	0	0	0	184	0	17
6.57	0	2597	0	0	0	0	54	1	0
6.59	0	2597	0	0	222.560196	23.984982	24	9	0
6.58	0	3525	0	0	57.494851	0	127	1	20

The hexagon feature class data was exported to a series of raster layers using the ArcMap Feature to Raster function to accommodate the conservation prioritization software requirements that all input data be in a raster format. Output raster layers were specified to have a 90 m resolution, were snapped to the same 90 m pixels as the ensemble habitat suitability models, and the raster values were derived from the values in each of the feature class attribute fields representing the 1 km^2 hexagon summarized data. The intersect, calculate field, and convert to raster processes were done in batches using the 5x5 degree NHF tile or by regional groupings of 7 tiles for the northern half of the range and 9 tiles for the southern half of the range for efficient processing. After each tile was converted to a raster layer, they were mosaiced together to create a series of rangewide raster layers, and then clipped to the BTPD range boundary (Fig. 3).

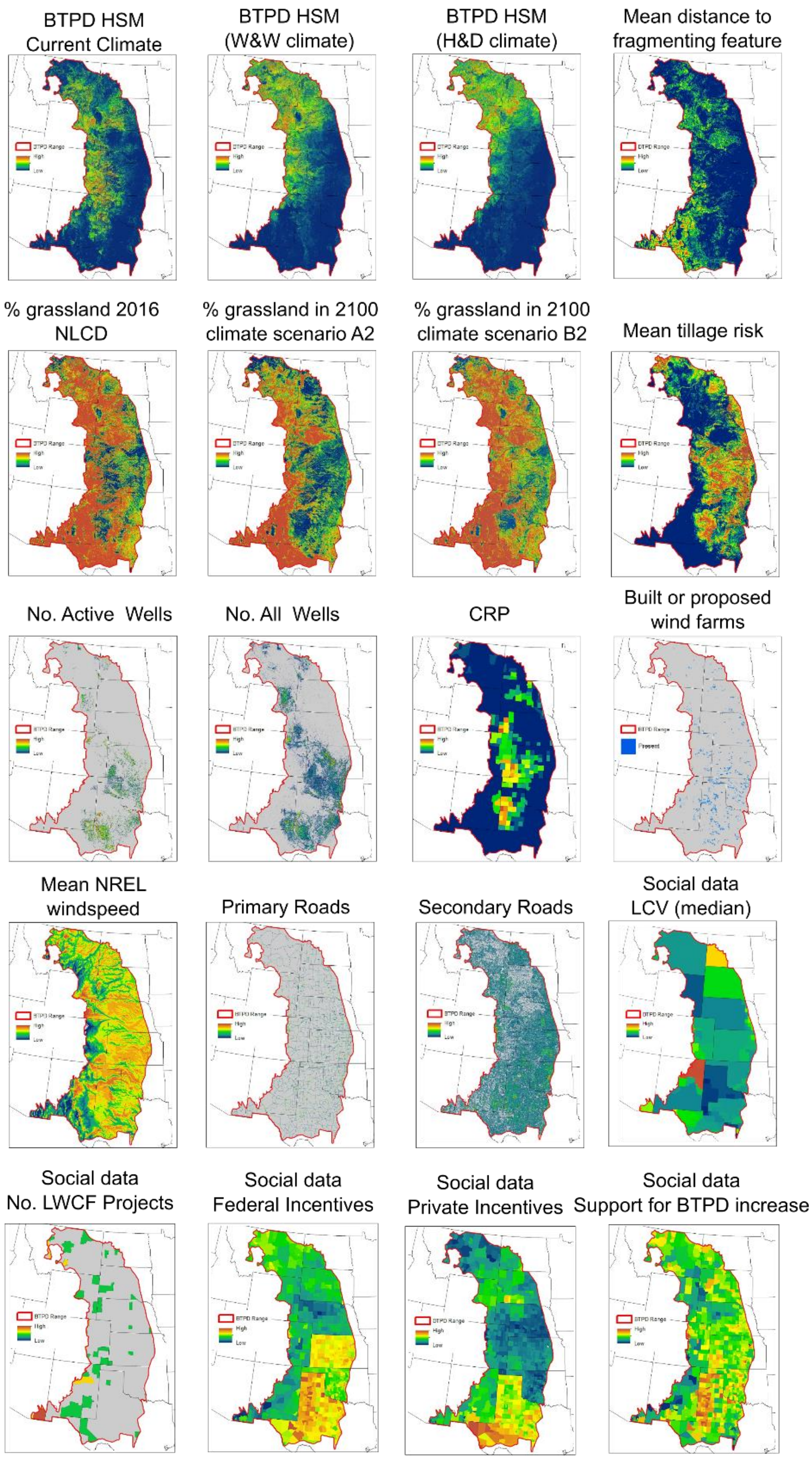

Fig. 3. *A subset of the data layers summarized to the NHF, rasterized, and used within the* Zonation *analysis to identify conservation priority areas for the black-tailed prairie dog (BTPD) ecosystem. See Table 1 for details.*

Zonation Modelling

We selected potential landscapes for prairie dog ecosystem conservation across the range of the black-tailed prairie dog within the USA, using the spatial conservation prioritization method and Zonation software [51]. Zonation produces a hierarchical spatial priority ranking of the study region, accounting for complementarity by considering local representation of the biodiversity features (species, ecosystem types, etc.). Zonation iteratively removes cells whose removal causes the smallest loss in feature representation across the overall remaining region until no cell is left in the region. The hierarchical conservation rank of the region is based on the order of cell removal, which is recorded and can be used later to select any given top fraction (e.g., best 25%) of the region. We used the additive benefit function (ABF) removal rule, which is based on the sum of the features representation in each cell, favoring places containing high habitat quality for a large number of biodiversity features.

We used different weights for the biodiversity features in the Zonation analysis. The relative weighting of biodiversity features is an important component of the Zonation algorithm and impacts the order in which cells are removed from the prioritization landscape. Cells that contain a high-weight feature are kept longer in the analysis than cells with only low-weight features. Features with a negative weight are considered undesirable. Consequently, they are found among the cells with low conservation priority and removed from the landscape early in the analysis. To select the best places for to focus prairie dog conservation efforts, we used spatial layers describing current and future (2100) habitat suitability for the species (weight 10), favorable landscape conditions (weight 1) and social willingness (weight 1) to embrace BTPD conservation. These layers were considered as features in the analysis with positive values (i.e., higher values indicated favorable places for BTPD conservation). Because suitable habitat is ultimately the most important variable for conservation, habitat suitability features had the highest weighting among all positive features. We also considered threats in the selection of priorities, aiming to avoid places with high intensity of threatening activities and conservation conflicts. Threat layers had negative weights (-4). Areas with high values of threatening activities had low values of conservation priority and were removed from the study region early in the analysis. Details on each feature used can be found in Table 1.

In the scenarios that involved current and future projected suitable BTPD habitat, we used the interaction function, which induces connectivity of suitable sites for the interacting features to account for distribution shifts due to climate change. Areas with low habitat suitability or high sandy soil (>90%) were masked out of the analysis using an area mask file, where cells with value "1" were included in the analysis, while cells with value "0" were excluded (Table 1). As conservation policies and funding decisions are usually made by political entities, we also selected conservation priorities considering the state boundaries, so that priorities are identified within each state. For this, we used the Administrative Units (ADMU) function in Zonation to also select state priorities in the final conservation ranking [52].

RESULTS

Our results show that potential landscapes for BTPD ecosystem conservation are largely found across the western portion of the current/historical range, and the priorities under current climate across the Southwest largely disappear under both future climate scenarios (Fig. 4). The areas with highest conservation priority are represented in red and pink. These areas primarily reflect high habitat connectivity, highly suitable habitat, and low threats. Very northeastern New Mexico, eastern Colorado, eastern Wyoming, eastern Montana, very eastern Nebraska, and western South Dakota harbor the greatest amount of priority habitat now and into the future. Much of (but not all) the high priority habitat in Arizona, southern New Mexico, and Texas under today's climate does not maintain such status under the future climate scenarios.

The entire prairie dog geographic range boundary within the US, encompasses 159,786,000 ha, not all of which is suitable habitat (see Part I of this report). Of this area we identified 27,121,311 ha (16%) that represent high conservation priority across all climate scenarios (Table 3; Fig. 4d). The priority rankings shown in Figure 4 are as follows: 2% (from 0.98 to 1 of priority rank) Light red; 5% (from 0.95 to 0.979 of priority rank) Dark red; 10% (from 0.90 to 0.949 of priority rank) Pink;25% (from 0.75 to 0.849 of priority rank) Yellow; 50% (from 0.50 to 0.749 of priority rank) Light blue; 75% (from 0.25 to 0.499 of priority rank) Dark blue; 100% (from 0.00 to 0.249 of priority rank) Black. The areas in red and pink are largely those with high habitat suitability for the BTPD ecosystem, intact grassland, high habitat connectivity, and low threats. On the other end of the scale, the areas represented in black have the lowest conservation priority. These areas include high elevation and urban landscapes, the Nebraska sandhills (high quality grassland habitat, but unsuitable sandy soils), and grassland that has been converted to cropland (much of the eastern portion of the BTPD range). For example, areas in the top 30% priority include the light read, dark red, pink, yellow and part of the light blue pixels.

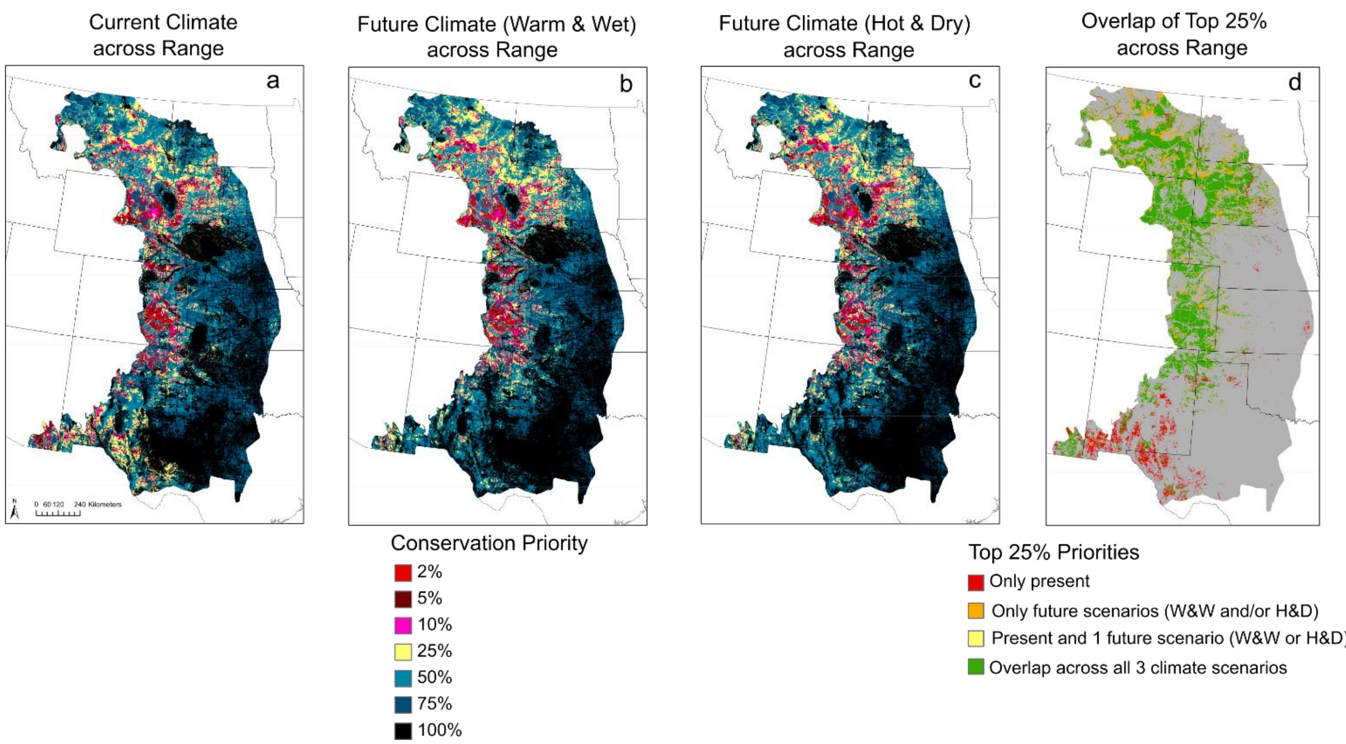

Fig. 4. *Current and future priority area scenarios across the black-tailed prairie dog geographic range. a) Conservation priorities under the current climate; b) conservation priorities under the warm and wet (W&W) future climate scenario; c) conservation priorities under the hot and dry (H&D) future climate scenario; d) overlap of the top 25% conservation priorities across the present and future climate scenarios.*

The priorities change dramatically when we look by state, instead of across the entire BTPD range; this is to be expected because we are specifically modelling for priority habitat *within* each state (Fig. 5). We did this because funding sources and conservation priorities are often at the state-level, and not range-wide. This way, each state has information on conservation priorities within their own jurisdictional boundaries. In these state-based scenarios, much of the high priority habitats in Arizona, New Mexico, and Texas remain high priority under the future climate scenarios. Using the state-based scenarios, we identified 26,935,416 ha (16%) that represent high conservation priority under current and projected future climates (Table 3; Fig. 5d).

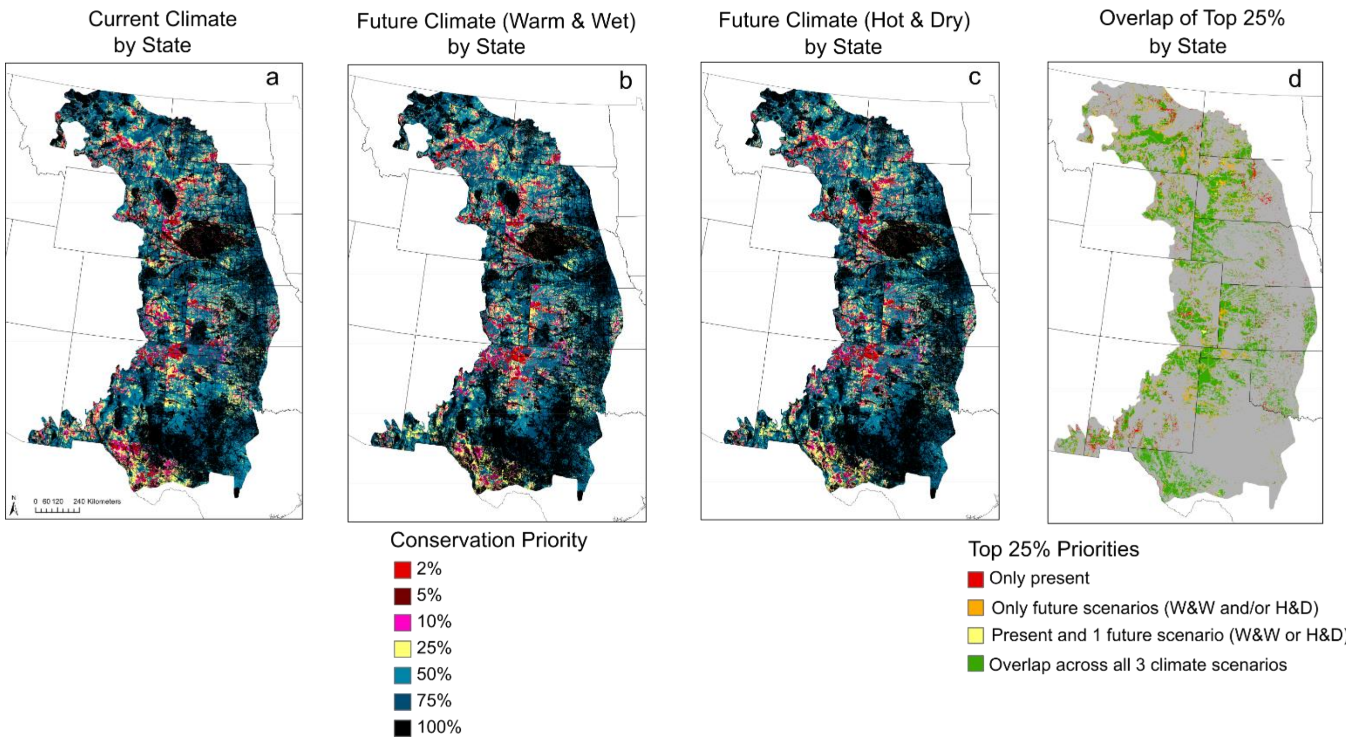

Fig. 5. *Current and future priority area scenarios across the black-tailed prairie dog geographic range, within each state. a) Conservation priorities under the current climate; b) conservation priorities under the warm and wet (W&W) future climate scenario; c) conservation priorities under the hot and dry (H&D) future climate scenario; d) overlap of the top 25% conservation priorities across the present and future climate scenarios.*

Table 3. *Amount and percent of area occurring within the top (25%) priority areas within each state, shown in Figure 5. Red represents top priority areas under current climate only. Orange represents where top priority areas overlap for one of the future climate scenarios (warm and wet, W&W; or hot and dry, H&D) and the present climate. Yellow represents where top priority areas overlap for both future climate scenarios, but not current climate. Green represents where top priority areas overlap across current climate and both future climate scenarios.*

Climate Scenario	Area (ha)	Area (km2)	%
Present	3,318,975	33,189.75	2.08
Future W&W	1,414,179	14,141.79	0.89
Future H&D	1,093,014	10,930.14	0.68
Future H&D and W&W	2,914,704	29,147.04	1.82
Present and Future W&W	977,670	9,776.7	0.61
Present and Future H&D	867,672	8,676.72	0.54
Total Overlap	26,935,416	269,354.16	16.86

Only a tiny fraction of the priority habitat that overlaps across all three climate scenarios (shown in green in Figures 4d and 5d) is currently protected (PAD-US Gap 1 and Gap 2 and Private Conservation Lands, see Table 1) (Fig. 6). Indeed, 0.63% of the high priority areas (top 25%) across the BTPD geographic range occur within protected areas (Fig. 6). The total amount of protected area that overlaps with the top 25% of priority areas across the BTPD range is 1,006,000 ha (0.63%). Whereas, 26,115,300 ha (16%) of the top priority areas remain unprotected (Fig. 6b). Among the high conservation priority areas by state, 757,647 ha (0.47%) occur within protected areas, whereas 26,177,742 ha (16%) remain unprotected (Fig. 6c).

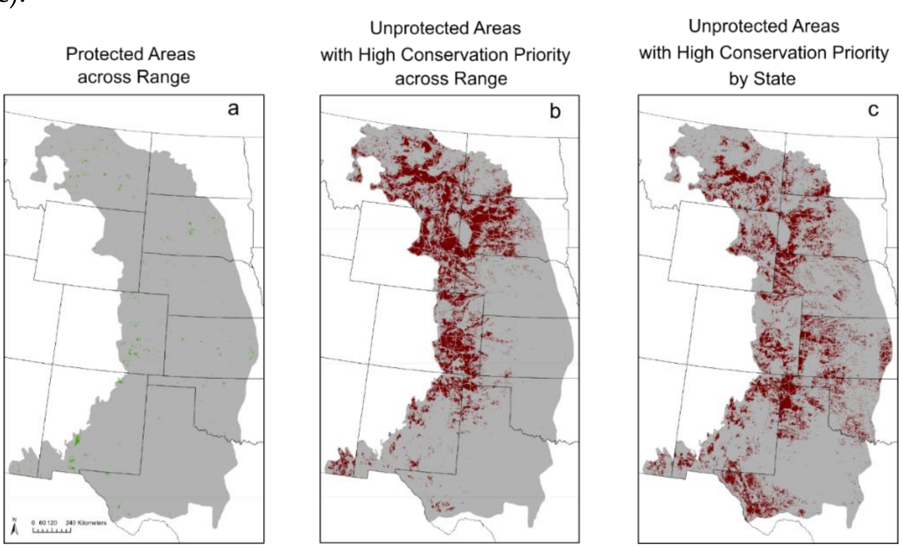

Fig. 6. *Relationship of the top 25% priority areas and lands already managed for conservation, based on the Protected Areas Database (Gap 1 & 2 status) and Private Land Conservation Areas (see Table 1). (a) Shows protected areas in green; (b) shows the high conservation priority areas (top 25%) that remain unprotected (16% of the BTPD range); (c) shows the high conservation priority areas within each state (top 25%) that remain unprotected (16% of the BTPD range).*

The overwhelming threat across the BTPD range is conversion of grasslands to croplands and consequent fragmentation of habitat (Fig. 7). The loss of native grasslands to agriculture has been and is predicted to be greatest across the eastern part of the BTPD range, especially across the central and southern plains in Texas, Oklahoma, and Kansas. Oil and gas development and wind turbine establishment also are significant threats, especially across this same region.

We found that general spatial patterns of priority area locations, across present and future climate scenarios, were not strongly impacted by the social and political data layers used in our analysis (Table 1). Habitat suitability, connectivity, and threats played a larger role in determining the potential landscapes for conservation priority. Nevertheless, social attitudes and political culture strongly impact the success of on-the-ground conservation efforts and may drive the decisions of local managers. Given this, we created several maps to help illuminate those areas where conservation might be positively or negatively impacted by the social and political landscapes (Figs. 8 and 9). The goal here was to help inform managers and conservation practitioners where there might be social support/contention and institutional resources for prairie dog ecosystem conservation.

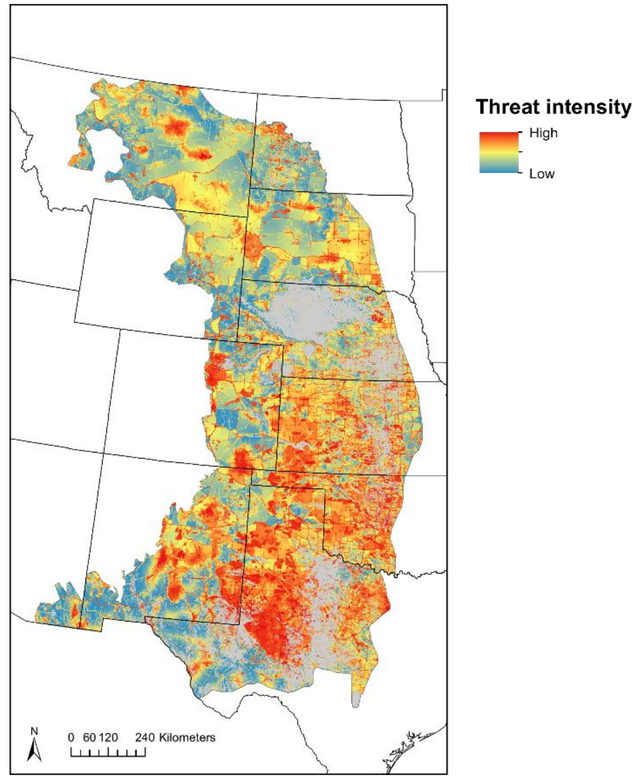

Fig. 7. *Gradient of threats (high to low) across the black-tailed prairie dog geographic range. Threats represented in this map: mean tillage risk, number of active oil wells, distance to transmission lines, presence of wind turbines, roads (primary and secondary), and percent of trees.*

When identifying conservation priorities for on-the-ground implementation projects, the primary goal should be to protect and restore habitat that is most suitable, followed by the surrounding landscape potential, and threats. The maps presented in Figures 8 and 9 aim to help inform decision making for prioritizing conservation efforts. The social layers, here, provide insights into the relative ease or difficulty in securing the best habitats (Fig. 8). Priority areas might change, for example, when habitat values are equal (or nearly equal). That is, assuming two high quality patches of habitat, we might choose the socially “cheapest” patch first. The other datasets showing Federal and Private Conservation Incentives (Fig. 9) illuminate how the availability of such incentives might reduce the social costs in high-priority habitats. The red areas in Figure 9 are places where conservation incentives are likely to be helpful for securing high priority conservation areas, whereas the blue areas are places where the incentive is likely to be adopted but may fail to secure meaningful conservation, and the yellow are priority areas that are not likely to be successfully secured with incentives.

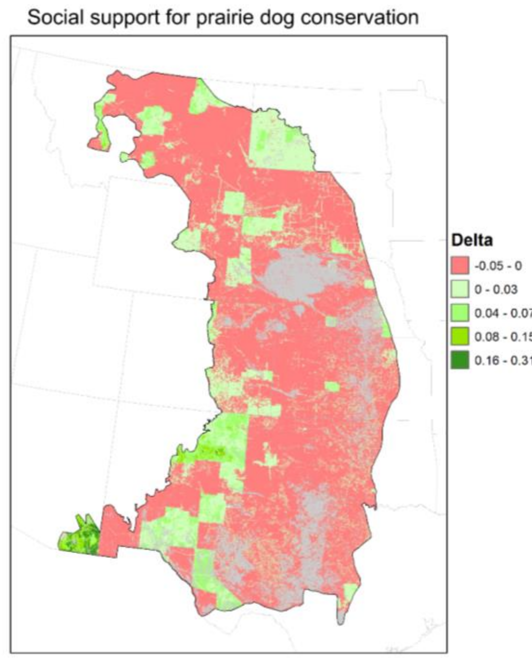

Fig. 8. *This map represents social willingness to support prairie dog conservation. Delta represents the change in the priority value when social layers were included versus excluded from the analysis shown in Figure 4a (Conservation priorities across full BTPD range under current climate and* *<u>with</u>* *social layers included in the model* ***<u>minus</u>*** *Conservation priorities across the full BTPD range under current climate* *<u>without</u>* *social layers). The positive values show places where conservation priorities (represented in Figure 4a) were increased by the presence of social support for prairie dog conservation, whereas negative values show areas that lost priority ranks due to low social support for prairie dog conservation. The original social data are from a range-wide Prairie Dog Survey conducted by Williamson et al. (unpublished). Grey areas represent masked-out regions of unsuitable habitat (see Table 1).*

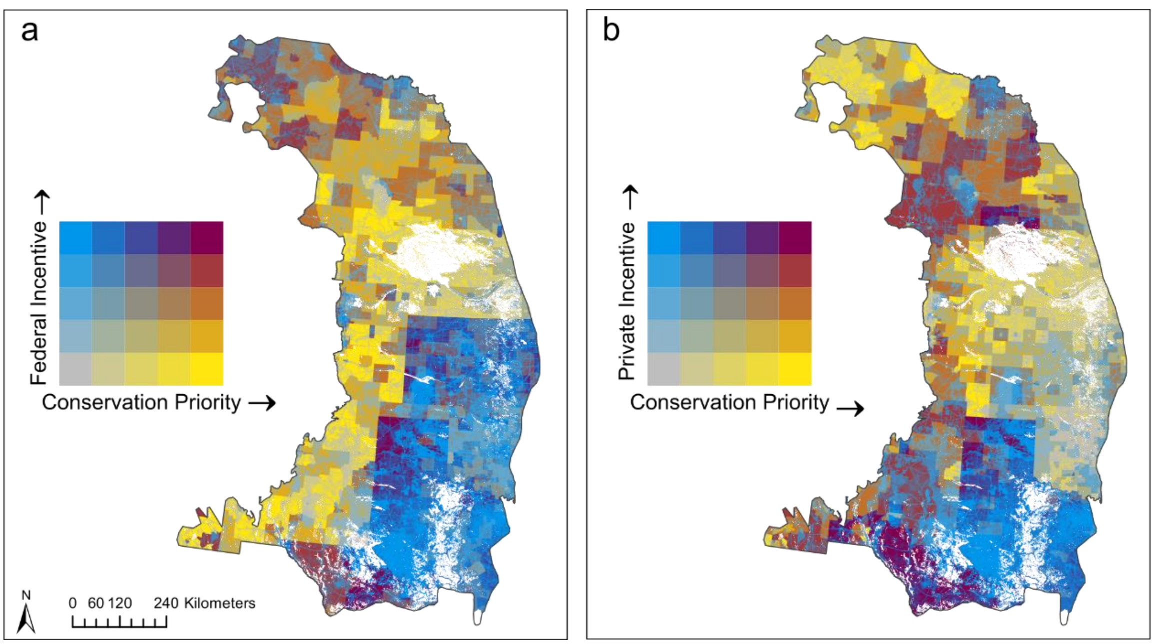

Fig. 9. *Bivariate maps showing the spatial distribution of conservation priorities across full BTPD range under current climate (priorities identified in Fig. 4a) and how they overlap with preferences for: a) federal and b) private conservation incentives. The positive values show places where conservation priorities were increased by the presence of social support for prairie dog conservation, whereas negative values show areas that lost priority ranks due to low social support for prairie dog conservation. The original social data are from a range-wide Prairie Dog Survey conducted by Williamson et al. (unpublished); see Table 1 for details.*

Landownership also plays an important role in on-the-ground conservation potential (Table 4, Fig. 10). Most of the priority areas for conservation that we identified, across all three climate scenarios, were located on private land, compared to public land. However, across the western distribution of the BTPD range there remains considerable public land, especially federal and state land, and indigenous land that may provide valuable opportunities for conservation of the BTPD ecosystem. Yet, the extent to which federal and state lands will support prairie dog ecosystem conservation, is strongly influenced by the social and political landscapes within which they are located. There also is considerable Private Lands Conservation along the western distribution of the BTPD range, which overlaps with many high priority areas. The landownership maps underscore the importance of working with private landowners and local communities when implementing conservation measures to support prairie dog ecosystem conservation.

Table 4. *Shows how much high priority habitat (identified in green in Fig. 4d) overlaps with different landownership categories, across the black-tailed prairie dog geographic range.*

Landownership	Area (ha)	%
Federal	2,908,617	11%
Federal, Designated	325,847	1%
Indigenous Lands	2,474,793	9%
Joint	8,910	0%
Local Government	44,465	0%
NGO	33,348	0%
Private Conservation Land	79,709	0%
Regional Agency Special District	2,902	0%
State	2,215,959	8%
Private Land	19,026,599	70%

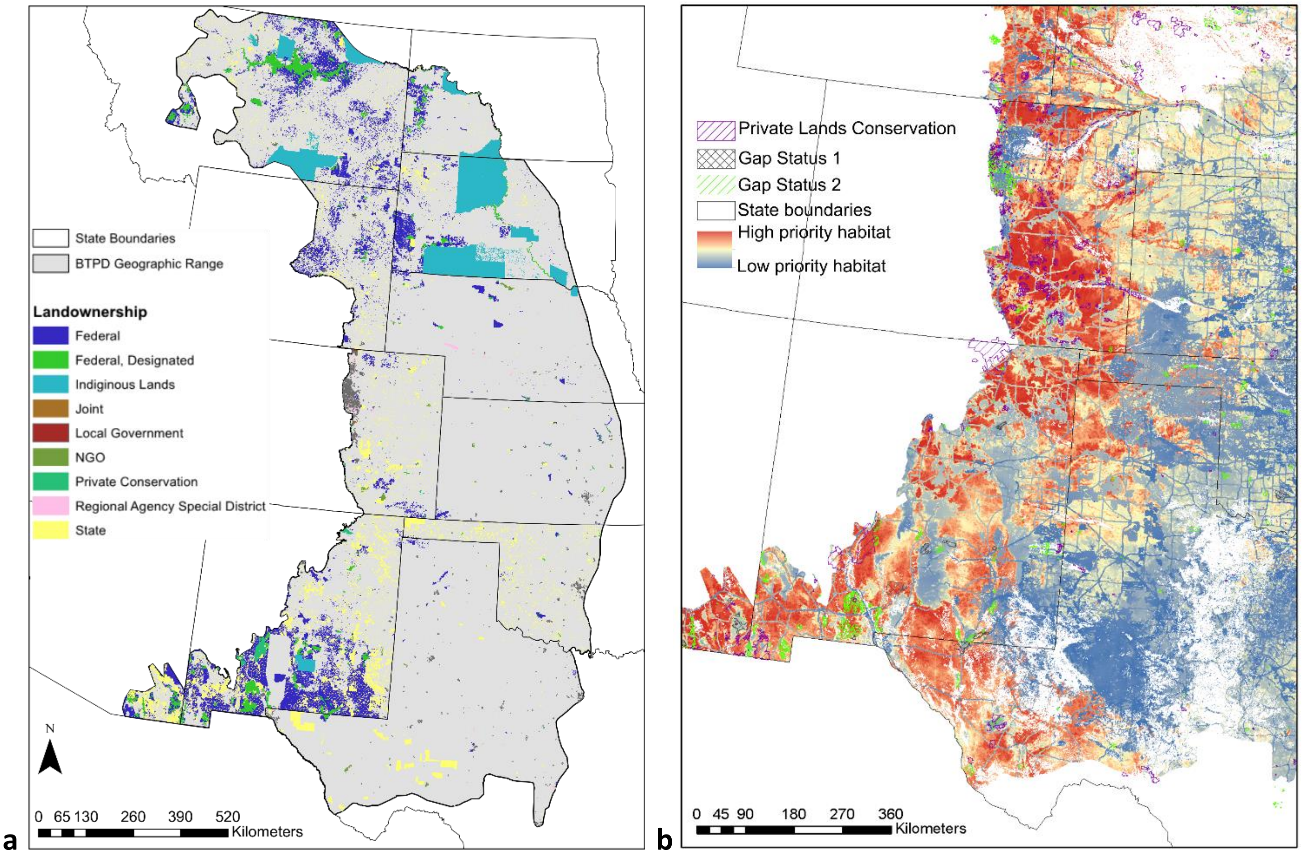

Fig. 10. *Map a) shows the different landownership types occurring across the black-tailed prairie dog (BTPD) geographic range (data is from PAD-US[44]), and b) shows a zoomed-in view of rangewide BTPD conservation priorities under current climate (as identified in Fig. 4a), with red areas showing high priority habitat for the BTPD ecosystem and blue showing low priority habitat. Panel b also shows some landownership classes (Private Lands Conservation Areas, Gap Status 1, and Gap Status 2; see Table 1 for details) and how they overlap with priority habitat.*

FINAL PRODUCTS

The final map products have been posted online through the Colorado Natural Heritage Program (CNHP) at Colorado State University, the Western Association of Fish and Wildlife Agency (WAFWA), and made available through an interactive web map [36] (Table 5). Within the interactive web map, users can view the output raster layers of the modeled priority areas and have the ability to query the NHF grid for additional information associated with each cell. The attribute table associated the NHF contains summaries (mean, percent, total area) of input variables and model outputs. Queries made against NHF cells reveal summarized data from over 30 layers to provide an array of useful information.

Table 5. List of data products produced.

Dataset product	type	format	resolution	access
Priority areas for the BTPD ecosystem across BTPD range, under current climate	raster	geo-TIF	90m; 900m	CNHP WAFWA
Priority areas for the BTPD ecosystem across BTPD range, under future climate (2100) warm & wet scenario	raster	geo-TIF	90m; 900m	CNHP WAFWA
Priority areas for the BTPD ecosystem across BTPD range, under future climate (2100) hot & dry scenario	raster	geo-TIF	90m; 900m	CNHP WAFWA
Overlap of the top 25% conservation priorities across BTPD range, under the present and future climate scenarios	raster	geo-TIF	900m	CNHP WAFWA
Priority areas for the BTPD ecosystem by state, under current climate	raster	geo-TIF	90m; 900m	CNHP WAFWA
Priority areas for the BTPD ecosystem by state, under future climate (2100) warm & wet scenario	raster	geo-TIF	90m; 900m	CNHP WAFWA
Priority areas for the BTPD ecosystem by state, under future climate (2100) hot & dry scenario	raster	geo-TIF	90m; 900m	CNHP WAFWA
Overlap of the top 25% conservation priorities by each state, under the present and future climate scenarios	raster	geo-TIF	900m	CNHP WAFWA
Readme Overlap Combinations	text	Text		CNHP
NHF hexagon grid	polygon	gdb	1 km^2	ku.maps.arcgis.com Search for "BTPD"
Threat map	Image	TIF	900m	CNHP
Landownership map (PAD-US) summarized	polygon	gdb	900m	CNHP
Delta map showing social willingness to support prairie dog conservation, based on Prairie Dog Survey by Williamson et al. (unpublished)	raster	geo-TIF	900m	CNHP

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