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Share with Wildlife Program

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EXECUTIVE SUMMARY

Our overarching goal was to estimate total acreage and distribution of black-tailed prairie dog colonies across eastern New Mexico. To achieve this goal, we used National Agricultural Imagery Product (NAIP) imagery paired with deep learning and classification models to identify individual 200 x 200 m units of space (hereafter 'cells') that contained likely prairie dog colonies across the study area from imagery captured in 2022 and 2024. We then validated these results with desktop review of 1,073 random locations that we examined and 610 in-field surveys to determine the accuracy and deficiencies of our existing modeling approaches and identify locations that have existing prairie dog burrows and extant prairie dog populations. We compared our results to surveys that were conducted in 2010 across a portion of our study area to determine patterns of change (including prairie dog retention and extinction) and identify potentially important management and conservation areas. Our most liberal assessment of prairie dog coverage yielded a total area of 127,636 ha in 2022 and 138,763 ha in 2024. When we consider only cells where the model has at least 95% confidence, the total acreage in 2022 was 80,132 ha and in 2024 was 73,809 ha. Across multiple metrics including total acreage, colony size, and average colony distance, prairie dog colonies and populations appear most stable in the northeastern portion of NM, with the highest number of prairie dog cells occurring in Union County. These patterns largely align with habitat assessments made by other studies in New Mexico (e.g., Davidson et al. 2022) and relate to environmental conditions including increased rainfall and primary productivity. From ground-validated data, we find similarly strong patterns of numbers and density of cells containing active prairie dog locations that increase toward northeastern NM. The number and proportion of active colonies or cells also increased with increased amounts of predicted habitat quality. The probability of observing an active prairie dog colony increases from 40% in the most southern portions of NM to 80% in the north of NM within our entire study area. Comparisons with the results of previous surveys indicate that 18.6% of colonies that were active in 2010 remain active and 14.4% appear to have gone extinct (Johnson et al. 2010). Areas with higher rates of extinction are in more southerly and western areas within the study area. Generally, we find that the deep learning models reliably classified prairie dog colonies vs. non-prairie dog cells 87% of the time. Environmental factors like increased Net Primary Productivity (NPP) and actual changes in vegetation or human development which occurred from when imagery was collected to when we validated those models negatively affected correct assignment of cells. Areas in the central portion of the study area had higher levels of vegetation type changes, or conversion to or from agriculture, that also appear to correlate with an inability of the model to accurately classify cells as containing (or not containing) prairie dogs. Overall, the methodology that we

used appears to be robust in identifying prairie dogs in many circumstances, but does not eliminate the need for ground-based information to help correctly assess the distribution of active prairie dog populations.

Aerial view from a drone showing prairie dog burrows and disturbed ground created mounds that were detected during ground validation surveys

INTRODUCTION

Black-tailed prairie dog populations (*Cynomys ludovicianus*) are distributed across eastern New Mexico (NM); however, their total spatial distribution, changes in distributions, and overall population trends are largely unknown. Prairie dog populations and distributions are infrequently assessed at the scale of their entire range in NM or in other states. In part, tracking populations of prairie dogs is challenging because of their wide distributions and presence in diverse grassland, desert, and agricultural vegetation types. Developing reliable and relatively low-cost methods to identify and quantify the amount of land occupied by prairie dogs and changes in the distributions of their populations in New Mexico that will allow for regular assessments (e.g., at 5-year intervals) is crucial to the management and conservation of this species across its range.

Comprehensive, range-wide assessments of black-tailed prairie dogs have not been conducted in NM since an effort by McDonald et al. in 2015. This effort was conducted by a private entity, and the results are not readily available to the public or wildlife management agencies. Johnson et al. 2010 conducted a study across portions of eastern NM which they described in a report to the Share with Wildlife program. This report covered much, but not all, of eastern NM and assessed acreage of black-tailed prairie dog colony sizes and their distribution throughout the study area. Johnson et al. (2010) used digital orthophoto quarter quadrangle (DOQQ) imagery to hand-review and identify likely locations of prairie dogs and to estimate colony size within 7.5-minute quad cells across portions of eastern NM. Johnson et al. (2010) also used ground validation to confirm locations that they identified from imagery as possibly containing prairie dog colonies. Davidson et al. (2023) used data collected from McDonald et al. (2015) along with several remotely sensed data layers (e.g., soil types, precipitation, and vegetation cover) to assess black-tailed prairie dog habitat suitability across the species' range in the United States (including its range in NM). Collectively, this information provides a baseline of information that can be compared to new studies that estimate patterns of distribution, colony size, and persistence, of black-tailed prairie dog populations in NM.

Within the last decade, new methods and information have become available which may aid in making rapid assessments of prairie dogs across their range. Accurately identifying active prairie dog colonies over a wide spatial expanse by conducting ground surveys is time-consuming and expensive. Researchers and managers have used aerial or satellite imagery to assess the total land apparently occupied by prairie dog colonies or mounds (Biggins et al. 2006, White et al. 2005, Kempema et al. 2015). Yet, as shown in the Johnson et al. (2010) report, these methods require individual researchers to manually examine large numbers of images to identify areas that are consistent with prairie dog mounds or colonies. Such assessments are time-consuming and therefore may reduce the ability for them to be conducted frequently. Moreover, previous authors have been unable to survey the entire state and only sampled specific areas or polygons to draw inferences. Developing methods that will reduce human effort and that can be applied over the entire state in relatively rapid succession can provide improved estimates of total spatial coverage of locations but also help to identify areas that never contained prairie dogs so that these areas can be omitted from future assessments.

Artificial intelligence (AI) methods such as Large Language Models may improve our ability to monitor and manage prairie dog populations across the landscape. Machine learning or deep learning (DL) methods are general versions of AI intended to be trained to identify specific patterns. Deep learning methods can be used to identify patterns such as prairie dog colonies and then work independently of human supervision to evaluate patterns across entire landscapes in relatively short order. Such methods, if useful and efficient, would be valuable in tracking prairie dogs and reducing, although not eliminating, the need for human oversight.

Any method that relies exclusively on remote sensing or imagery is unlikely to accurately estimate total acreage or numbers of prairie dogs on the landscape. Errors due to imagery quality or confusion with other structures or vegetation are likely to bias the interpretation of any remotely sensed data, so ground validation is needed to verify the underlying training and to document prairie dog presence. At the finest scale, the total number of burrows or the area occupied by them may not accurately reflect prairie dog abundances because prairie dogs live at different densities based on region (Facka et al. 2008a, Facka et al. 2008b). However, more detailed studies cannot be undertaken without high-level estimates of overall distribution, apparent colony size, or changes in these parameters as they relate to changes in the environment or human development.

We used (DL) models approaches to identify prairie dog colonies across eastern NM and used ground validation to confirm the presence of burrows and colonies and confirm whether those colonies show evidence of being actively occupied by prairie dogs. We used these data, along with other publicly-available information, to estimate the total distribution of prairie dogs across 13 counties in eastern NM. We then compared specific locations visited in 2009 and then again in 2025 to determine if there are broad patterns of colony decline, extinction, retention, or any changes in overall colony size. We evaluated the ability for deep learning models to accurately categorize prairie dog burrows and estimate colony size, and used this information to assess prairie dog colony distribution across eastern NM.

METHODS AND ANALYSIS

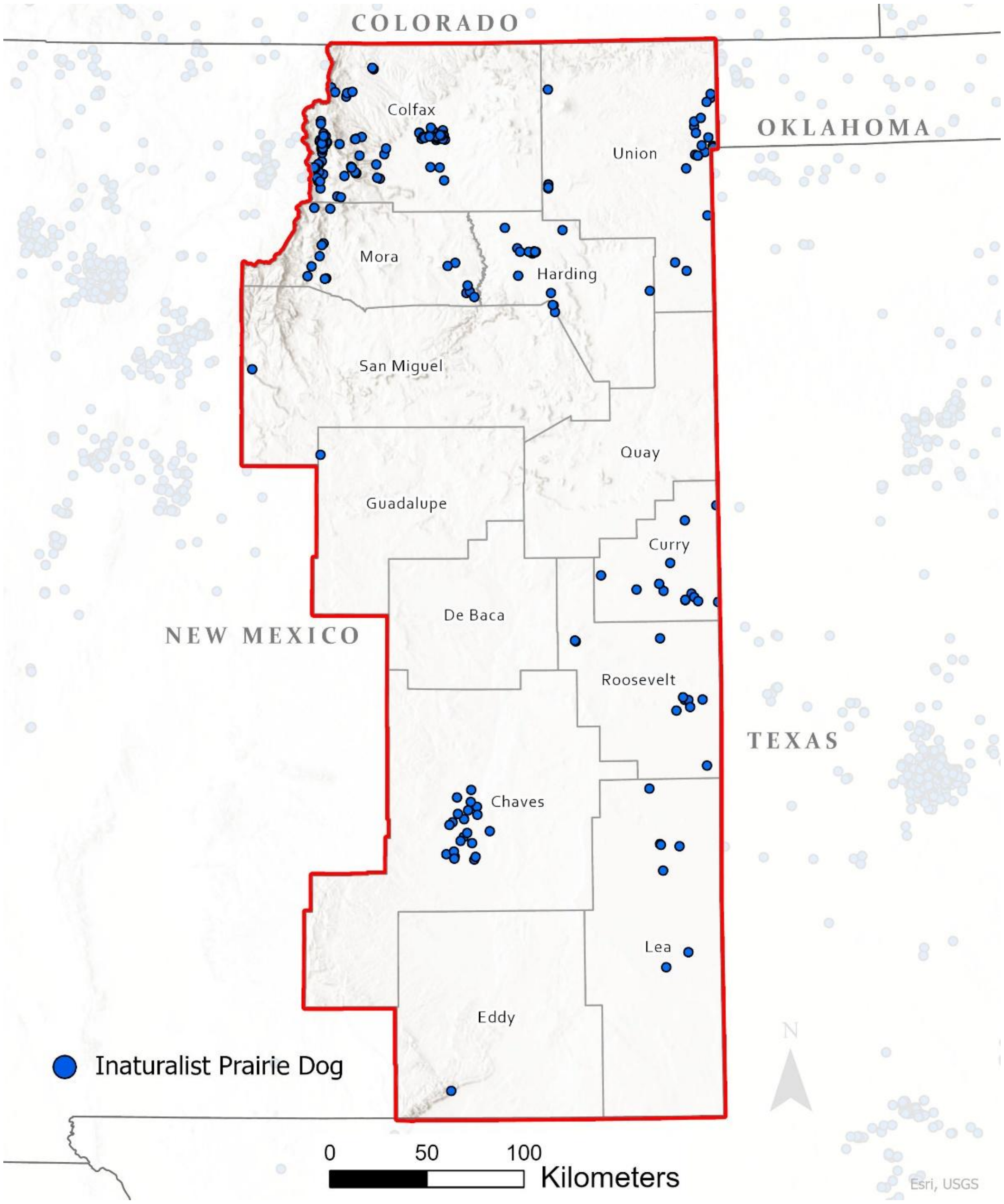
Initial Data Gathering

In Year 1 of the project we gathered data, developed appropriate modeling approaches, and initiated field surveys in order to compare current prairie dog colony distributions with data collected during previous surveys and to validate our own modeling. We gathered data on existing, or likely, prairie dog colonies across eastern NM through direct observation, inspected existing NAIP imagery to identify likely prairie dog colonies, and reaffirmed spatial signatures of known colonies. We also contacted various private and public entities that had recently conducted prairie dog surveys to confirm the location and presence of active colonies and obtain data on colony perimeters and acreage. These entities included the Vermejo Ranch in northcentral NM, the Kiowa National Grasslands in northeastern NM, and the Las Cruces District of the Bureau of Land Management. Additionally, we used data collected from public sources including iNaturalist, OnX Hunt Maps, the National Science Foundation's catalogues (Vertnet.org), and through our own direct observation (Figure 1). These efforts yielded estimated perimeters for 623 black-tailed prairie dog colonies across eastern NM and 629 points representing possible prairie dog colonies (perimeters and points often overlapped. We then estimated or obtained colony perimeters from local individuals or organizations that have mapped prairie dogs on their lands: 123 locations in northeastern NM (roughly centered on Clayton), 319 from south-central NM (i.e., Tucumcari to Portales), 120 from southeastern NM (i.e., south of Portales), and 46 from northeastern NM (i.e., Cimarron to Maxwell).

Modeling

In previous efforts using DL, we attempted to identify individual burrows across the landscape (Facka et al. 2023). We found this method useful but also prone to identifying random spots of bare ground, dead trees, or other structures as prairie dog burrows. Based on this experience, we concluded that a modeling approach that identified clusters of likely burrows would be superior to identifying individual burrows. Using experience gained from the development of model for Gunnison's prairie dogs (*Cynomys gunnisoni*) (Facka et al. 2023), we initiated our formal modeling process. We selected three regions distributed across eastern NM. In each region, we used 60-centimeter resolution NAIP cells from 2022 to identify more than 20,000 visible prairie dog burrows by placing individual point locations within ArcGIS, informed by polygons of known active prairie dog colonies detected during previous field surveys or from information we gathered through online sources. The resulting burrow points served as test data for our models. During Year 1, we developed two modeling approaches: Iso Cluster-based and DL-based (see Facka and Dax 2025 for description of Iso Cluster method), After extensive testing, we used the Iso Cluster approach only as a secondary approach to compare to the results of our DL models, but found that the Iso Cluster approach was too time-intensive to use across large portions of the study area.

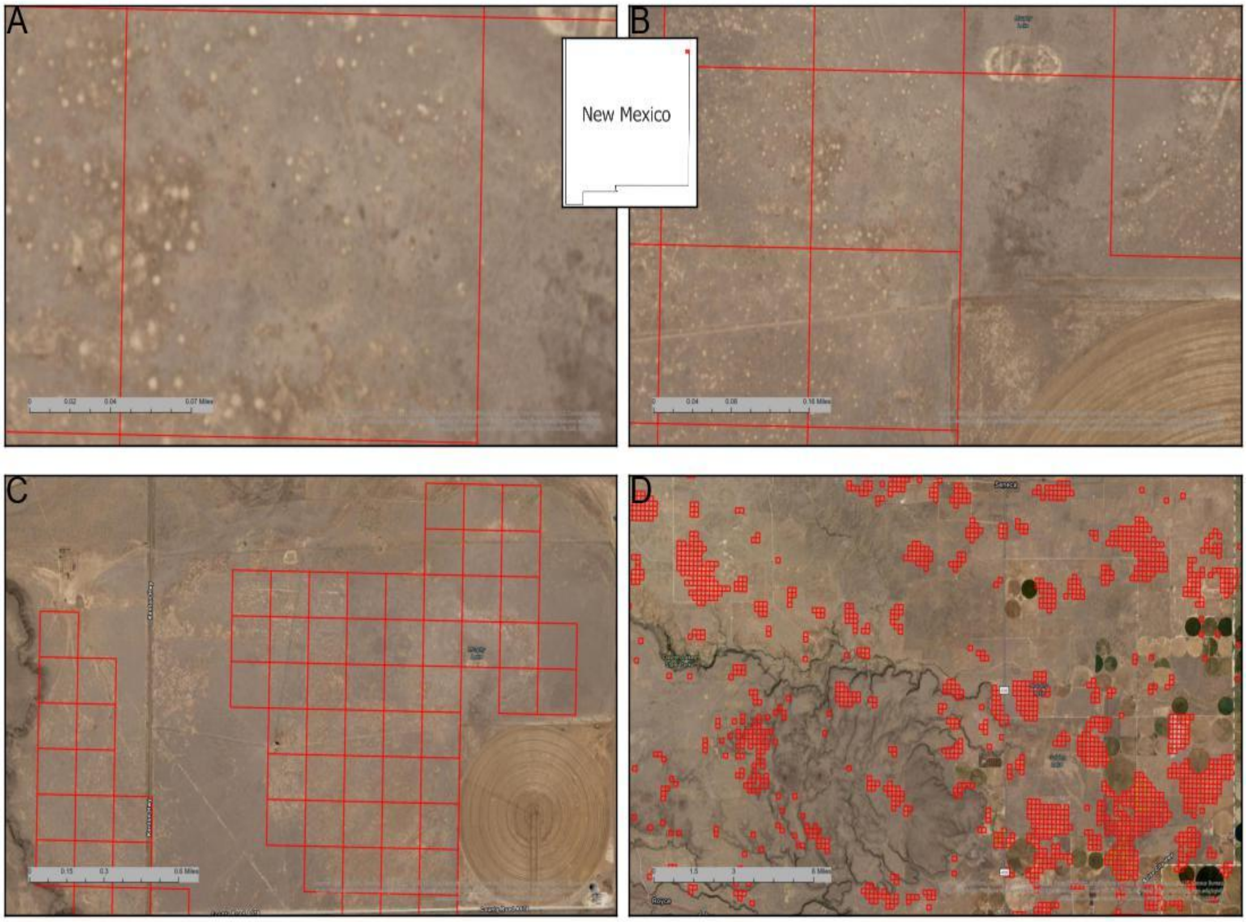
Figure 1. Location of iNaturalist.org prairie dog observations in New Mexico (blue circles) and the study area used for current investigation (red outline). Data on prairie dog colonies from outside of the project area were used for the purposes of training models.



Overall, we used the DL approach to classify individual cells as having prairie dog burrows or not. Initially, we intended to only predict, or classify the landscape, based on NAIP imagery from 2022, but at later stages 2024 imagery data became available and served as a second estimate for the presence of prairie dog colonies across the study area.

To construct DL models, we used training data created from NAIP imagery that was collected only in 2022 but classified the landscape from imagery collected in both 2022 and 2024. We incorporated data from 2024 because field validation occurred during 2025 and we were concerned that real-world conditions (e.g., previously existing prairie dog colonies that were converted to agricultural fields) may have changed substantially between 2022 and 2024. Additionally, the estimates from the 2024 imagery allowed us to examine differences between years that are likely to be attributable to differences in imagery quality. Finally, the inclusion of 2024 data allowed us to develop a separate estimate of colonies to estimate potential errors in identification or training or small changes that occurred over this 2-year period. DL methods require the inclusion of training data created from actual imagery; therefore, we divided the entire breadth of the study area (eastern NM) into 200 × 200 m cells where georeferenced NAIP imagery would be evaluated digitally (from the desktop). Future models could potentially be trained from either year (i.e., 2022 or 2024), from multiple years of imagery, or from alternative data sets. From these cells, we manually selected 5,000 cells containing imagery that we were highly confident represented prairie dog burrows based on our experience, our existing preliminary data, and previously-conducted opportunistic ground validation. We selected another 10,000 cells containing no apparent prairie dog burrows or features that could be mistaken for prairie dog burrows. Cells for prairie dog burrows and non-prairie-dog burrows were selected to represent various vegetation types, topography, and levels of human development across eastern NM. These training NAIP images were then used to train an image classifier in EffecientNet (Google; Mountain View, CA) through the Python (version 3.13) programming language. The image classifier produced a model, and we then created a programming script to run through each NAIP cell for the study area (n=2,797,970). The image classifier identified each NAIP image within the 200x200 cell as 'prairie dog' or 'other' independently for 2022 and for 2024 imagery. All results were outputted into a GeoJSON file which was then imported into ArcGIS for desktop review and evaluation. We then identified representative examples of cells that were clearly false (e.g., boulders, manmade objects) or without prairie dog burrows and placed those into our training dataset for 'other.' We also found examples of prairie dog colonies that had been incorrectly identified as 'other' and placed these into the prairie dog training dataset. We then retrained the model and reclassified the imagery data. We did this iteratively until we developed a model that correctly identified cells at a rate of >85% for all locations or areas which we were confident contained prairie dog colonies (Figure 2). Using this methodology, we estimated the presence or absence of prairie dog colonies across the entire study area of eastern NM for 2022 and 2024 imagery.

Figure 2. A) Single 200 x 200 meter cell (red outline) indicating that the *DL* model classified this location as having prairie dog colonies; B) *A* series of cells (*red* outline) indicating the presence of prairie dog colonies; C) *E*xpanded area (cell from panel A *at the approximate* center) showing *the* distribution of tiles classified as having prairie dog colonies; D) Output of *DL* model across one portion of the northeastern corner of N*M* showing possible prairie dog colonies (red dots). Inset map shows *the outline of* N*M;* the small red square in upper right *is* centered on panels A, B, and C and the square showing the extent of panel D.



Field Validation

In June 2025, we began collecting field data on new sites that we identified as potential prairie dog colonies and on sites previously visited by Johnson et al. 2010. From June to November 2025, we visited 610 locations to confirm the presence of prairie dog burrows and colonies and evaluate if prairie dogs existed on those colonies (Figure 3). In the field, we visited sites that were 1) Predicted by our DL models to have prairie dog burrows and colonies, 2) Visited in previous surveys described in Johnson et al. 2010, or 3) Opportunistic locations where prairie dogs were observed and that could help to train our model or verify new results. At each location, observers attempted to get as close to the polygon of interest as possible to make an assessment. If they were able to enter a potential colony, they did so and searched to try positively affirm prairie dog burrows and signs of current prairie dog presence. In situations where observers could not enter a potential colony (generally because the colony was on inaccessible private land), they used public access near the potential colony to observe areas with binoculars or spotting scopes to identify any burrows and prairie dogs that were present. We evaluated if prairie dogs were present at a colony by attempting to view at least one live animal in or near the colony. If we heard prairie dogs vocalizing or saw evidence of their presence (e.g., fresh digging or scat) we also considered that to be sufficient evidence that prairie dogs occupied the colony. On rare occasions, human residents provided information on their observations of local prairie dogs. We used these reports as complimentary information to our own direct observations of a site. At sites where we could not directly affirm prairie dog presence, we assigned a determination of no activity if the observer felt confident the colony contained no prairie dogs or a status of "unknown" If they felt they could not conclude if prairie dogs were present or not. Observers noted the time that they arrived and left the location, their relative distance to the potential colony, weather conditions, vegetation status, and information regarding how they made determinations of burrow presence or prairie dog presence at the site. Observers also categorized colony size into either 1.5 acres (e.g., smaller than a football field), 1.5-150 acres (e.g., smaller than a pivot-based agricultural field), or > 150 acres. The categories were intended to help provide context to our assessments of DL-based size estimates. In cases where no prairie dog burrows were detected, observers noted other features on the ground that could be mistaken for prairie dog burrows (e.g., ant hills, rocks). In some cases, observers flew drones over accessible air space (or over private lands with permission from the landowners) to confirm the presence of burrows and prairie dogs. In these cases, observers took photos to document the presence of burrows. On select occasions, drones were used to map the visible perimeters of colonies to provide independent information on colony size and distribution. Observers also noted any species classified by New Mexico Department of Wildlife as a Species of Greatest Conservation Need (SGCN); . All data was recorded in ESRI Field Maps.

Analysis

Evaluation of Deep Learning Models

After development of our DL model and field validation, we needed to evaluate the model's performance at several levels. We began by determining if the model agreed with our own evaluation of NAIP imagery in both 2022 and 2024. To do this, we selected 2,003 cells (approximately 1%) from the entire study area to evaluate independently of the DL model's outputs. We randomly generated 1,300 cells that we evaluated only from desktop imagery, and we added 610 locations from field valuation sites and 50 locations that we knew had or had not contained prairie dogs within the last 5 years. These 50 locations were taken from our preliminary data collection and were sites where we had the most confidence in their status. We then evaluated the imagery of each of these cells to determine if it appeared to be consistent or inconsistent with prairie dog presence. This evaluation was conducted for NAIP imagery from 2022 and 2024. We also used other imagery from Google Earth and ESRI to provide additional context in situations where the raw imagery was nebulous. Next, we evaluated the 660 locations where we had information on whether prairie dog burrows were present in 2025.

We conducted two types of analyses at both scales of investigation. Because many variables can interact in complex ways to influence detection, we used a Random Forest Classifier (RFC) from the scikit-learn package in Python to identify which variables appeared to have the most effect on the model's ability to accurately detect cells containing prairie dog burrows. For all RCF, we split data into training and prediction data sets and used 100 estimators with a fixed random state of 42. We generated estimates for feature importance and permutation importance to identify which variables were most influential in predicting prairie dog classification. Permutation scores were generated through the RCF procedure and estimate the predictive performance of metric by randomly shuffling specific values for that metric. For analysis at the landscape scale, we provided the RCF with all of the variables identified in Table 1 for the landscape. We used these variables because they are environmental factors that can be quantified across the state and used to modify or correct model performance (Table 1. Rationale). We wanted to evaluate how these variables affected the model's ability to correctly identify prairie dog burrows. After conducting RCF, we used the top five most important variables in a logistic regression to directly quantify the linear relationships between the variables and the probability of accurately detecting prairie dog burrows. If appropriate, we used Akaike's Information Criteria corrected for small sample size (AICc) and selected the top performing model (i.e., the model with the lowest AICc score) to generate parameter estimates. We used parameter estimates from the top models. We performed separate analyses from results in 2022 and 2024 to identify differences in year that may be important for consideration in final model development or conclusions.

Active Burrow Assessment

Active burrows (i.e., burrows inhabited by prairie dogs), are the most important consideration for prairie dog conservation. Large swaths of burrows may have some value to other species or ecological processes but are not of themselves a measure of prairie dog population size or health. After conducting analyses to determine rates of burrow misidentification, we used similar methods (e.g., RFC and logistic regression) to identify patterns of environmental conditions and survey efforts to explain the presence of extant prairie dog colonies. For these analyses we used only ground-validated data collected in 2025. We counted only the locations where observers could affirm that prairie dogs were present based on evidence of an active colony; all other observations were treated as negative (i.e., colony was inactive).

Temporal Changes and Vegetation

During desktop review and early evaluations of field validation data, we realized there were differences between what collected imagery appeared to show and what actually existed on the ground . Imagery could potentially simply be insufficient to detect prairie dog burrows that were present, or the environment could have changed. Changes in vegetation types are one reason that the models' outputs may have been deemed incorrect in the field or different between 2022 and 2025. To evaluate this possibility, we used annual disturbance data from LandFire (LandFire.gov) for 2023, 2024, and 2025 to estimate the proportion of cells that may have had their classification altered over time. The LandFire disturbance layers generally identify large disturbances like wildfires but may not detect subtle changes on the landscape like natural prairie conversion to agricultural fields. Consequently, we also used the "Existing Vegetation Type (EVT)" datasets from 2022 and 2024 to quantify changes at all cells identified as prairie dog burrows across the study site. We compared cells between years to determine if their classification was changed and then quantified the total numbers of cells that changed across the study area.

Spatial Distributions and Ecological Relationships

Deep learning categorizes whether cells contain prairie dog burrows based on 200x200m tiles. These tiles can encapsulate the entire colony or only a portion of colonies or complexes. Full colonies or complexes are more appropriate metrics to use for understanding changes in prairie dog conservation and management. Consequently, for a series of tiles that were adjacent (i.e., shared a common border), we used the Aggregate tool in ArcGIS Pro to combine the adjacent tiles into one polygon representing an individual colony. We then used each colony's size in hectares to estimate total acreage, mean size of colonies, and their proximity or connectedness to one another.

The DL model produces an estimate of confidence for the prediction of an object -- in our case, individual cells. Based on the results of our analysis that assesses how confidence related to accuracy (see methods and results) and ability to classify cells correctly we incorporated a minimum 95% confidence for further procedures to try and minimize errors in identification. This confidence threshold was applied to other analyses we did including when we aggregated cells to identify colonies. From these aggregations, we produced 4 total estimates of colony distribution and size for the study area (2 estimates for 2022 and 2 for 2024), both using all cells and only those cells with >0.95 confidence.

We used the estimated perimeters of prairie dog colonies from the drone surveys conducted in 2025 to determine which metric would be best to use in other analyses and conclusions. We compared drone estimate boundaries to appropriate DL colonies s by conducting a spatial join at each drone perimeter to each of the 4 estimates of colony size. We then calculated the difference between the area estimated by the drone and the area estimated from the DL-derived aggregate colonies. We then used linear regression to identify which method resulted in the higher coefficient of determination (R^2).

We used these data to evaluate patterns based on the county-level metrics and potential drivers of change including disturbance, total agriculture or development, and other environmental drivers (e.g., NPP). We used generalized linear models to determine which of these drivers best explained the observed patterns in colony size across eastern NM.

Comparison with Previous Assessments

Using field-validated data and an initial set of models, we examined patterns in colony size and distribution changes from those documented in Johnson et al. 2010. As part of our research design, we intentionally planned to visit sites that were originally validated by Johnson and colleagues. To conduct these analyses, we used the polygon outlines from the 2010 data study (provided by Natural Heritage New Mexico). We imported these data into ArcGIS Pro (version 3.7) and then used a spatial join to relate the data to points obtained from our field validation surveys . Johnson et al. categorized the locations that they visited into 1 of 5 categories: 1) Prairie dog town with observed prairie dogs, 2) Prairie dog town with no observed prairie dogs, 3) Possible prairie dog town, 4) Not a prairie dog town, and 5) Old prairie dog town, but not active. We compared these classifications to our own field validation data to determine if the statuses of these locations had changed by 2025.

RESULTS AND DISCUSSION

Model evaluation

Landscape

From NAIP imagery collected in 2022, 1,742 (87%) tiles were evaluated correctly as being consistent with prairie dog presence and 1,709 (85%) tiles from 2024 NAIP imagery were determined to have been categorized properly by the DL model. For the landscape level analysis in 2022, the RCF estimated overall model accuracy of 0.85 with an estimated precision for classifying prairie dog presence of 0.87 and recall of 0.83. The variables identified as most influential were the confidence of the DL model, estimated mean habitat quality of the cell, and the northing and easting of the cell location. For 2024 imagery, the RCF overall model accuracy was 0.85 with precision of 0.90 and recall of 0.87. As with analysis of 2022 imagery, confidence of the DL model, mean habitat quality, and northing and easting were found to be most influential (Table 2).

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Table 1. List of variables considered in evaluation of the accuracy of DL models and patterns of prairie dog activity across 13 counties in eastern NM during 2025.

Scale	Metric	Description	Rationale
Landscape	Confidence	The estimated model confidence produced by DL for each object that it identifies (values vary from 0 to 1)	Higher confidence should result in better accuracy to detect prairie dog burrows.
Landscape	County	The 13 counties in eastern NM where we conducted the analyses	These counties serve as proxies for unknown variation among regions including vegetation, local weather patterns, agriculture, or other factors which could affect model performance.
Landscape	NPP24	Mean Net Primary Productivity during 2024 for a tile of interest	NPP reflects vegetative growth during a time period which could have a negative effect on detecting burrows from either aerial imagery or from the ground. 2024 preceded field validation by 1 year and was the time frame for which NAIP imagery for 2024 was collected.
Landscape	NPP25	Mean Net Primary Productivity during 2025 for a tile of interest	NPP reflects vegetative growth during a time period which could have a negative effect on detecting burrows from either aerial imagery or from the ground. We collected field validation data in 2025 and vegetation could affect detection.
Landscape	Mean Habitat	The mean habitat quality (range 0 to 1) for a location as estimated by the habitat suitability model produced by Davidson et al. 2023	Habitat quality could relate to stability of colonies or conditions that affect our ability to detect them through imagery analysis or ground survey.
Landscape	Mean Precip	Mean precipitation from 1950 to 2010 for a location	Spatial patterns of rainfall could affect vegetation growth and soil conditions which would affect ability to classify burrows accurately.
Landscape	Mean Temp	Mean temperature from 1950 to 2010 for a location	Spatial patterns of temperature could affect vegetation growth and soil conditions which would affect ability to classify burrows accurately.

Scale	Metric	Description	Rationale
Landscape	Easting	The measure of location from east to west in New Mexico	Conditions and habitat quality could change from east to west which could affect ability to detect and classify prairie dog burrows within 200 x 200 m cells.
Landscape	Northing	The measure of locations from north to south in New Mexico	Conditions and habitat quality could change from north to south1 which could affect ability to detect and classify prairie dog burrows.
Landscape	EVT22	The major existing vegetation type (as defined by Landfire.gov) on a cell in 2022	Differences in vegetation type could explain ability for models to perform or account for where prairie dogs are most likely to exist or be detected. Because imagery from 2022 was analyzed, it could be important.
Landscape	EVT24	The major existing vegetation type (as defined by Landfire.gov) on a cell in 2024	Differences in vegetation type could explain ability for models to perform or account for where prairie dogs are most likely to exist or be detected. Because imagery from 2024 was analyzed, it could be important.
Landscape	Delta EVT	A "True" or "False" designation indicates whether the vegetation types in 2022 and 2024 were the same (True) or different (False)	Changes in vegetation could explain differences in model performance or could be associated with changes in prairie dog presence or activity.
Landscape	Random	A random variable we used to test relative descriptive abilities to other hypothetical variables.	A random variable that has not biological correlation to prairie dog presence or activity but allowed us to compare biologically viable models to assess overall ability to describe data. Variables that perform similar or worse to random should not be considered in final interpretations.
Colony	Structure	A variable identifying the most likely structure that could be confused for prairie dog burrows	Allows identification of likely structures on the ground that confuse deep learning models or that are associated with changes in prairie dog presence or activity.

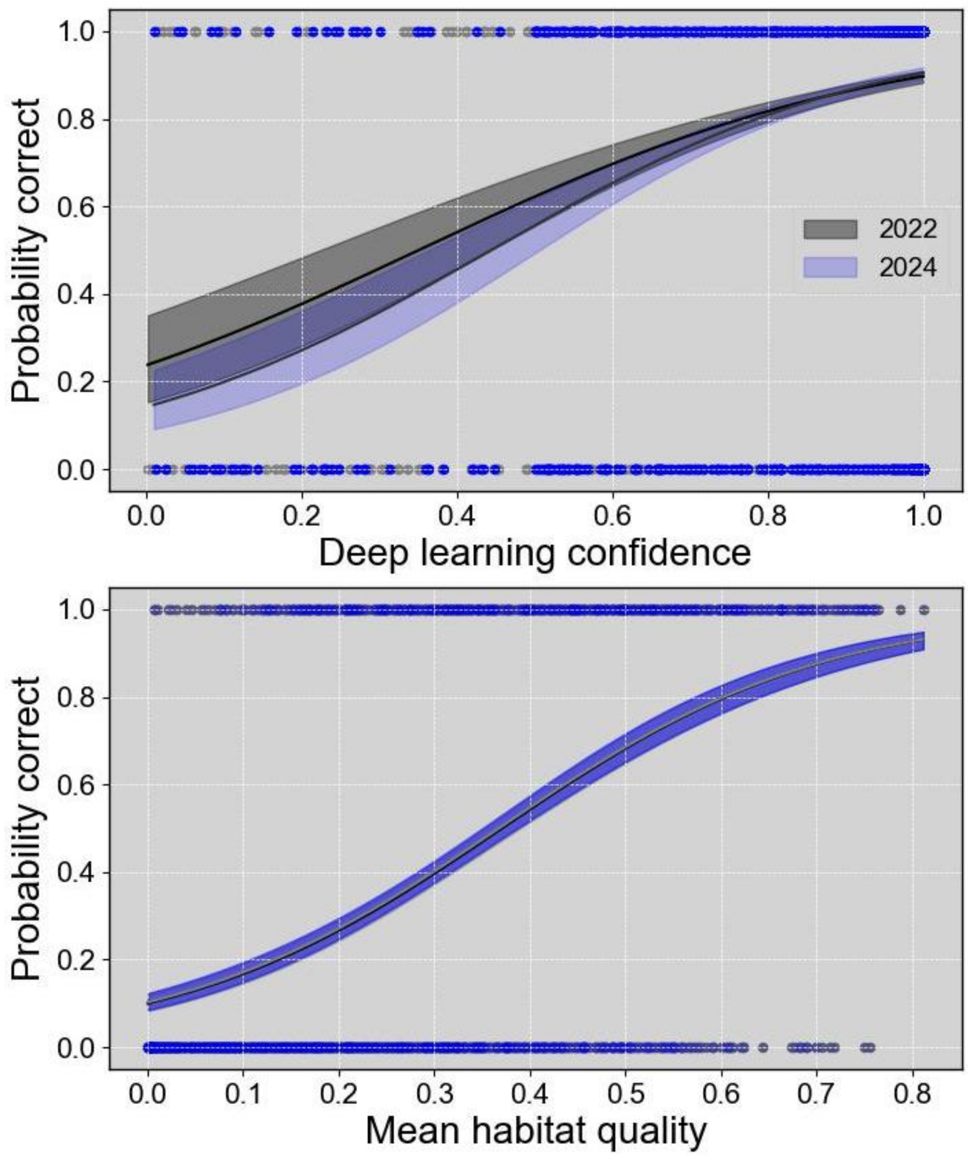
Scale	Metric	Description	Rationale
Colony	Observer	Categorical variable identifying the individual observers on the ground (numbered for anonymity)	Differences among field observers could explain biases associated with identifying burrows or recognizing activity.
Colony	NearestMound	The nearest observable prairie dog mound, in meters, the field personnel could identify from survey point.	This distance indicates how close observes got to polygons and could explain differences in identification of burrows or activity.
Colony	Method	The specific method used to survey (within colony, observed from distance, drone, or other)	Differences in method could explain biases with identification of burrows or observing activity.
Colony	Cloud	Cloud cover at the time of a field survey	Cloud cover could affect prairie dog activity and alter behavior or ability to determine activity of colony.
Colony	Hour	Time of the day of the survey	The time of day could affect prairie dog activity or alter their behavior.
Colony	WindSpeed	A categorical variable estimating wind speed at the time of the survey	Wind speed could alter behavior or visibility during a survey and explain ability to detect prairie dogs.
Colony	ColonySize	A categorical estimation of the size of an observable prairie dog colony	The size of colonies could affect ability for deep learning models to identify them or for observers to find them or identify activity.

Table 2. Variable importance scores for random forest classifier model permutation importance results summary for competing models describing correct classification of 200 x 200 m cells for the presence of prairie dogs across New Mexico in 2022 and 2024. Values greater than 0 (zero) improved model description whereas those at or below zero are unimportant.

Feature	Importance Mean 22	Importance Std 22	Importance Mean 24	Importance Std 24
Confidence	0.142	0.014	0.155	0.020
Mean Habitat	0.072	0.011	0.080	0.016
Easting	0.015	0.007	0.021	0.006
Northing	0.000	0.005	0.016	0.006
NPP22	0.009	0.005	0.009	0.008
NPP24	0.006	0.004	0.009	0.003
Random	0.003	0.003	0.009	0.004
County	-0.003	0.003	0.008	0.003
EVT22	0.000	0.005	0.007	0.004
EVT24	0.006	0.004	0.007	0.004
Mean Precip	-0.002	0.006	0.006	0.006
Mean Temp	-0.007	0.005	0.005	0.006
Delta EVT	0.001	0.002	0.002	0.002

The confidence that the model assigned to a cell should be an expected result if higher confidence from the DL increases the probability of the model correctly identifying imagery containing prairie dog burrows. Because RCF identifies which variables are most influential in classifying cells that contain prairie dog burrows, but does not quantify the specific relationship between dependent and independent variables, we used logistic regression to quantify those relationships. For both years, there was a positive relationship between confidence and the probability of correctly classifying a cell (Figure 3). These relationships for 2022 imagery ($\beta = 3.33 \pm 0.30$, OR = 27.93, DF = 1, $\chi^2 = 122.84$, $p < 0.001$) and 2024 imagery ($\beta = 4.0 \pm 0.31$, OR = 56, DF = 1, $\chi^2 = 168$, $p < 0.001$) were very similar (Figure 3). The odds ratios for both estimated relationships (2022: 27.9; 2024: 56) indicate that every unit of change in

Figure 3. Top *panel:* Estimated relationship between the confidence of *DL* algorithm to classify 200 x 200 cells as having prairie dog burrows *(*or not*)* and the probability of *the* correct identification of those cells based on human review. Bottom *panel:* Estimated relationship between the mean habitat quality and *the* correct identification of those cells. For both panels, data are based *the* 2,003 locations in New Mexico *that were* evaluated in 2022 and 2024. Shaded areas *a*round *relationship* line*s represent* 95% Confidence Intervals.



confidence increases the odds by substantial margins. Values of confidence >0.95 indicate a 90% probability of correctly identifying a cell.

The confidence value produced by the DL process is a combination of the training data provided and the unknown amount of variation that affects the underlying imagery. Consequently, the environmental metrics that may influence correct identification are important. Mean habitat quality was the single most influential environmental metric (Table 2). As with confidence, mean habitat values are positively associated with correct identification of prairie dog presence within a cell (Figure 3). Beta (β) estimates for 2022 imagery ($\beta = 5.91 \pm 0.29$, OR = 371.9, DF = 1, $\chi^2 = 396.67$, $p < 0.001$) and 2024 imagery ($\beta = 5.89 \pm 0.20$, OR = 362.2, DF = 1, $\chi^2 = 202.6$, $p < 0.001$) showed almost identical patterns. Mean habitat quality appears to have a strong positive effect on the ability of the model to correctly identify cells with prairie dogs, perhaps because colonies are easier to identify in good habitat due to being larger, denser, and more distinct from the surrounding matrix. The other important variables, northing and easting, had weaker effects than mean habitat. For imagery from both years, there was a pattern of more accurate classification the further east and north that a cell was located. Based on these evaluations, subsequent analyses performed used a confidence threshold of ≥0.95 and we discounted those locations where the mean habitat was <0.60 (Figure 3).

Colony

We then evaluated the accuracy of prairie dog burrow identification by the model compared to data collected during field validation surveys (n = 660). This analysis quantifies and identifies patterns and variables associated with on-the-ground reality of how well the DL model classified cells that potentially contained real prairie dog colonies. Most sites that we visited (482; 73%) contained prairie dog burrows. This percentage is slightly lower than what we estimated we would find based only on the imagery data. This RFC model indicated an overall model accuracy of 0.96 with a precision of 0.97 and recall of 0.96, suggesting that our model correctly classified the vast majority of cells where we actually found prairie dogs. The most influential variables from this analysis were generally those that were colony-specific like relative colony size, distance of observation, or surrounding vegetation types. Structures that could be confused for prairie dog burrows, like ant hills, kangaroo rat mounds, or rocks, had a permutation importance score of 0.25, colony size was 0.10, the nearest mound distance was 0.03, and mean precipitation was 0.018 indicating weak but valuable explanatory power. We examined these variables in logistic regression. Structures that could be confused for prairie dog burrows had a significant effect (DF = 7, $\chi^2 = 171.4$, $p < 0.001$). Examination of the individual structure effects revealed that when no alternative structure was identified, the odds that we correctly identified a cell contained prairie dog burrows were 1.49 better than when structures were present.. This result makes sense because it indicates that technicians could easily identify burrows in the field and saw nothing that could be easily mistaken for prairie dog burrows. The presence of structures including vegetation, boulders or rocks, or ‘other,’ resulted in the lowest probability of the model correctly classifying a cell. Structures such as bare ground, ant hills, and kangaroo rat mounds produced similarly low probabilities of accurately classifying cells. The colony size had a large effect on the correct classification of burrows being present ($\beta = 4.1 \pm 0.37$, OR = 61.9, DF = 1, $\chi^2 = 120.9$, $p < 0.001$). Locations with more vegetation are likely to either be old colonies without prairie dogs or difficult to identify from the ground. Colony size was not a continuous variable but rather a series of 4 categories reflecting relative size as assessed by an observer and were placed into a numerical order based on their actual areas in hectares (ha). Colonies that could not be identified by the model had only a 25% chance of being correctly classified as prairie dogs, colonies <1.5 ha were correctly classified 75%, and colonies larger than 1.5 ha were effectively correctly classified 100% of the time. That size influences properly classifying prairie dog burrows is unsurprising because cells located in large complexes are often more obvious from imagery (reflecting more landscape change from prairie dog activity) and burrows are easier to confirm from ground surveys. The distance from which the burrows were observed was an important variable in the RFC. We found it was also significant in logistic regression (DF = 3, $\chi^2 = 82.4$, $p < 0.001$). As with colony size, this variable consisted of 4 categories whose values correspond to increasing distance from the suspected burrows. When observers did not find burrows in the field, they did not record any value, which thus decreased the odds of properly classifying or finding burrows (because they were not found). Distances of 10 to 500 m of the observers from the nearest mound did not appear to have had a negative effect on the ability of observers to identify burrows.

Active Colony

During field validation we visited 659 sites across eastern NM (Figure 4A), which largely overlapped with areas that were visited during the Johnson et al. 2010 study in an attempt to have the same spatial coverage and thus allowing comparisons of the same location through time. However, some of our validation points were outside of polygons that had been evaluated by Johnson et al. Nevertheless, we were able to evaluate colony activity at 355 sites common to our study and Johnson as well as sites that were not surveyed by Johnson et al. 2010 (Appendix A). Generally, our classification method could reliability classify active colonies based on several variables. The RFC had an overall model accuracy of 0.92 with precision 0.93 and recall 0f 0.90. Colony size, mean precipitation, northing, easting, and NPP data collected in 2025 for each visited site were the most influential variables used in the RFC model for cell classification (Table 3). Mean habitat quality was also found to have a small but positive influence on whether a colony was active or not. A model created from logistic regression that included these top variables and a northing-easting interaction term displayed high descriptive power. Colony size had a strong positive relationship with the probability of colony activity ($\beta = 4.56 \pm 0.33$, OR = 96.54, DF = 1, $\chi^2 = 184.6$, $p < 0.001$) whereas mean precipitation had relatively weak and negative relationship ($\beta = -0.028 \pm 0.007$, OR = 0.97, DF = 1, $\chi^2 = 13.69$, $p < 0.001$; Figures 5 A and B). Northing was also positively related ($\beta = 0.51 \pm 0.07$, OR = 1.67, DF = 1, $\chi^2 = 58.85$, $p < 0.001$; Figure 5 C) but easting was negatively associated with the probability of observing an active prairie dog locations ($\beta = -0.29 \pm 0.20$, OR = 0.74, DF = 1, $\chi^2 = 1.97$, $p = 0.15$). The interaction between northing and easting was also significant ($\beta = -1.56 \pm 0.32$, OR = 4.48, DF = 1, $\chi^2 = 23.6$, $p < 0.001$), suggesting that moving further west across the landscape decreased the probability of observing active prairie dogs at a location compared to colonies further north. Effectively, moving to the west more strongly decreases the probability of observing an active colony in the south than in the north. Although mean habitat quality was not identified as a strongly influential variable in the RFC, it did have a relatively strong positive correlation with colony activity in the logistic regression ($\beta = 2.59 \pm 0.46$, OR = 13.3, DF = 1, $\chi^2 = 5.39$, $p < 0.001$; Figure 5 D).

Temporal Changes and Vegetation

Throughout our model development and imagery review, we noted that there were important changes in imagery and actual vegetation (Figure 6) over time. In some instances, imagery collected from 2022 and from 2024 showed marked differences in apparent prairie dog burrows or density that made it challenging for both humans and DL to accurately classify a cell as having prairie dog burrows or now (Figure 6 top panels). In other cases, there were actual changes (e.g., new agricultural fields) between years in the vegetation on the ground which appeared to have caused prairie dog colonies to disappear (Figure 6 bottom panels). For all cells identified as prairie dog colonies in 2022 (n=34,131), there were only 6 (0.01%), 3 (0.008%), 39 (0.11%) cells that displayed any indications of disturbance. None of the 2003 validation cells overlapped with areas of apparent disturbance. Consequently, we conclude that disturbance, as quantified by the Landfire datasets, was not a significant contributor to errors associated with the model's misidentification of cells using classification imagery vs. field-validated conditions. Some locations had prairie dogs during the 2025 field validation, and our assessment of the 2022 and 2024 imagery indicated that prairie dogs were likely also there in 2022 and 2024. Across all cells that were identified as containing prairie dogs in 2022, 92% (29,761) had the same vegetation type classification in both 2022 and 2024. Seven percent of cells were classified differently using 2022 vs. 2024 imagery. Of those cells that did not match between years, 84% were classified as an agricultural environment in either year. The majority of these (51%) were classified as converted to "Fallow/Idle Cropland." Other prominent habitat classes were Temperate Row Crops (19%), Temperate Wheat (6%), and Pasture or Hay (2%). The most common non-crop vegetation types associated with change between 2022 and 2024 were shortgrass prairie (7%) and mesquite shrubland (1.5%). Generally, cells classified as containing prairie dogs that changed between 2022 and 2024 were located south of Interstate 40 whereas less change in vegetation was observed north of I40 (Table 4, Figure 7).

Figure 4. A) The eastern NM scope of the project showing areas surveyed in 2009 (blue boxes) and current field validation locations (black dots) from 2025; B) Red polygons are the DL model output from 2022 NAIP imagery projected across eastern NM. Counties of interest for this study are outlined and labeled in black.

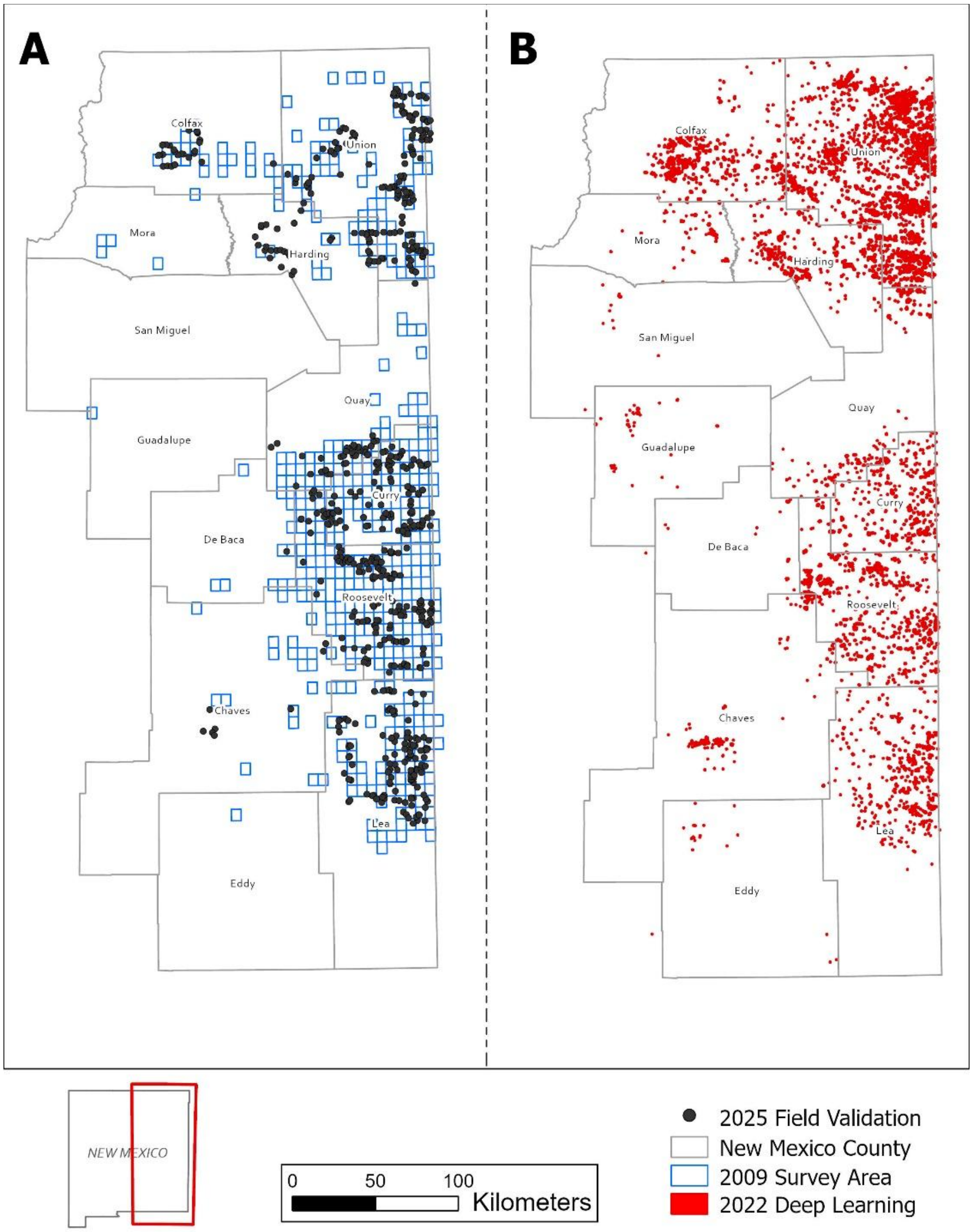


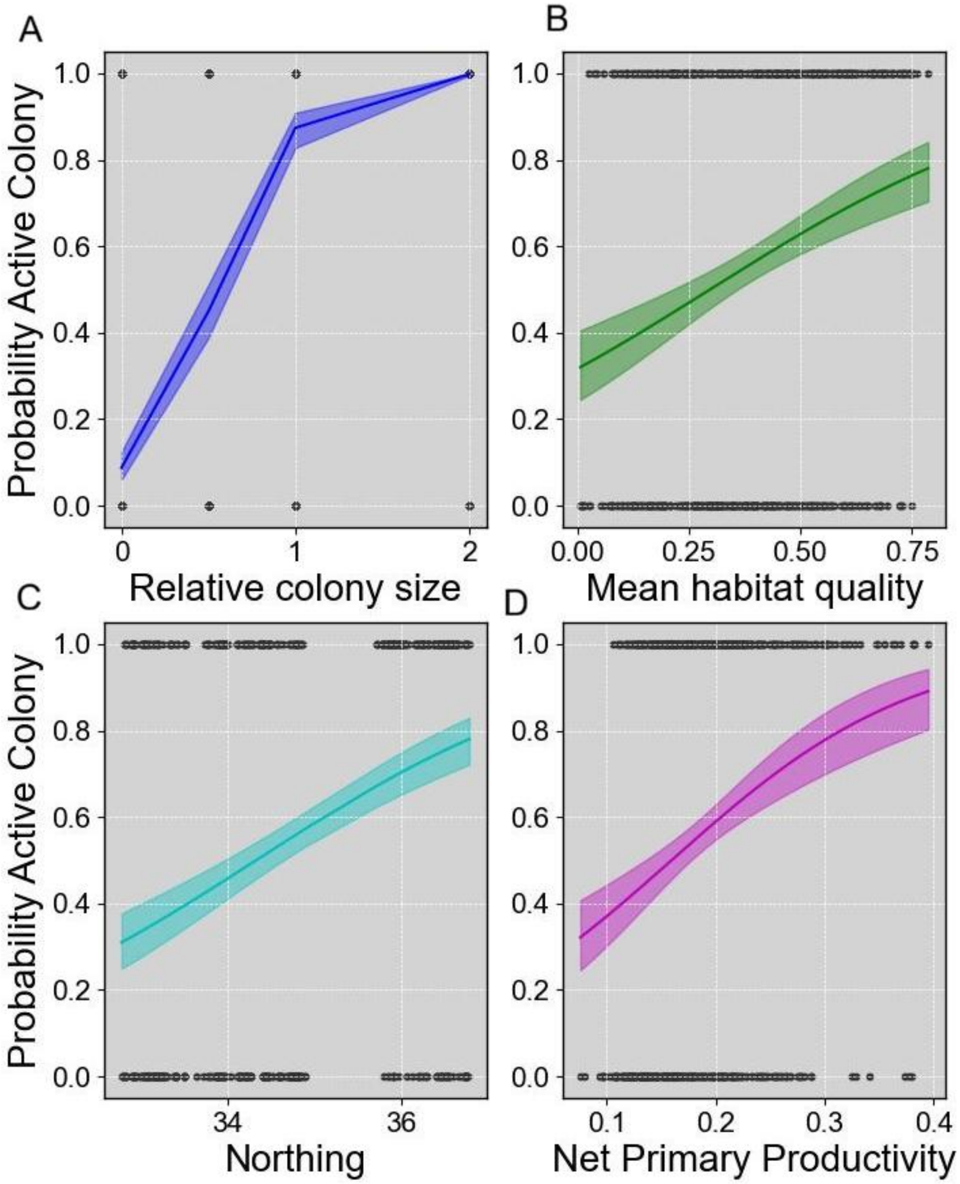
Table 3. Variable importance scores for random forest classifier model permutation importance results summary for variables describing active vs inactive colonies prairie dogs across New Mexico during field validation in 2025. Values greater than 0 (zero) improved model description whereas those at or below zero are unimportant.

Variable	Importance Mean	Importance Std
ColonySize	0.371	0.030
Mean Precip	0.030	0.010
Northing	0.024	0.008
Easting	0.015	0.011
NPP24	0.014	0.009
NPP25	0.010	0.006
Mean Temp	0.008	0.015
Mean Hab	0.002	0.005
EVT24	0.002	0.003
NPP22	0.002	0.003
County	0.001	0.002
EVT22	0.000	0.000
Random	-0.004	0.004
Delta EVT	-0.005	0.005

Spatial Distributions and Ecological Relationships

From our best DL model, we estimated total acreage from cells that are consistent with prairie dog presence in 2022 and 2024. Considering all cells irrespective of confidence level, 32,179 cells were consistent with prairie dogs for a total area of 127,636 ha within our study area in 2022. In 2024, this value was 38,941 cells (138,763 ha). When we consider only cells with 95% confidence level, the total acreage in 2022 was 80,132 ha and in 2024 was 73,809 ha. As noted in our model evaluation, we decided to use a 95% confidence level because it appears to reduce errors of false positives. Changes in confidence level tended to reduce the number of single isolated cells and removed limited numbers of cells from outer perimeters of colonies (Figure 8).

Figure 5. Linear relationships between the probability of observing an active prairie dog colony and A) Relative colony size mean habitat; B) The estimated mean habitat value (Davidson et al. 2023) of 200 x 200 cell by; C) the north-south location of a cell; and D) the Net Primary Productivity of a cell in 2024. For all panels, data are based 660 locations in NM that were verified in the field during 2025. Shaded areas around relationship lines represent95% Confidence Intervals.

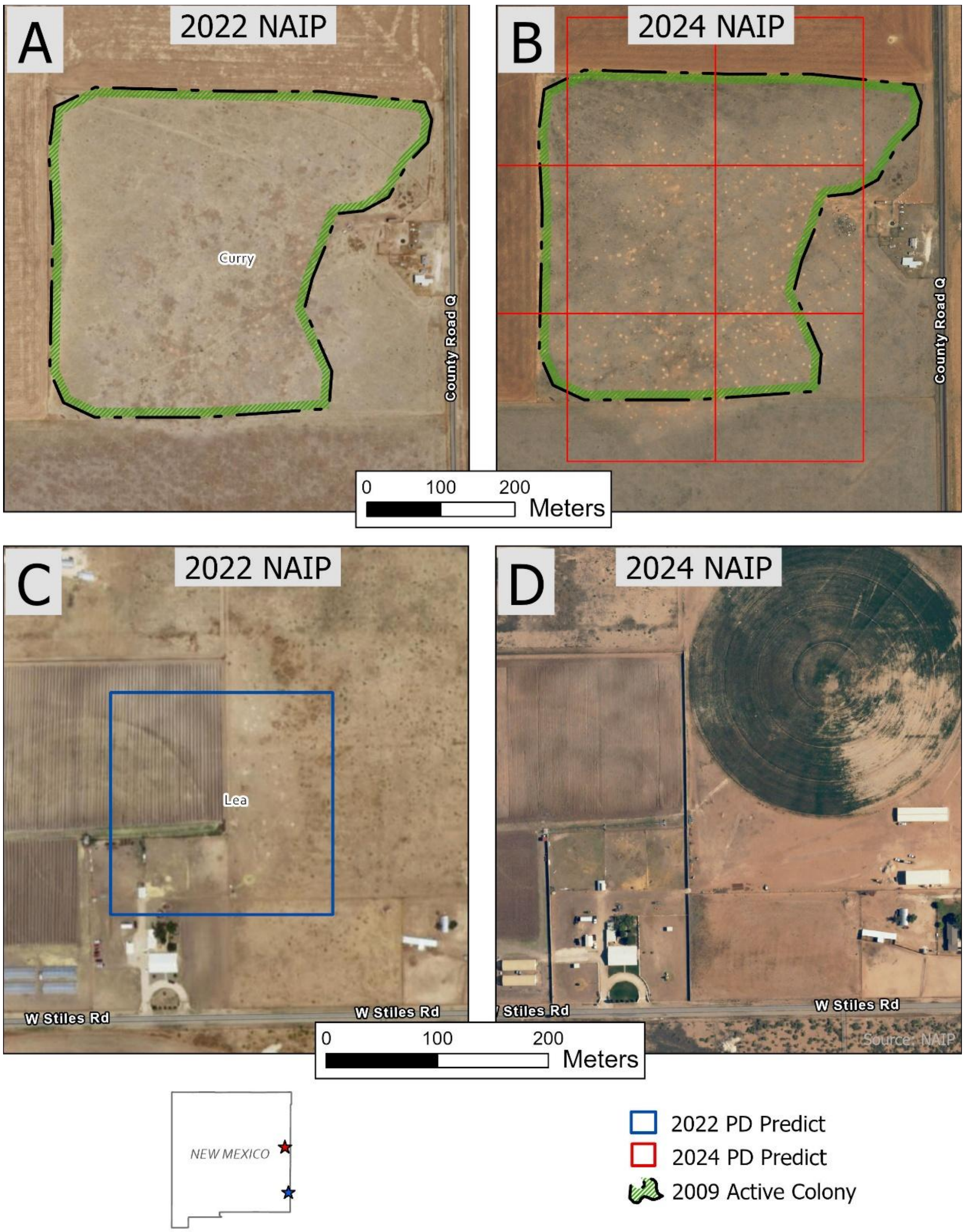


Contiguous aggregations of cells identified as containing prairie dog burrows (colonies) were similar to individual cells in their distribution across the study area. The highest number of colonies were identified in Union County (1,248 in 2022), with Roosevelt County ranking 2nd (578 in 2022; Table 5). There was a strong correlation between cell numbers and colony numbers in 2022 ($\beta = 0.11 \pm 0.10$, $p = 0.1$, $R^2 = 0.88$, $n=14$) across all counties. Across all the study area in NM and calculated using both years, mean colony size was 13.29 ± 8.10 ha. Union County had the largest mean colony size in both 2022 (33.85 ± 143 ha) and 2024 (27.62 ± 105 ha), followed by Harding County (28.5 ± 66.77 ha in 2022, 27.21 ± 68.1 ha in 2024). NM counties that were more westerly and southerly (e.g., Eddy, De Baca, and San Miguel) has smaller colony sizes that those in the east and north of the state (Table 5).

Table 4. Estimated vegetation status of individual cells predicted by deep learning models to have prairie dogs in 2022. Numbers reflect the total number of cells where the vegetation classification was identical between 2022 and 2024 (Vegetation Unchanged) or the vegetation changed (Vegetation Changed) and the percentage of vegetation classification change in each county. Comparisons between 2024 to 2022 were not done because 81% of cells identified as having prairie dog burrows.

County	Vegetation Unchanged	Vegetation Changed	Percent Change
Curry	1,312	679	51.75%
Roosevelt	3,179	668	21.01%
Lea	2,283	460	20.15%
Eddy	225	38	16.89%
Quay	882	65	7.37%
San Miguel	123	7	5.69%
Chaves	1,185	56	4.73%
De Baca	109	4	3.67%
Colfax	2,945	103	3.50%
Union	13,944	190	1.36%
Mora	614	6	0.98%
Guadalupe	310	3	0.97%
Harding	2,592	23	0.89%

Figure 6. Differences in NAIP imagery from 2022 and 2024 at two locations. Red and Blue square cells show areas that were classified as containing prairie dogs by deep learning algorithms. In the top panel, the green area is an estimated colony surveyed in 2009.



Counties in the upper northeastern portion of NM had more individual cells identified as containing prairie dogs, more prairie dog colonies, and larger colony sizes (Table 5). Union County had 4-5 times more cells and acreage than the next highest county (Roosevelt). Cumulatively, Union, Harding, and Colfax Counties accounted for 71% of total acreage estimated to contain prairie dogs in 2022 and 67% in 2024. There was a strong correlation between county estimates of prairie dog acreage between the 2 years ($\beta = 0.77 \pm 0.19$, $p < 0.001$, $R^2 = 0.97$, n=14). Union County showed the highest change between years with 1,974 fewer cells in 2024 compared to 2022 (Figure 3, Table 3). Other counties, aside from Lea, show patterns of modest increase in loss of cells, although these patterns could be the product of between-year differences in imagery and not actual changes in real numbers of colonies or locations with apparent prairie dog. Lea county declines the most between years.

Table 5. Number of cells in 2022 (#Cell22) and 2024 (#Cell24), total estimated hectares of prairie dog coverage by county in 2022 (Area22) and 2024 (Area24) as classified by a deep learning algorithm from NAIP with a minimum model confidence of 0.95 in each of those years. Also shown: colony numbers in 2022 (Colony Num22) and 2024 (Colony Num24) and the change between years (ΔColony Num); and the average colony size (ha) in 2022 (MSC22) and 2024 MSC(24) with standard deviations. Data is for eastern New Mexico.

County	#Cell22	#Cell24	Δcells	Colony Num22	Colony Num24	ΔColony Num	Area22 (ha)	Area24 (ha)	MCS22±SD	MCS24±SD
Union	10,618	8,644	-1,974	1,248	1,197	-51	42,259.20	33,059.74	33.86± 143.7	27.62± 105.3
Roosevelt	2,116	2,149	33	578	521	-57	8,431.07	7700.75	14.59 23.4	14.78 21.2
Harding	1,982	2,451	469	276	278	2	7,864.82	7565.26	28.5 66.8	27.21 68.8
Colfax	1,828	2,742	914	423	636	213	7,260.33	10,092.05	17.16 34	15.87 32.4
Curry	1,154	1,500	346	287	364	77	4,579.49	5,409.86	15.96 25.8	14.86 19.4
Lea	1,113	606	-507	469	264	-205	4,392.21	2,404.47	9.37 16.5	9.11 13.6
Quay	552	765	213	137	138	1	2,151.34	2,017.69	15.7 31	14.62 26.3
Chaves	470	132	-338	151	72	-79	1,813.48	373.6	12.01 22.4	5.19 3.8
Mora	225	749	524	78	251	173	872.27	2,334.54	11.18 21.5	9.3 14.1
Guadalupe	63	278	215	46	162	116	236.19	928.7	5.13 4.8	5.73 5.3
Eddy	26	70	44	20	37	17	104.08	276.17	5.2 3.7	7.46 8.5
De Baca	24	33	9	18	19	1	96.06	108.08	5.34 2.4	5.69 3.9

Figure 7. A) Counties within our study area with the Existing Vegetation Type Vegetation Physiognomy designation from LandFire.gov; B) DL model outputs that identify prairie dogs in 2022 or 2024. Grey cells indicate no change in underlying vegetation classification; and red cells showing indicate changes in vegetation classification between 2022 and 2024.

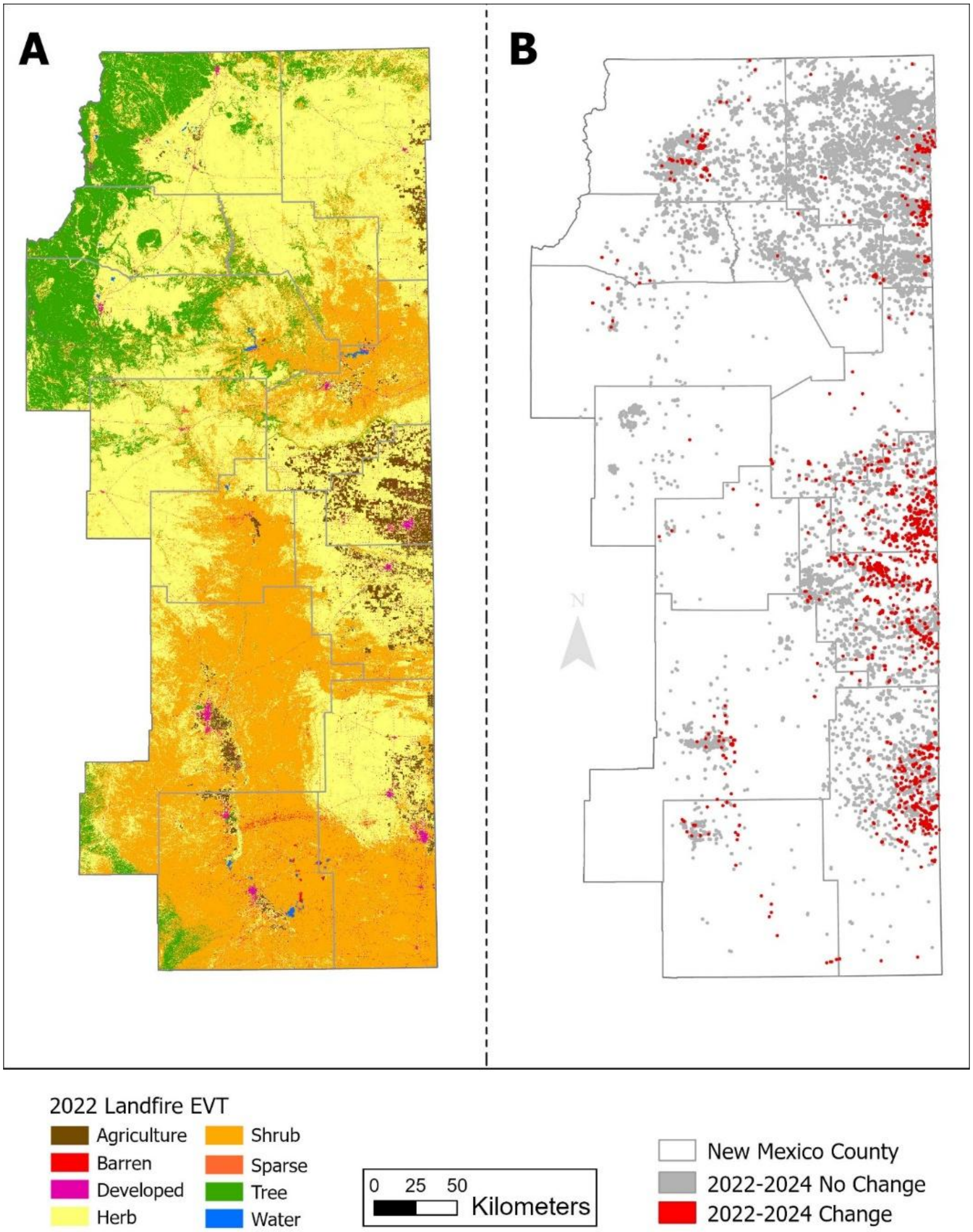
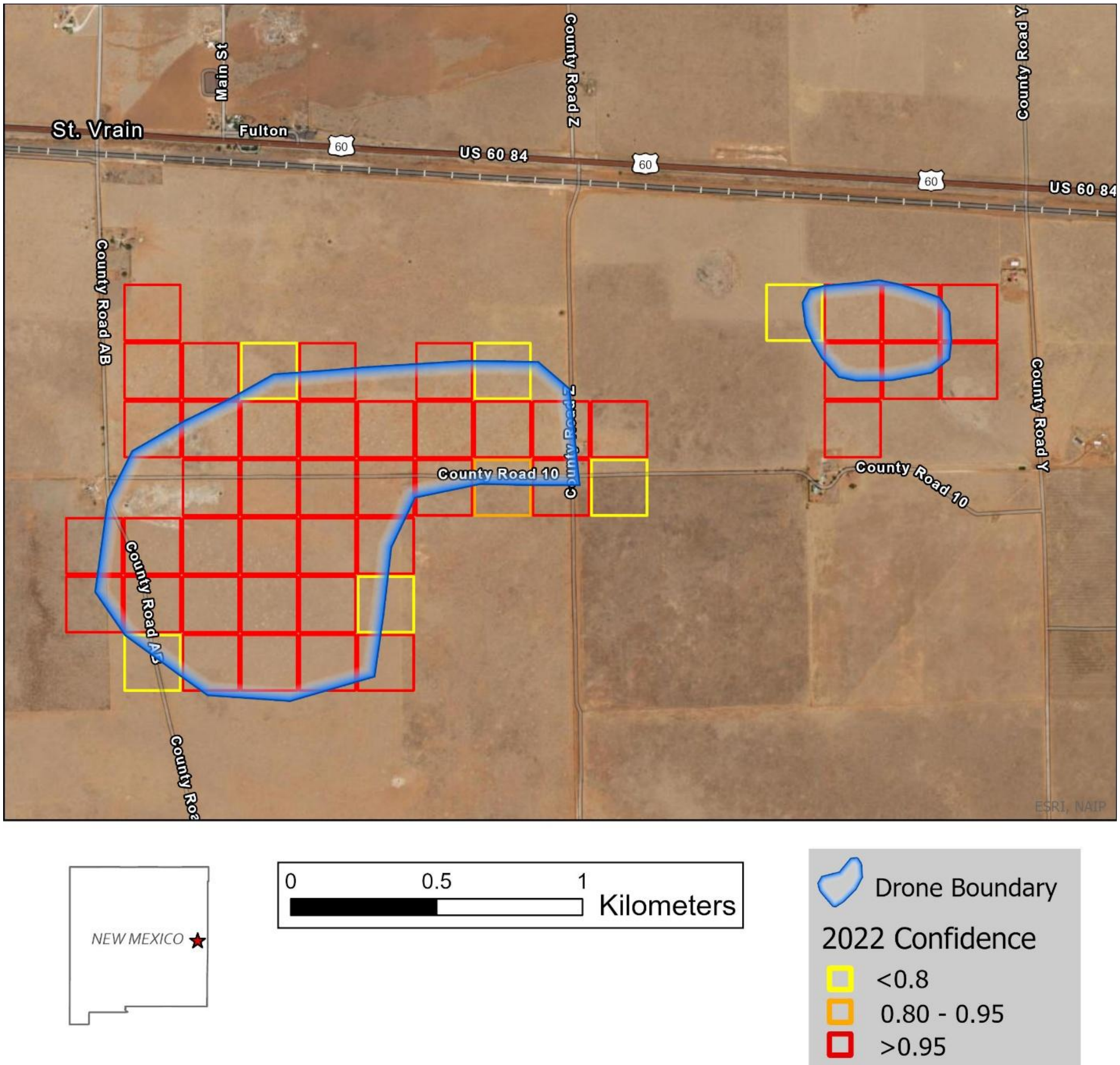
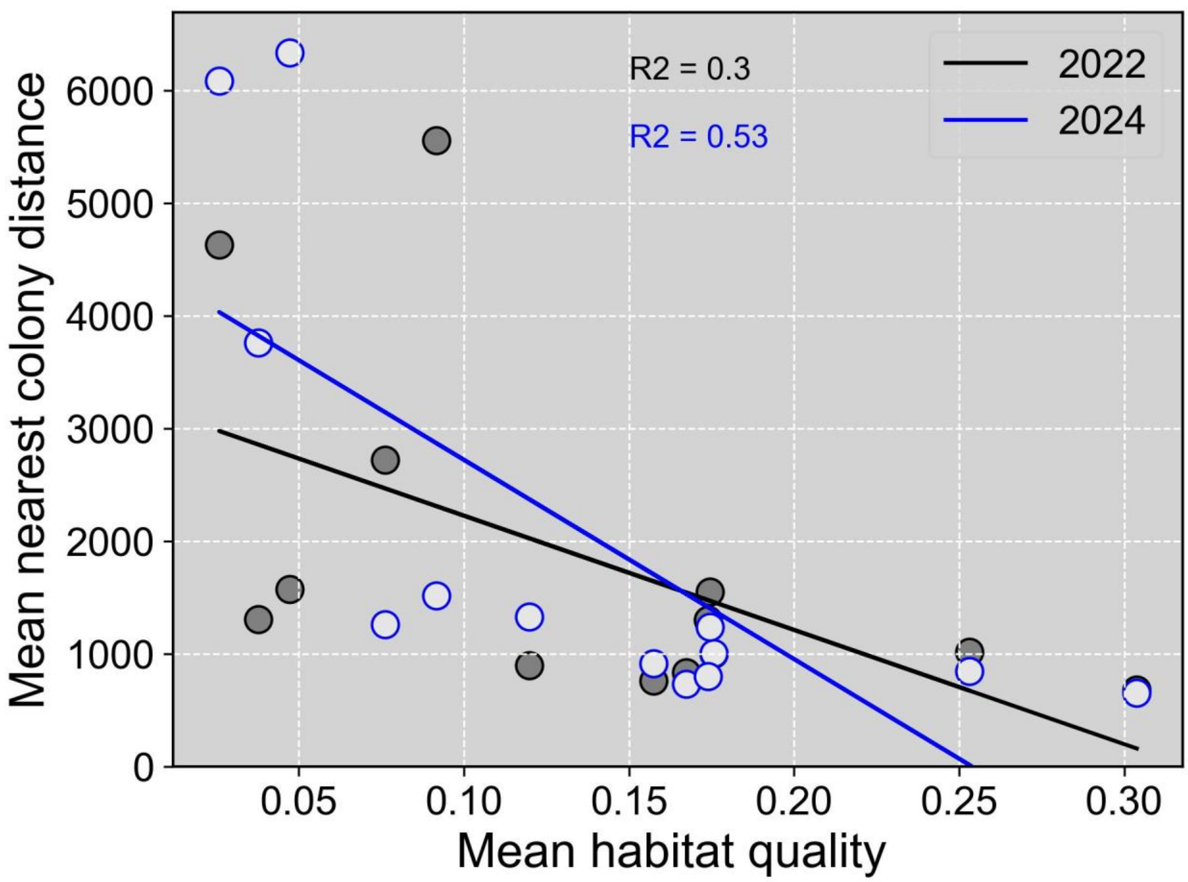


Figure 8. Two prairie dog colonies in eastern New Mexico with perimeter outlines (blue) derived from in-field drone survey during 2025 and individual 200 x 200 m cells from NAIP 2022 imagery at 3 levels of confidence from deep learning algorithm. Thick red cell borders indicate confidence of >0.95, orange borders indicate confidence of 0.8-0.95, and yellow borders indicate confidence of <0.8. Using different confidence thresholds provides slightly different perspectives on overall colony size and total distribution.



Average nearest neighbor analysis for individual cells predicted to contain prairie dogs indicated the presence of clustered patterns. In 2022, the average nearest neighbor was 303 m with an index of 0.25 (values closer to 1 indicate clustered distributions). In 2024, the average nearest neighbor was 253 m with an index of 0.26. Evaluating nearest neighbors at the colony level for 2022 indicated a mean nearest neighbor distance of 1,414 m with an index of 0.50; in 2024, the nearest neighbor distance was 1,440 m with an index of 0.50. At the county level, the shortest nearest neighbor distances were found in Union County in both 2022 (681 ± 886 m) and 2024 (653 ± 858 m). Counties further west (including Guadalupe, Eddy, and San Miguel) had large mean nearest neighbor distances ranging from 1,263 to 556 m). There were negative correlations between the mean habitat quality found in a county and the mean nearest neighbor distance (Figure 9). This correlation was weaker in 2022 ($\beta = 0.0014 \pm 4{,}943$, $p = 0.04$, $R^2 = 0.30$, n=14) than in 2024 ($\beta = 0.00178 \pm 7609$, $p = 0.02$, $R^2 = 0.53$, n=14).

Figure 9. The individual scatter plots from the mean values of habitat and distance for each county and to nearby colony across New Mexico in 2022 and 2024 with estimated linear regression lines for 2022 (blue) and 2024 (black). Both estimated relationships were significant at an alpha = 0.05.



Collectively, the patterns of total acreage, mean colony size, and colony nearest neighbor distance all indicate higher densities of prairie dog colonies in northern and eastern NM. Union County stands out in nearly all descriptive statistics as having more and denser prairie dog colonies, followed by Roosevelt County, and then other northern counties in NM.

We sampled 63 colonies with drones to estimate their perimeters and their total acreage. The average colony size calculated by using this approach was 36.8 ± 78 ha. On average, creating colonies using the 200x200m cells, and at the 95% model threshold, appears to have underestimated colony size by 17% but with high variability among the different colonies we sampled. However, creating estimates with all cells, irrespective of the DL model confidence threshold overestimated colony size by 116% on average, also with high amounts of variability. When applying our 0.95 confidence threshold for classifying cells, some small, generally single cell colonies were missed (n = 18 for both 2022 and 2024 estimates), but using all cells appears to have overestimated perimeter cells that have few actual burrows. Consequently, we used the 0.95 confidence threshold for remaining cells and calculated a 17% increase in total colony size between when attempting to adjust colony acreage for potential sampling bias. Nevertheless, misclassification also tends to overestimate cells with prairie dogs by 19%. So, these two metrics appear to roughly balance out on average although more research is needed to adequately account for biases in specific years, regions of NM, or under specific circumstances.

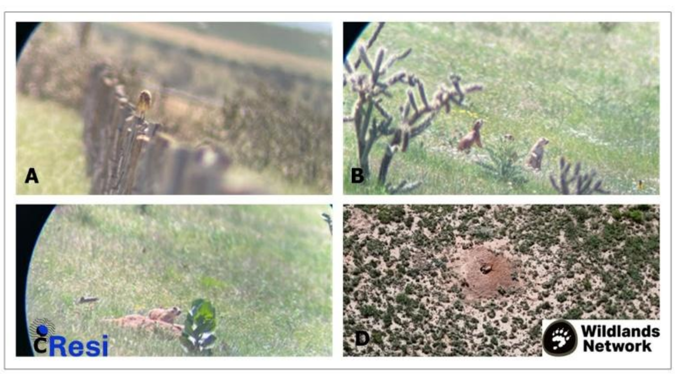
Field Validation

Of the 660 locations, 70% (431) have evidence of prairie dogs burrows whether those burrows are old (inactive colonies) or currently active prairie dog colonies, 14% (90) showed no evidence of prairie dog burrows or colonies, and the status of 15% (89) of locations could not be determined. Of the 431 locations with prairie dog burrows, 77% (330) were classified as "active" (i.e., we either saw, heard, or found evidence [fresh digging or saw fresh scat] of recent prairie dog activity at that colony), but 22% (93) showed no evidence of having extant prairie dogs. At 1% of locations, we could not determine activity. At 34% of active colonies, we saw prairie dogs; 62% of active colonies had multiple lines of evidence suggesting activity. At 8 sites (2.4%), contractor personnel were told by local people that colonies had prairie dogs. On at least 6 instances, the areas where we identified colonies from NAIP imagery had been converted to agricultural fields and we could not confirm evidence of current prairie dog activity. Consequently, we are aware that the imagery from 2022 may not completely align with current conditions on the ground in 2025. At 77 (13% of) sites, we observed burrowing owls (*Athene cunicularia*) directly on colonies, on nearby fences or poles, or flying away from the colonies (Figure 10). We did not observe any other species that are listed as Species of Greatest Conservation Need in New Mexico although we had less experience or ability to detect invertebrates or plants.

Comparisons with Previous Assessments

We visited a total of 355 of the original colonies predicted from the 2009 survey efforts (Johnson et al. 2010; Table 6). After evaluation of DL models, we suspect that some validation locations may represent the same colonies although the on-ground surveys assessed the status of an individual cell and not the entirety of a colony (Figure 11 A). Sampling the same colony had some benefits because we learned that some large colonies could have obvious prairie dog activity in some locations but displayed no evidence of prairie dogs, or sometimes even burrows, in other areas. Consequently, we attempted to make one determination of activity for the entire colony (any series of bordering cells) where we sampled more than 1 place rather than treating these as independent. When colonies had different evaluation points with different assessments within its borders, we chose cells that had higher confidence in their assessment (e.g., were closer to the colony or where we could make a definitive assessment). If any locations within a colony's perimeter showed signs of activity, we classified the entire colony as active. Of the 355 locations visited in 2025, 66 colonies were active in 2009 and were still active. Fifty-one colonies that were confirmed to be active in 2009 showed no signs of activity in 2025. Fifty sites displayed no signs of having prairie dog burrows in 2009, but we detected mounds or active prairie dogs in 2025. Thirty-one colonies were inactive historically but were confirmed to be active in 2025. We could not confirm the status of 60 sites, meaning that the observer did not see any signs or evidence of prairie dogs, but felt like they could not see enough of the colony from a distance or because of the vegetation to make a confident assignment. We visited 51 "new" sites that were identified in 2009 as a colony from desktop review but was never visited by Johnson et al. 2010 in 2009.

Figure 10. Clockwise from upper left: A) Burrowing owl on fence in Quay County; B) Two prairie dogs standing near burrows in Chaves County; C) Prairie dog in burrow entrance as seen from above in Curry County; D) Prairie dog crouched on burrow in Curry County.



Comparisons of active colonies across counties used all known data from within the respective counties rather than being only sites that were sampled in 2009 and 2025. Because our method of identifying potential survey sites differed from Johnson et al.'s and 16 years had passed between the two survey efforts, some historic locations no longer appeared active while new locations had become active. Additionally, the Johnson et al. surveys did not always identify polygons with potential prairie dogs in all portions of the counties they visited, whereas our results may not always have occurred at the exact same locations or representing the same prairie dog colony. Comparisons between the two surveys by county indicate marginal increases in the proportion of active colonies in 2025 compared to 2009 (Table 7). The highest observable differences were in northern counties including Union (39.8% increase), Colfax (36.7% increase), and Harding (21.7% increase). Lea County showed the lone apparent decline (11.4%), but other southern counties showed effectively no change in activity (Table 7). Generally, these results agree with the results of our other analyses: northern counties in NM have larger and more stable populations of prairie dogs while southern counties have smaller, more isolated, and less resilient populations of prairie dogs.

Figure 11. Comparison of 2025 DL prediction model output (red squares) with the colony status-based polygons from Johnson et al. 2010 (colored polygons) and the 2025 field-validation data (colored symbols) in eastern NM. Data for model were taken from the following locations: A) Near Maxwell in Colfax County; B) Near Clayton in Union County; C) Near Portales in Roosevelt County; and D) Near Lovington in Lea County.

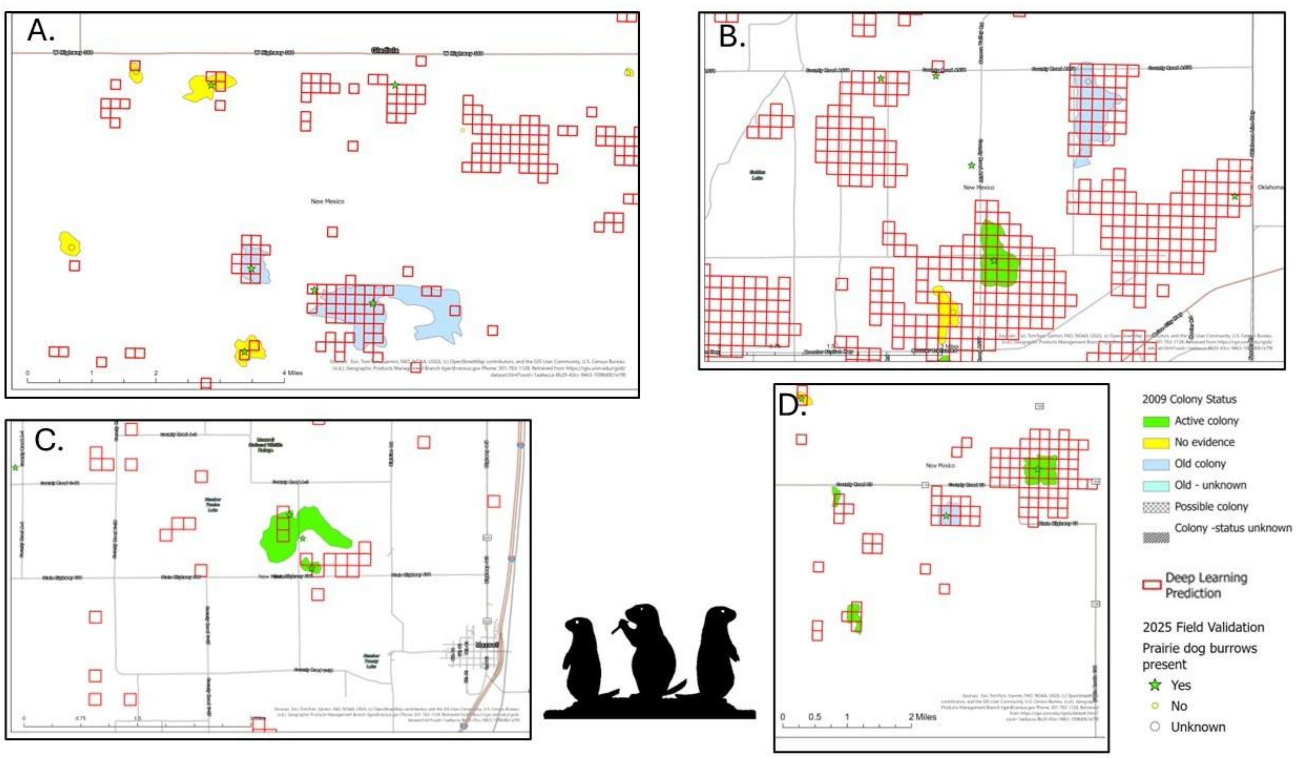


Table 6. Comparison of results from surveys by Johson et al. 2010 and those of our field validation in 2025 in eastern New Mexico at 355 common locations.

Interpretation	Description	Site Count	% of Total Sites
Still active	Historically active; still active now	66	18.6
Visit inconclusive	Field visit could not confirm status	60	16.9
First-ever visit	No prior historic visit, now assessed for first time	52	14.6
Was active, now inactive	Historically active; now inactive or no longer a town	51	14.4
New activity detected	Historically not a town; now showing active dogs or signs	50	14.1
Recolonized	Historically inactive town; now active with dogs	31	8.7
Still inactive town	Historically inactive town; still no active dogs	17	4.8
Confirmed not a town	Historically not a town; confirmed again now	16	4.5
Inactive town, now gone	Historically inactive town; now no evidence of prairie dogs	10	2.8
Historic unknown, confirmed	Historic status unknown; now confirmed as having active	2	0.6
TOTAL		**355**	**100**

Table 7. Comparison of results of surveys to document the activity of prairie dog colonies in eastern New Mexico during 2025 (this study) and 2009 (Johnson et al. 2010). Positive values in the last column (Change in Prop of Active Colonies [2009 to 2025]) indicate increases in the proportion of active colonies between survey years and negative values indicate decreases. Only Lea County experienced a decrease in the proportion of active colonies from 2009 to 2025.

2025 Study					2009 Study				
County	**# of Inactive Colonies**	**# of Active Colonies**	**Total # of Colonies Surveyed**	**Proportion of Active Colonies**	**# Active**	**# Other**	**Total #**	**Proportion Active**	**Change in Proportion of Active Colonies (2009 to 2025)**
Chaves	8	0	8	0.000	0	3	3	0.000	0.000
Colfax	1	29	30	0.967	3	2	5	0.600	0.367
Curry	55	40	95	0.421	60	84	144	0.417	0.004
De Baca	.	.	.	.	.	.	0	.	
Guadalupe	.	.	.	.	.	.	0	.	
Harding	6	32	38	0.842	5	3	8	0.625	0.217
Lea	85	58	143	0.406	40	37	77	0.519	-0.114
Mora	.	.	.	.	.	.	0	.	
Quay	24	16	40	0.400	8	32	40	0.200	0.200
Roosevelt	69	57	126	0.452	75	93	168	0.446	0.006
Union	45	134	178	0.753	22	40	62	0.355	0.398
TOTAL	**293**	**366**	**658**	**0.556**	**213**	**294**	**507**	**0.420**	**0.136**

We extracted all of the polygons from the Johnson et al. 2010 study in addition to all DL model-identified colonies from 2022 and 2024 imagery in common search areas. For our estimates from 2022 and 2024, we maintained a confidence threshold of 0.95 but also used the 17% estimation correction. For each county, we compared these total hectares of potential prairie dogs colonies for each county (Table 8). Generally, we found an increase in indices of total prairie dogs including numbers of colonies and active colonies but across counties (with the exception of Curry County, which showed a decline in both years compared to estimates from Johnson et al. 2010), Union and Colfax Counties showed the most significant increase in prairie dog colony area since 2009. We were concerned that large apparent increases or decreases in those counties in 2025 could signal a problem with our methodology. For example, locations in Colfax County show large increases in prairie dog colony area in 2025 as compared to 2009 (Figure 12A). Yet, the lead author of this report (A. Facka) personally visited most of the locations seen in the area shown in Figure 12A and observed large numbers of sizeable colonies consistent with the predictions of the DL model. In contrast, locations in Curry County show the opposite pattern, in which previously large colonies (some of these are colonies with burrows but not apparent prairie dogs) are no longer identified by our DL model and in-field validation(Figure 12B). The DL models identify small subsets of the original colonies and field validation are consistent with small and isolated colonies.

Caveats and Conclusions

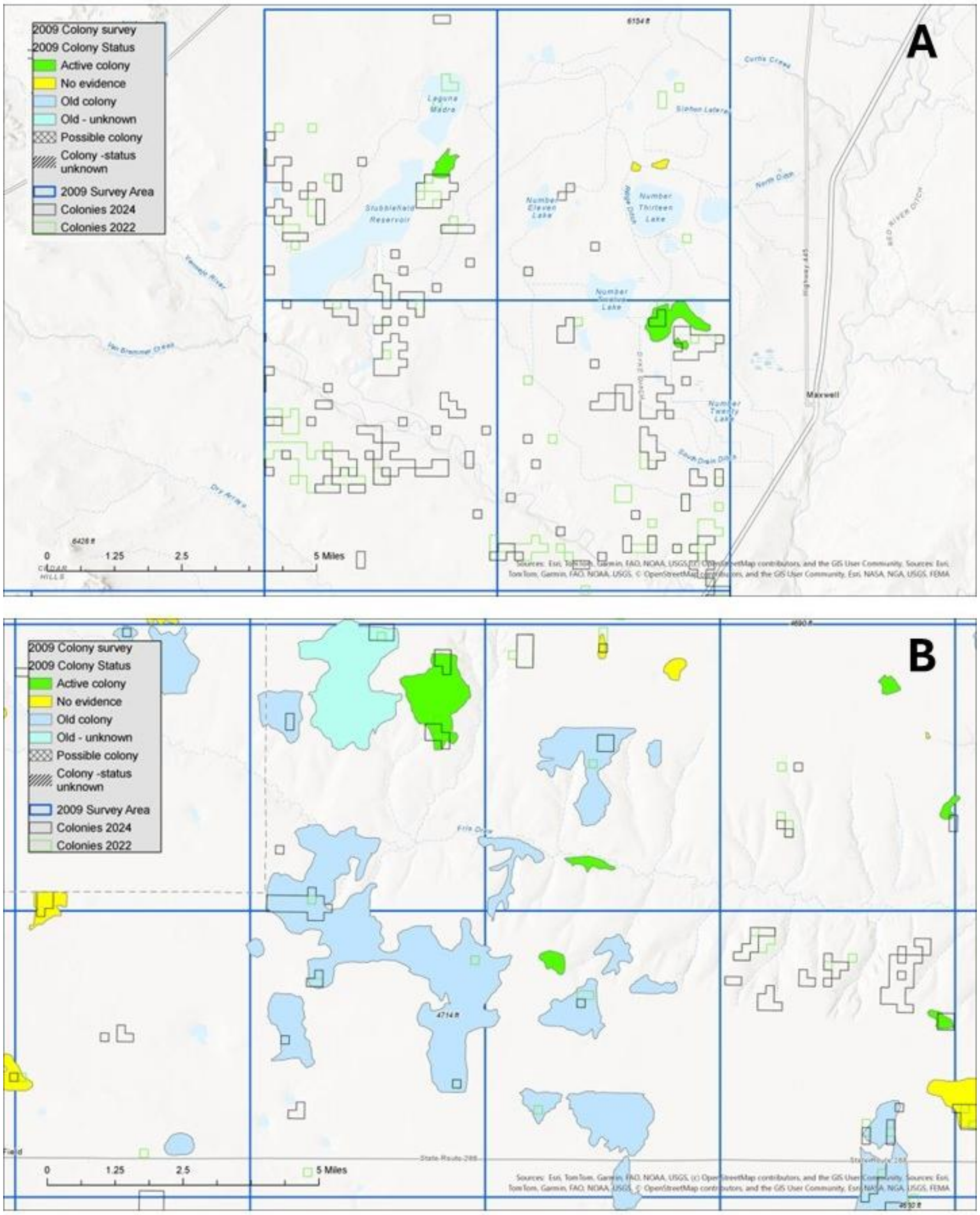
Generally, we find the DL models to be useful, but we recognize a number of important factors that should be considered. Firstly, comparisons to the 2009 surveys are inherently different because the underlying imagery technology has advanced and new imagery has increasingly high resolution. Resolution in NAIP imagery went from 0.6 m in 2022 to 0.3 m in 2024. Imagery from 2003 to 2017 was at 1 m. As we have documented, imagery from year to year may change and provide different signatures from the landscape. Moreover, factors like recent precipitation, relative to when imagery was captured, may influence vegetation or soil conditions, which may have profound influences on our ability to detect prairie dog burrows. Long-term drought may also remove vegetation making prairie dogs burrows, especially at the periphery of colonies, more visible, and a lack of vegetation may promote short-term expansion of prairie dog digging and burrowing giving the impression of increased numbers of animals (Hoogland 1995). Thus, the precision of estimates of total area is limited based on imagery, changes on the landscape relative to the imagery, population dynamics within colonies or complexes where prairie dogs exist, and other factors we may not understand. We suggest that considering averages from 2022 to 2024 is the best approach when evaluating change because biases in imagery are likely to balance out to some degree. On ground changes in conditions, like local precipitation patterns in a year, plague, or human eradication can also remove prairie dogs quickly from a location they may have persisted. Thus, imagery is always going to be representative of the time it was taken and not present conditions. Overall, the DL process appears sufficiently reliable to provide a broad assessment of changes in prairie dog distribution across the landscape that we studied. We have compared our results to those of Johnson et al. 2010, but because our sampling regimes are different, we suggest that readers or managers avoid dwelling on specific estimates but consider overall spatial patterns and empirical relationships to metrics we have evaluated. Additional surveys and research are required to better tune models and to identify problem areas or landscape features which may be confused for prairie dog burrows. There was high variation in estimates that arise in both the formal statistics as well as the way we have implemented DL results. For example, changing the DL thresholds to 0.90 or 0.99 would alter estimates considerably. Within our DL training, we attempted to capture all features on the landscape that could be prairie dog burrows. Aggregations of structures like ant hills, kangaroo rat mounds, boulders, or other features may be present in these results that we could not dismiss because we could distinguish between them and either inactive or active prairie dog burrows. These issues are likely to be magnified the further south and west in NM where bare ground and other burrowing animals become more prominent. Our research primarily focuses on identifying prairie dog burrows and colonies and documenting patterns of activities. Our research cannot estimate densities of prairie dogs within, or across, colonies, and we cannot determine underlying population dynamics controlling such densities. Because plague, drought, poisoning, or other factors can quickly alter total populations of prairie dogs, even when their burrows remain, over reliance on specific estimates of prairie dog area should be avoided.

Overall, we find that prairie dogs colonies in the north and east of NM appear to be larger, closer together, and more likely to be occupied by prairie dogs than those further south. These patterns broadly follow associated patterns of precipitation and vegetation production, estimated habitat quality, and are negatively associated with areas of human crop agriculture. We have identified and developed an effective, though imperfect, method to monitor prairie dogs at the broadest level in relatively efficiently. We encourage use of these methods, or those similar to ours, to conduct these types of monitoring efforts on a consistent and frequent basis (at least 1 time every 5 years). The information we provide can be used to identify areas that have never contained prairie dog colonies and to discount these areas in future monitoring efforts and to prioritize area that are known to have active prairie dog colonies. We urge that this report be a first step in developing more rigorous methods to assess prairie dogs in New Mexico, and beyond, including sampling of densities (e.g., Facka et al. 2008).

Table 8. Prairie dog spatial extent (hectares) for common search areas in eastern NM, compared between Johnson et al. 2010 and for deep learning models produced from this study. For Johnson we provide the hectares for each category they identified; for our study we list the number of 200 x 200 cells consistent with prairie dog presence at a 0.95 confidence in both 2022 and 2024. Delta is the difference between the average between 2022 and 2024 subtracted from the total hectares from Johnson et al.

	Johnson et al. 2010					This Study		
County	**Active**	**Old**	**Possible**	**Inactive**	**Total**	**P2022**	**P2024**	**Delta**
Chaves	.	4.9	.	.	4.9	365.5	83.0	219.3
Colfax	100.6	.	.	.	100.6	3,624.8	3,743.7	3,583.7
Curry	1,567.1	3,790.0	84.7	319.0	5,760.7	3,507.7	4,056.9	-1,978.4
De Baca	.	.	.	.		46.5	29.9	38.2
Guadalupe	.	.	.	.		29.8	19.9	24.9
Harding	221.6	167.8	.	.	389.5	2,036.6	1,397.9	1,327.8
Lea	1,582.9	528.8	.	20.7	2,132.4	3,149.2	1,603.7	244.1
Mora	.	.	.	.		6.6	267.4	137.0
Quay	180.5	474.5	.	29.2	684.2	738.4	1,286.2	328.1
Roosevelt	1,551.7	755.2	21.5	555.6	2,884.0	5,951.7	5,730.3	2,957.0
Union	1,651.8	1,753.2	.	46.5	3,451.6	20,357.9	16,013.8	14,734.3

Figure 12. A) Four cells in Colfax County and B) Four cells in Curry County originally evaluated in 2009 for prairie dogs. Underlying colored polygons indicate boundaries of prairie dog colonies and their status with estimates of colony boundaries from 200x200 m cells classified as prairie dogs from DL model estimates in 2022 and 2024.



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