Range-Wide Monitoring of Black-Tailed Prairie Dogs in the United States: Pilot Study

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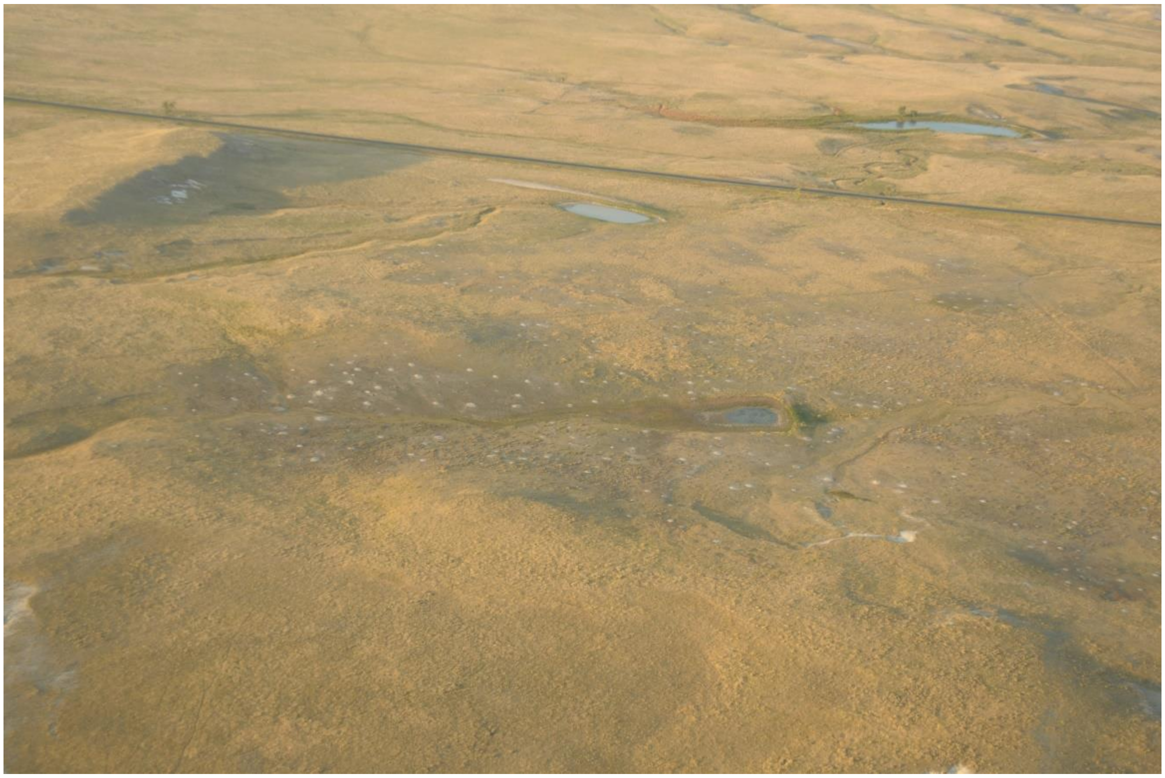

Photo by John Sidle

Glossary of Abbreviations

BAS	Balanced Acceptance Sampling
BLM	Bureau of Land Management
BTPD	Black-tailed prairie dog
GIS	Geographic Information System
NAD	North American datum
NAIP	National Agriculture Imagery Program
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WAFWA	Western Association of Fish and Wildlife Agencies
WEST	Western EcoSystems Technology Inc.

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INTRODUCTION

We surveyed the latest available National Agriculture Imagery Program (NAIP) images within the current range of black-tailed prairie dog (BTPD, *Cynomys ludovicianus*) colonies in a pilot study to estimate the current extent of apparent BTPD colonies. We estimated the range-wide extent of apparent BTPD colonies on the latest NAIP images for each of 11 states and on lands managed by the Bureau of Land Management (BLM) in Part 1. Western EcoSystems Technology, Inc. (WEST, Inc.) was contracted by the Western Association of Fish and Wildlife Agencies (WAFWA) in a separate project to estimate the extent of apparent BTPD colonies in Wyoming using a census of land units containing BTPD habitat in Wyoming. We gave results for the census in Wyoming and sample surveys for BLM Land and the other 10 states in Part 2. Apparent BTPD colonies that were potential active or inactive BTPD colonies were digitized and delineated in a Graphical Information System (GIS). Apparent BTPD colonies were called "features" for brevity.

Our primary objective was to provide estimates of total acres of all features in the sampling frame of survey units for each state with confidence intervals on estimates. Estimates were corrected for features missed (false negatives) as determined by the use of independent observers on a subset of survey units. Objectives also included estimation of the number of features in each state, the number that were greater than 1,000 acres and the number that were greater than 5,000 acres. In Wyoming, we digitized features on a census of BTPD habitat units in the state and corrected the estimates of total acreage for false negatives. In addition, aerial and ground surveys were conducted in Wyoming to correct estimates for false positives (i.e., digitized features that were not active or inactive BTPD colonies).

We estimated sample sizes necessary to achieve acceptable levels of precision (for example, coefficients of variation less than 15 %) and recommended long term monitoring methods for acreage and abundance of potential BTPD colonies in each state, on BLM managed lands, and range-wide in 11 states based on sample surveys of habitat units.

Objectives included preparation of GIS shapefiles and digital map products showing digitized features, representing potential back-tailed prairie dog (BTPD) colonies associated with 2 mile by 2 mile grid cells in a probabilistic sample of at least 1,000 cells from each state and for BLM managed lands. Data were summarized in spreadsheets and/or data bases giving abundances, locations, and sizes of digitized images in the sample survey of cells. In Wyoming, census values were given.

Objectives on BLM managed lands differed somewhat in that we estimated total acres of features that were on BLM managed lands with confidence intervals. We also, estimated total acres of features that were associated with BLM managed lands in the sense that at least part of the feature was on BLM managed lands.

METHODS

We conducted a desktop survey of BTPD colonies using the latest National Agriculture Imagery Program (NAIP) imagery to identify potential BTPD colonies. NAIP images have at least one square meter resolution, were inexpensive and easy to obtain. Plans exist to update images every 3 years or more often, facilitating a long term monitoring program. The study area was defined as the current known range of BTPD as established by the State wildlife agencies or historic surveys of BTPD colonies (Figure 1.1), see Part 2 for the state study areas and sampling frames.

We created a contiguous 2-mile square grid feature class over all 11 Western U.S. states in our study area, using the projection USA_Contiguous_Albers_Equal_Area_Conic_USGS_version. Each grid cell was given a unique identifier (grid ID) that included the name of one and only one state; grid cells that overlapped multiple states were assigned to the state that had the greatest amount of area within the cell. State-by-state and BLM sample frames were then created by sub setting the grid by state and those grid cells containing BLM managed lands. NAIP imagery was unavailable for areas including and surrounding White Sands Missile Range in New Mexico. Further modifications were described in the section presented for each state.

We used 2 by 2 mile viewing units to facilitate complete coverage of the BTPD habitat and defined a sampling frame within each state and for BLM managed lands. This allowed implementation of the multiple interpreter approach in McDonald et al. (2011) and provided analysis units that were compatible with units being used in the other 11 states containing BTPD (e.g., Kempema et al. 2015). We selected a sample of 2 by 2 mile grid cells within each state and for BLM managed lands. In addition, a sub-sample of the grid cells were also surveyed by two interpreters to make it possible to construct a "capture history" or "double sample" for features in survey units. The double sampling methods enabled estimation of the number of features not detected by either interpreter using logistic regression statistical models (Zar 2009).

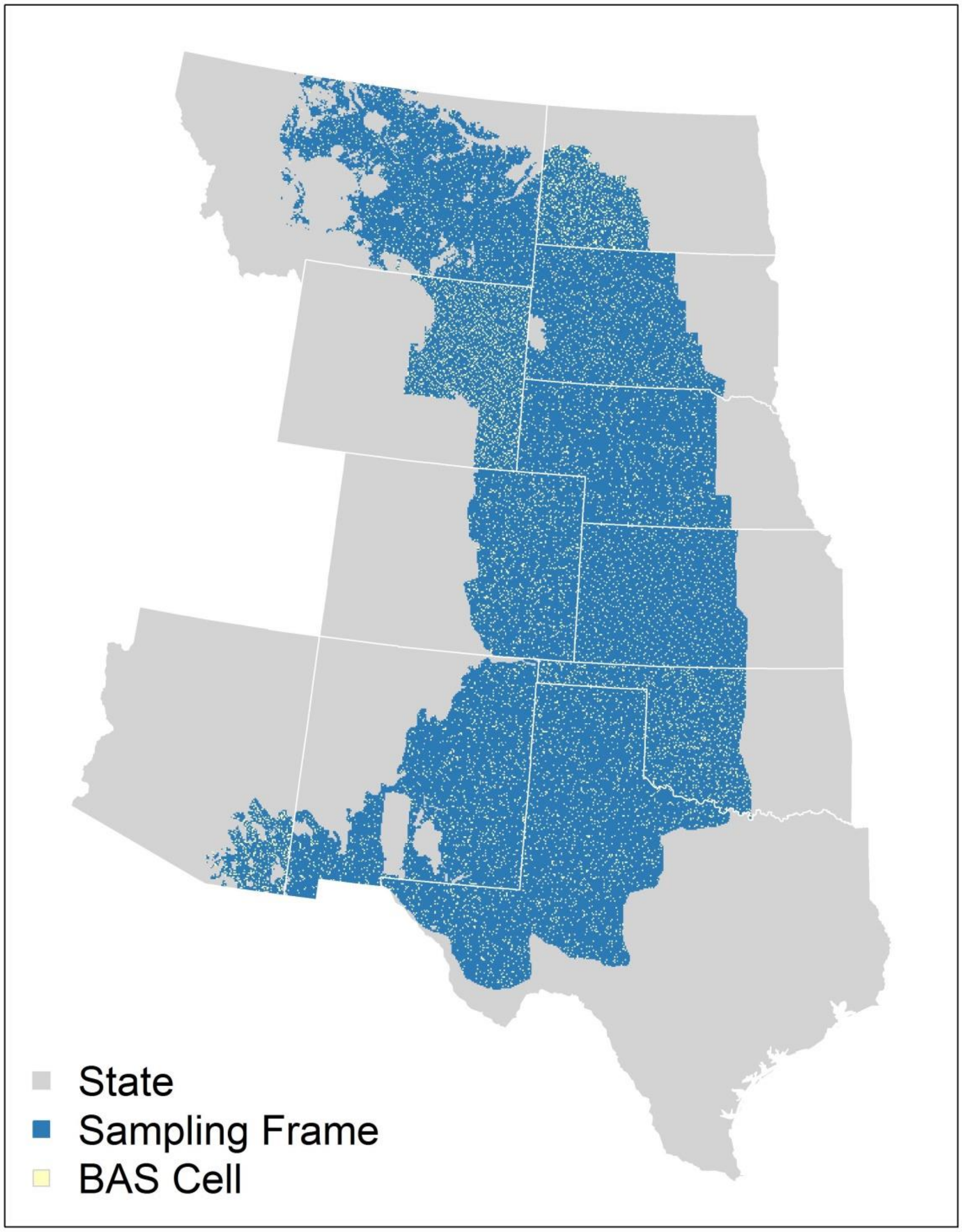


Figure 1.1. Study areas and sampling frames of 2 mi by 2 mi grid cells in 11 states. See the results section for each state for detailed descriptions of the sampling frames for each state and for BLM managed lands within the states.

Digitizing Methods

The digitizers used the latest version of ArcGIS (ArcMap10.2.2) to conduct the GIS work in this study. Using ArcMap, we generated an MXD file for digitizers to use as a template throughout the entire project. In each state and for BLM lands, we constructed a sampling frame consisting of 2 mile by 2 mile grid cells to overlay the NAIP imagery so that observers could systematically search selected cells. To make the process of searching easier and more efficient, we created a smaller mini-grid system within each 2 by 2 mile grid cell. Each 2 by 2 mile cell contains 5 rows and 5 columns for a sum of 25 smaller cells for digitizers to search. The smaller grid system allows full coverage of selected 2 by 2 mile cells and assured that no area was overlooked by observers. Observers viewed the cells of the mini-grid at a scale of approximately 1:4,000.

The observers searched each selected 2 mile by 2 mile cell starting in the northwest corner and worked their way to the southeast corner scanning the cells of the mini-grid one at a time. When an observer found a potential prairie dog colony, they digitized the feature's perimeter at their discretion. Observers zoomed in and out on the images depending on the geographic area and the feature to be digitized. Digitizing was done at a scale no larger than 1:4,000. The interpreters used a "connect the dots" method to connect the outermost burrows that could be identified on the NAIP imagery (Sidle et al. 2002). For some colonies, visible clip lines of vegetation were observable to help identify the outer most burrows. Digitizers were instructed not to digitize colony perimeter by following the clip line in an effort to provide consistency across years with variable vegetation growth and to produce the most comparable results through time. Further details on digitizing methods and methods for the double sampling procedure were given in Appendix A.

Sampling Methods

Observers digitized detected features on a sample of at least 20% of grid cells in the Arizona sampling frame, at least 1,000 grid cells from each of the other states, and more than 10% of grid cells in the sampling frame for BLM managed lands (Table 1. 1). We selected grid cells for sampling from the sample frame by an equal probability sampling procedure known as Balanced Acceptance Sampling (BAS, Robertson et al. 2013). This selection procedure resulted in essentially a stratified random sample from each state and a separate random sample from units containing BLM managed lands. Grid cells were ranked by the BAS procedure and sampling of grid cells proceeded through the ranked order of grid cells. The BAS sample was a spatially balanced sample of grid cells such that any contiguous subset, when taken in order, was an equal probability sample of the target population. We digitized detected features on a census of grid cells in Wyoming.

Table 1.1. 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

Observers visually inspected each sampled grid cell and digitized those areas judged to be potential black-tailed prairie dog colonies. BTPD burrows were usually surrounded by mounds of bare soil one to three meters in diameter. Mounds were often of different color than color of surrounding surface soil. Vegetation was typically reduced in height with different texture that contrasts with vegetation outside the “clip line.” The size of mounds, color contrasts, presence of clip lines, and distances between mounds combined to form the search image which triggered the detection of a potential BTPD colony, e.g., Figure 1.2.

Figure 1.2. Black-tailed prairie dog colony with burrow opening visible in a Google earth image at high level of resolution.

For each sample from each state and BLM lands, we digitized features detected and computed their acreage. We estimated total acreage of digitized features and abundance of features on or partly on each surveyed grid cell. Total acreage and abundance of features digitized in the state and BLM sample frames were estimated (see estimation methods below). The precision of these estimates were evaluated to make recommendations on adequate samples sizes required for future work. Details on the digitizing methods for the double sampling procedure were given in Appendix A.

In Wyoming, we completed a census of grid cells under a separate contract with WAFWA, however, we recorded the Wyoming data to enable simulation of the results of a sample size approximately 10% of the cells. Using these sampled cells, we computed estimates of total acreage of digitized features with confidence intervals. These estimates were compared to the census values in Wyoming in order to make recommendations on adequate samples sizes required for future work should a decision be made to monitor acreages based on digitizing features in a sample of cells rather than conducting a census of the entire state.

Estimation Methods

We used three fundamental methods for estimation of the total number (N) and total acreage (S) of features in each state and on BLM managed lands. We called the three methods the clipping, centroiding, and transecting methods. Probabilistic estimates underlie the three methods utilized here, for which small-sample statistical theory allows estimates of both total number (N) of features present and areal extent (S) expressed in acreage. Within Wyoming, we compared these estimates to the estimates made from a census of the entire study area.

The delineation of features with centroids that reside in a selected cell frequently leads to features that spill outside a sample survey grid cell of interest. Concurrently, other features, whose centroids fail to reside in the cell of interest, have extents that reach into a sampled cell. The resulting ambiguous dichotomy that results from the failure of features to reside completely in any one cell suggests the use of multiple estimation approaches, with the aim that concordance resulting from differing approaches will increase confidence in results.

The clipping method involved determination of areal extent (S) of acreage of digitized features within each sampled cell and could be obtained without digitizing the entire perimeter of features when they extend outside the cell. The resulting data analysis involves straight forward methods for estimation of the total areal extent of features in a state or on BLM land, however estimation of abundance and size of large features would not be possible. The centroiding and transecting methods were developed to potentially improve the precision of estimates of the abundance and sizes of features greater than 1,000 acres or features greater than 5,000 acres. Such features were extremely rare or do not exist in some states.

The centroiding method assigns each feature to one and only one grid cell in a sampling frame based on the location of the centroid. Each cell in the sample frame was assigned the number and sizes of features whose centroids were in the cell. Total areal extent of features can be estimated as well as the number and sizes of features using standard statistical estimation methods.

The transecting method was developed based on methods used for Russian snow surveys of animal tracks (Stephens et al. 2006). Animal tracks were detected by crossing the track while following straight line transects. In our application, features were detected by the sample of grid cells when the perimeters of features were intersected by the sides of our sample cells. We used the sides of the 2 mi by 2 mi sample grid cells as “transects” to “capture” features. The objective was to improve the detection of large, rare features and to evaluate the precision of estimates of the size and abundance of rare, large features, e.g., number of features greater than 5,000 acres in size.

Features whose perimeter were intersected by the transects were “in the sample” with probability, P, given by the following formula (Stephens et al. 2006)

$$P = \frac{2LM}{\pi A},$$

where L was the length of the transects, A was the total area of the sampling frame, and M was the perimeter of the digitized feature. Given the probability of detection of features digitized in the sample, it was possible to estimate the total areal extent of features in a sampling frame and the abundance and sizes of features. Further details on the formulas and their derivation were given below and in Appendix B.

Probability of Detection

We developed models to estimate the probability of an observer detecting a feature given the size of the feature. The double-observer approach, when applied to BTPD feature delineation, involved two observers who reconciled the presence of features in a grid cell following the methods described in Appendix A. Differences in feature delineation between the two observers suggest that their probabilities of detection of a feature differ. We utilized logistic regression to estimate the probability that at least digitizer A or B detects a given feature, assuming independence between observers, and allowing adjustment for covariates such as size of the features. We investigated the effects of several covariates in the models including feature size, log of feature size, digitizer pairings, and a measure of convolutedness. Appendix A contains detailed methods for this analysis.

The Horvitz-Thompson Estimator

The estimation of the probability of detection for a feature enables us to utilize the Horvitz-Thompson estimator (Horvitz and Thompson 1952) to estimate both total number of features present and areal extent. The estimate of total number (N) of features was written as

$$\hat{N} = \sum_{j=1}^{G} \frac{1}{p_j}$$

where p_j was the probability of detection of feature j, and G was the number of features detected. The estimate of areal extent (S) of features was written as

$$\hat{S} = \sum_{j=1}^{G} \frac{s_j}{p_j}$$

where s_j was the size, in acres, of the j^{th} feature.

Clipping Method

The clipping method involves computation of the acreage of features inside a given sampled cell. Areal extents of the j^{th} feature only retain those portions of the feature that falls within the cell of interest. The Horvitz-Thompson estimator of aerial extent, S, incorporates the probability of detection of a feature. Using this method, we averaged the digitized acreage per cell and multiplied the average by the number of cells in the sample frame to estimate total acreage. We used bootstrapping methods to estimate percentile confidence intervals (Manly 1997) for the total.

Note this method was only used to estimate the areal extent S, not the number of features N since one delineated colony may clip to several smaller distinct regions artificially inflating the observed total number of features. Additionally, this method cannot be used for estimation of the number of features greater than 1,000 acres or the number of features greater than 5,000 acres.

Centroiding Method

In the centroiding method, each digitized feature was uniquely assigned to one grid cell, namely the cell to which the centroid of the digitized polygon resides. The Horwitz-Thompson estimators were applied to estimate S and N, based on the numbers and sizes captured in a given sample. By using the acreage of features whose centroids belong to the sample of grid cells, we also estimated the total acreage of features in Wyoming. When estimating the number of features greater than 1,000 acres, we only used digitized features greater than 1,000 acres whose centroids belong to one of the grid cells in the sample.

The centroiding method allowed us to estimate the number of features present when only sample data were available. One pitfall to using this method arose when the centroid of a digitized feature belonged to a grid cell outside of the sample of cells. This may be a particular problem for "large" features, i.e., those greater than 5,000 acres, because there may not be many such large features in the state and fewer in the sample of grid cells.

Transect Method

The third estimation method, known as the Formozov-Malyshev-Pereleshin formula (Stephens et al. 2006), was used to potentially provide better estimates of the number of large features greater than 1,000 acres and the number greater than 5,000 acres. This method depends on identifying those features that intersect the boundary of a sample grid cell. The probability that a feature will intersect with one side of a sampled grid cell was given by $P = {2LM}/{\pi R}$, where M was the length of the perimeter of the feature in miles, L was the sum of the lengths of the sides of all sample grid cells in miles, and R was the area of the study area in a state in square miles (Stephens et al. 2006). Using features that intersect one side of a grid cell and knowing the probability that a feature with perimeter M intersected one side of the gird cell, we estimated the total number of features and total acreage of features in a state using a Horwitz-Thompson estimator for unequal probability sampling. Similarly, using features > 1,000 acres (or > 5,000) acres that intersect one side of the grid cell, we can estimate the number of features > 1,000 acres (or > 5,000) acres in a state. By applying the procedure four times, once for each side of the grid cell, we can compute 4 estimates and average them. We used bootstrapping methods to estimate the confidence interval on estimates of N and S (Manly 1997). See Appendix B for more details of the transect analysis method.

Adjustment for False Negatives

Observers were required to participate in training exercises where images of known BTPD colonies on NAIP images were shown and the observers were to work through the instructions in the Standard Operating Procedure (Appendix A). Images of ant colonies, rocks, patches of bare ground, etc. were included in the training exercises in initial attempts to help the observers develop a “search image” for active or inactive BTPB colonies.

It was expected that observers will miss some active or inactive BTPD colonies (false negatives) as well as include some features that resemble BTPD colonies and trigger the “search image” (false positives). Images of mounds which triggered the search image for BTPD colonies were digitized by connecting the outermost mounds visible on the latest NAIP images available in each state and were referred to as “features” for brevity. For example, if a small feature was digitized by an observer and probability of detection was 0.70 then the acreage of the feature was multiplied by (1/0.70) = 1.43 to account for features of that size that were missed (false negatives). Similarly, the estimate of the number of such small features was increased by 1.43.

Estimation Methods for Features on and Associated with BLM Managed Lands

Estimation of acreage of features on BLM managed land required that a detected feature be clipped to both the selected 2 mi by 2 mi grid cell and BLM land (Figure 1.3). Acreages of detected features on BLM lands and in selected grid cells in the sample survey were averaged and expanded to the number of cells in the BLM sampling frame. We also estimated the number and acreage of features “associated” with BLM managed land in the sense that features overlapped at least partially with BLM land. This required that a feature overlapped BLM managed land and the centroid of the feature belonged to the sampled cell, otherwise associated features could belong to more than one grid cell. For example, the top feature in Figure 1.3 would be counted as associated with BLM managed land because it overlaps BLM managed land and the centroid was in the sampled cell. The feature in the bottom left of the cell would not be counted because its centroid was in the neighboring cell. If the centroid of the bottom left feature had been in the sample cell it would have been counted as associated with BLM managed land and the entire acreage would have been “associated” with BLM land even though some of the feature was on non-BLM land.

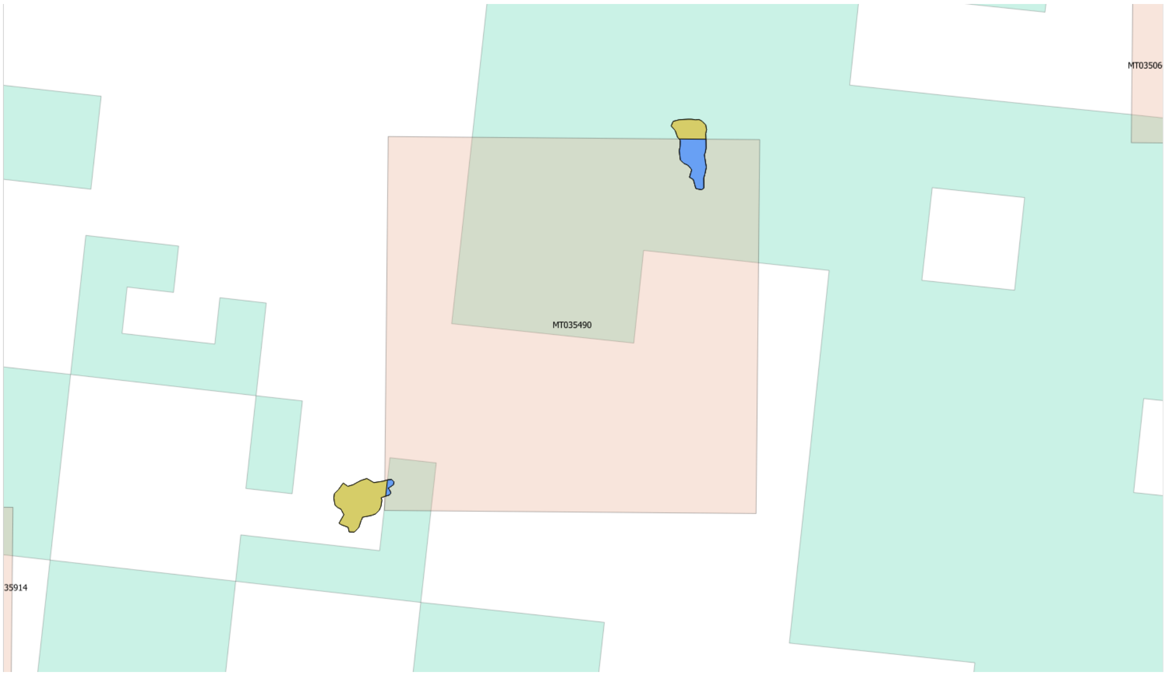


Figure 1.3. Example of features overlapping BLM managed lands (green). The sampled cell (beige) had two digitized features. The centroid of the top feature was in the sampled cell while the centroid of the bottom left feature was in the neighboring cell. The acreage on BLM land and in the sampled cell (blue) was averaged over sampled cells. The top feature was counted as “associated with BLM managed land” because it overlaps BLM managed land and its centroid was in the sampled cell.

PART 1: RANGE-WIDE RESULTS

Range-Wide Estimates of Acreage and Abundance of Potential BTPD Colonies

As part of the training exercises to help observers develop a search image for colonies, and to allow development of models to adjust for probability of detection we required that teams of two observers independently digitize features detected on a sample of grid cells. Composition of the teams varied from state to state and more than one team worked simultaneously in a state. One of the team members was designated as primary observer (A) and the other as secondary observer (B). Each team member was the primary observer on approximately 50% of the team's survey units.

We used features detected by one observer as a "test" set and determined whether the second observer detected those features or not, fitting logistic regression models to the data. Representative graphs of these models for Kansas, South Dakota and Wyoming were contained in Figures 1.4, 1. 5 and 1.6 respectively. The estimated probability of detection by individual observers was 0.70 to 0.80 for small features and increased to 0.9 or more for features greater than 1,000 acres, with the exception of viewing 2012 NAIP images of Wyoming. In all states, the probability of detection of small features by at least one of two independent observers was estimated to be greater than 0.90. The probability of detection by at least one member of a team was greater than 0.95 for relatively large features.

The most difficult NAIP images that we worked with were the 2012 images for the State of Wyoming. Many of the Great Plains States, including Wyoming, experienced a severe drought during spring 2012. Unfortunately, the 2012 images for Wyoming indicated the presence of very little green vegetation. Identification of BTPD colonies was much more difficult in Wyoming than in the other states where NAIP images were taken in 2013 or 2014. Detection of features on 2013 and 2014 images were more reliable due to vegetative vigor and height at the time the images were taken. While it was possible to identify potential prairie dog colonies in Wyoming with 2012 imagery, the probability of detection varied among observers and the probability of detection of large colonies was estimated to be less than 1.00 for some observers (Figure 1.6). For example, observer A was estimated to have probability of detection of about 0.70 for all size features when viewing the 2012 NAIP images of Wyoming. When only observer A searched a grid cell and detected a feature, the inflation factor was about (1/0.70) = 1.43, i.e. for every feature detected by observer A, another 0.43 feature was estimated to have been missed to adjust for false negatives. Also seen in Figure 1.6, observer B's estimated probability of detection in Wyoming was higher, ranging from about 0.90 to 0.95, but exhibited high variation and a negative slope with increasing size. Despite the difficulties experienced with the Wyoming imagery, the probability of detection by at least 1 observer was quite high across the range of colony sizes.

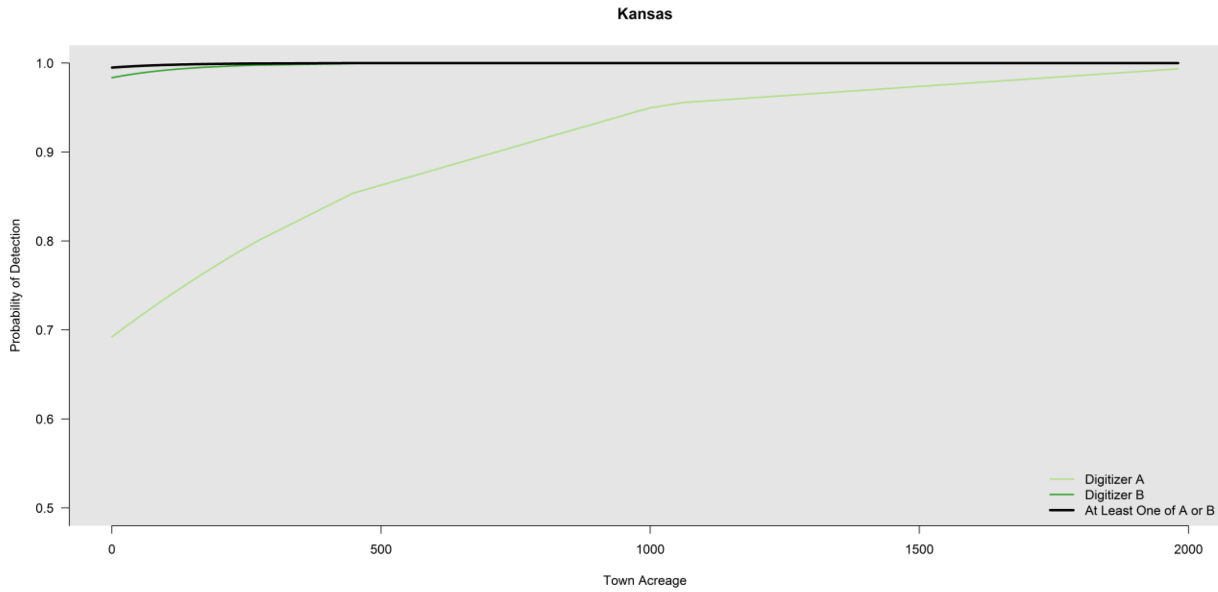


Figure 1.4. Estimated average probability of detection of potential BTPD colonies as a function of size by two observers labeled A and B when searching 2014 NAIP images of Kansas. The black curve was the estimated average probability of detection by at least one of the two observers on grid cells independently searched by observers A and B.

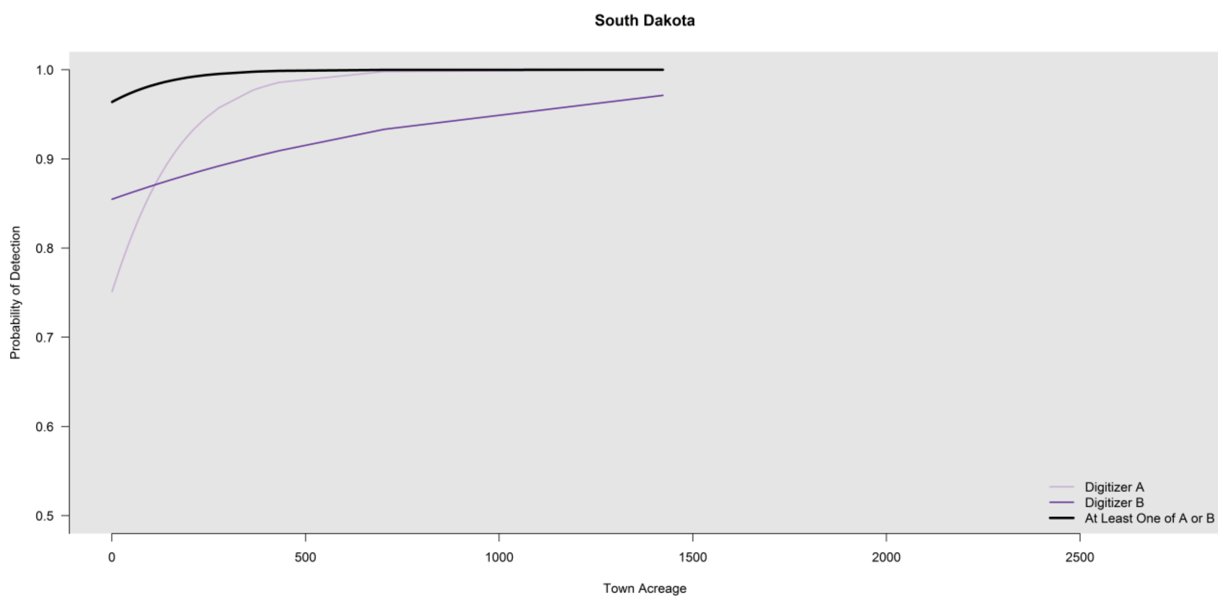


Figure 1.5. Estimated average probability of detection of potential BTPD colonies as a function of size by two observers labeled A and B when searching 2014 NAIP images of South Dakota. The black curve was the estimated average probability of detection by at least one of the two observers on grid cells independently searched by observers A and B.

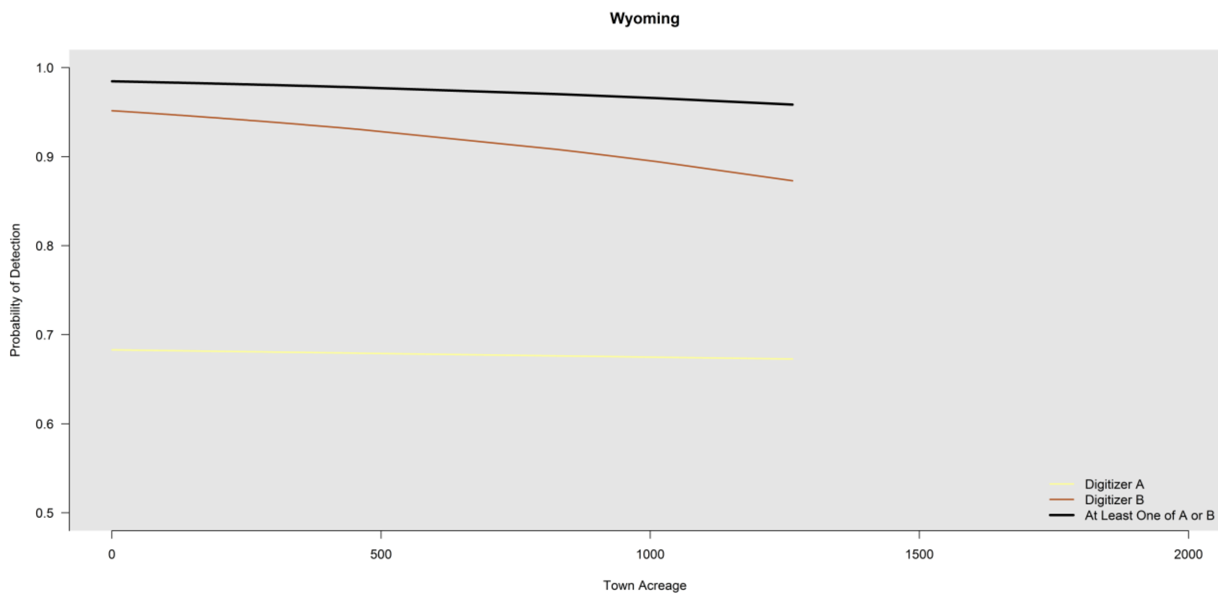


Figure 1.6. Estimated average probability of detection of potential BTPD colonies as a function of size by two observers labeled A and B when searching 2012 NAIP images of Wyoming. The black curve was the estimated average probability of detection by at least one of the two observers on grid cells independently searched by observers A and B.

Estimated Total Acreage of Features in Each State and for BLM Managed Lands

We digitized all features detected on a sample survey of grid cells in 10 states and for BLM managed lands. We digitized all features detected on all grid cells in Wyoming. We also recorded results for the first 1,722 grid cells digitized in the BAS randomized list of 8,790 cells from Wyoming to mimic a probabilistic sample.

We estimated the total acreage of features by the clipping method. The clipping and centroid methods gave unbiased estimates of total acreage of features, however we reported only estimates for acreage of digitized features by the clipping method. The clipping method was simpler to understand, simpler to compute, and there was a 13.5% mean increase in the coefficient of variation (CV) of the centroid method relative to the clipping method.

<u>Eleven states</u>

We estimated the total acreage of all potential BTPD colonies in each state using our digitizing methods and correcting for false negatives (features missed during digitizing) using the double observer methods (Table 1.2). These estimates likely contain an unknown proportion of false positives, i.e., digitized features which were neither active nor inactive BTPD colonies.

Using these methods, total acreage of potential BTPD colonies in these 11 states corrected for false negatives was estimated to 1,932,792 acres uncorrected for false positives (90% Confidence Interval (CI) [1,810,089 to 2,130,030], Coefficient of Variation (CV) 4.9%). Colorado had the largest estimate of total acreage with 532,251 acres while North Dakota had the smallest estimate at 15,561 acres. Coefficients of variation ranged from 8.3% in Montana to 33.1% in North Dakota.

Arizona

Observers detected and digitized only 2 potential BTPD colonies in the sample of 524 cells in Arizona. Based on a close examination using Google Earth, one of the two features digitized was very small (0.05 acre) and was judged to not be a potential BTPD colony. For Arizona, we reported the acreage of three "known" BTPD colonies (17.4 acres, Holly Hicks, Arizona Department of Game and Fish) plus the one feature (16.1 acre) judged to be a potential BTPD colony for a total of 34 acres. It was not meaningful to report confidence intervals, standard errors and coefficients of variation for estimates in Arizona.

Wyoming

The estimated acreage for Wyoming was 288,606 acres (CV = 12.9%; Table 1.2) based on a probabilistic random sample of 1,722 digitized cells and not corrected for false positives. These estimates were reported to be comparable to values reported in the other states and to be comparable to future sample survey monitoring results for trend, should a census of cells not be digitized. Census values for Wyoming, corrected for false positives using aerial survey "truthing," were reported in Part 2 of this report.

Table 1.2. Estimated acreage of potential black-tailed prairie dog colonies in 11 states corrected for false negatives. Standard errors, coefficients of variation (CV), and bounds of 90% confidence intervals were reported.

		90% Confidence Interval			
State	Estimated Acreage	Lower Bound	Upper Bound	Standard Error	CV
Arizona	34	-	-	-	-
Colorado	532,251	454,519	621,546	50,511	0.095
Kansas	154,775	102,084	262,123	45,984	0.297
Montana	184,055	166,219	210,408	15,203	0.083
Nebraska	89,208	77,181	107,481	9,501	0.107
New Mexico	124,098	103,228	155,709	16,778	0.135
North Dakota	15,561	9,578	27,760	5,151	0.331
Oklahoma	81,224	63,015	107,187	13,199	0.163
South Dakota	224,145	187,303	270,383	25,059	0.112
Texas	238,871	193,281	304,826	34,015	0.142
Wyoming	288,606*	236,700	361,896	37,201	0.129
Range-wide Total	1,932,826	1,810,089	2,130,030	94,707	0.049

*Estimated acreage in Wyoming was based on the sample of digitized cells and not corrected for false positives (see Part 2, Wyoming).

BLM managed lands

We estimated 77,723 acres of features to be associated with BLM managed lands in the sense that features partly or wholly intersected BLM managed lands and 31,209 acres of features on BLM managed lands (Table 1.3). Coefficients of variation were 18.3% and 18.4%, respectively.

Table 1.3. Estimated acres of potential black-tailed prairie dog colonies associated with BLM managed land and on BLM managed lands corrected for false negatives. Upper and lower bounds were reported for 90% confidence intervals. The standard error of the estimate and its coefficient of variation (CV) were reported.

				90% Confidence Interval			
Area of Inference	Sample size	No. cells in sampling frame	Estimated acreage	Lower Bound	Upper Bound	Standard Error	CV
Associated with BLM lands[1]	2,422	21,790	77,723	60,374	108,572	14223	0.183
On BLM lands[2]	2,422	21,790	31,209	23,933	43,221	5,743	0.184

[1]Centroid method, [2]Clipping method

Estimated Number of Features

Eleven states

Estimation of the number of features present in a state or associated with BLM land was by two methods. The centroid method essentially counted the number of features with centroids located in a sampled cell, adjusted the count to account for probability of detection (i.e., for false negatives), computed the adjusted number for each sampled cell, computed the mean per cell and applied the mean to every cell in a state (Table 1.4). The method used straight forward standard statistics adjusted for false negatives and was an unbiased estimator of the total number of features. We estimated the number of potential BTPD colonies corrected for false negatives in the 11 states (Table 1.4). We estimated a total of 29,467 potential BTPD colonies in the entire sampling frame (90% CI = [28,757; 30,962], CV = 2.4%). Colorado and South Dakota had the largest estimated numbers of features at 5,793 and 5,204, respectively.

Arizona

We report 3 “known” BTPD colonies in Arizona plus one potential colony for a total of 4 features.

Wyoming

We estimated 3,158 features in Wyoming based on a random probabilistic sample of 1,722 grid cells from the total 8,790 cells to mimic results of a probabilistic sample (Table 1.4). These estimates were reported to be comparable to values reported in the other states and to be comparable to future sample survey monitoring results for trend should a census of cells not be digitized. Census values for Wyoming, corrected for false positives using aerial survey "truthing," were reported in Part 2 of this report.

Table 1.4. Estimated number of potential black-tailed prairie dog colonies in 11 states corrected for false negatives. Standard errors, coefficients of variation, and bounds of 90% confidence intervals were reported.

State		90% Confidence Interval			
State	Estimated number of features	Lower Bound	Upper Bound	Standard Error	CV
Arizona	4	-	-	-	-
Colorado	5,793	5,248	6,361	339	0.059
Kansas	2,553	2,141	3,023	268	0.105
Montana	4,006	3,877	4,188	201	0.050
Nebraska	2,317	2,222	2,456	137	0.059
New Mexico	1,964	1,856	2,123	166	0.084
North Dakota	299	219	394	53	0.177
Oklahoma	1,816	1,542	2,115	174	0.096
South Dakota	5,204	4,693	5,763	326	0.063
Texas	2,353	2,256	2,496	146	0.062
Wyoming	3,158	2,872	3,460	179	0.057
Range-wide Total	29,467	28,757	30,962	707	0.024

BLM managed lands

We estimated the number of BTPD colonies associated with BLM managed lands and corrected for false negatives to be 800 features (90% CI = [748; 882], CV = 8.2%.

Table 1.5. Estimated number of potential black-tailed prairie dog colonies associated with BLM managed land corrected for false negatives. Standard error (SE), coefficient of variation (CV), and bounds of 90% confidence interval were reported.

	90% Confidence Interval			
Estimated number features	Lower Bound	Upper Bound	SE	CV
800	748	882	66	0.082

Estimated abundances of potential BTPD colonies greater than 100 acres and 500 acres

We attempted to estimate the abundance of features greater than 1,000 acres and greater than 5,000 acres in size using the transect method (Appendix B). Unfortunately, there remains unresolved controversy in the formula for probability of detection of features based on intersections of the perimeter of the feature with the "transects" (sides of our grid cells). We obtained improbable estimates of probability of detection, i.e. values greater than 1.0 = 100% using the formulas in Appendix B.

The centroid method provided an unbiased estimated of the total number of features (Table 1.4). However, the method did not work well for estimation of the number of features greater than 1,000 acres and greater than 5,000 acres in the individual states, because such features with centroids in the sampled cells were extremely rare or not present. For example, we detected and digitized 4 features greater than 5,000 acres; however, none of the centroids of the four were in sampled cells.

After reviewing these results, we changed our objectives and estimated the number of potential BTPD colonies greater than 100 acres in size and the number greater than 500 acres in size. We believe these estimates were reliable and will be repeatable should a similar design and analysis be conducted in the future. We estimated 4,234 potential BTPD colonies greater than 100 acres and 419 potential BTPD colonies greater than 500 acres in the 11 state study area (Tables 1.6 and 1.7).

Table 1.6. Estimated number of potential black-tailed prairie dog colonies greater than 100 acres in 11 states corrected for false negatives. Standard errors, coefficients of variation, and bounds of 90% confidence intervals were reported.

		90% Confidence Interval			
State	Estimated number greater than 100 acres	Lower Bound	Upper Bound	Standard Error	CV
Arizona	0	NA[1]	NA[1]	NA[1]	NA[1]
Colorado	1,372	1,181	1,578	121	0.088
Kansas	198	111	297	53	0.270
Montana	372	335	434	44	0.118
Nebraska	188	151	250	40	0.215
New Mexico	334	297	409	47	0.141
North Dakota	30	15	59	12	0.409
Oklahoma	218	141	305	49	0.227
South Dakota	458	352	577	68	0.149
Texas	446	409	508	48	0.109
Wyoming	620	518	728	64	0.103
Range-wide Total	4,234	4,023	4,649	195	0.046

[1]NA = Not Applicable; Denotes confidence bounds, standard errors and coefficients of variation were not possible to compute.

Table 1.7. Estimated number of potential black-tailed prairie dog colonies greater than 500 acres in 11 states corrected for false negatives. Standard errors, coefficients of variation, and bounds of 90% confidence intervals were reported.

		90% Confidence Interval			
State	Estimated number greater than 500 acres	Lower Bound	Upper Bound	Standard Error	CV
Arizona	0	NA[2]	NA[2]	NA[2]	NA[2]
Colorado	190	127	269	43	0.23
Kansas	25	12	74	17	0.70
Montana[1]	7	NA[2]	NA[2]	NA[2]	NA[2]
Nebraska	12	12	50	12	0.99
New Mexico	25	25	74	15	0.61
North Dakota	5	5	20	5	1.00
Oklahoma[1]	3	NA[2]	NA[2]	NA[2]	NA[2]
South Dakota	20	10	59	14	0.71
Texas	87	62	124	24	0.28
Wyoming	56	31	87	17	0.31
Range-wide Total	419	349	544	62	0.15

[1]No features greater than 500 acres existed with centroids in sampled cells. The estimated number was a conservative underestimate of the number present.

[2]NA = Not Applicable; Denotes confidence bounds, standard errors and coefficients of variation were not possible to compute.

PART 2: INDIVIDUAL STATE AND BLM RESULTS

State study areas and sampling frames

We created a contiguous 2-mile square grid feature class over all 11 Western U.S. states in our study area, using the projection USA_Contiguous_Albers_Equal_Area_Conic_USGS_version. Each grid cell was given a unique identifier (grid ID) that included the name of one and only one state; grid cells that overlapped multiple states were assigned to the state that had the greatest amount of area within the cell. State-by-state sample frames were then created by subsetting the grid by state and making further modifications as described below.

We searched a sample of grid cells in each state and digitized features on the latest available NAIP images judged to be potential BTPD colonies. Shapefiles of the digitized features in each state will be made available to WAFWA, representatives of the wildlife agencies in each state, and the Bureau of Land Management. In addition, high resolution county maps showing the sample of cells searched and features digitized will be distributed. Example low resolution county maps were given below for each of the states and BLM managed lands below. Figures of digitized features were included on the state and county maps to establish the general distribution of potential BTPD colonies. However; clearly, colonies that we missed were not included in the county maps. Also, we did not know which of the individual polygons in the county maps were active or inactive BTPD colonies; that is, some of the individual polygons on the county maps were false positives.

Estimated acreages and numbers of features were given for each state and for BLM lands. Estimated total acreages and numbers of potential BTPD colonies were adjusted for false negatives.

ARIZONA

We started with the shapefile of potential BTPD habitat in Arizona (Holly Hicks, Arizona Game and Fish Department, personal communication, Feb. 18, 2015) to develop a sampling frame consisting of grid cells that met the following criteria (Figure 2.1):

1) the cell contained any portion of area within the 6 county area of interest (Cochise, Graham, Greenlee, Pima, Pinal, and Santa Cruz),
2) the cell had <50% of the land area within the grid cell overlapping US Forest Service designated land,
3) the cell had >25% of the land area within the grid cell designated as “Black-Tailed Prairie Dog Habitat” according to the model layer provided by the Arizona Game and Fish Department, and
4) an exception to criterion 3 above was applied to Cochise, Graham, and Greenlee counties from the eastern edge of the modeled BTPD habitat east to the New Mexico border.

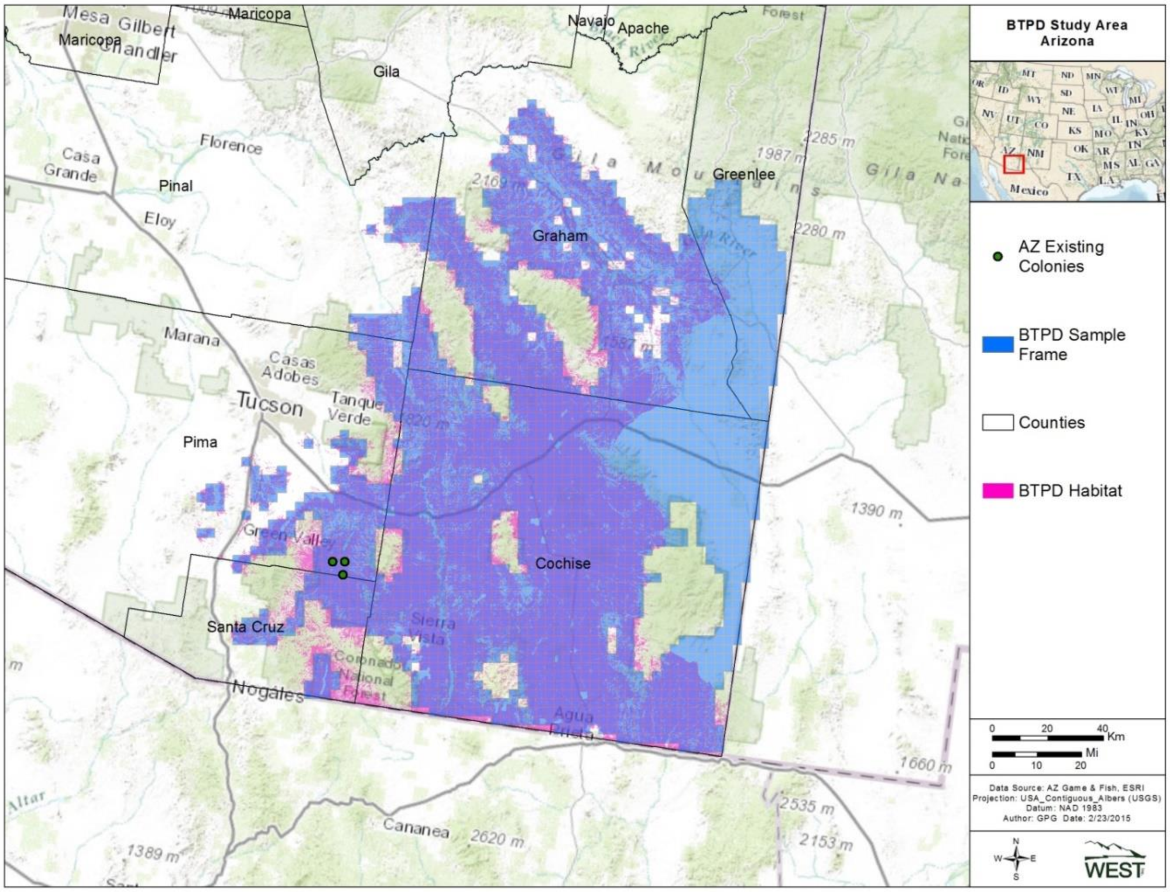


Figure 2.1. Sampling frame of 2,361 grid cells each 2 mi by 2 mi in Arizona for black-tailed prairie dog sample survey, 2015.

We detected and digitized two features on our sample of 477 units (Figure 2.2 and 2.3). After checking on Google earth it appeared the feature detected in Cochise County was unlikely to be a BTPD colony. Figure 2.4 from Google Earth at very high resolution indicates a possible BTPD colony.

There were 3 small "known" BTPD colonies in Pima County, Arizona (Figure 2.5). Two of these colonies were in grid cells searched by our observers on 2013 NAIP images. Neither of the colonies were detected by our observers. Total acreage of 3 known BTPD colonies and the potential colony was 34 acres.

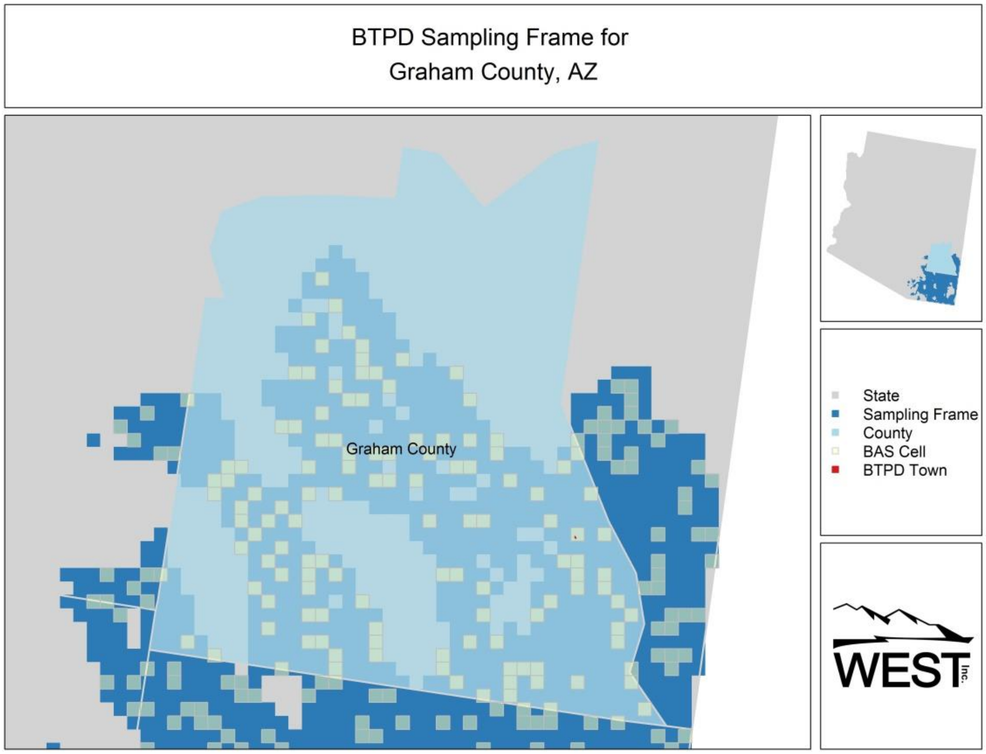


Figure 2.2. Sampling frame and selected grid cells in Graham County with one digitized potential black-tailed prairie dog colony.

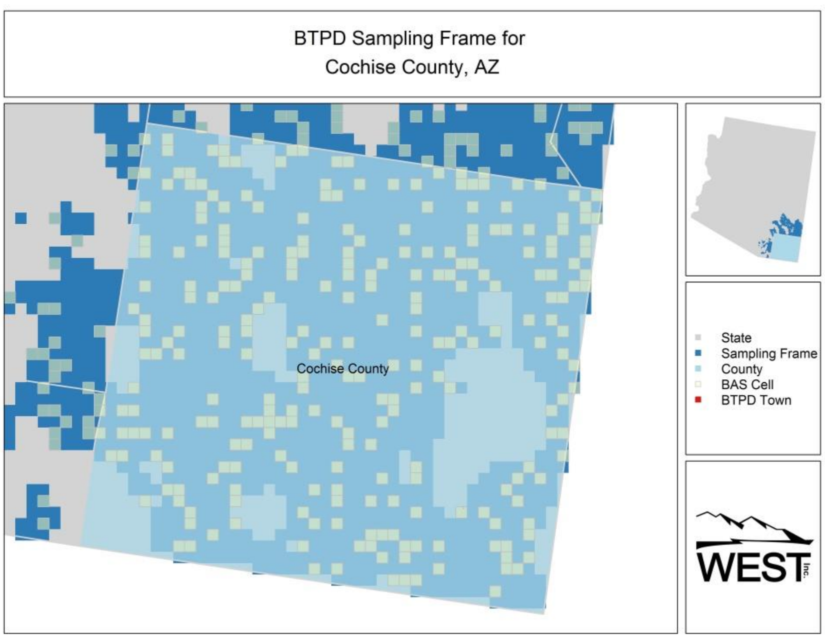


Figure 2.3. Sampling frame and selected grid cells in Cochise County with one very small digitized feature judged to not be a potential black-tailed prairie dog colony.

Figure 2.4. Digitized feature in Arizona. The digitized polygon was shown on this Google Earth screen shot. There appear to be burrow openings in the centers of mounds.

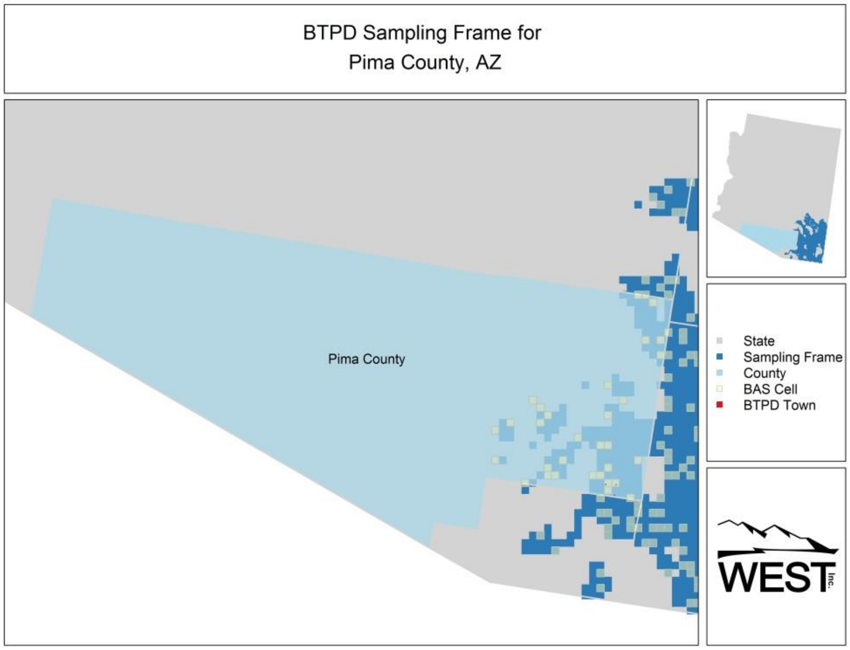


Figure 2.5. Pima County, AZ, with locations of 3 known black-tailed prairie dog colonies.

BUREAU OF LAND MANAGEMENT (BLM)

The sample frames created for the 11 states in the Range-wide BTPD survey were intersected with existing federal lands managed by the Bureau of Land Management, according to the Surface Management Agency GIS dataset compiled and maintained by BLM and updated Jan 1, 2015. Once intersected, we computed the portion of each overlapping grid cell in the sample frame that was managed by the BLM. All cells in which over 0.1% of the grid cell's area (1.28 acres) was BLM land were included in the BLM sample frame (Figure 2.6).

After adjusting for false negatives (missed features) we estimated 31,209 acres of features (90% CI = [23,933; 43,221] with CV = 18.4%) on BLM managed lands (Part 1, Table 1.3). We also estimated the acreage of features that were associated with BLM lands in the sense that the features overlapped totally or partly with BLM land. We estimated 77,723 acres of features (90% CI = [60,373; 108,572], CV = 18.3 %) to be associated with BLM managed lands consisting of an estimated 800 potential BTPD colonies (90% CI = [748; 882], CV = 8.2%) (Part 1, Table 1.5).

There were 21,790 grid cells in the sampling frame for BLM managed lands, of which we searched 2,422 cells. Coefficients of variation for estimated acreage of potential BTPD colonies on BLM land and acreage associated with BLM land were about 18%.

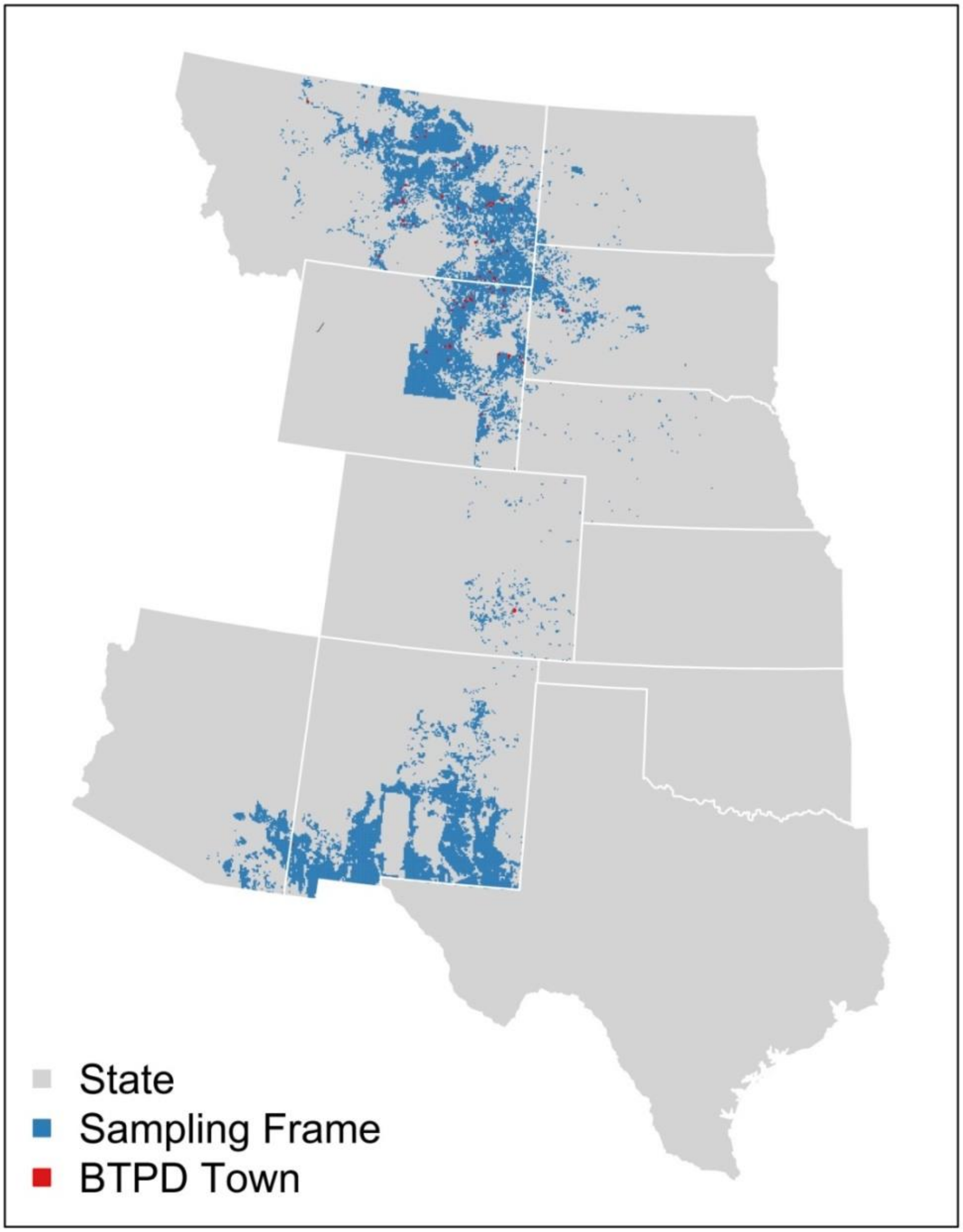


Figure 2.6. Sampling frame for BLM managed lands with 21,790 grid cells each 2 mi. by 2 mi and digitized potential black-tailed prairie dog colonies.

COLORADO

We started with the shapefile of the overall range for BTPD in Colorado (Tina Jackson, Colorado Parks and Wildlife, personal communication, February 4, 2015) to develop a sampling frame consisting of grid cells that contained any portion of the overall range (Figure 2.7). We digitized the perimeters of all features detected on 1,122 sampled grid cells selected from the universe of 11,101 cells in the sampling frame for Colorado (Figure 2.8). We estimated a total of 532,251 acres of potential BTPD colonies in Colorado (90% CI = [454,519; 621,546], CV = 9.5%) (Part1, Table 1.2) and that a total of 5,793 features exist in the state (90% CI = [5,248; 6,361], CV = 5.9%) (Part 1, Table 1.4). We estimated 1,372 features greater than 100 acres (90% CI = [1,181; 1,578], CV = 8.9%) and 190 greater than 500 acres in Colorado (90% CI = [127; 269], CV = 23%) (Part 1, Tables 1.6 and 1.7).

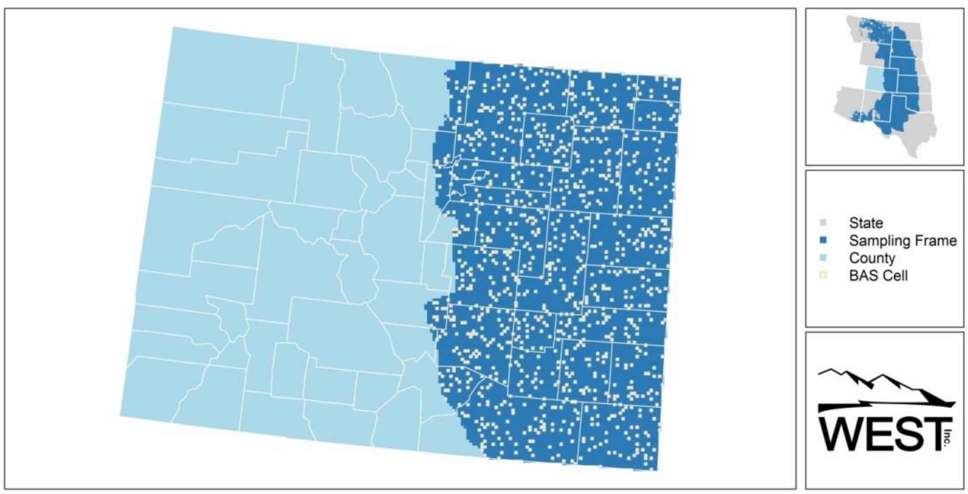


Figure 2.7. Sampling frame for Colorado with 11,101 grid cells each 2 mi. by 2 mi. The 1,122 grid cells selected by the Balanced Acceptance Sampling (BAS) probabilistic sampling procedure were shown.

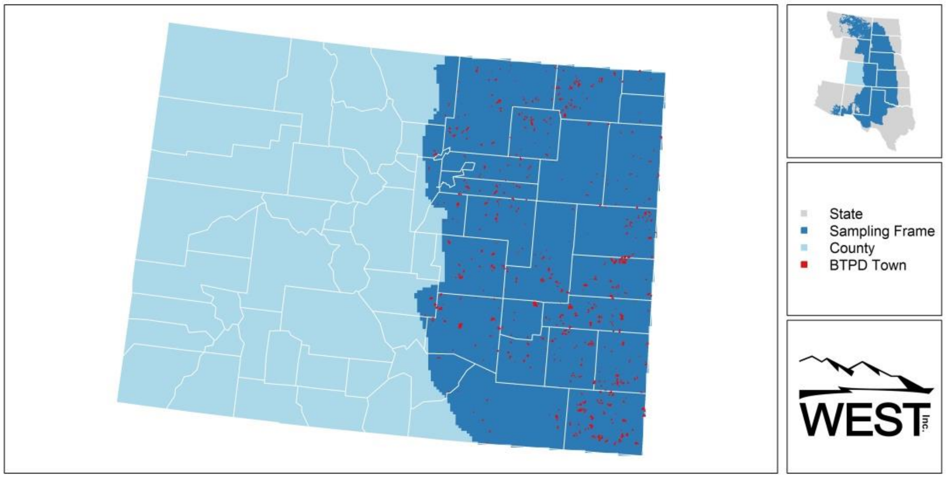


Figure 2.8. Map of features digitized in a sample survey of grid cells in Colorado.

We plotted the estimates of total number of features and acreage of features as a function of the sample size (Figures 2.9 and 2.10). The estimated total acreage and number of features begins to converge to final estimates (horozontal line) at a sample size of about 1,000 (Figure 2.10). Increasing the sample size to 1,100 grid cells did not change the estimated total number of features appreciably. The effect of detecting rare relatively large features on estimated total acreage of features was evident in Figure 2.9. As the sample size was increased and a rare large feature detected, relatively large jumps occurred in the estimated total acreage.

The estimated total acreage and number of colonies began to converge to final estimates at a sample size of about 1,000 grid cells yielding coefficients of variation of 9.5% for total acreage and 5.9 for total number of potential BTPD colonies with a sample of 1,122 cells.

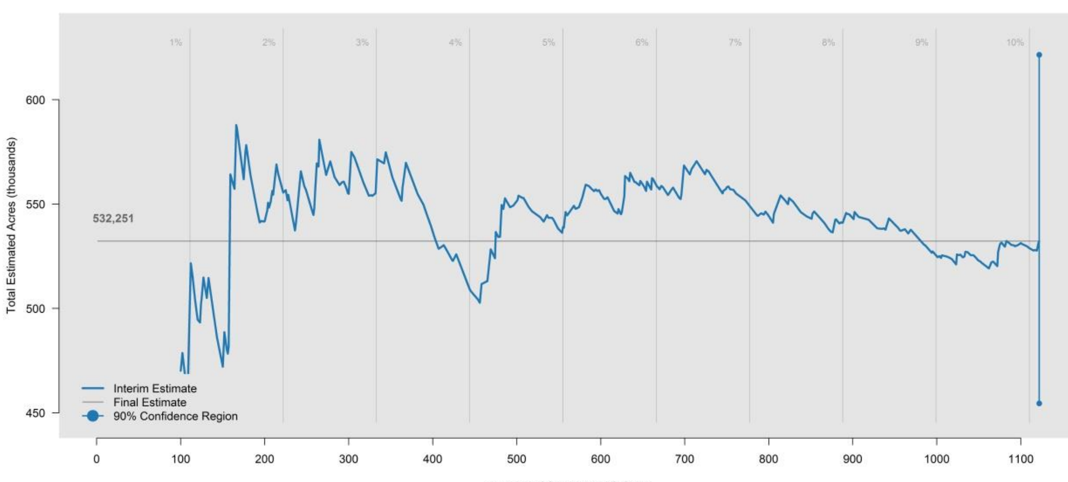


Figure 2.9. Estimated acreage of potential black-tailed prairie dog colonies in Colorado as a function of the sample size.

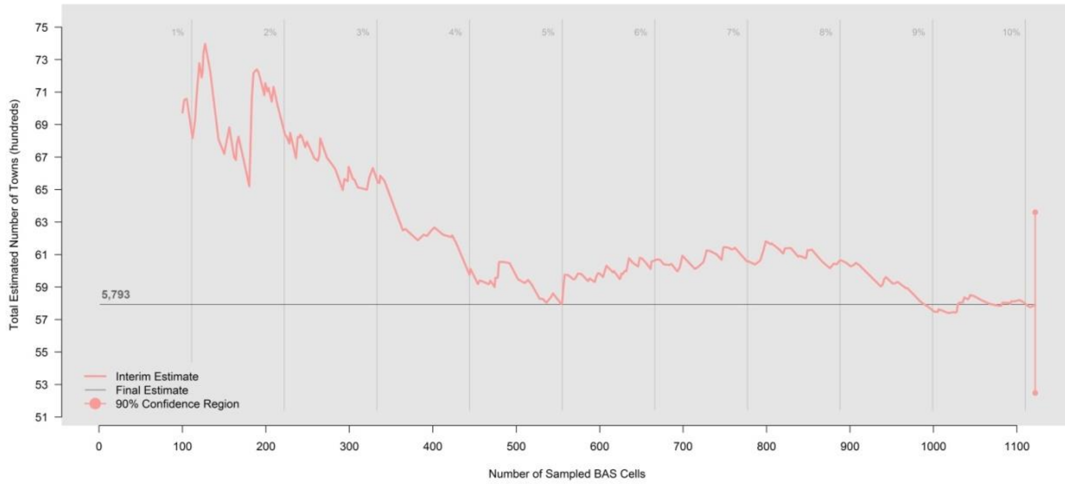


Figure 2.10. Estimated number of potential black-tailed prairie dog colonies in Colorado as a function of the sample size.

GIS shapefiles and electronic maps will be made available to the State of Colorado with the digitized features in the state and in each county. For example, figure 2.11 depicts the location of features detected and digitized in Pueblo County, CO. These maps were created with sufficient resolution to be viewed in detail on a computer monitor.

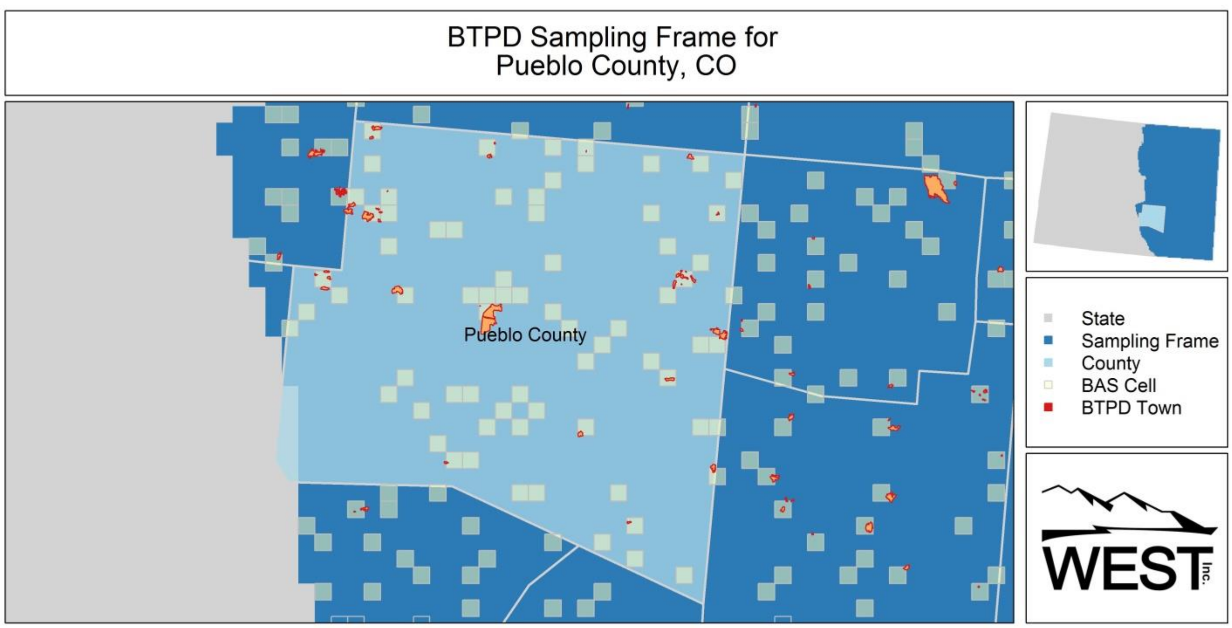


Figure 2.11. Digitized features on a sample survey of grid cells in Pueblo County, Colorado.

KANSAS

We used the shapefile of potential BTPD habitat provided by the Kansas Department of Wildlife and Parks (Matt Peek, personal communication, January 13, 2015) to develop a sampling frame consisting of grid cells that contained any portion of the overall range (Figure 2.12. We digitized the perimeters of all features detected on 1,034 sampled grid cells selected from the universe of 12,785 cells in the sampling frame for Kansas (Figure 2.13). We estimated a total of 154,775 acres of potential BTPD colonies in Kansas (90% CI = [102,084; 262,123], CV = 29.7%) (Part1, Table 1.2). We estimated that a total of 2,553 features exist in the state (90% CI = [2,141; 3,023], CV = 10.5%) (Part 1, Table 1.4). We estimated 198 features greater than 100 acres (90% CI = [111; 297], CV = 27%) and 25 greater than 500 acres in Kansas (90% CI = [12; 74], CV = 70%) (Part 1, Tables 1.6 and 1.7).

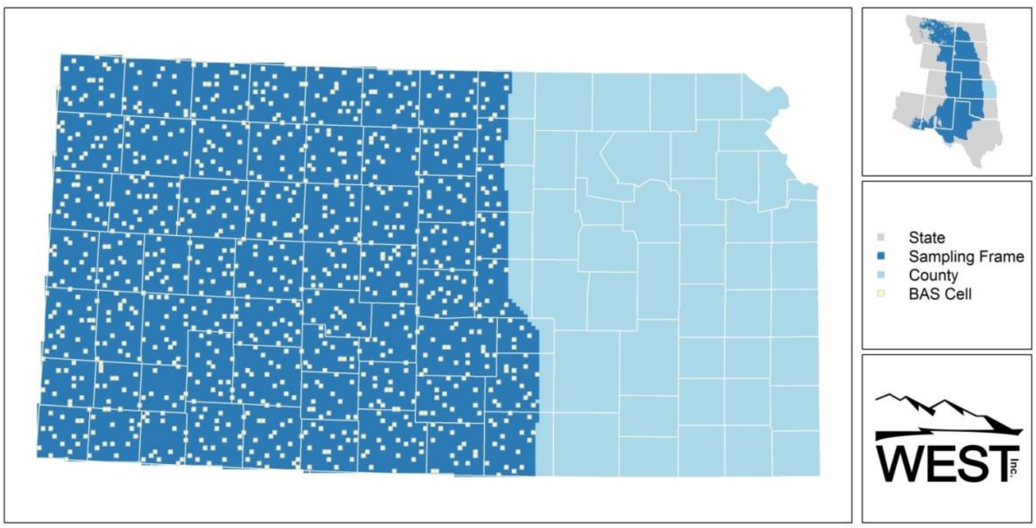


Figure 2.12. Sampling frame for Kansas with 12,785 grid cells each 2 mi. by 2 mi. The 1,034 grid cells selected by the Balanced Acceptance Sampling (BAS) probabilistic sampling procedure were shown.

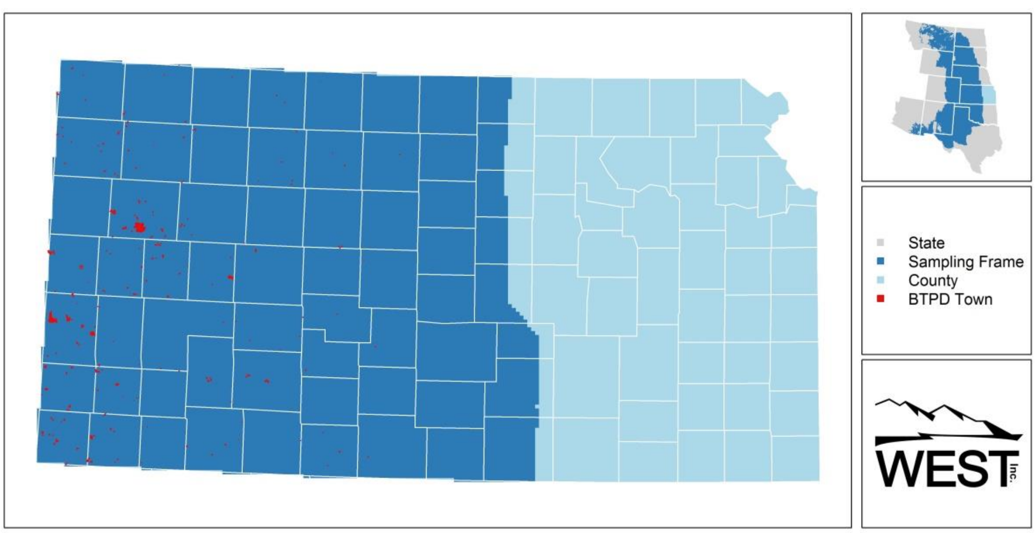


Figure 2.13. Map of features digitized in a sample survey of grid cells in Kansas.

We plotted the estimates of total acreage of features and the total number of features as functions of the BAS sample size (Figures 2.14 and 2.15). The estimated number of features began to converge to final estimates at a sample size of about 800 (Figure 2.15). Increasing the sample size to 1,100 grid cells did not change the estimated total number of features appreciably. The effect of detecting relatively large, but rare, features on estimated total acreage of features was evident in Figure 2.14. As the sample size was increased and rare large features detected, relatively large jumps occurred in the estimated total acreage.

The estimated total acreage was more variable (CV = 29.7%) than the estimated number of colonies (CV = 10.5%), because many cells had no features and one very large feature was detected. However the averaged values began to converge to final estimates at a sample size of about 1,000 grid cells (Figures 2.14 and 2.15).

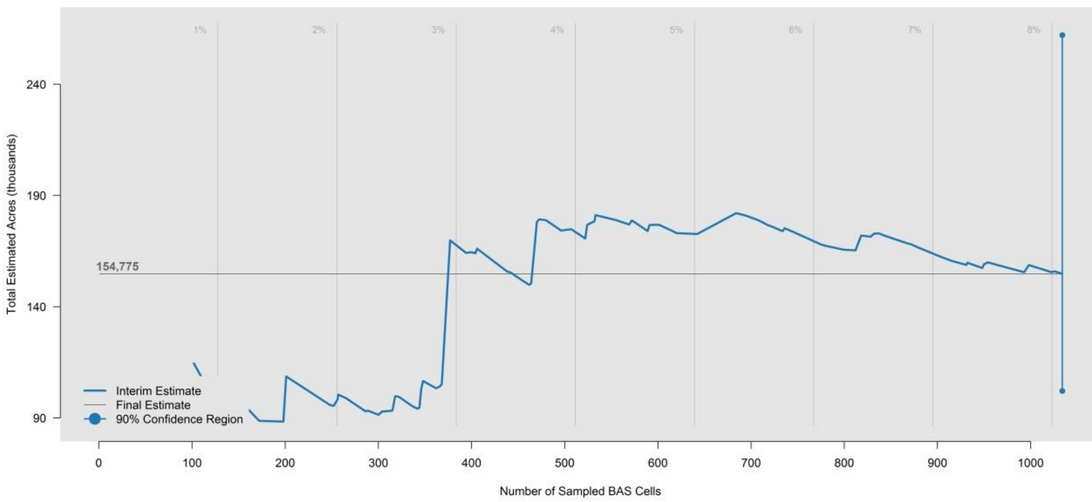


Figure 2.14. Estimated acreage of potential black-tailed prairie dog colonies in Kansas as a function of the size of the probabilistic sample of cells. One relatively large feature was detected at about the 390th cell, resulting in a relatively large increase in the estimated total acreage in Kansas.

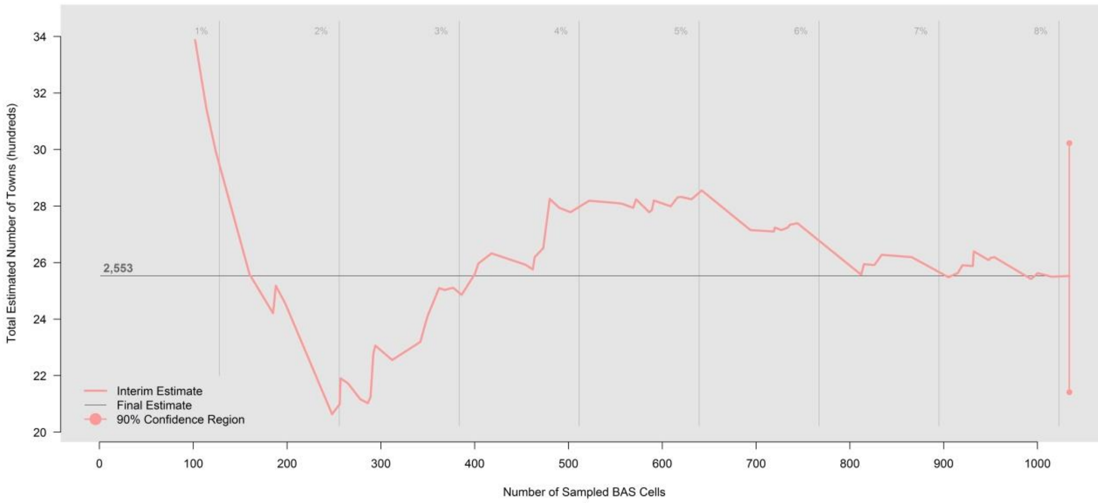


Figure 2.15. Estimated number of potential black-tailed prairie dog colonies in Kansas as a function of the sample size. The estimate begins to converge to final estimates at a sample size of about 800.

GIS shapefiles and electronic maps will be made available to the State of Kansas with the digitized features in the state and in each county. For example, figure 2.16, depicts the location of features detected and digitized in Logan County, KS. These maps were created with sufficient resolution to be viewed in detail on a computer monitor.

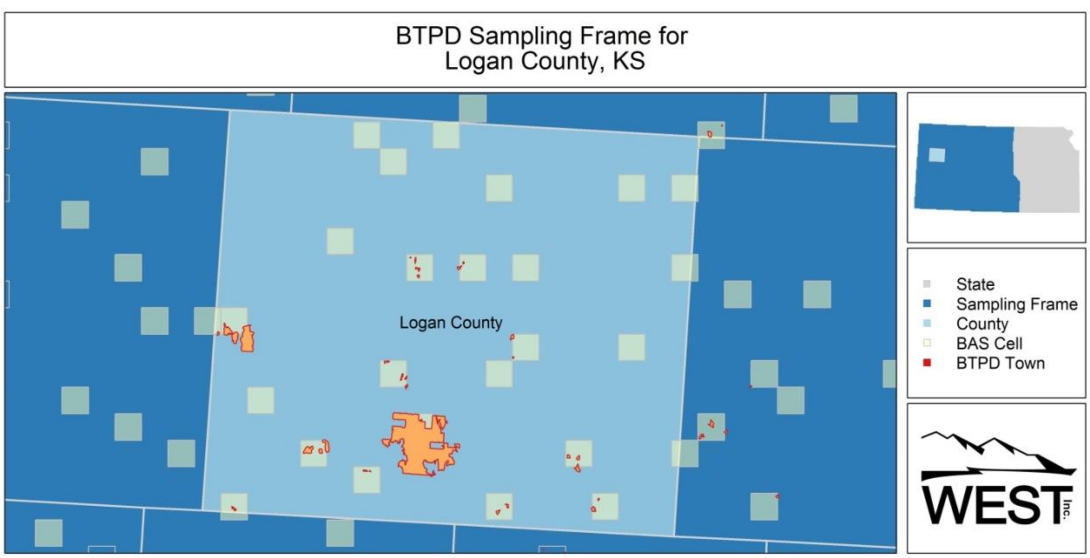


Figure 2.16. Digitized features on a sample survey of grid cells in Logan County, Kansas.

MONTANA

We used the shapefile of potential BTPD habitat provided by the Montana Natural Heritage Program (Dave Ratz, personal communication, February 19, 2015) to develop a sampling frame consisting of 16,302 grid cells that met the following criteria (Figure 2.17):

1) the cell contained any portion of area within the BTPD range according to the layer provided by the Montana National Heritage Program,
2) the cell had >50% of the land area within the grid cell designated as "Suitable Black-Tailed Prairie Dog Habitat" according to a predictive raster model provided by the Montana National Heritage Program (not shown), and
3) the cell had >50% of the land area within the grid cell situated at less than 5500 feet in elevation, using intersections with 1-arcsecond Digital Elevation Model layers from the National Elevation Dataset (USGS).

We digitized the perimeters of all features detected on 1,318 sampled grid cells selected from the universe of 16,302 cells in the sampling frame for Montana (Figure 2.18). We estimated a total of 184,055 acres of potential BTPD colonies in Montana (90% CI = [166,219; 210,408], CV = 8.3%) (Part1, Table 1.2). We estimated that a total of 4,006 features exist in the state (90% CI = [3,877; 4,188], CV = 5%) (Part 1, Table 1.4). We estimated 372 features greater than 100 acres (90% CI = [335; 434], CV = 11.8%) and 7 greater than 500 acres in Montana (Part 1, Tables 1.6 and 1.7).

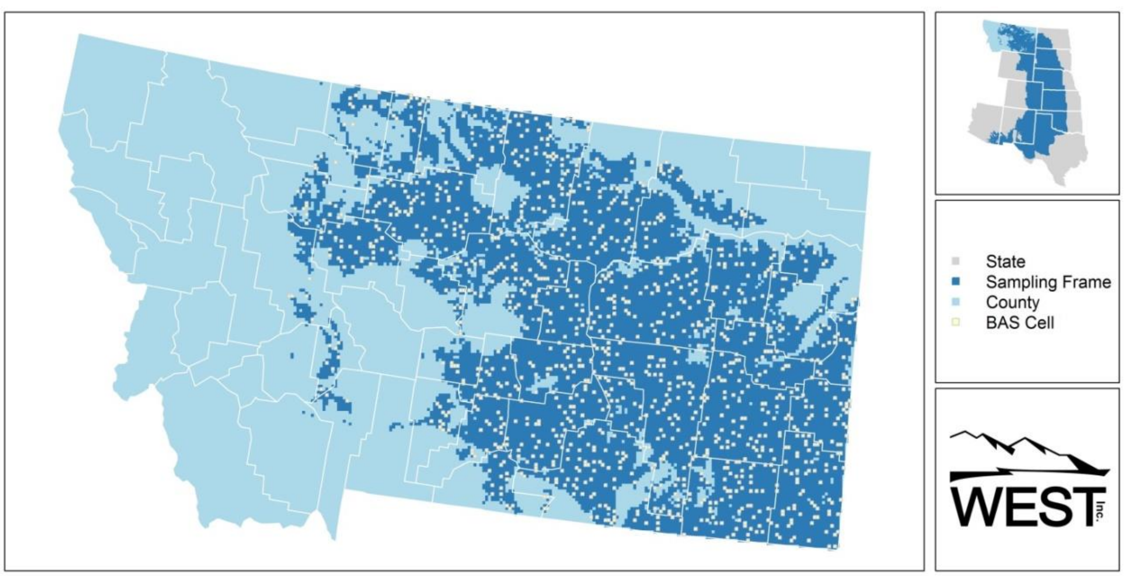


Figure 2.17. Sampling frame for Montana with 16,302 grid cells. The 1,318 grid cells selected by the Balanced Acceptance Sampling (BAS) probabilistic sampling procedure was shown.

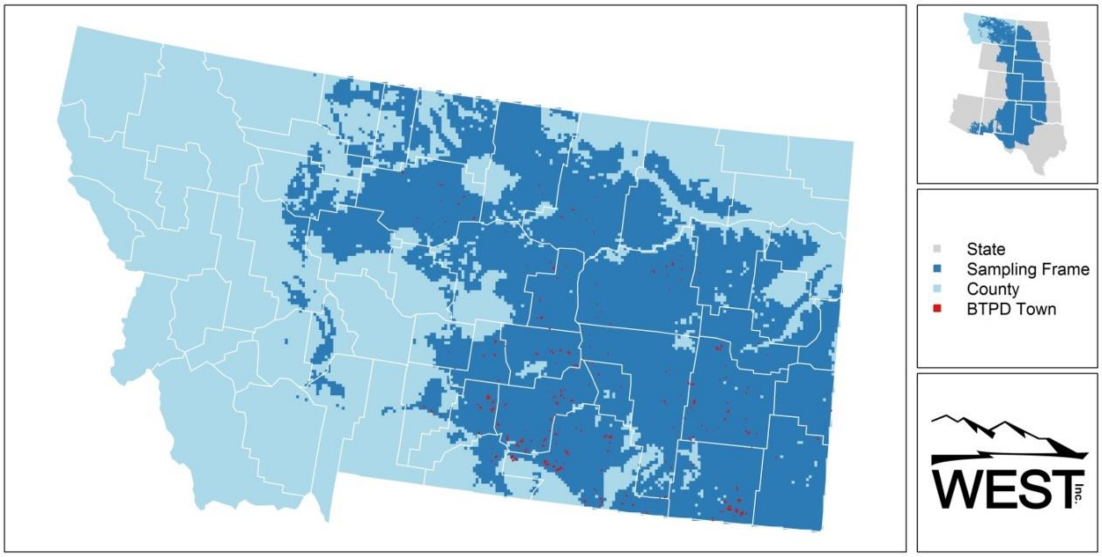


Figure 2.18. Map of features digitized in a sample survey of grid cells in Montana.

We plotted the estimates of total acreage of features and the total number of features as functions of the sample size (Figures 2.19 and 2.20). The estimated acreage and number of features began to converge to final estimates at a sample size of about 1,000 (Figure 2.19 and 2.20). Increasing the sample size to 1,318 grid cells yielded coefficients of variation less than 10%, values adequate for detecting important trends in long term monitoring projects. Estimates had adequate CVs of 8.3% and 5% for total acreage and number of features respectively at the sample size of 1,012.

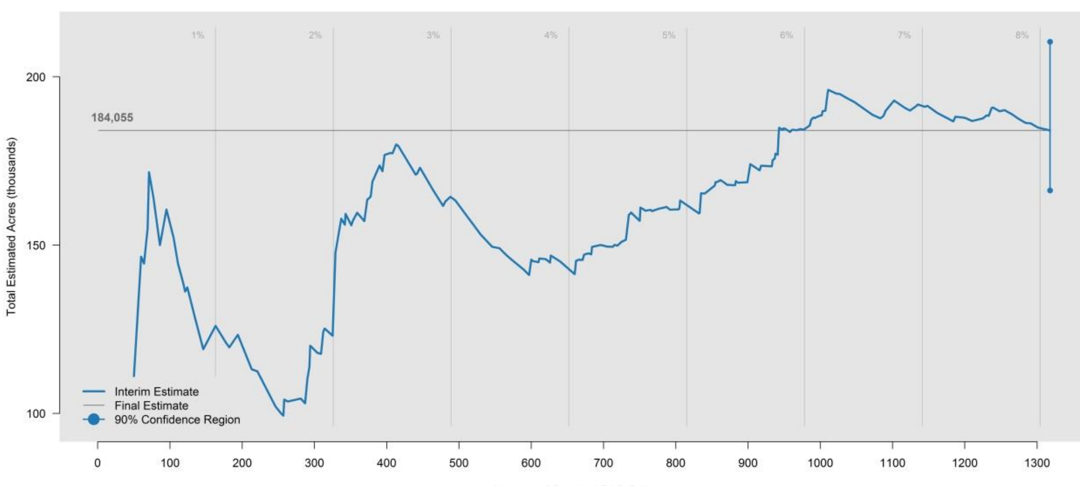


Figure 2.19. Estimated acreage of potential black-tailed prairie dog colonies in Montana as a function of the sample size. Sample size of approximately 1,000 was required for the estimate of total acreage to begin to converge to final estimates.

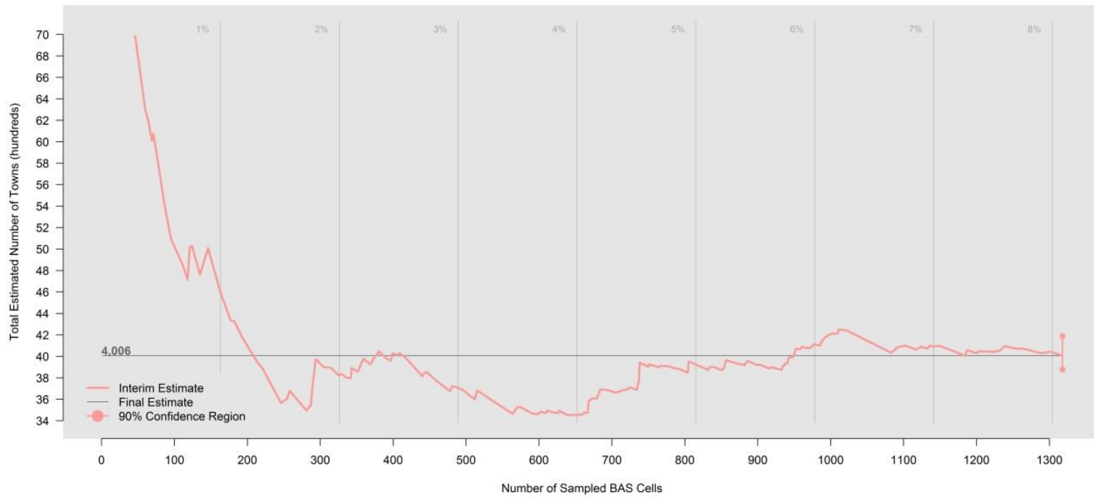


Figure 2.20. Estimated number of potential black-tailed prairie dog colonies in Montana as a function of the sample size.

GIS shapefiles and electronic maps will be made available to the State of Montana with the digitized features in the state and in each county. For example, figure 2.21 depicts the location of features detected and digitized in Powder River County, MT. These maps were created with sufficient resolution to be viewed in detail on a computer monitor.

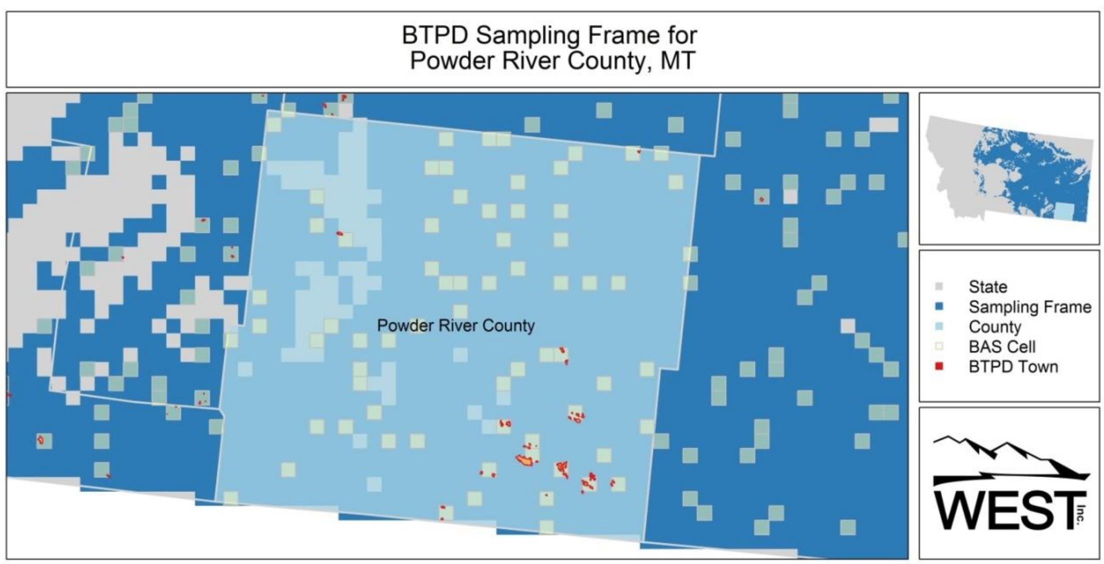


Figure 2.21. Digitized features on a sample survey of grid cells in Powder River County, Montana.

NEBRASKA

We used the shapefile of potential BTPD habitat provided by the Nebraska Game and Parks Division (Mike Fritz, personal communication, April 30, 2015) to develop a sampling frame consisting of grid cells that contained any portion of area within the 54 county area of interest (Adams, Arthur, Banner, Blaine, Box Butte, Boyd, Brown, Buffalo, Chase, Cherry, Cheyenne, Clay, Custer, Dawes, Dawson, Deuel, Dundy, Franklin, Frontier, Furnas, Garden, Garfield, Gosper, Grant, Greeley, Hall, Harlan, Hayes, Hitchcock, Holt, Hooker, Howard, Kearney, Keith, Keya Paha, Kimball, Lincoln, Logan, Loup, McPherson, Morrill, Nuckolls, Perkins, Phelps, Red Willow, Rock, Scotts Bluff, Sheridan, Sherman, Sioux, Thomas, Valley, Webster, Wheeler; Figure 2.22).

We digitized the perimeters of all features detected on 1,128 sampled grid cells selected from the universe of 13,960 cells in the sampling frame for Nebraska (Figure 2.23). We estimated a total of 89,208 acres of potential BTPD colonies in Nebraska (90% CI = [77,181; 107,481], CV = 10.7%) (Part1, Table 1.2). We estimated that a total of 2,317 features exist in the state (90% CI = [2,222; 2,456], CV = 5.9%) (Part 1, Table 1.4). We estimated 188 features greater than 100 acres (90% CI = [151; 250], CV = 21.5%) and 12 greater than 500 acres in Nebraska (90% CI = [12; 50], CV = 99%) (Part 1, Tables 1.6 and 1.7).

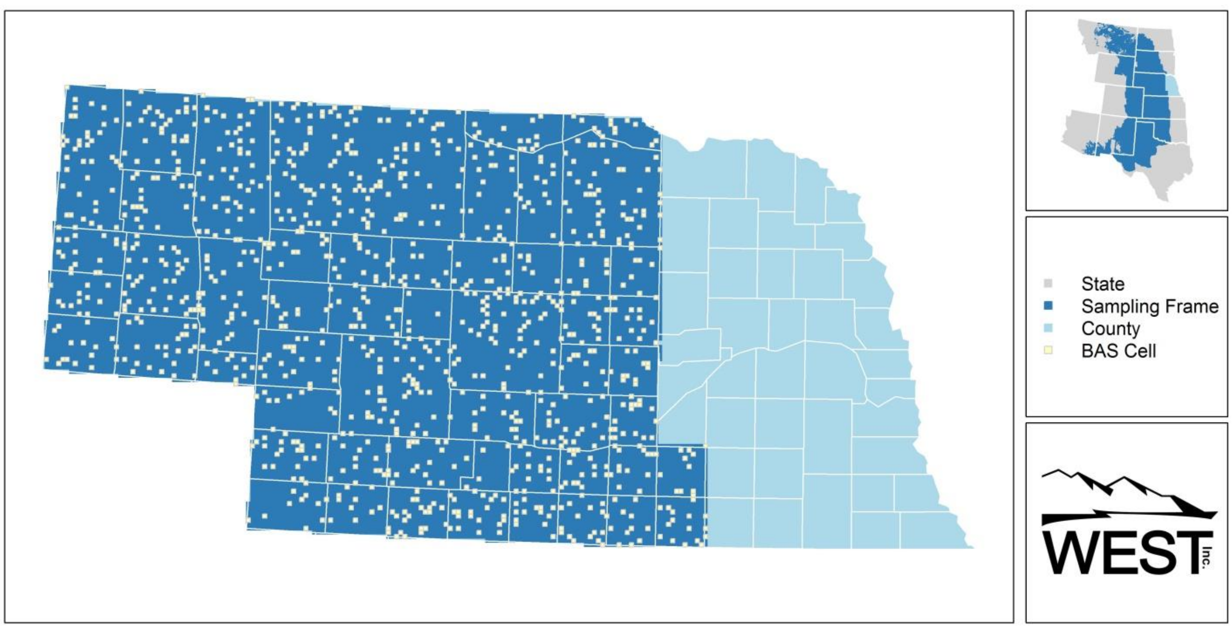


Figure 2.22. Sampling frame for Nebraska with 13,960 grid cells each 2 mi. by 2 mi. The 1,128 grid cells selected by the Balanced Acceptance Sampling (BAS) probabilistic sampling procedure were shown.

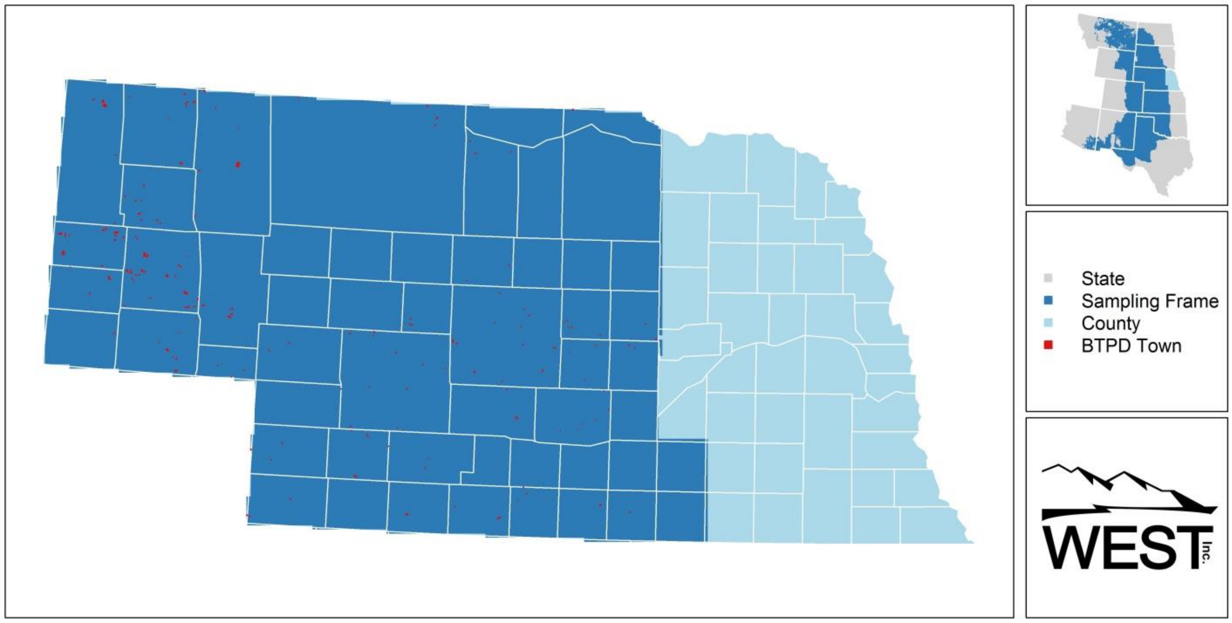


Figure 2.23. Map of features digitized in a sample survey of grid cells in Nebraska.

We plotted the estimates of total acreage of features and the total number of features as functions of the BAS sample size (Figures 2.24 and 2.25). The estimated number of features began to converge to final estimates at a sample size of about 800 (Figure 2.25). Increasing the sample size to 1,128 grid cells did not change the estimated total number of features appreciably. The effect of detecting relatively large, but rare, features on estimated total acreage of features was evident in figure 2.24. As the sample size was increased and rare large features detected, relatively large jumps occurred in the estimated total acreage. The estimated total acreage was more variable than the estimated total number of features; however it began converge to final estimates at a sample size of about 900 grid cells. Estimates had adequate CVs of 10.7% and 5.9% for total acreage and number of features respectively at the sample size of 1,128.

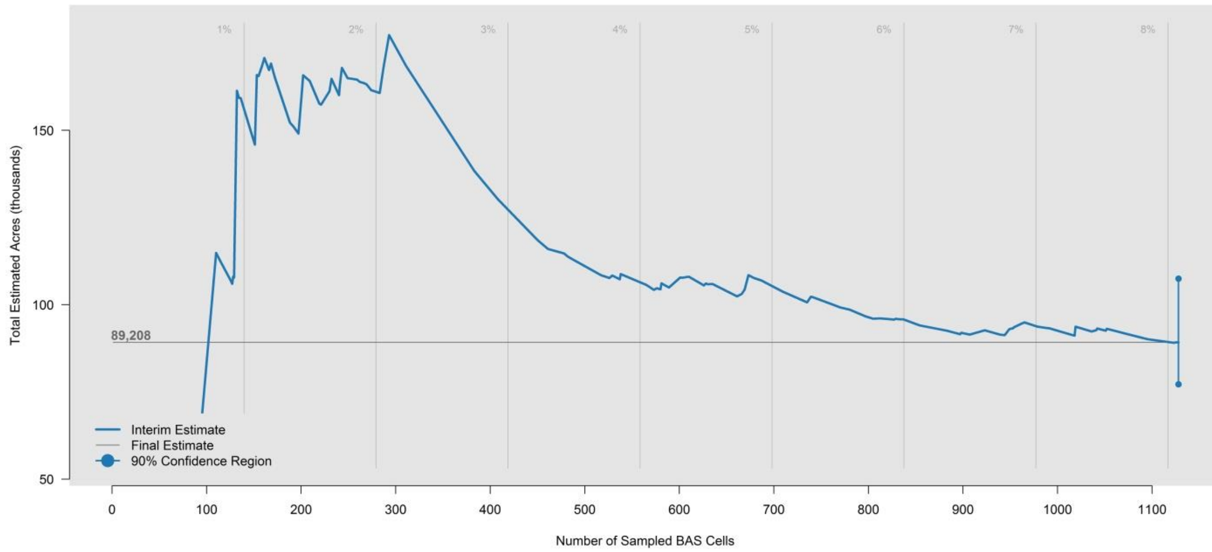


Figure 2.24. Estimated acreage of potential black-tailed prairie dog colonies in Nebraska as a function of the sample size. One or more relatively large features were detected early in the sample.

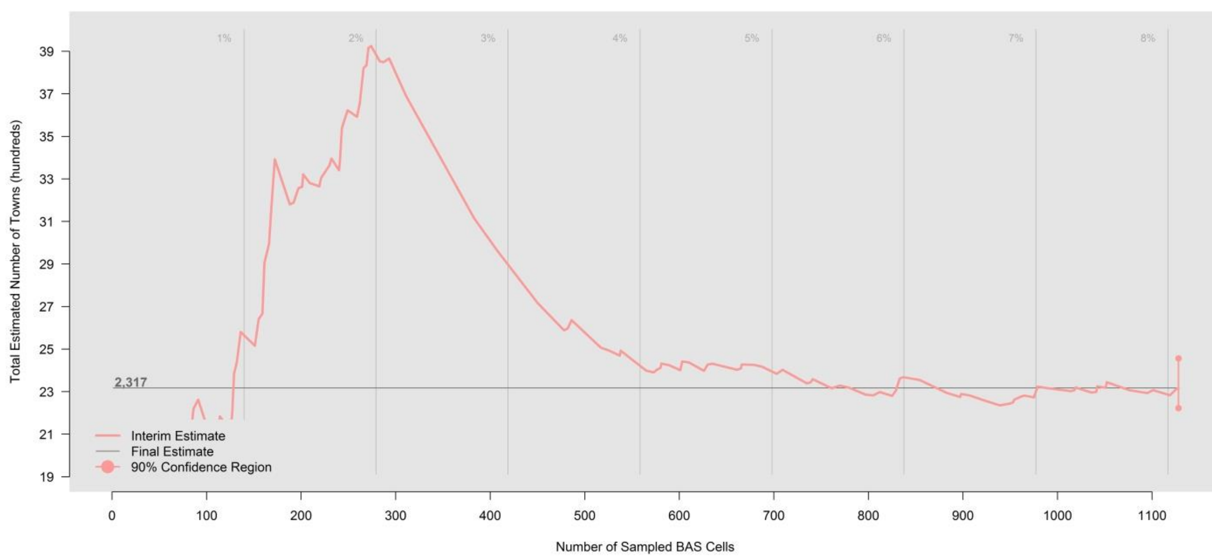


Figure 2.25. Estimated number of potential black-tailed prairie dog colonies in Nebraska as a function of the sample size.

GIS shapefiles and electronic maps will be made available to the State of Nebraska with the digitized features in the state and in each county. For example, figure 2.26 depicts the location of features detected and digitized in Morrill County, Nebraska. These maps were created with sufficient resolution to be viewed in detail on a computer monitor.

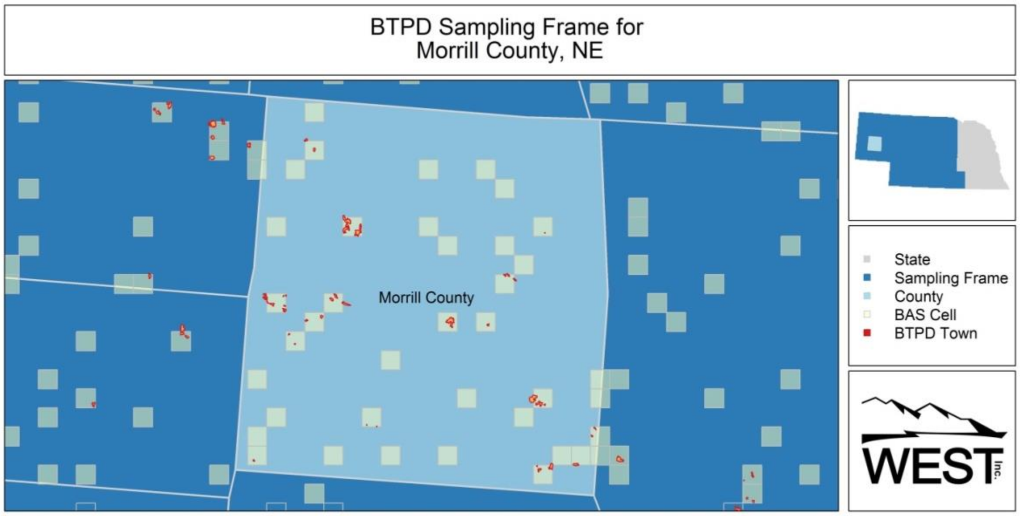


Figure 2.26. Digitized features on a sample survey of grid cells in Morrill County, Nebraska.

The Rainwater Basin Joint Venture (Grosse 2015) conducted a black-tail prairie dog colony inventory of Nebraska using 1-meter National Agriculture Imagery Program (NAIP, 2010) aerial imagery. They estimated the extent of each colony by placing polygon vertices on the furthest visible burrows, the same method implemented in this report. Burrows were then re-evaluated using 2013 sub-meter resolution imagery (Google earth images, 2013). They estimated 97,438 acres of BTPD colonies across the state of Nebraska. This estimate compares favorably with our estimate of 89,308 acres of features in Nebraska based on digitizing on a sample of cells on 1-meter resolution NAIP images taken in 2014.

NEW MEXICO

We used the shapefile of potential BTPD habitat provided by Natural Heritage New Mexico (Teri Brotman Neville, personal communication, March 11, 2015) to develop a sampling frame consisting of grid cells that met the following criteria (Figure 2.27):

1) the cell contained any portion of area within the "historic range for Black-Tailed Prairie Dogs" according to the layer provided by Natural Heritage New Mexico, and
2) did not contain any portion of area with unavailable NAIP imagery (imagery unavailable over area including and surrounding White Sands Missile Range).

We digitized the perimeters of all features detected on 1,362 sampled grid cells selected from the universe of 16,852 cells in the sampling frame for New Mexico (Figure 2.28). We estimated a total of 124,098 acres of potential BTPD colonies in New Mexico (90% CI = [103,228; 155,709], CV = 13.5%) (Part1, Table 1.2). We estimated that a total of 1,964 features exist in the state (90% CI = [1,856; 2,123], CV = 8.4%) (Part 1, Table 1.4). We estimated 334 features greater than 100 acres (90% CI = [297; 409], CV = 14.1%) and 25 greater than 500 acres in New Mexico (90% CI = [25; 74], CV = 61%) (Part 1, Tables 1.6 and 1.7).

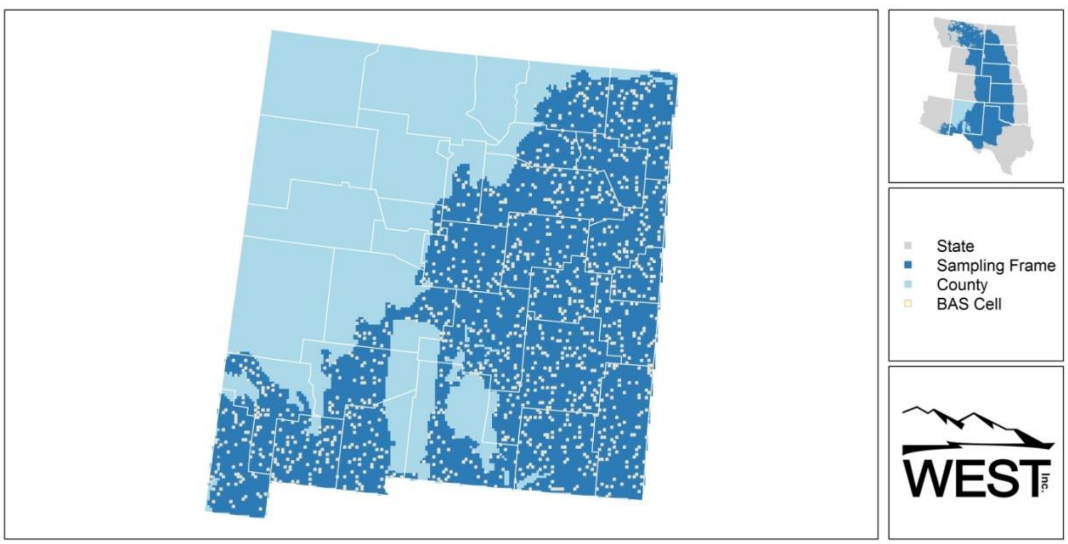


Figure 2.27. Sampling frame for New Mexico with 16,852 grid cells each 2 mi. by 2 mi. The 1,362 grid cells selected by the Balanced Acceptance Sampling (BAS) probabilistic sampling procedure were shown.

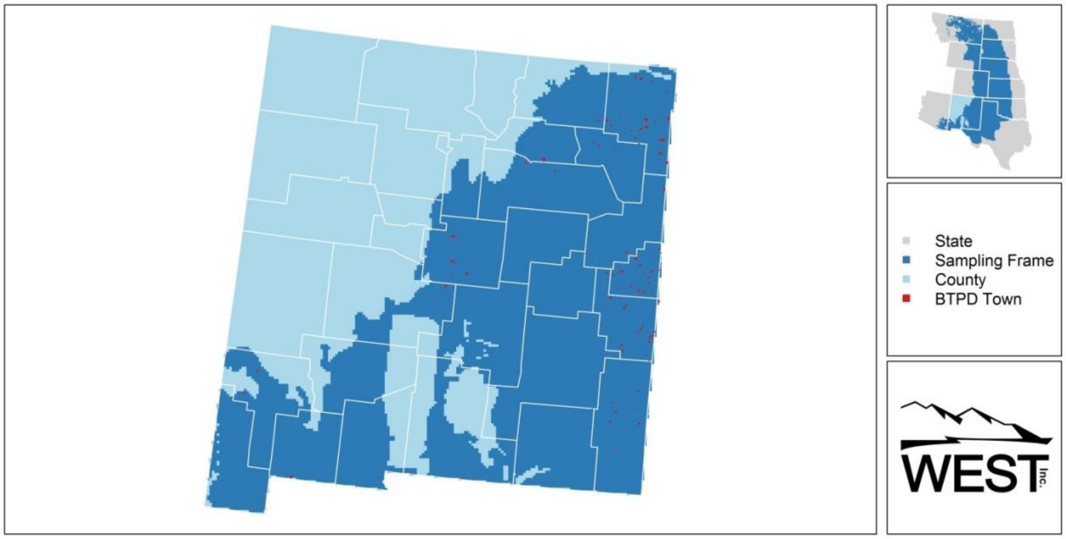


Figure 2.28. Map of features digitized in a sample survey of grid cells in New Mexico.

We plotted the estimates of total number of features and acreage of features as a function of the BAS sample size (Figures 2.29 and 2.30). The estimated number of features began to converge to final estimates at a sample size of about 700 (Figure 2.30). Increasing the sample size to 1,362 grid cells did not change the estimated total number of features appreciably. The effect of detecting rare relatively large features on estimated total acreage of features was evident in Figure 2.29. As the sample size was increased and a rare large feature detected, relatively large jumps occurred in the estimated total acreage. The estimated total acreage began to converge to final estimates at a sample size of about 1,000 grid cells. Estimates had adequate CVs of 13.5% and 8.4% for total acreage and number of features respectively at the sample size of 1, 362.

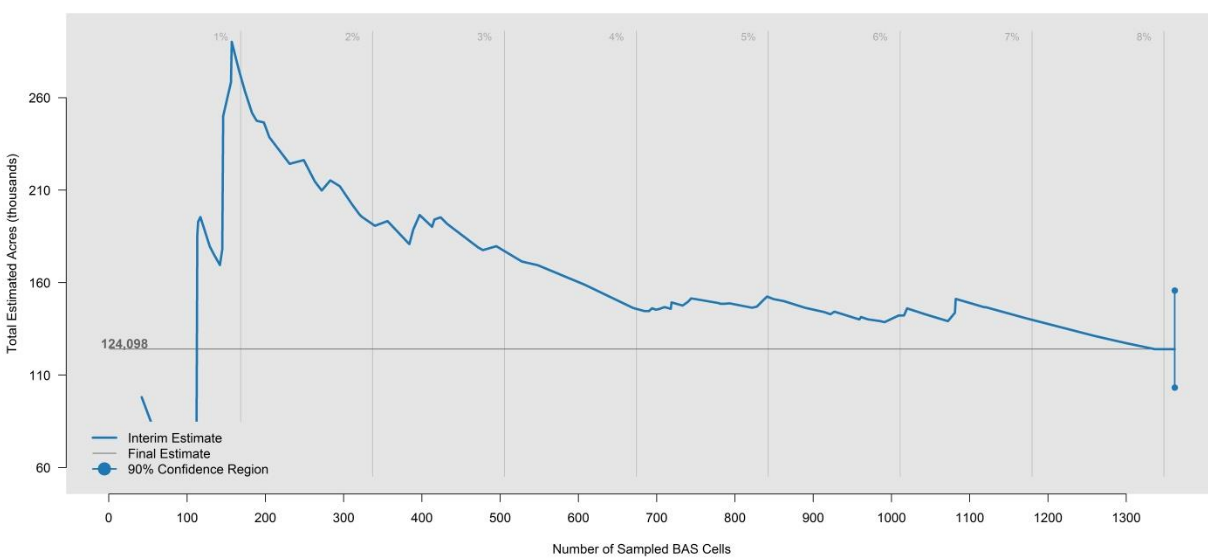


Figure 2.29. Estimated acreage of potential black-tailed prairie dog colonies in New Mexico as a function of the sample size.

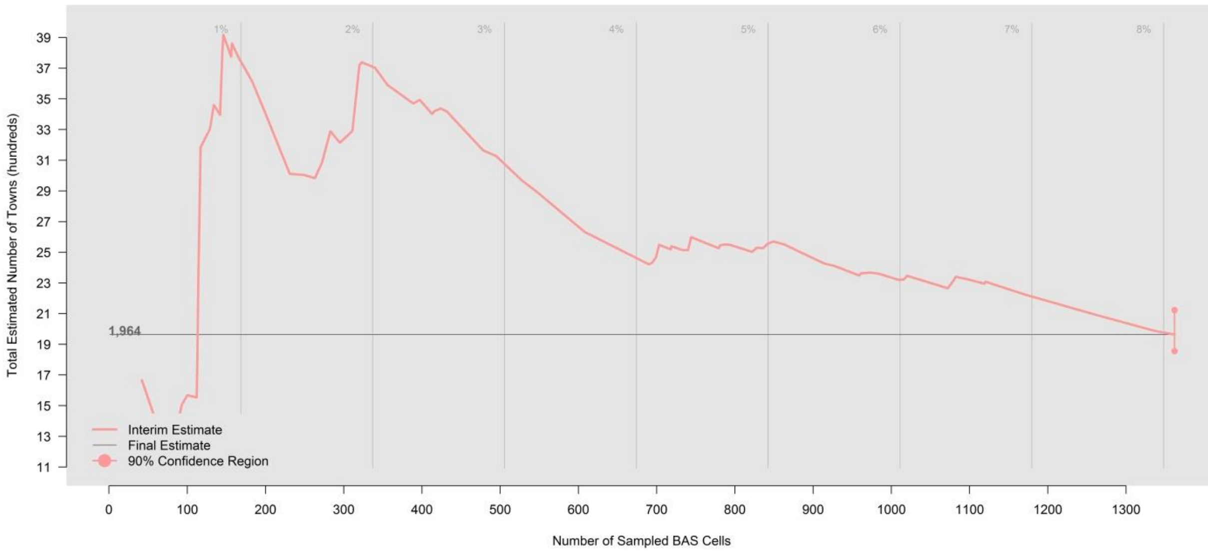


Figure 2.30. Estimated number of potential black-tailed prairie dog colonies in New Mexico as a function of the sample size.

GIS shapefiles and electronic maps will be made available to the State of New Mexico with the digitized features in the state and in each county. For example, figure 2.31, depicts the location of features detected and digitized in Curry County, New Mexico. These maps were created with sufficient resolution to be viewed in detail on a computer monitor.

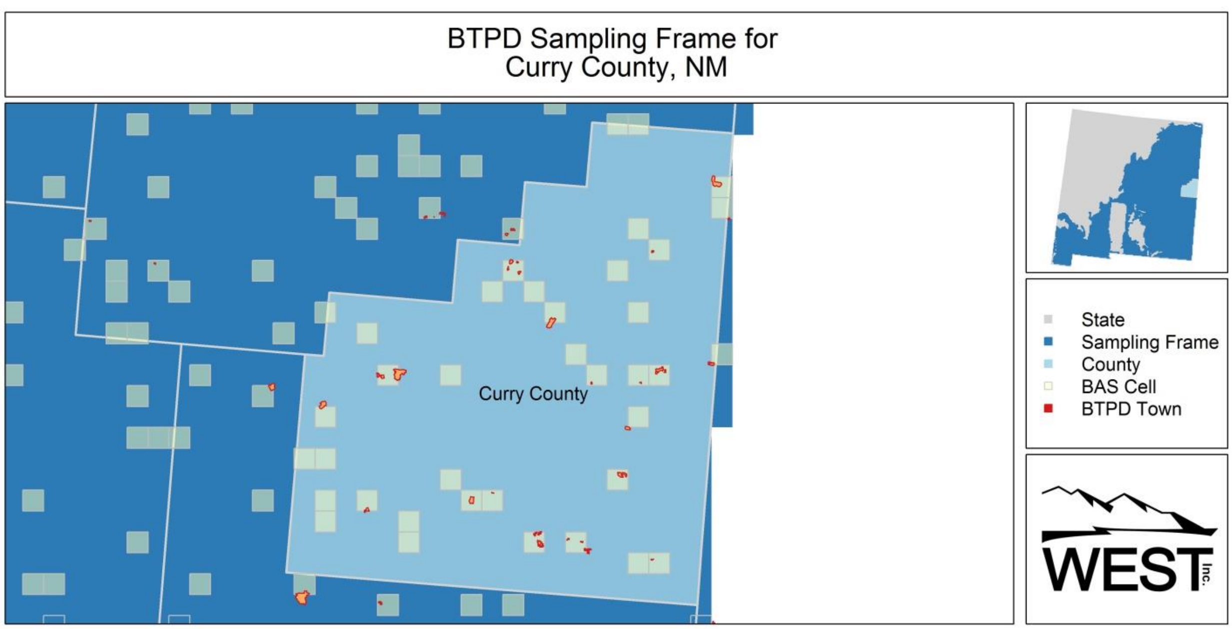


Figure 2.31. Digitized features on a sample survey of grid cells in Curry County, New Mexico.

NORTH DAKOTA

We used the shapefile of potential BTPD habitat provided by the North Dakota Game and Fish Department (Patrick Isakson, personal communication, March 9, 2015) to develop a sampling frame consisting of grid cells that contained any portion of the overall range (Figure 2.32).

We digitized the perimeters of all features detected on 1,012 sampled grid cells selected from the universe of 5,011 cells in the sampling frame for North Dakota (Figures 2.33). We estimated a total of 15,561 acres of potential BTPD colonies in North Dakota (90% CI = [9,578; 27,760], CV = 33.1% (Part 1, Table 1.2) and that a total of 299 features exist in the state (90% CI = [219; 394], CV = 17.7%) (Part 1, Table 1.4). We estimated 30 features greater than 100 acres (90% CI = [15; 59], CV = 40.9%) and 5 greater than 500 acres in North Dakota (90% CI = [5; 20], CV = 100%) (Part 1, Tables 1.6 and 1.7).

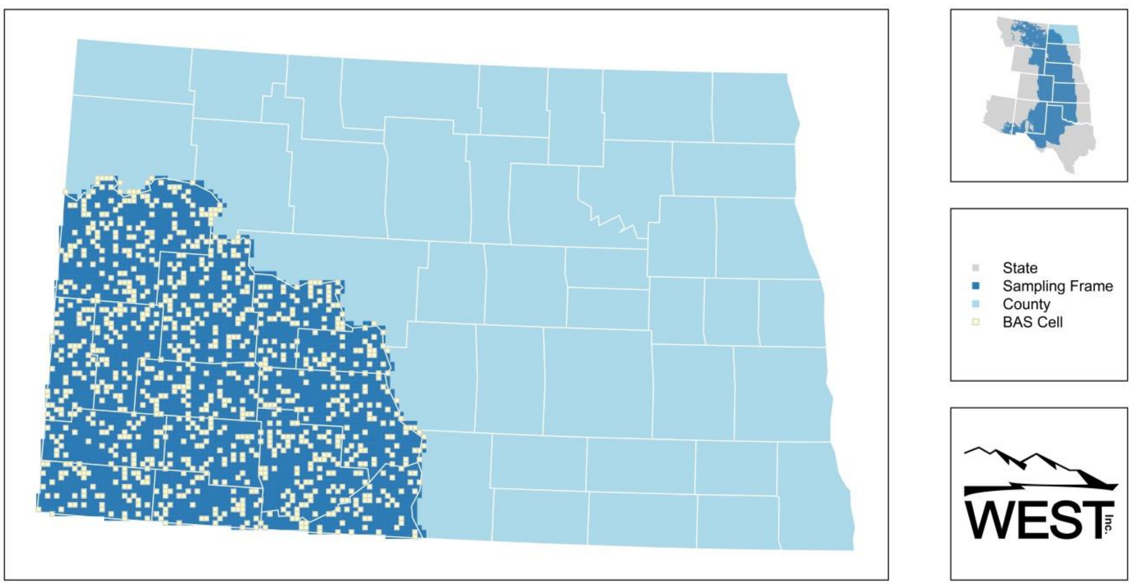


Figure 2.32. Sampling frame for North Dakota with 5,011 grid cells each 2 mi. by 2 mi. The 1,012 grid cells selected by the Balanced Acceptance Sampling (BAS) probabilistic sampling procedure were shown.

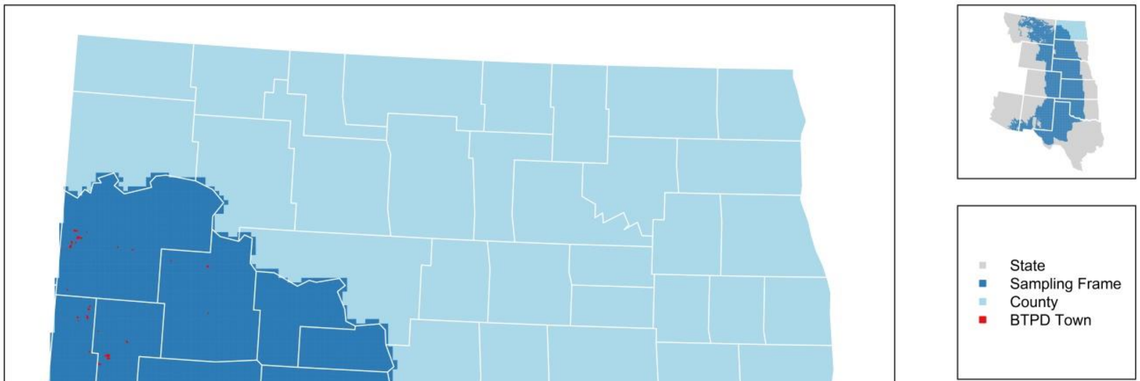


Figure 2.33. Map of features digitized in a sample survey of grid cells in North Dakota.

We plotted the estimates of total number of features and acreage of features as a function of the BAS sample size (Figures 2.34 and 2.35). The estimated number of features began to converge to the final estimate at a sample size of about 300 (Figure 2.35). Increasing the sample size to 1,012 grid cells did not change the estimated total number of features appreciably. The effect of detecting rare relatively large features on estimated total acreage of features was evident in Figure 2.34. As the sample size was increased and a rare large feature detected, relatively large jumps occurred in the estimated total acreage. The estimated total acreage began to converge to final estimates at a sample size of about 1,000 grid cells. Estimates had CVs of 33.1% and 17.7% for total acreage and number of features respectively at the sample size of 1,012. Estimates with CV greater than 30% were marginally adequate for detection of important trends in long term monitoring programs, indicating that the sample size should be increased in North Dakota.

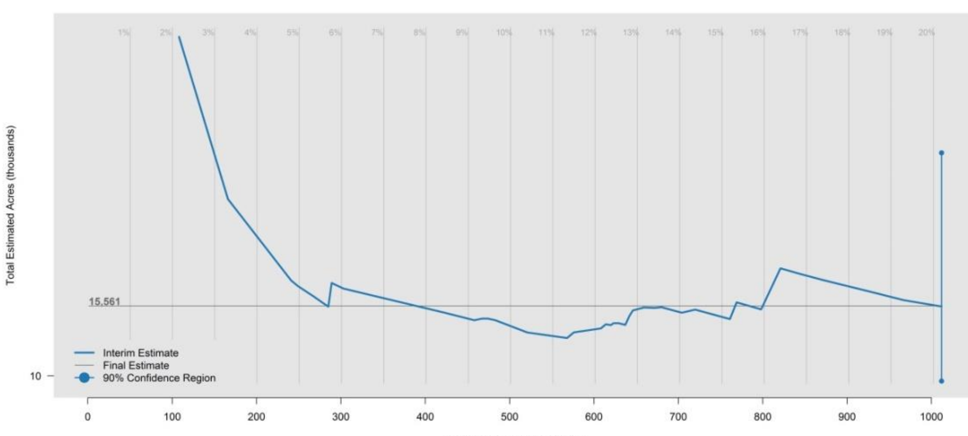


Figure 2.34. Estimated acreage of potential black-tailed prairie dog colonies in North Dakota as a function of the sample size.

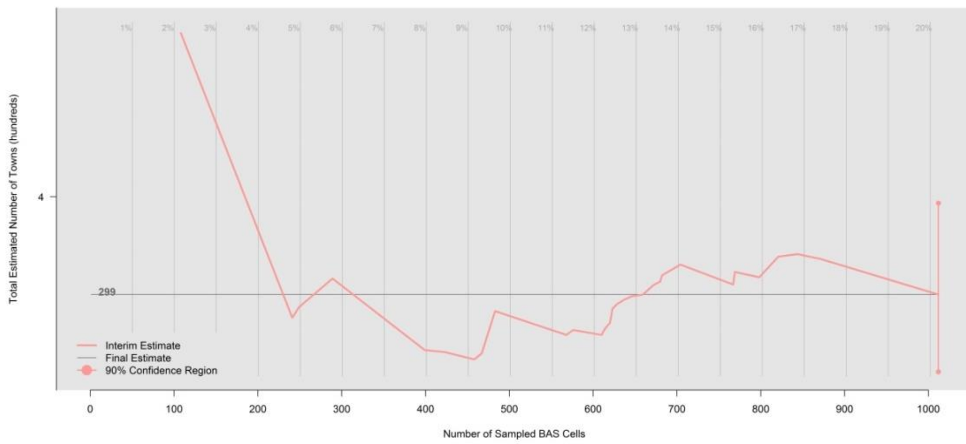


Figure 2.35. Estimated number of potential black-tailed prairie dog colonies in North Dakota as a function of the sample size.

GIS shapefiles and electronic maps will be made available to the State of North Dakota with the digitized features in the state and in each county. For example, figure 2.36, depicts the location of features detected and digitized in Billings County, North Dakota. These maps were created with sufficient resolution to be viewed in detail on a computer monitor.

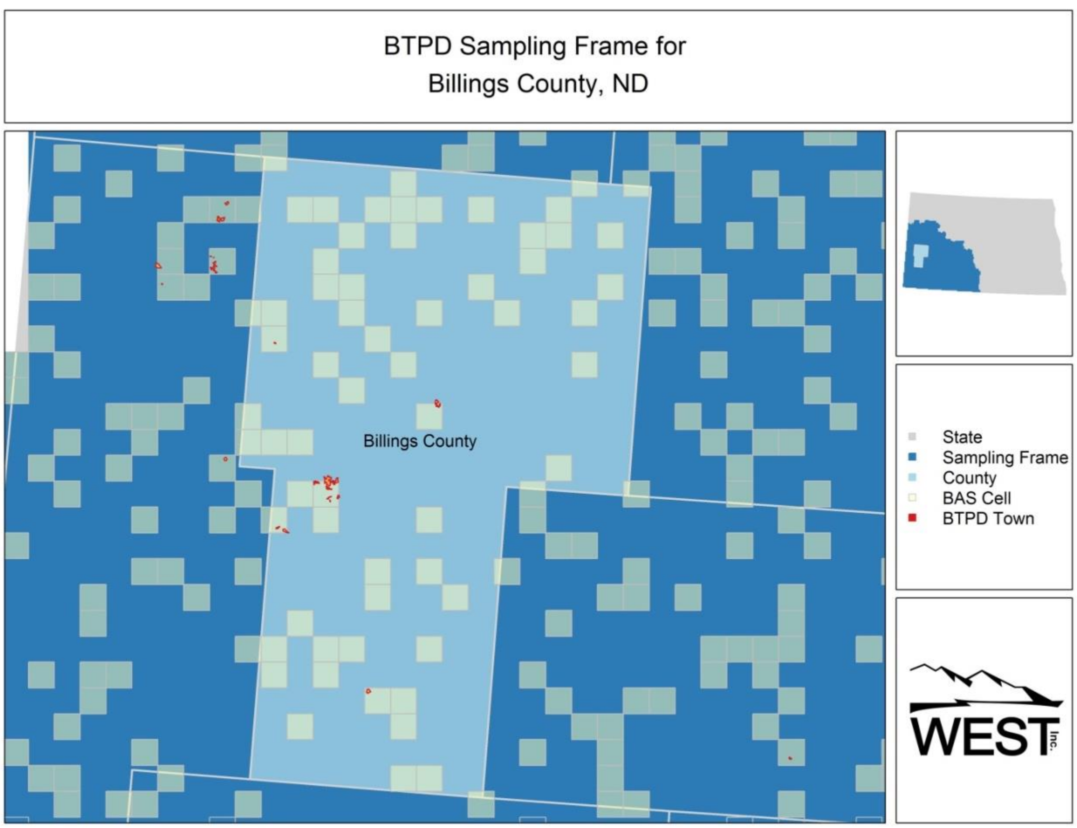


Figure 2.36. Digitized features on a sample survey of grid cells in Billings County, North Dakota.

OKLAHOMA

We used the shapefile of potential BTPD habitat provided by the Oklahoma Department of Wildlife Conservation (Kara M. Caricato-Michalke, personal communication, February 11, 2015) to develop a sampling frame that consisted of grid cells that contained any portion of the overall range (Figure 2.37). We digitized the perimeters of all features detected on 1,078 sampled grid cells selected from the universe of 8,888 cells in the sampling frame for Oklahoma (Figure 2.38). We estimated a total of 81,224 acres of potential BTPD colonies in Oklahoma (90% CI = [63,015; 107,187], CV = 16.3%) (Part 1, Table 1.2). We estimated that a total of 1,816 features exist in the state (90% CI = [1,542; 2,115], CV = 9.6%) (Part 1, Table 1.4). We estimated 218 features greater than 100 acres (90% CI = [141; 305], CV = 22.7%) and 3 greater than 500 acres in Oklahoma (Part 1, Tables 1.6 and 1.7).

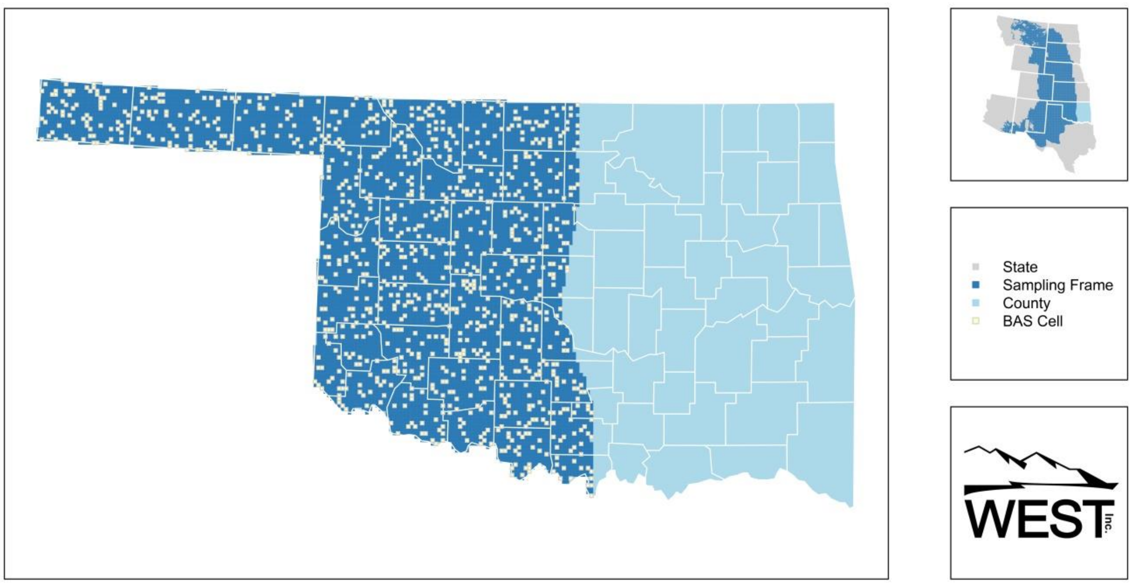


Figure 2.37. Sampling frame for Oklahoma with 8,888 grid cells each 2 mi. by 2 mi. The 1,078 grid cells selected by the Balanced Acceptance Sampling (BAS) probabilistic sampling procedure were shown.

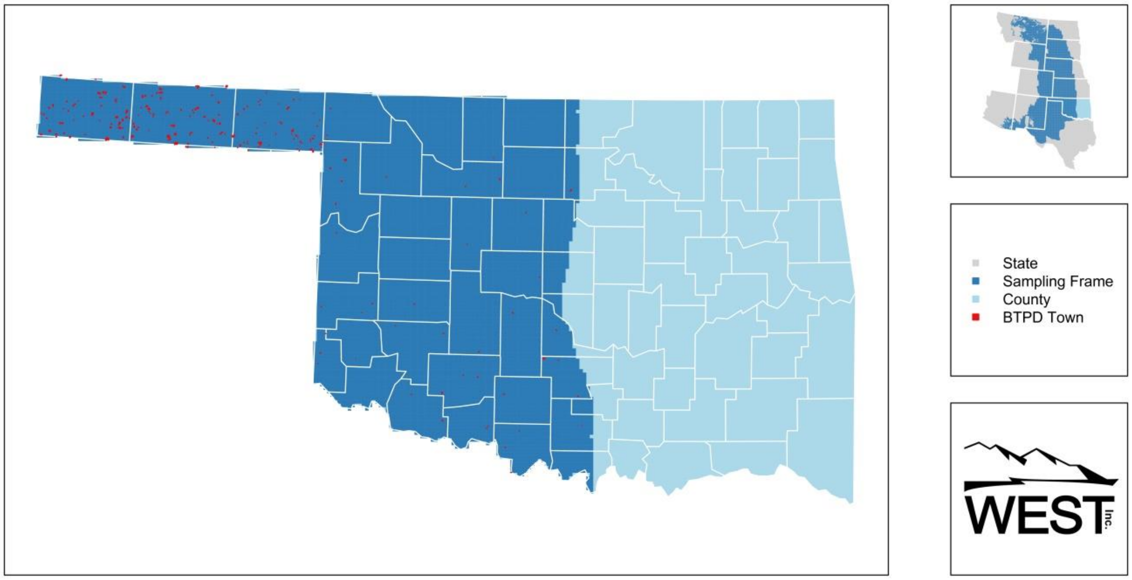


Figure 2.38. Map of features digitized in a sample survey of grid cells in Oklahoma.

We plotted the estimates of total acreage of features and the total number of features as functions of the BAS sample size (Figures 2.39 and 2.40). The estimated total acreage of features began to converge to final estimates at a sample size of about 500 (Figure 2.39). Increasing the sample size to 1,078 grid cells did not change the estimated total acreage appreciably. The estimated total number of features was more variable than the estimated total acreage (Figure 2.40). Estimates had adequate CVs of 16.3% and 9.6% for total acreage and number of features respectively at the sample size of 1,078.

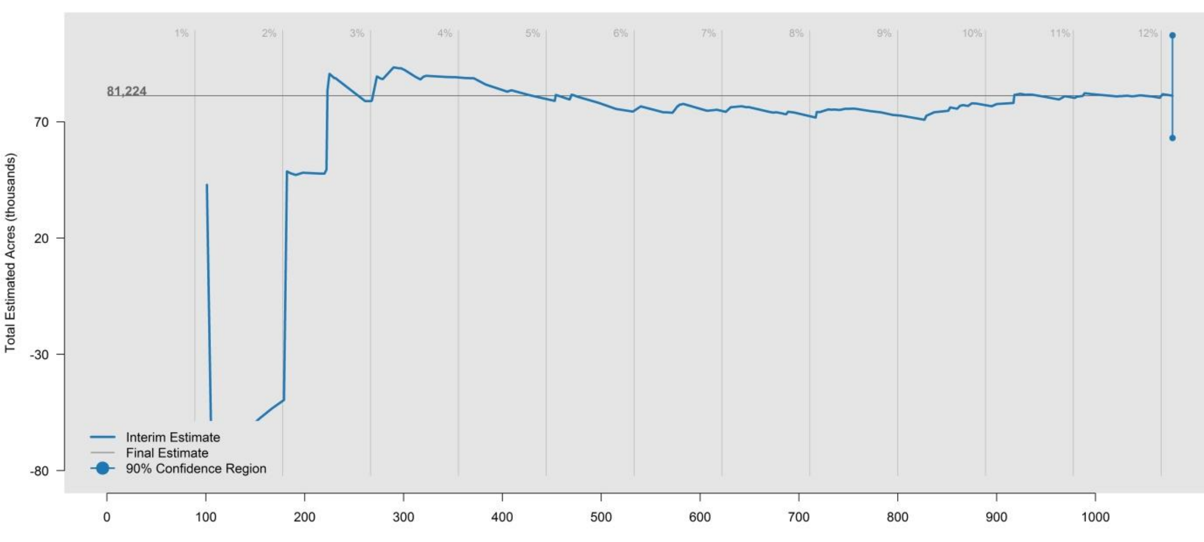


Figure 2.39. Estimated acreage of potential black-tailed prairie dog colonies in Oklahoma as a function of the sample size.

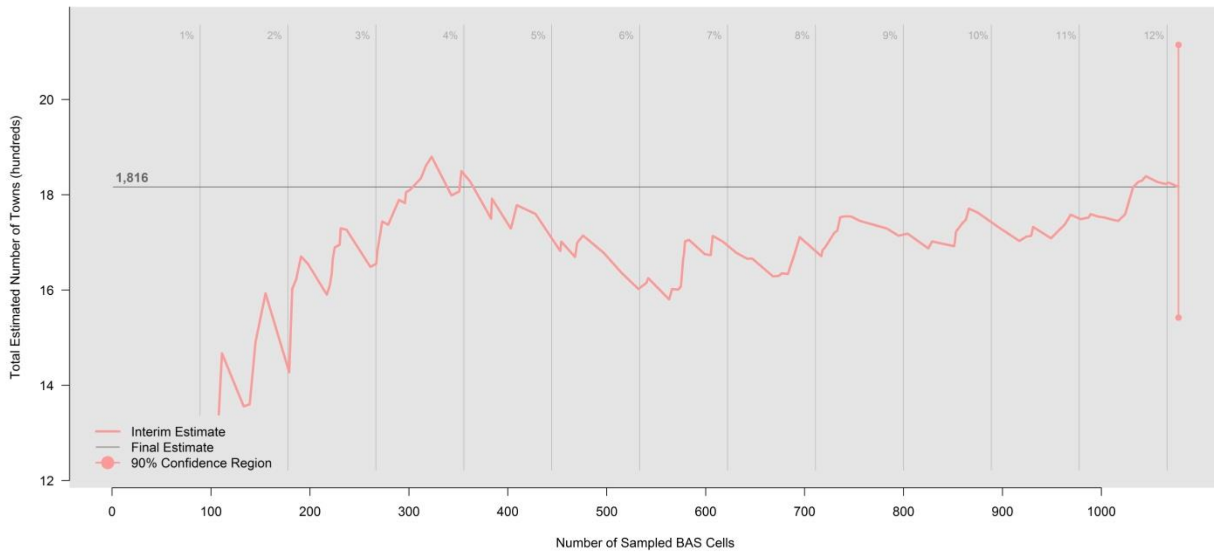


Figure 2.40. Estimated number of potential black-tailed prairie dog colonies in Oklahoma as a function of the sample size.

GIS shapefiles and electronic maps will be made available to the State of Oklahoma with the digitized features in the state and in each county. For example, figure 2.41, depicts the location of features detected and digitized in Texas County, Oklahoma. These maps were created with sufficient resolution to be viewed in detail on a computer monitor.

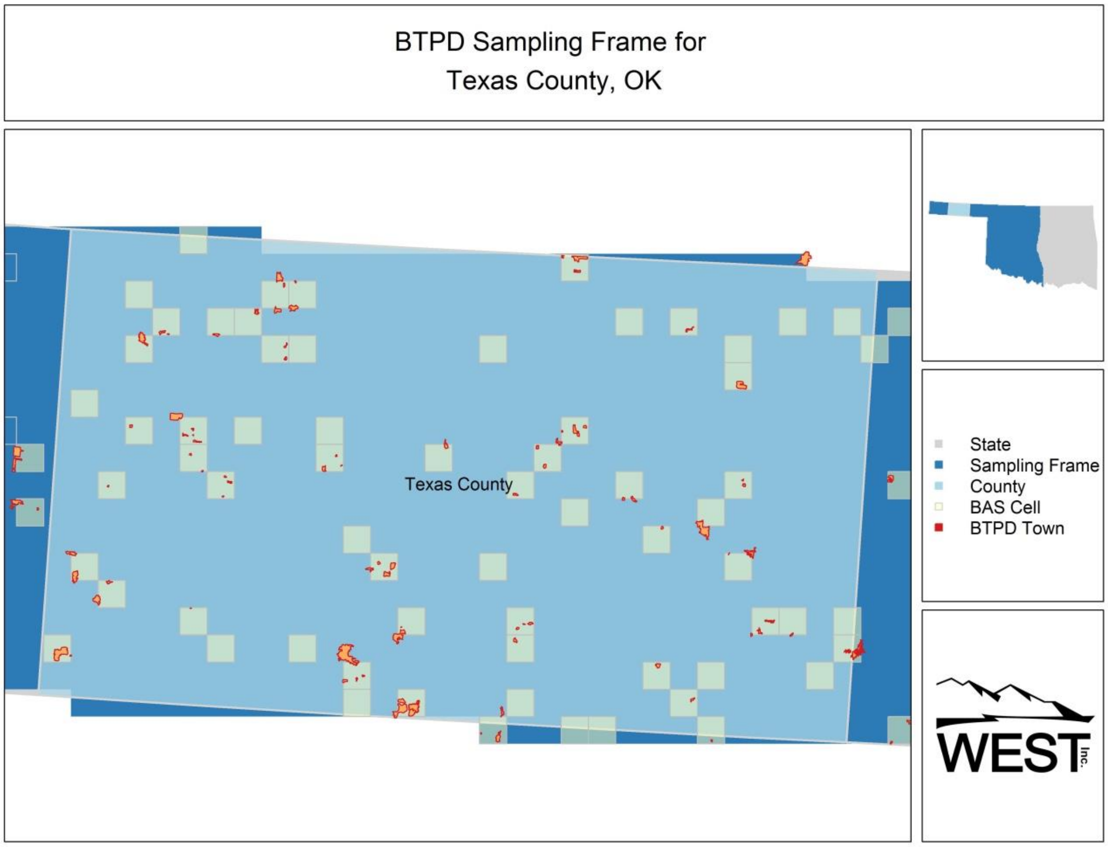


Figure 2.41. Digitized features on a sample survey of grid cells in Texas County, Oklahoma.

SOUTH DAKOTA

We used the shapefile of potential BTPD habitat provided by the South Dakota Department of Game, Fish and Parks (Silka L. F. Kempema, personal communication, January 28, 2015) to develop a sampling frame that consisted of grid cells that contained any portion of the overall range (Figure 2.42). We digitized the perimeters of all features detected on 1,230 sampled grid cells selected from the universe of 12,165 cells in the sampling frame for South Dakota (Figure 2.43). We estimated a total of 224,145 acres of potential BTPD colonies in South Dakota (90% CI = [187,303; 270,383], CV = 11.2%) (Part 1, Table 1.2) and that a total of 5,204 features exist in the state (90% CI = [4,693; 5,763], CV = 6.3 %) (Part 1, Table 1.4). We estimated 458 features greater than 100 acres (90% CI = [352; 577], CV = 14.9%) and 20 greater than 500 acres in South Dakota (90% CI = [10; 59], CV = 71%) (Part 1, Tables 1.6 and 1.7).

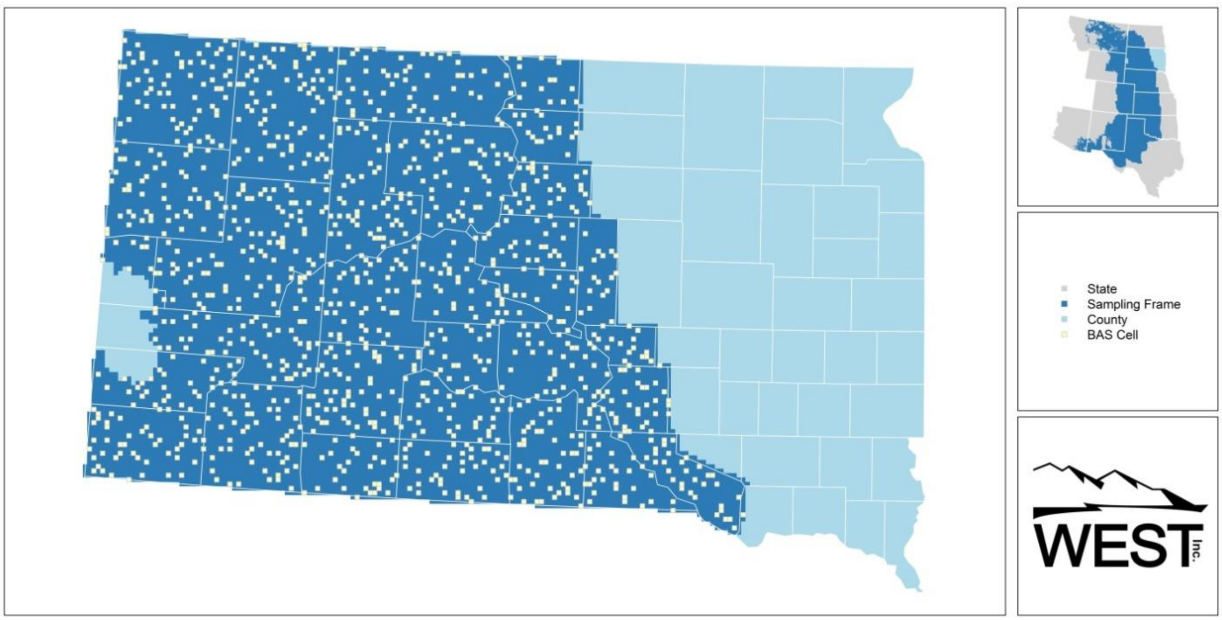


Figure 2.42. Sampling frame for South Dakota with 12,165 grid cells each 2 mi. by 2 mi. The 1,230 grid cells selected by the Balanced Acceptance Sampling (BAS) probabilistic sampling procedure were shown.

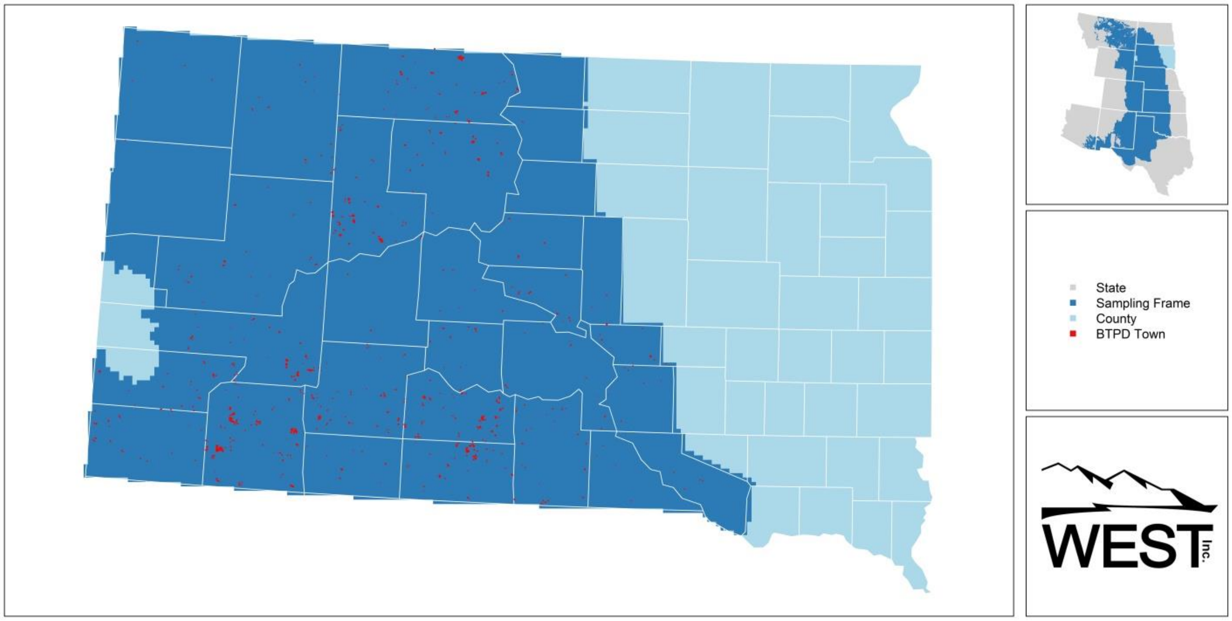


Figure 2.43. Map of features digitized in a sample survey of grid cells in South Dakota.

We plotted the estimates of total acreage of features and the total number of features as a function of the BAS sample size (Figures 2.44 and 2.45). The estimated total acreage of features began to converge to final estimates at a sample size of about 700 (Figure 2.44). The estimated number of features began to converge to final estimates at a sample size of about 1100 (Figure 2.45). Estimates had adequate CVs of 11.2% and 6.3% for total acreage and number of features respectively at the sample size of 1,230.

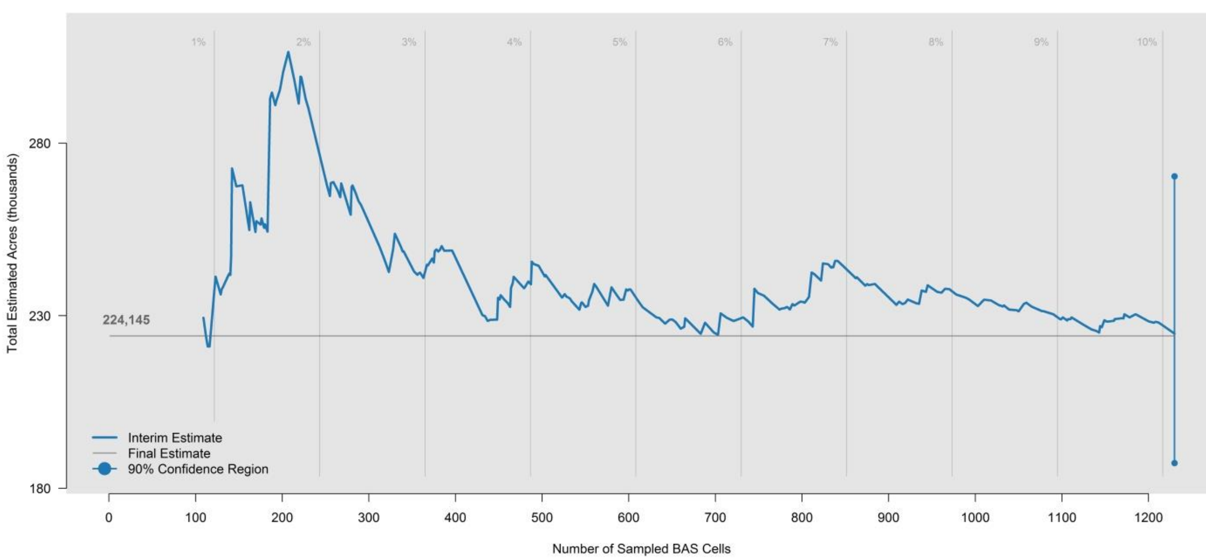


Figure 2.44. Estimated acreage of potential black-tailed prairie dog colonies in South Dakota as a function of the sample size.

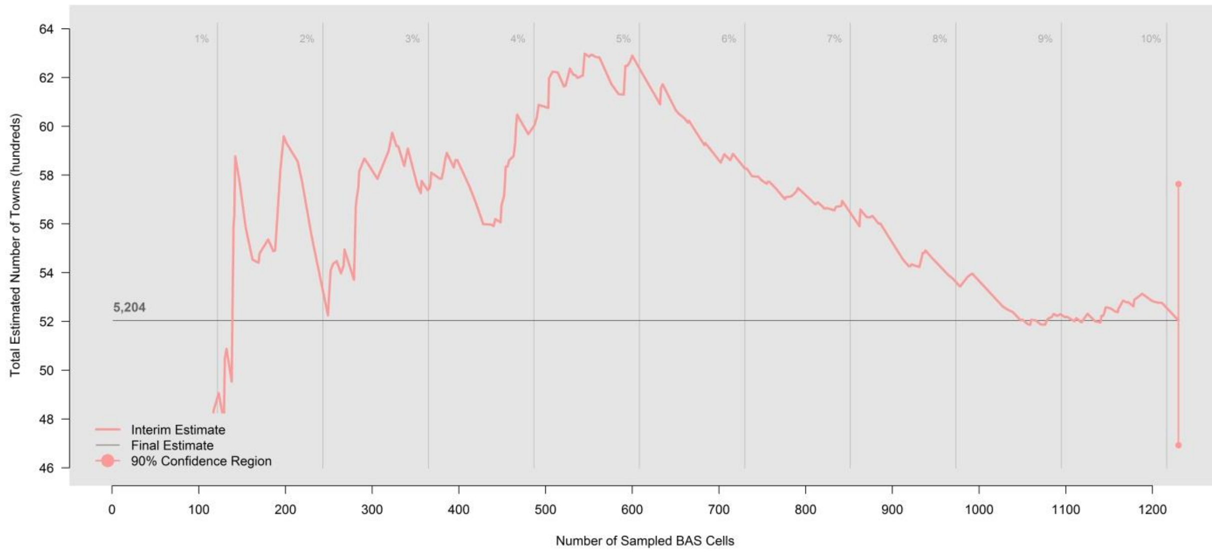


Figure 2.45. Estimated number of potential black-tailed prairie dog colonies in South Dakota as a function of the sample size.

GIS shapefiles and electronic maps will be made available to the State of South Dakota with the digitized features in the state and in each county. For example, figure 2.46, depicts the location of features detected and digitized in Oglala Lakota County (Shannon County), South Dakota. These maps were created with sufficient resolution to be viewed in detail on a computer monitor.

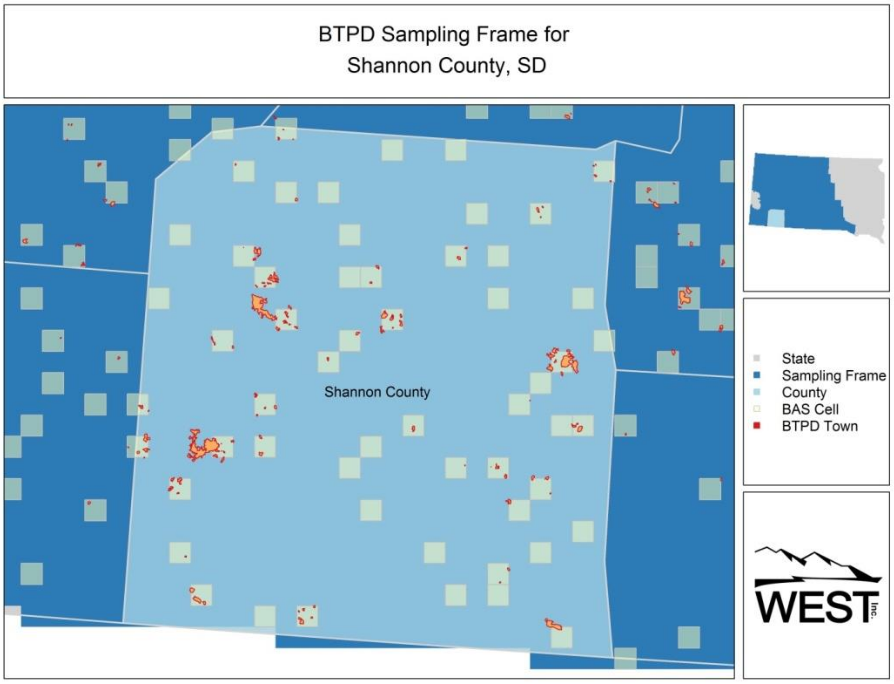


Figure 2.46. Digitized features on a sample survey of grid cells in Oglala Lakota County (Shannon County), South Dakota.

Analysis of Features Digitized by South Dakota Department of Game, Fish and Parks' Personnel

Employees of the South Dakota Department of Game, Fish and Parks independently digitized features on the same sample survey of 1,230 grid cells selected by the BAS probabilistic sampling procedure (Silka L. F. Kempema, personal communication). Training and experience of observers differed; however, the primary difference in methods was that South Dakota employees attempted to digitize polygons that "followed the clip line." We analyzed the features digitized by the South Dakota Department of Game, Fish and Parks using the same analysis methods as used by WEST, Inc. We adjusted for probability of detection (false negatives) using the average probability of detection curve for WEST observers. The estimated acreage of potential BTPD colonies in South Dakota as a function of the sample size was plotted in Figure 2.47 where the estimated acreage converged to 285,318 acres.

Our estimate of 224,145 acres (Figure 2.44) was 79% of the estimate that we derived using the shapefile provided by the South Dakota Department of Game, Fish and Parks (Figure 2.47). The estimated acreage derived from the South Dakota effort was 21% larger than our estimate for two reasons. First, the South Dakota observers detected and digitized many more small features than our observers. The histogram in Figure 2.48 showed that South Dakota observers digitized more features of less than 20 acres than WEST observers. However, an enlarged Figure 2.49 of Oglala Lakota County (Shannon County) indicated that WEST observers also digitized features that were not detected by South Dakota observers. Second, South Dakota observers digitized the outer most "clip line" of detected features resulting in larger acreages in each colony and a larger overall estimate.

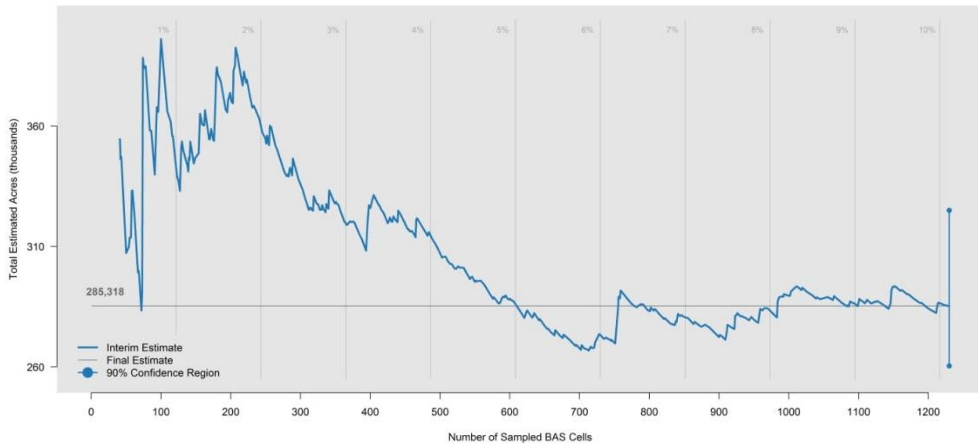


Figure 2.47. Estimated acreage of potential black-tailed prairie dog colonies in South Dakota as a function of the sample size, based on features digitized by South Dakota Department of Game, Fish and Parks employees.

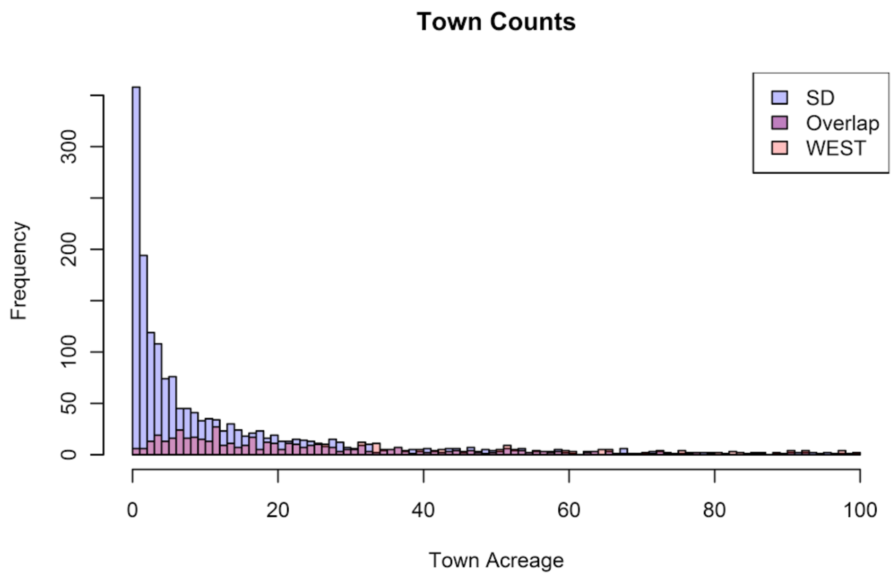


Figure 2.48. Frequency of features by size category digitized by: South Dakota observers and not detected by WEST observers, WEST observers and not detected by South Dakota observers, and overlap of the two sets of observers. Frequencies were shown for features less than 100 acres in size.

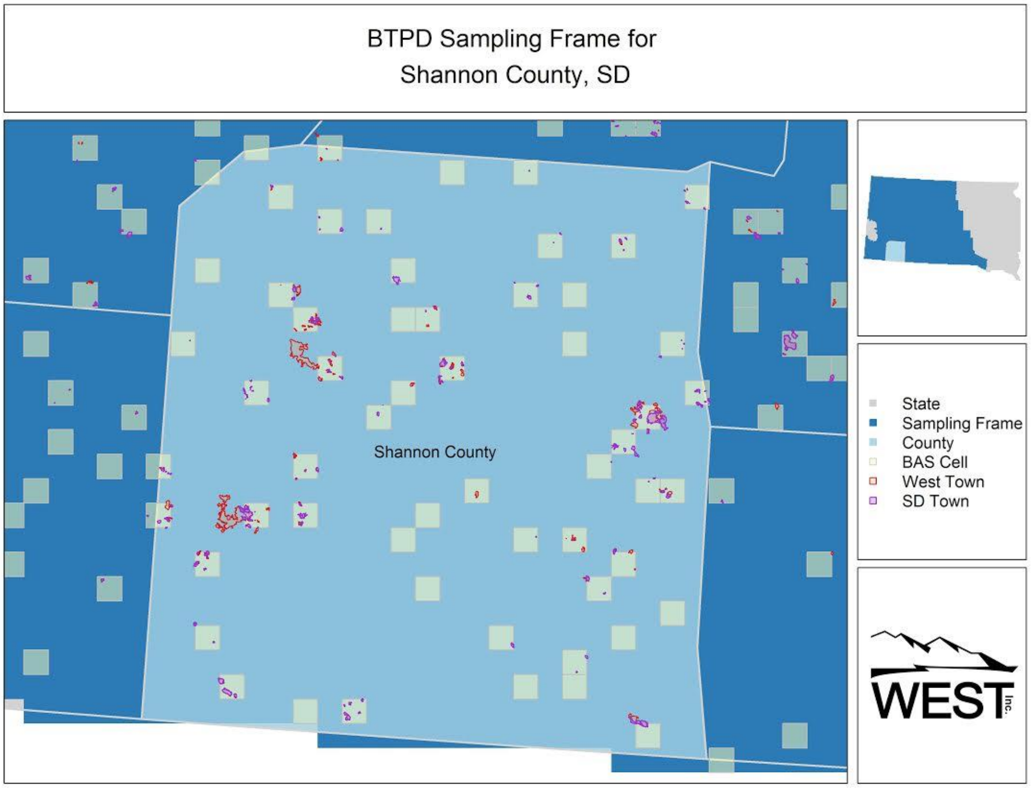


Figure 2.49. Digitized features on a sample survey of grid cells in Shannon County (recently renamed Oglala Lakota County), South Dakota by WEST observers and by South Dakota observers.

TEXAS

We started with two shapefiles of potential BTPD habitat in Texas provided by the Texas Parks and Wildlife (Bob Gottfried, personal communication, Texas Natural Diversity Database Administrator, March 10, 2015). We included grid cells in the sampling frame which met the following criteria (Figure 2.50):

1) cells contained any portion of area within the "Verified BTPD records within 7.5 minute quads" layer provided by Texas Parks and Wildlife (verified through 2008),
2) cells contained any portion of area within the "Texas range of Black-tailed Prairie Dogs," digitized from Figure 2 in the "Texas Black-tailed Prairie Dog Conservation and Management Plan," prepared by the Texas Black-tailed Prairie Dog Working Group (2004),
3) cells contained any portion of area within the "Estimated current (2002-2004) distribution of the black-tailed prairie dog in Texas," digitized from Figure 4 in the article "Estimating black-tailed prairie dog (*Cynomys ludovicianus*) distribution in Texas" (Singhurst, J.R., J.H. Young, G. Kerouae, and H.A. Whitlaw. 2010. Texas J. of Sci. 62: 243-262.),
4) cells contained any portion of area within the "Estimated historical (pre-2000) distribution of the black-tailed prairie dog in Texas" from where it intersects the east border of Brewster County west to the New Mexico border, digitized from Figure 3 in the article "Estimating black-tailed prairie dog (*Cynomys ludovicianus*) distribution in Texas" (Singhurst, J.R., J.H. Young, G. Kerouae, and H.A. Whitlaw. 2010. Texas J. of Sci. 62: 243-262.),
5) cells did not contain any portion of area with unavailable NAIP imagery (imagery unavailable over a small area of Hudspeth County, and
6) the southern boundary was "smoothed" to fill in jagged gaps between component layers as listed above.

We digitized the perimeters of all features detected on 1,982 sampled grid cells selected from the universe of 24,539 cells in the sampling frame for Texas (Figure 2.51). We estimated a total of 238,871 acres of potential BTPD colonies in Texas (90% CI = [193,281; 304,826], CV = 14.2 %) (Part1, Table 1.2) and that a total of 2,353 features exist in the state (90% CI = [2,256; 2,496], CV = 6.2%)(Part 1,Table 1.4). We estimated 446 features greater than 100 acres (90% CI = [409; 508], CV = 10.9%) and 87 greater than 500 acres in Texas (90% CI = [62; 124], CV = 28%) (Part 1, Tables 1.6 and 1.7).

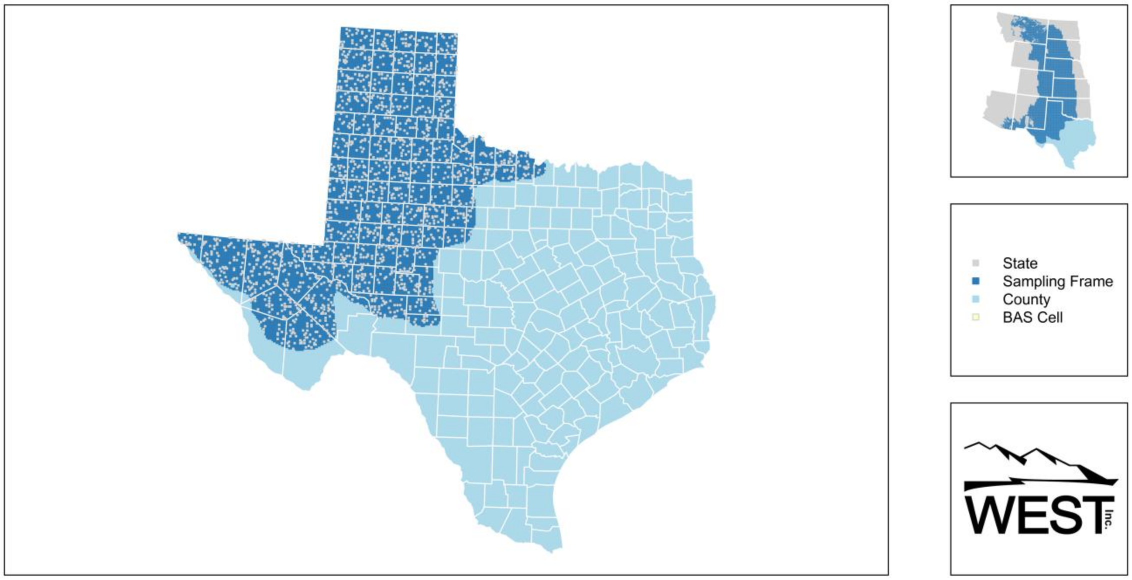


Figure 2.50. Sampling frame for Texas with 24,539 grid cells each 2 mi. by 2 mi. The 1,982 grid cells selected by the Balanced Acceptance Sampling (BAS) probabilistic sampling procedure were shown.

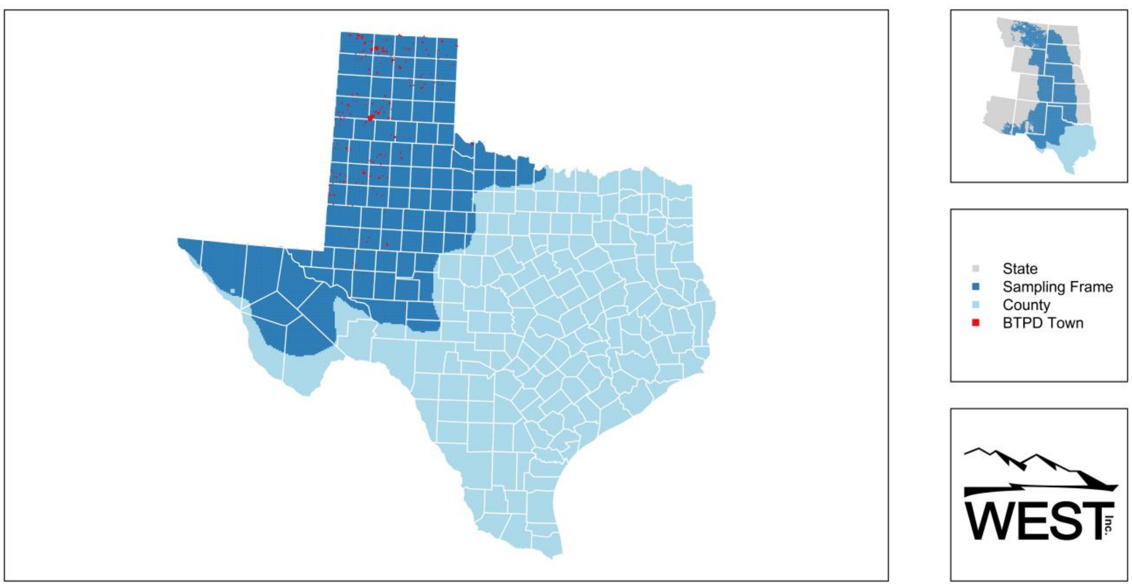


Figure 2.51. Map of features digitized in a sample survey of grid cells in Texas.

We plotted the estimates of total number of features and acreage of features as a function of the sample size (Figures 2.52 and 2.53). The estimated number of features began to converse to our final estimate at a sample size of 700 (Figure 2.53). Increasing the sample size to 1100 grid cells did not change the estimated total number of features appreciably. The effect of detecting rare relatively large features on estimated total acreage of features was evident in Figure 2.52. As the sample size was increased and a rare large feature detected, relatively large jumps occurred in the estimated total acreage. The estimated total acreage began to converge to final estimates at a sample size of about 1,000 grid cells. Estimates had adequate CVs of 14.2% and 6.2% for total acreage and number of features respectively at the sample size of 1,982.

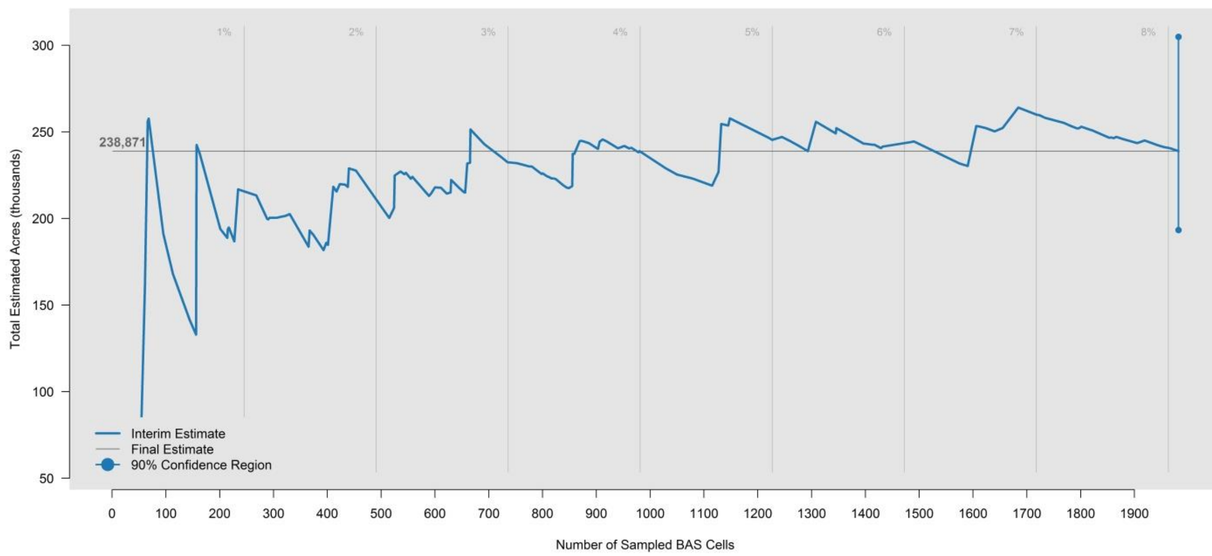


Figure 2.52. Estimated acreage of potential black-tailed prairie dog colonies in Texas as a function of the sample size.

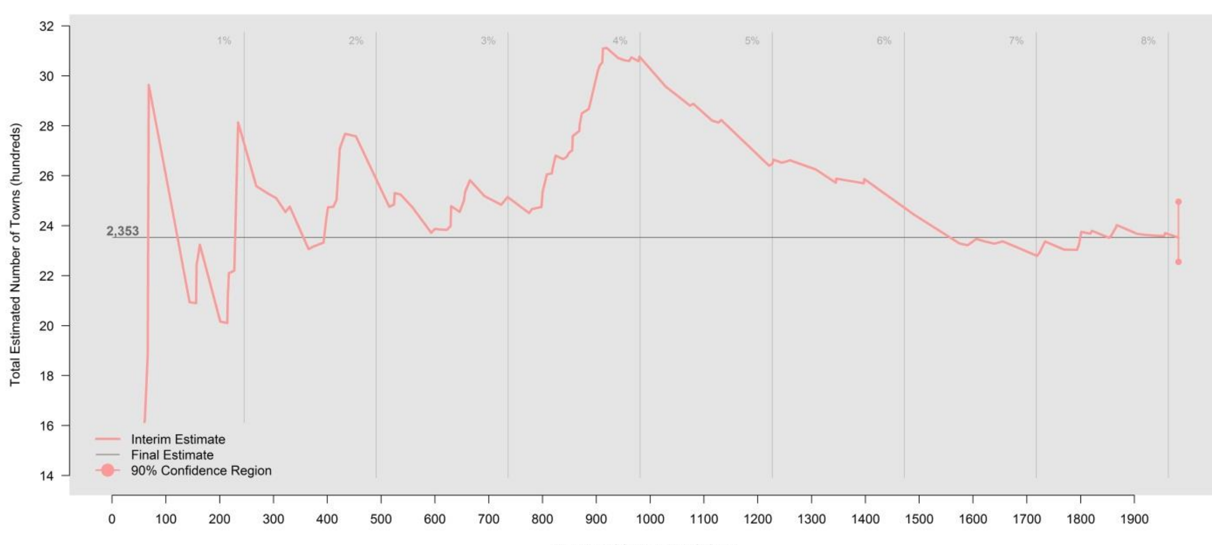


Figure 2.53. Estimated number of potential black-tailed prairie dog colonies in Texas as a function of the sample size.

GIS shapefiles and electronic maps will be made available to the State of Texas with the digitized features in the state and in each county. For example, figure 2.54, depicts the location of features detected and digitized in Randall County, Texas. These maps were created with sufficient resolution to be viewed in detail on a computer monitor.

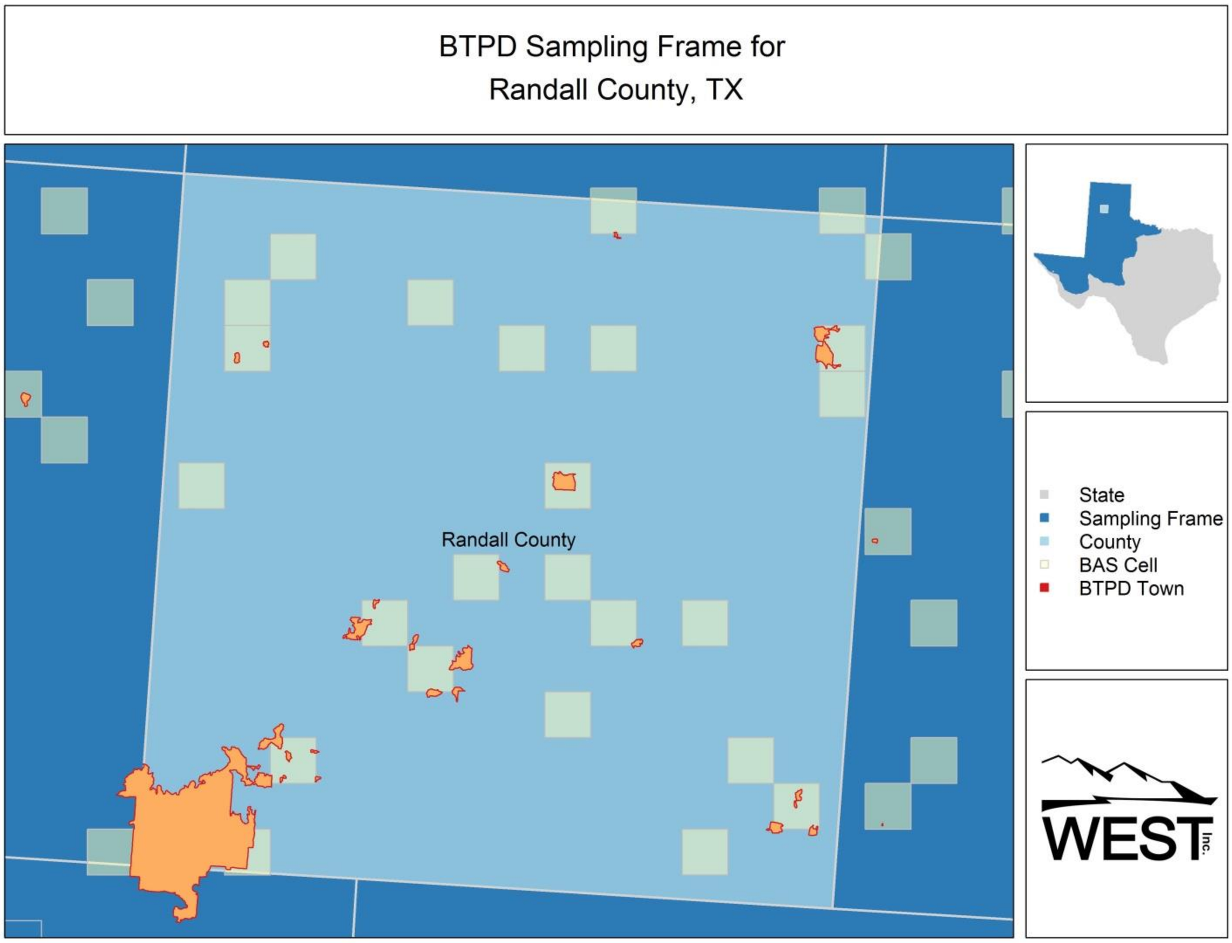


Figure 2.54. Digitized features on a sample survey of grid cells in Randall County, Texas.

WYOMING

The sample frame consisted of 8,790 grid cells that met the following criteria: 1) identified as a Wyoming cell with >50% of the land area in Wyoming, 2) containing any portion of area within the 11 county area of interest (Campbell, Converse, Crook, Goshen, Johnson, Laramie, Natrona, Niobrara, Platte, Sheridan, and Weston Counties), and 3) having >50% of the land area within the grid cell situated at less than 2377 meters (7,800 feet, NRCS 2004) in elevation, using intersections with 1-arcsecond Digital Elevation Model layers from the National Elevation Dataset (USGS). We surveyed a census of (2 mile by 2 mile) grid cells in the 11 county area in Wyoming (Figure 2.55). Figure 2.55 also displayed the sample of 1,722 grid cells, the results of which we reported as a “sample survey” in Part 1. We digitized all features detected in all grid cells and corrected for less than 100% probability of detection, i.e., for missed features called “false negatives.”

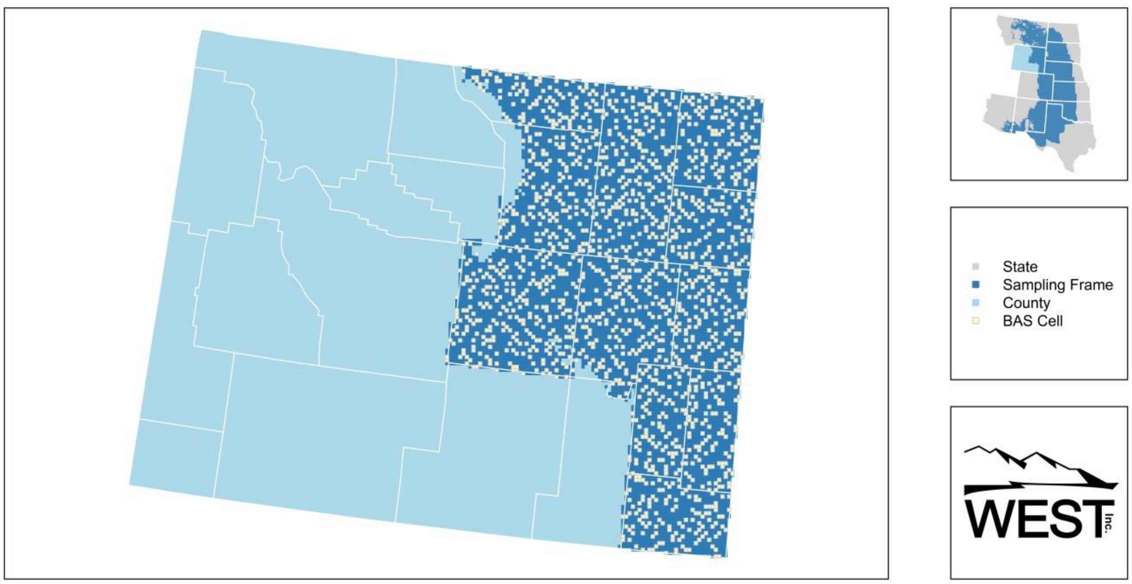


Figure 2.55. Sampling frame for the State of Wyoming showing 1,722 grid cells selected by Balanced Acceptance Sampling (BAS).

Wyoming Black-tailed Prairie Dog Aerial and Ground Truthing Results 2015

Aerial Surveys

Aerial surveys were conducted from July 20 to August 4, 2015 at 400 features digitized on the census of grid cells ("targets"). The targets were selected from the population of digitized potential BTPD prairie dog colonies using a BAS sample to ensure spatial representativeness across the habitat in the state. A probabilistic sample of 377 digitized features less than 1,000 acres was selected for aerial survey (n=377). In addition 23 features greater than 1,000 acres were selected for aerial surveyed (n=23) from the set of 27 features present. Targets were visited and identified as either an active black-tailed prairie dog colony, inactive black-tailed prairie dog colony, or null (not a black-tailed prairie dog colony) (Table 2.1) .

Table 2.1. Classification of aerial surveyed features in Wyoming.

Classification	Features less than 1,000 acres	Features greater than 1,000 acres
Active BTPD[1] colony	311 (82.5%)	16 (69.6%)
Inactive BTPD[1] colony	9 (2.4%)	0
Null (not a BTPD[1] colony	57 (15.1%)	7 (30.4%)
Total	377	23

[1] BTPD = black-tailed prairie dog

Of the 23 large features (greater than 1,000 acres), 69.6% (n=16) were found to be active prairie dogs colonies and 30.4% (n=7) were found to not be prairie dog colonies. Of the 377 small features, 82.5% (n=311) were found to be active prairie dogs colonies, 2.4% (n=9) were found to be inactive prairie dog colonies and 15.1% (n=57) were found to not be prairie dog colonies. The targets that were found to not be prairie dog colonies were generally anthills (88%; n=59), ground squirrels (8%; n=5), or a combination of old holes and bare patches of dirt.

<u>Ground Surveys</u>

Ground surveys were conducted from August 6 to August 11, 2015 at 87 digitized prairie dog colonies ("targets"). The ground truthing targets were selected from the 336 colonies visited by the aerial truthing and found to be prairie dog colonies (active or inactive). The site selection was also limited to targets near a public road based on the TIGER dataset published in 2014 (2014 TIGER/Line Shapefiles (machine readable data files) / prepared by the U.S. Census Bureau, 2014). We visited the first 100 targets that met these criteria following the BAS ranked order of grid cells. In addition, we visited 16 colonies greater than 1,000 acres. For the 116 colonies selected, 87 colonies were successfully accessed for ground truthing.

Eighty four (84) colonies classified as active in the aerial surveys and 3 classified as inactive were selected and visited for ground truthing subject to the requirement that they were accessible from public roads. Four of the colonies classified as active during aerial surveys did not have good access from roads and no mounds or live prairie dogs were detected. Of the 83 colonies with good access, there was agreement with the classification made during aerial flights. The 4 targets with no evidence of prairie dog colonies were found to have tall grasses present in the part of the feature that could be viewed from the ground.

<u>Potential BTPD colonies on all 8,790 grid cells in Wyoming</u>

In our census of grid cells, there was no “sampling error”; however, there was variance due to measurement errors, detection errors, and error in modeling the probability of detection. We accounted for these non-sampling errors by bootstrap sampling the entire census of 8,790 grid cells without replacement, as if we were to backup time and repeat the entire census effort. For each bootstrap sample we computed the estimated number and acreage of potential colonies corrected for false positives. We estimated the confidence intervals by the percentile method and the standard errors by computing the standard deviations of the sets of bootstrapped values for number and acreage of potential colonies (Table 2.2).

Table 2.2. Estimated acreage of total potential colonies, adjusted for false negatives, in the census of grid cells in Wyoming black-tailed prairie dog habitat were reported. Digitized potential colonies have been adjusted for false negatives and false positives.

	Features < 1,000 acres	Features > 1,000 acres	Total
Acreage of Potential Colonies	221,547	47,973	269,520
90% Conf. Intervals	[209,605; 240,131]	[31,830; 70,762]	[250,713; 300,125]
Standard Error	15,021	11,795	9,303
Coefficient Variation	6.8%	24.6%	3.5%
===================	==================	================	=========
Number of Potential Colonies	3,015	26	3,041
90% Conf. Intervals	[2,881; 3,154]	[18; 35]	[2,905; 3,181]
Standard Error	84	5	84
Coefficient Variation	2.8%	19.2%	2.8%

The sample survey of 1,722 grid cells from the total of 8,790 cells in Wyoming resulted in an estimate of 3,158 potential BTPD colonies totaling 288,606 acres with CV = 12.9% (Part 1, Tables 1.2 and 1.4), which compared favorably to the census value of 269,520 acres.

<u>Active BTPD colonies on all 8,790 grid cells in Wyoming</u>

Each time we selected a bootstrap resample of the 8,790 grid cells, we selected a bootstrap resample of the aerially surveyed 377 features less than 1,000 acres and of the 23 features greater than 1,000 acres, to generate bootstrapped values for the estimates of the total number and acreage of active colonies in Wyoming. We estimated the confidence intervals for number and acreage of active colonies by the percentile method and the standard errors by computing the standard deviations of the sets of bootstrapped values for number and acreage of potential colonies (Table 2.3)

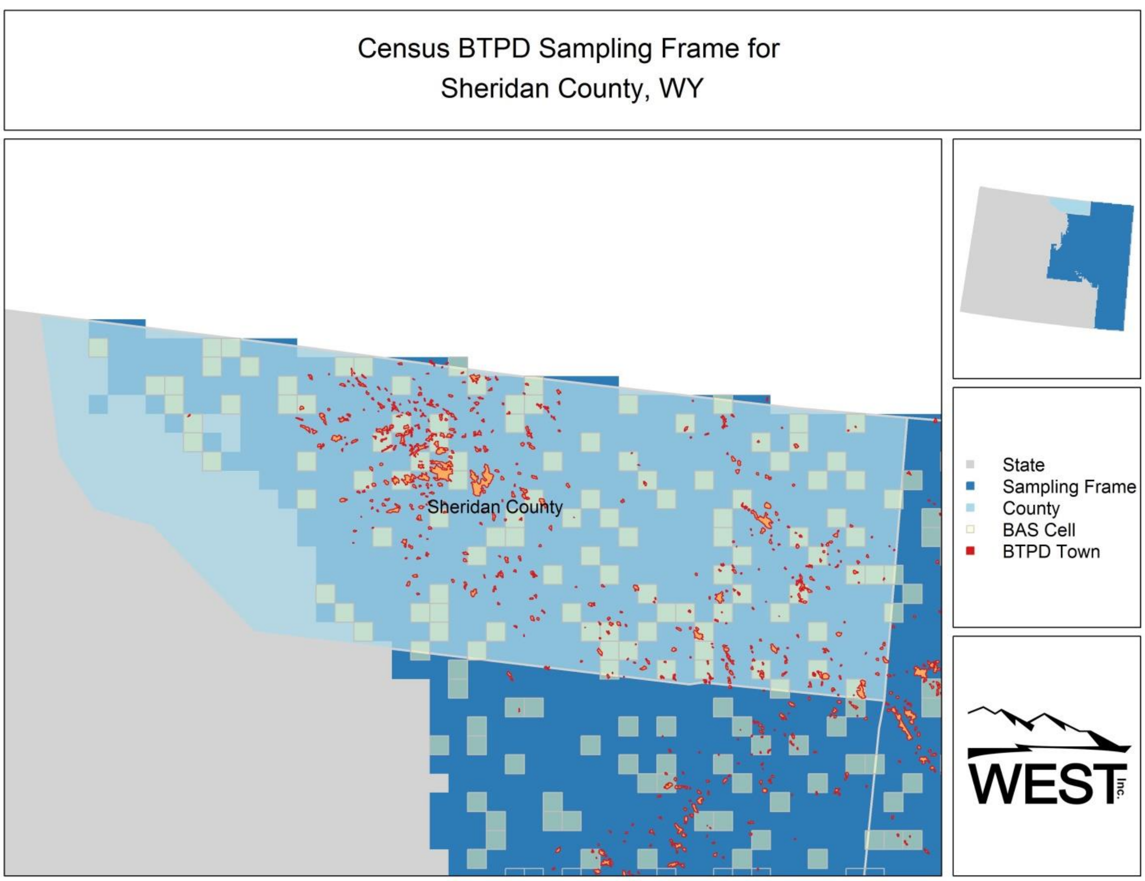
We stratified and estimated the acreage and number of features less than 1,000 acres and features greater than 1,000 acres in the census of grid cells in Wyoming. Adjusting for less than 100% probability of detection, measurement errors and detection errors, we estimated 3,041 (90% CL = [2,905; 3,181], CV = 2.8%) potential BTPD colonies totaling 269,520 acres (90% CL = [250,713; 300,125], CV = 3.5%) in Wyoming (Table 2.2).

We adjusted the number and acreage of estimated potential BTPD colonies based on the aerial survey of 400 features. We estimated 2,505 active BTPD colonies (90% CL = [2,356; 2,656], CV = 3.6%) in Wyoming totaling 216,166 acres (90% CL = [199,776; 242,419], CV = 4.1%) (Table 2.3).

Table 2.3. Estimated total numbers and acreage of active colonies in the census of grid cells in Wyoming black-tailed prairie dog habitat were reported.

	Features < 1,000 acres	Features > 1,000 acres	Total
Acreage of Active Colonies	182,777	33,389	216,166
90% Conf. Intervals	[170,975; 199,936]	[20,826; 52,051]	[199,776; 242,419]
Standard Error	13,107	9,584	8,798
Coefficient Variation	7.2%	28.7%	4.1%
===================	==================	================	=========
Number of Active Colonies	2,487	18	2,505
90% Conf. Intervals	[2,337; 2,637]	[11; 26]	[2,356; 2,656]
Standard Error	91	5	90
Coefficient Variaton	3.7%	27.8%	3.6%

Electronic maps will be made available to the State of Wyoming with the digitized features in each county. For example, figure 2.56, depicts the location of features detected and digitized in Sheridan County, Wyoming. These maps were created with sufficient resolution to be viewed in detail on a computer monitor.



DISCUSSION AND SUMMARY

Our objective was to develop an economical long term sample survey monitoring procedure for assessment of current status and future trends in range-wide numbers and acreage of black-tailed prairie dog colonies. The procedures included a sample survey of colonies on BLM managed lands and a census of black-tailed prairie dog habitat in Wyoming with aerial and ground surveys in Wyoming for "truthing" results. The census of cell in Wyoming was to serve as a pilot for potential future census work in the other states and for BLM lands.

Part 1 of the report contains the results of our sample surveys of 2 mile by 2 mile grid cells in each state, on BLM managed lands, and included a sample survey of cells in Wyoming that was compared to census results in Wyoming (Part 2). We searched sampled cells and digitized polygons around "features" judged to be potential colonies on the newest National Agriculture Image Program (NAIP) images available in each state. We adjusted our estimates for missed colonies (i.e., false negatives) by using two independent observers on a sample of grid cells and modeling the probability of detection of potential colonies. Our range-wide estimate based strictly on the sample surveys was 29,467 potential colonies totaling 1,932,826 acres. We estimated a total of 4,234 potential colonies greater than 100 acres in size and 419 greater than 500 acres in size.

Precision of the estimates for the entire range-wide 11 state totals were excellent with coefficients of variation of 2.4% and 4.9% for total acreage and number of potential colonies, respectively. The 90% confidence interval for acreage was [1,810,000 to 2,130,000 acres] and the 90% confidence interval for total number of potential colonies was [28,800 to 31,000 potential colonies] range-wide.

Precision of the range-wide estimated number of potential colonies greater than 100 acres was also excellent with coefficient of variation = 4.6% (90% confidence interval [4,000 to 4,650 potential colonies]). Precision of the range-wide estimated number of potential colonies greater than 500 acres in size was very good with coefficient of variation = 15% (90% confidence interval [349 to 544 potential colonies]). Unfortunately, our methods and sample sizes did not provide reliable estimates of the numbers of relatively rare potential colonies greater than 1,000 acres or the number greater than 5,000 acres, because detection of these large colonies within individual states were very rare events.

We conducted a sample survey of grid cells from each state and for BLM lands. The bottom line was that searching about 1,000 grid cells produced statistical estimates that were stable and precise (coefficients of variation < 15%) for number and acreage of potential colonies adjusted for missed features, except for Kansas and North Dakota. In those cases, a large number of cells had no detected potential colonies with the occasional cells containing large acreage or numbers resulting in high variance relative to the other states. We searched 1,078 cells in Oklahoma and 2,422 cells containing BLM lands and to achieve marginally acceptable coefficients of variation of 16% and 18%, respectively.

The estimates of abundance and acreage of potential colonies were most likely biased underestimates of the population totals. We base this conclusion on four observations. First, WEST's observers and South Dakota Department of Game, Fish and Parks' observers independently searched the same sample of grid cells in South Dakota. South Dakota's observers also consulted maps of features from previous NAIP images and detected more small features than WEST observers did. The estimated acreage derived from South Dakota's effort was 21% larger than the WEST estimate. Second, our corrections for the proportion of small potential colonies missed depended on the assumption that each member of the team of independent observers obtained a random sample of features present, specifically a random sample of small features. There were likely small features that were essentially invisible in the sense that they did not trigger the observer's search image for a colony. Third, the first author (McDonald) participated in the spring 2015 range-wide lesser prairie-chicken survey in Texas County, Oklahoma, flying in a helicopter at 25 meters elevation. Groups of 3 to 5 mounds with live prairie dogs were observed. Such "colonies" would be difficult to detect on NAIP one-meter resolution images. Fourth, two of the small known colonies in Arizona were in the sampled cells. We miss both of them. We estimated that an individual WEST observer detected 70% to 80% of small features in each state and corrected for missing features; however, these estimated detection rates were likely too high for small features resulting in a biased underestimate of the total acreage and numbers of potential colonies.

The first time that a long-term sample survey monitoring program is implemented, interest is primarily on accuracy and elimination of bias in survey methods. If the program is repeated in the future using the same methods and biases on the same sampled units, interest switches to changes and trends in the population estimates. We believe our sample survey estimates in Part 1 were biased underestimates of the numbers and acreage of potential colonies; however, if repeated with the same methods and training of observers, correct conclusions would be drawn regarding changes and trends in population statistics.

There was interest not only in estimation of the total numbers and acreage of potential colonies present, but also the numbers and acreage of large potential colonies (e.g., colonies greater than 1,000 acres and greater than 5,000 acres). This introduced a major problem within the individual states, because large potential colonies were very rare. The detection of even one 5,000 acre feature in, for example, Kansas increased the total estimated number and acreage of 5,000 acre features in Kansas by a multiplication factor of about 10, because we searched about 10% of the grid cells in Kansas. That is, the estimated total number and acreage of all features greater than 5,000 in Kansas would jump by as much as 50,000 acres, depending on the statistical method used.

We detected 4 potential colonies that were greater than 5,000 acres in size in the sample surveys of 11 states. We detected 42 potential colonies that were greater than 1,000 acres (including the 4 greater than 5,000 acres). However, none of the centroids of the 5,000 acre potential colonies were in a sampled cell and several of the centroids of the 1,000 acre potential colonies were not in a sampled cell. Consequently, the centroid method would estimate no potential colonies greater than 5,000 acres exist in the 11 states when in fact we detected 4. The centroid method was not reliable for estimation of the number of these large potential colonies.

Because of interest in acreage of large, rare potential colonies, this was the most difficult estimation problem that the first author (McDonald) had encountered in his practice of designing and analyzing environmental studies for rare events. We judged that the state and range-wide estimates of numbers and acreage of features greater than 1,000 and greater than 5,000 acres were unreliable and we did not report them. We reported estimates of the abundance of potential colonies greater than 100 acres and greater than 500 acres within each state. The precision of the estimates of features greater than 100 acres were in an acceptable range within the individual states, however the estimated numbers of potential colonies greater than 500 acres had coefficients of variation too large to be useful in some states.

The sample survey results for number and acreage of potential colonies include “false positives,” i.e., some digitized features were not prairie dog colonies. We searched all grid cells in Wyoming and corrected for false negatives using the same methods as in the other states. We conducted aerial and ground surveys of digitized features and corrected our estimates for false positives to estimate the number and acreage of active colonies in Wyoming. There was perfect agreement between aerial and ground surveys for classification of prairie cog colonies as active or inactive on colonies that had good access on the ground.

The flagship for our pilot monitoring program was to be the census of grid cells in Wyoming with: 1) double sampling on a sample of cells to develop correction factors for false negatives, and 2) aerial and ground surveys to “truth” the results and correct for false positives. Results of the census (Part 2) were compared to results of a sample survey (Part 1) and the estimates of potential colonies, corrected for false negatives, were very close. Unfortunately, the latest NAIP images for Wyoming were from the early summer of 2012, taken during one of the worst droughts on record. While it was possible to correct for missed potential colonies, the images were very poor quality with little vegetation to help detect potential colonies. Correction factors from the aerial surveys were large. In hindsight, we should have stopped work on the 2012 images, saved WAFWA and Wyoming’s funds and waited for 2015 images. Better products would have been obtained.

RECOMMENDATIONS

<u>Recommendation</u>. Methods and training of observers should be standardized as much as possible in future sample or census surveys. If results of future surveys are to be compared to results in this report, methods and training of observers should be as consistent as possible with our methods and training. Training of observers should include “blind” observation of grid cells containing known small colonies to improve search images for small features.

<u>Recommendation</u>. Future sample surveys for monitoring long-term trends should use two independent observers on all cells in a sample of at least 1,000 grid cells from each state and from the cells containing BLM lands. The probability that potential colonies will be missed by two independent observers was very small and the corrections for missed features were small providing robust estimates of statistics.

<u>Recommendation</u>. Sample sizes used in this pilot study were adequate except for Kansas, Oklahoma, North Dakota and BLM managed lands. In those cases, simulation exercises using data from this study should be conducted to estimate sample sizes necessary to achieve coefficients of variation below 15%.

<u>Recommendation</u>. If the objective in future sample surveys is to detect statistically significant trends or abrupt changes as early as possible; then, the same probabilistic sample of grid cells should be searched. After sample surveys are conducted two or three times, WAFWA or state wildlife agencies might consider implementing rotating panel designs where some cells are dropped and new ones are added each time a survey is conducted.

<u>Recommendation</u>. Viewing features using very high resolution Google earth images should be implemented as an aid in judging whether a feature detected on NAIP images was a potential colony. Burrow openings were clearly detected using very high resolution 2013 and 2014 Google earth images of features judged to be active or inactive colonies during 2015 aerial surveys of features in Wyoming. Unfortunately, some mounds in ant colonies have a dark spot which can be confused with prairie dog burrow openings when viewed on Google earth in Wyoming.

Recommendation. If aerial surveys are conducted to observe a sample of digitized potential colonies, the same sample of potential colonies should be searched by different observers using Google Earth without knowledge of the aerial results, i.e. searched "blind." Aerial and Google Earth search results should be compared to determine if "Google Earth truthing" can be substituted for "aerial truthing" in some states.

Recommendation. Implement aerial survey of a sample of digitized potential colonies regardless of sample survey or census of grid cells in a state. Classify colonies as active, inactive or null (not black-tailed prairie dogs) and estimate the number and acreage of colonies classified as active, regardless of whether the study is a census or sample survey of grid cells.

Recommendation. For study of trend in numbers of large potential colonies within the states use the number of potential colonies greater than 100 acres. The estimated number of potential colonies greater than 500 acres was a reliable statistic for study of trend in range-wide abundance.

Recommendation. Establish a baseline for long-term monitoring of abundance and acreage of potential colonies by searching all grid cells in a state one time. After the first census wide survey for distribution of colonies and large features, increasing or decreasing trends can be based on sample survey results. If a census of cells is conducted, a sample of at least 1,000 grid cells should be searched by two independent observers and the results reconciled to train observers, establish or "re-calibrate" search images on new NAIP images, and allow estimation of the probability that features will be missed by a single observer on the rest of the cells.

Recommendation. Include all potential colonies greater than 1,000 acres in aerial truthing exercises. In our census of grid cells in Wyoming, we stratified the features into potential colonies less than 1,000 acres and potential colonies greater than 1,000 acres. We surveyed 23 of the 27 features greater than 1000 acres from the air. In retrospect, we should have flown to all 27, because survey of only 23 introduced a small sample of 27 and relatively high variance into the procedures for estimation of the number and acreage of active colonies.

Recommendation. Future sample or census surveys using our methods should not be conducted on NAIP images collected during severe drought.

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APPENDIX A

Standard Operating Procedure:

Digitizing potential black-tailed prairie colonies using NAIP imagery

National Agriculture Imagery Program (NAIP) Images and Sampling Grid

The study area consisted of the estimated current range for black-tailed prairie dogs (BTPD) as defined by the Wildlife Departments in the 11 states containing BTPD habitat (Figure C.1, repeated from Part 1). We clipped the latest NAIP imagery available for each state to the study area. For example, the estimated current range for BTPD covered the 12 most eastern counties in Wyoming. National Agriculture Imagery Program (NAIP) images were the choice for the study area because they were at least one square meter resolution, inexpensive, and were replicated on a three year or more often rotation.

The digitizers used the latest version of ArcGIS (ArcMap10.2.2) to conduct the GIS work in this study. In order to keep a consistent geometry across the western United States, we chose to apply the continental projection. The USGS version of this projection, USA Contiguous Albers Equal Area Conic, sets the projection of the entire project.

Using ArcMap, we generated an MXD file for digitizers to use as a template throughout the entire study area. In each state, we constructed a sampling frame that consisted of 2 mile by 2 mile grid cells to overlay the NAIP imagery. Observers systematically searched selected cells to detect potential BTPD colonies, dubbed “features” for brevity. We created a smaller mini-grid system within each 2 by 2 mile grid cell. Each 2 by 2 mile cell contained 5 rows and 5 columns for a sum of 25 smaller cells for digitizers to search. The smaller grid system allowed full coverage of selected 2 by 2 mile cells and helped assure that no area was overlooked in selected grid cells. Observers viewed the cells of the mini-grid at a scale of approximately 1:4000.

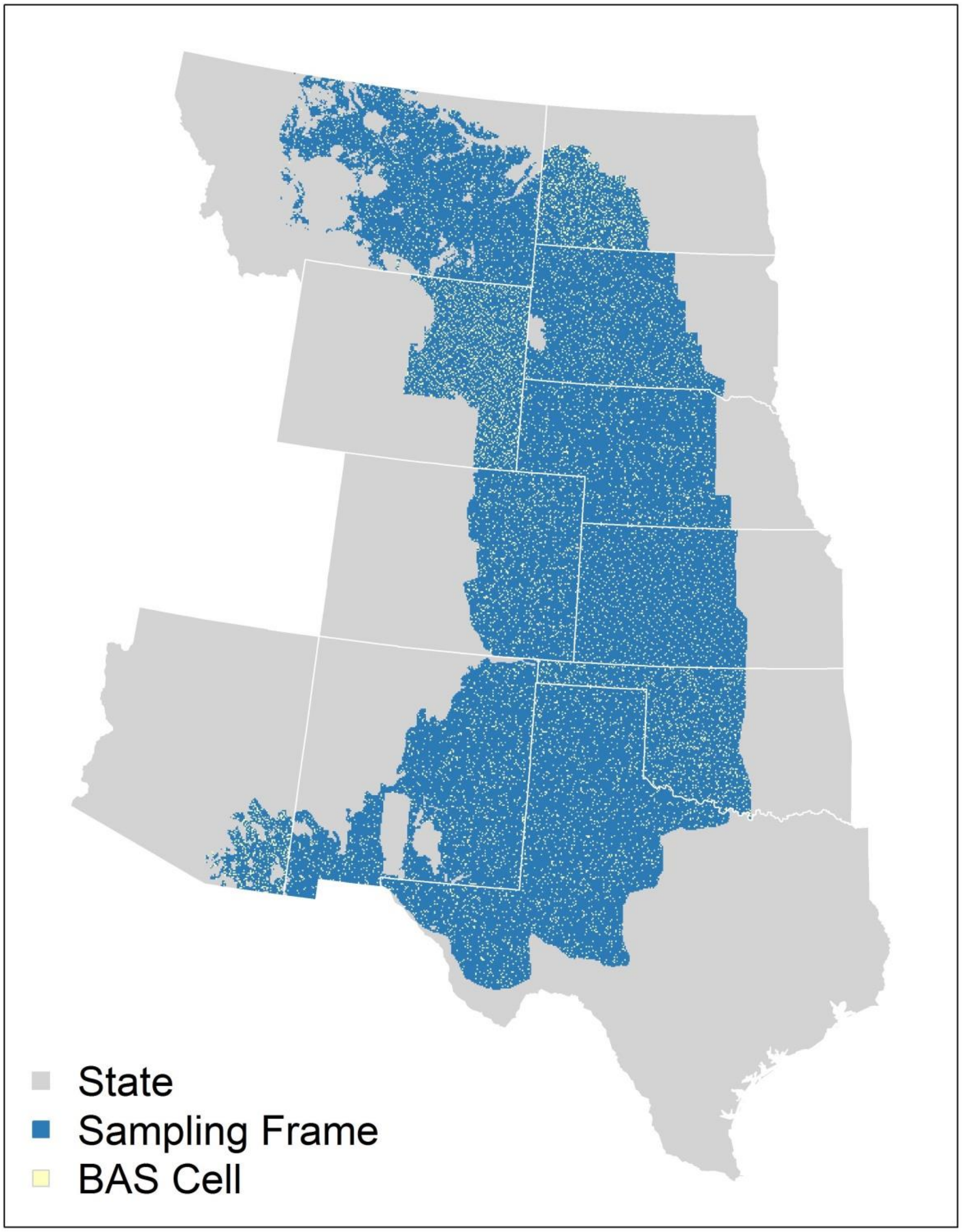

Figure 1 (Part 1). Study area for the range-wide monitoring of black-tailed prairie dogs using NAIP imagery. Sample grid cells were selected by a probabilistic random procedure known as Balanced Acceptance Sampling (BAS).

Methods for Selection of a Sample of Grid Cells

We ranked the grid cells in the study areas for each state by an equal probability sampling procedure known as Balanced Acceptance Sampling (BAS, Robertson et al. 2013). Cells selected by the BAS procedure represent a spatially balanced sample of grid cells such that any contiguous subset, when taken in order, was an equal probability sample of the target population.

We digitized potential BTPD colonies that overlapped a sample of grid cells in each state. Features were digitized by "connecting the dots", i.e., connecting the outer most mounds and burrows in a potential colony. Using two independent observers on a sub-sample of cells, we were able to model and estimate the probability that an observer will miss a potential colony of a given size (see Methods, Part 1). All grid cells were selected with equal probability by following the rank order in the original BAS list for a state.

Observer Training

Possibly the most difficult aspect of training new observers was helping them to develop their search image of prairie dog colonies on NAIP imagery. In many of the areas searched by WEST, Inc., prairie dogs were likely to occur in the same areas as ants or ground squirrels and could easily blend in with the surrounding landscape. As ant colonies can be quite large, it was important that observers learn to distinguish between them. During training, prairie dog colonies were described as small, raised, white mounds in the landscape. The observers then learned to refine that general image with help from example images, other observers, contextual cues, and other imagery sources.

As part of training, observers were required to participate in reconciliation of their independently digitized results with a partner. Observers were assigned the same cells as their partner, but they searched and digitized those cells independently. When completed, they met, compared polygons, and finalized how the feature would be digitized (see section, Double Sampling with Independent Observers).

One important objective in reconciling results was to help observers develop "search images" for features by communicating why they decided to digitize or not digitize a feature as well as observe features others choose to digitize. By explaining their process, observers refined their search images. The objective was for observers to develop consistent and similar search images.

Images of confirmed prairie dog colonies, ant colonies, and ground squirrel colonies were used in the training (see section, Images used in Training). Observers were given images to reference while conducting their searches. While prairie dog colonies vary in appearance, there were a few key features that observers checked for. Such features included mounds, burrow openings, trails between mounds, and a clip line in the surrounding vegetation.

Digitizing in Kansas, South Dakota, Colorado, Oklahoma, North Dakota and Wyoming was completed using two observers and independent double sampling and reconciliation. After those states were completed and observers had obtained consistent search images, digitizing in Montana, Arizona, New Mexico, Texas, and Nebraska was completed using only single sampling. The survey on BLM managed lands was also completed using one observer.

Double Sampling with Independent Observers

Sub-samples of grid cells were selected and interpreted by two independent observers. The observers searched the same set of randomly generated cells and digitized "features" defined as potential prairie dog colonies. The observers searched each selected 2 mile by 2 mile cell starting in the northwest corner and worked their way to the southeast corner scanning the cells of the mini-grid one at a time. For approximately half of the units that each team interpreted, one observer (1-A) was designated as the primary observer. For the other half of the units, the other observer (1-B) was designated as the primary observer.

When an observer found a potential prairie dog colony, they digitized the feature perimeter at their discretion. Observers zoomed in and out depending on the area that they were in and the feature to be digitized. Digitizing was done at a scale no larger than 1:4,000, It was suggested to digitize features at a scale of 1:3,000 to achieve the most accurate values for acreage. The observers used a "connect the dots" method to connect the outermost burrows that could be identified on the NAIP imagery (Sidle et al. 2002). For some colonies, visible clip lines were observable to help identify the outer most burrows. However, in order to be consistent and to produce the most comparable results through time, digitizers were instructed to not digitize a colony perimeter by following the clip line.

Original features digitized by an observer were recorded in an original shapefile and post-reconciliation features were recorded in a reconciliation shapefile. With these different sets of shapefiles, we were capable of comparing the sizes of original and reconciled features.

Observers were instructed to digitize the entire perimeter of the potential colony that overlapped the assigned grid cell. Even in situations where the centroid of the polygon did not belong to the cell assigned, the observer still digitized the entire potential colony. The same protocol applied when an observer found a potential colony with a centroid that lies within another state in which they were not working in at the time.

During the process of digitizing, observers within each team were also responsible for recording unique identification names for detected features in a spreadsheet and syncing information from those spreadsheets to the values in the attribute table for each of their shapefiles. After an observer digitized a potential colony, they recorded the appropriate values in the spreadsheet. In ArcMap, they also edited the attribute table for each feature that they digitized. The observer assigned a town ID to potential colonies when the centroid of that colony fell within an assigned cell. For example, if an observer found two potential colonies within the grid cell WY078456 and assigned each a town ID. They assigned the first colony the town ID of 1 and the second colony the town ID of 2. For each cell, the town ID reset and starts at 1 while the grid ID remains constant as a unique identifier for each of the 2 by 2 mile cells. Observers also recorded other data such as which observer found which colonies and which observer failed to find a given colony. Observers used the centroid finder function in the Arc toolbox to identify the unique cell containing the centroid of a feature.

Positive and negative outcomes arose during the reconciliation period. The optimal scenario occurred when both observers found and digitized the same feature in an assigned cell or when they agreed that no features were present. If features were present, the primary observer placed the shapefiles into the MXD file. Together, the two observers discussed each feature and made decisions about the size and shape of the potential colony in question. To obtain the "reconciled" feature, the primary observer re-digitized the feature while the secondary observer was present.

Another scenario occurred when one observer found and digitized a feature missed by the other team member. In this case, the observers discussed the feature in question and made the decision whether it was a potential colony or not. When observers decided it was a potential colony, the primary observer was responsible for "re-digitizing" the reconciled feature while the secondary observer was present. The observers deleted features they decided were not potential colonies.

Bureau of Land Management Survey

In addition to the Wyoming and range-wide surveys, WEST, Inc. also conducted a survey of Bureau of Land Management (BLM) land in Arizona, Colorado, Montana, North Dakota, Nebraska, New Mexico, South Dakota, Texas, and Wyoming (see Methods, Part 1). Observers digitized features that intersected BLM managed land and continued to digitize the entire feature regardless of how far it expanded.

Google Earth Use

Google Earth was a useful tool for digitizers while they were searching and developing their search images. It was also helpful in resolving disagreements during reconciliation of survey results collected by two independent observers.

Use of Google Earth remained an option for use when questionable features were detected on the NAIP images and observers were encouraged to use Google Earth imagery throughout the surveys. When an observer found a potential colony in NAIP imagery while digitizing, they could optionally look for the feature in Google Earth to confirm their decision to digitize the potential colony. With Google Earth, observers were usually able to zoom in on the questionable feature to look for distinct burrow openings, paths between burrows, and clip lines, which may not have been visible on NAIP imagery.

Images used in training

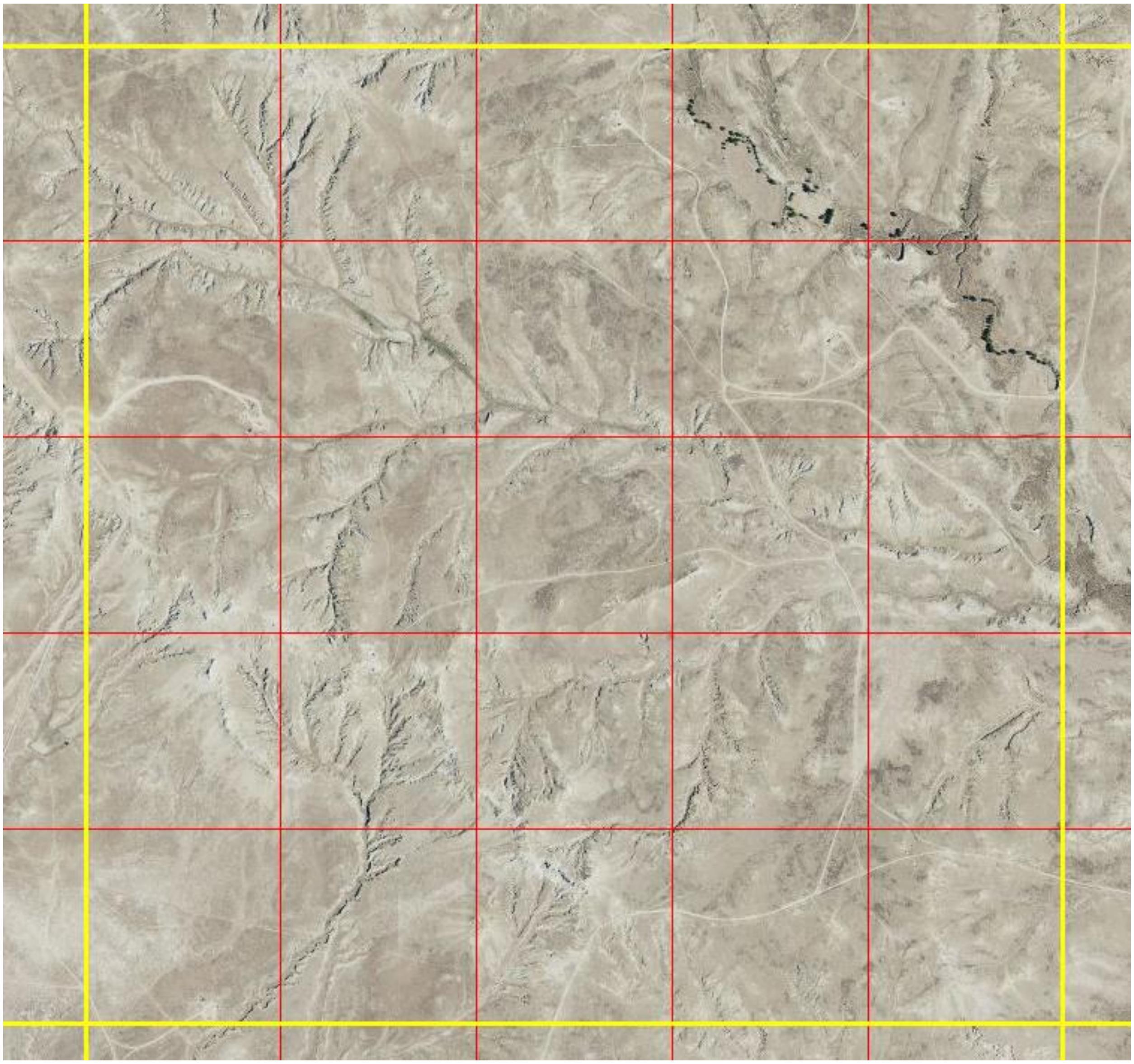

Figure A1. In all surveys, observers used a combination of 2 x 2 mile grid cells (yellow) and smaller mini-grid cells (red) to search for potential prairie dog colonies. Grid cells had unique identification names and were searched for features. Digitized features were given unique names identifying the grid cell and features associated with the cell. Mini-grid cells were used for navigation within the grid cell and to help insure that all parts of the cell were searched. Observers digitized an entire prairie dog colony, even if it extended beyond their assigned grid cell.

Figure A2. A digitized potential black-tailed prairie dog colony. Identifying mounds was difficult in this landscape. The observer was able to use the “connect-the-dots” method on this 2012 NAIP image in Wyoming. When using this method, the observer digitized the outline of the colony by connecting the outer most mounds, rather than following a clip line. Aerial truthing confirmed this feature to be a black-tailed prairie dog colony.

Figure A3. Observers were able to confirm digitized colonies using Google Earth. The above image was the same colony as Fig. A2. Due to a much higher resolution, mounds, burrows, and trails between mounds were more frequently visible in Google Earth than in the 2012 NAIP imagery.

Figure A4. Though some small, white dots were visible on this 2012 NAIP image of Wyoming, there were no visible wear patterns or clip lines so it was judged that this was not a potential black-tailed prairie dog colony.

Figure A5. This figure shows a small segment of the area in Figure A4 viewed in Google Earth. In this image, it was more apparent that paths between burrows and clip lines were not present. This feature was judged to be a colony of ants or a very old prairie dog colony. Unfortunately, as was the case in this image, dark spots appear on Google Earth images of ant mounds and can be confused with black-tailed prairie dog burrow openings.

Figure A6. Google Earth image of a large ant colony in central Wyoming. Although dark spots were visible on the mounds, the mounds were judged to be too small for a black-tailed prairie dog colony and there was no other evidence of the presence prairie dogs.

Figure A7. In areas with developed land and rectangular property lines, prairie dog colonies can also take on rectangular shapes. The owner of this property in Kansas may allow black-tailed prairie dog to remain on selected areas.

Figure A8. In developed agricultural areas, ants will often colonize old cultivated fields and between pivot-irrigated fields. Though they had a similar appearance to prairie dog colonies, anthills often had much smaller mounds. Unfortunately, anthills often have a dark spot on the mound when viewed using Google Earth. The above image was not included as a feature, as it was most likely an ant colony.

Figure A9. Roads often intersect prairie dog colonies and potentially split a large colony. Depending on the size of the colony, the type of road and how close the mounds were to the road, digitizers may break up the colony into smaller colonies. In this image, the observer digitized the mounds as one entire prairie dog colony. This was due to mounds present right up to the road and immediately on the other side which indicates that prairie dogs were moving across these roads. Large roads such as interstate highways were considered to be barriers to significant black-tailed prairie dog movement.

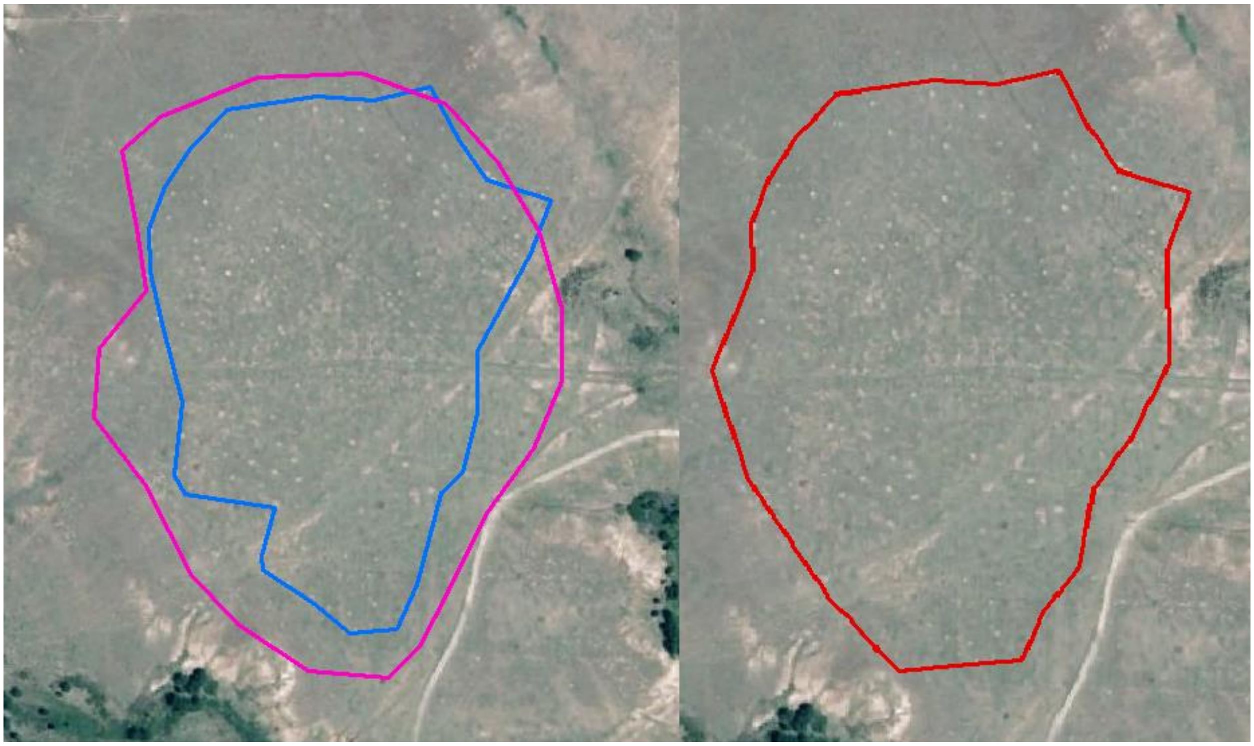

Figure A10. During training and independently digitizing features, observers compared their digitized features and reached an agreement on how the feature should be enclosed. When digitizer pairings were consistent with each other, only minor changes needed to be made. In the above images, the independently digitized features were shown on the left and the post-reconciled feature on the right.

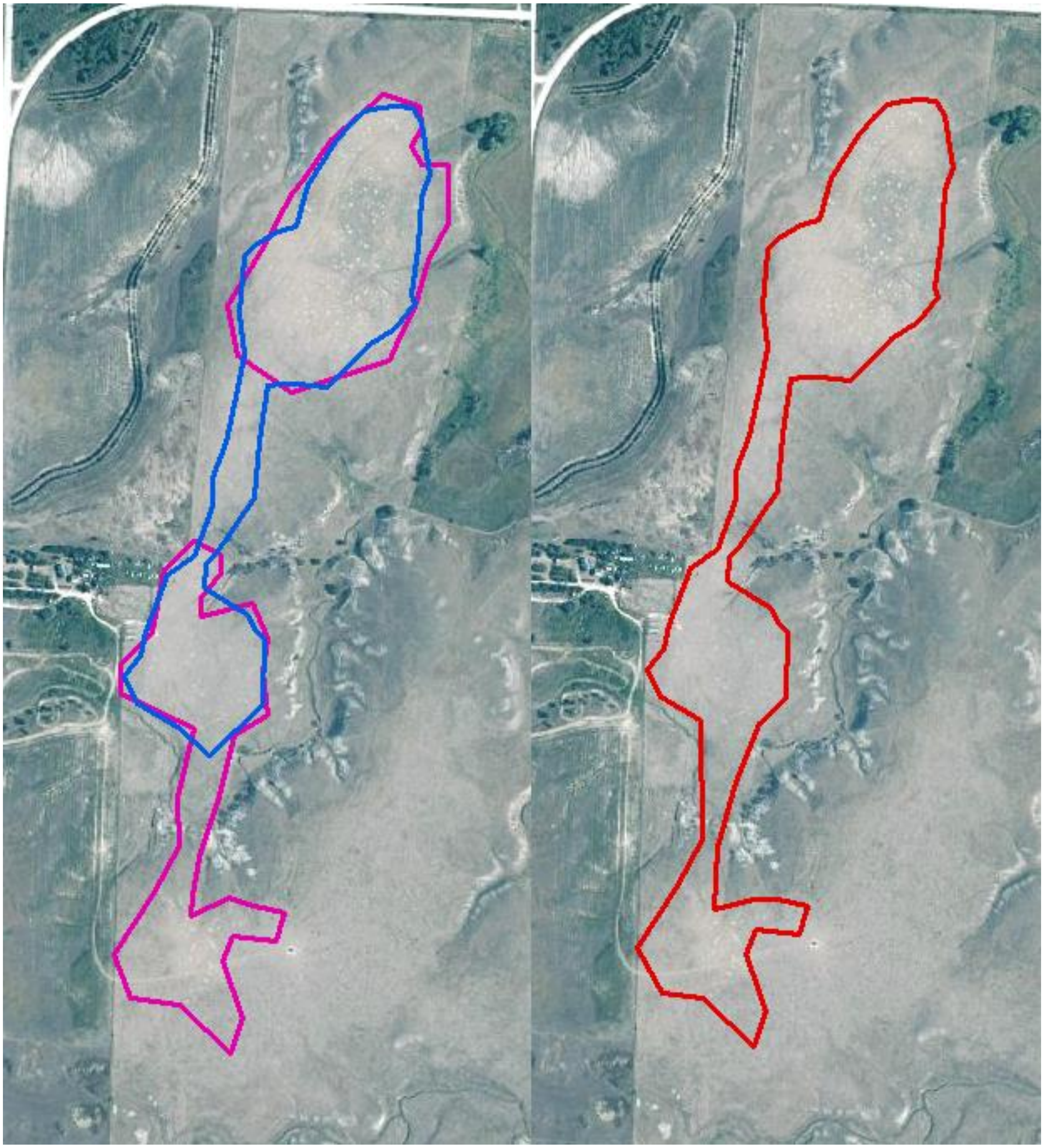

Figure A11. When observers were not consistent with each other, they needed to make modifications to their features to come to an agreement. While the observers digitized the same areas in this image, one drew it as a single feature while the other split it into separate ones. The post-reconciling image on the right reflects the decision to connect them into a single feature.

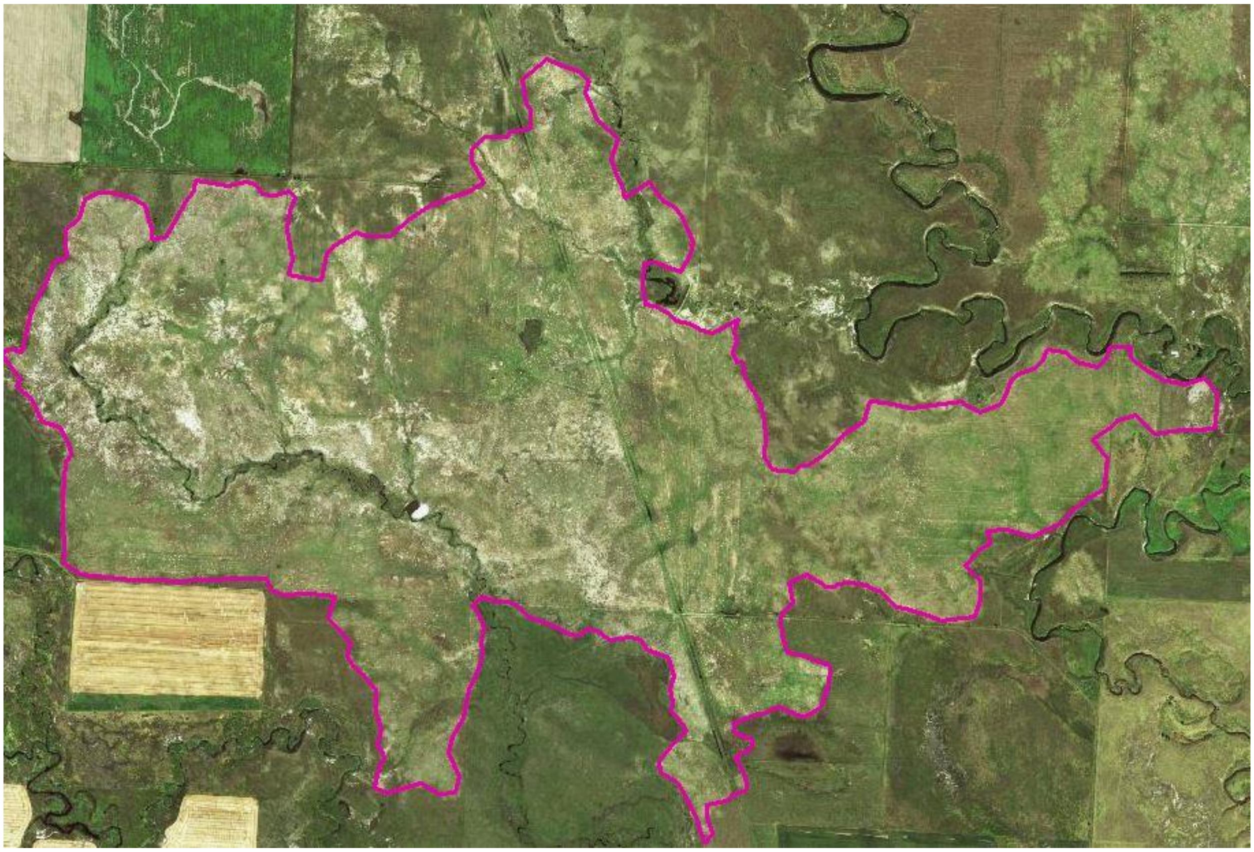

Figure A12. For this large potential colony in South Dakota, the presence of a prairie dog town was evident by the difference in vegetation color. Compared to the imagery available in Wyoming, South Dakota towns were easier to identify. Observers were required to keep in mind regional differences and drought conditions as they digitized.

Figure A13. A close up of an area in the previous image (Fig. A12). Mounds, burrows, and some trails were visible in Google Earth. This image was from a different date than the NAIP imagery. It was captured in September 2011 while the NAIP imagery was captured during the summer of 2014. Such a difference in time can yield discrepancies in what was visible, but the images also often corroborated each other. In this example, because it was later in the season and it was drier, less vegetation was present.

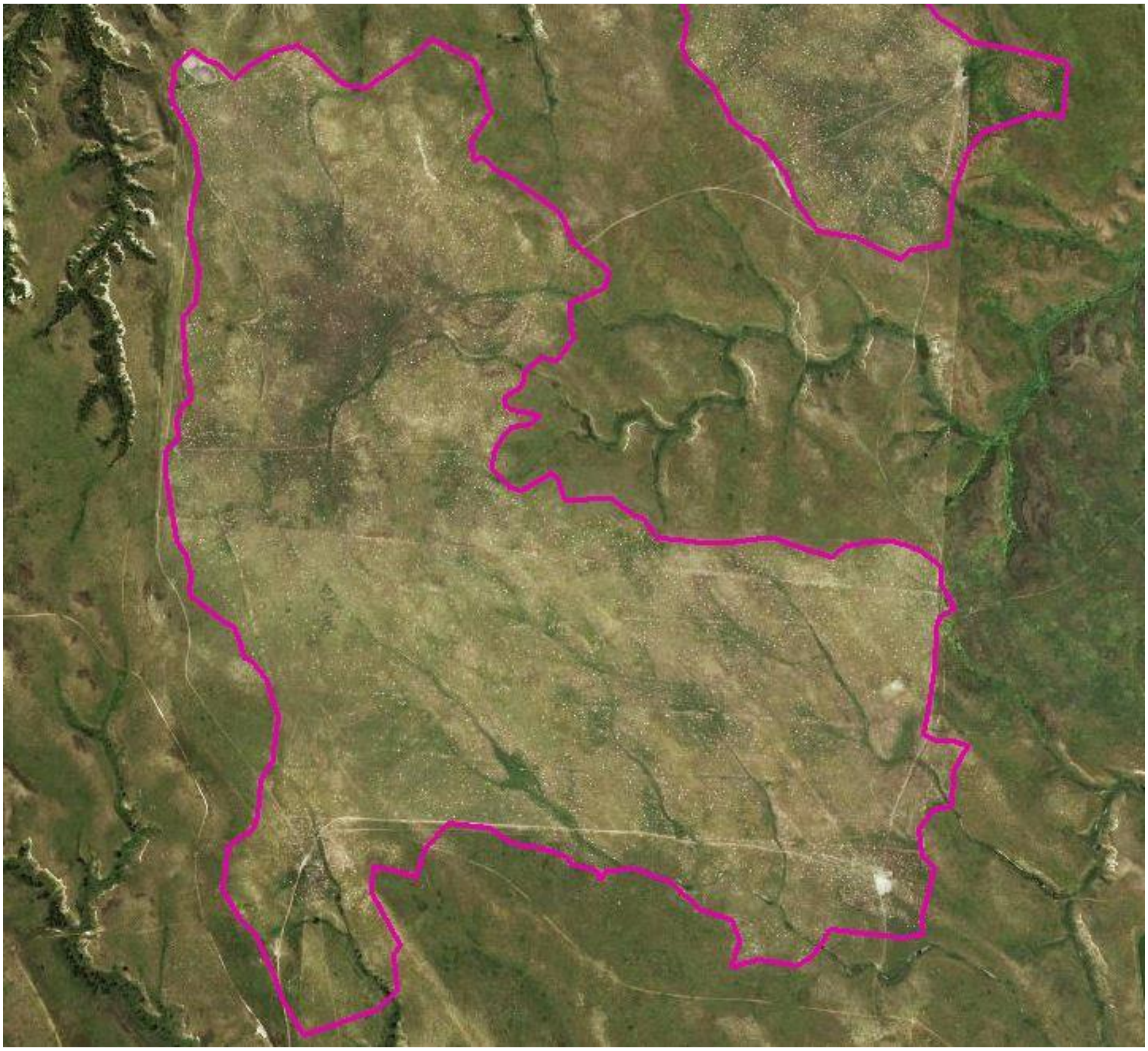

Figure A14. While the protocol for observers was to draw the colony by connecting the outermost mounds, a clip line was useful in identifying a potential black-tailed prairie dog colony. Mounds, a wear pattern, and a clip line were visible in this image from South Dakota. Wear patterns were created by prairie dogs moving between burrows; often creating paths in between them and were often visible when using Google Earth.

Figure A15. Another regional difference that observers needed to be aware of was the presence of agricultural land. Hay bales, as in this image, looked like mounds but will often cast a shadow and follow systematic patterns.

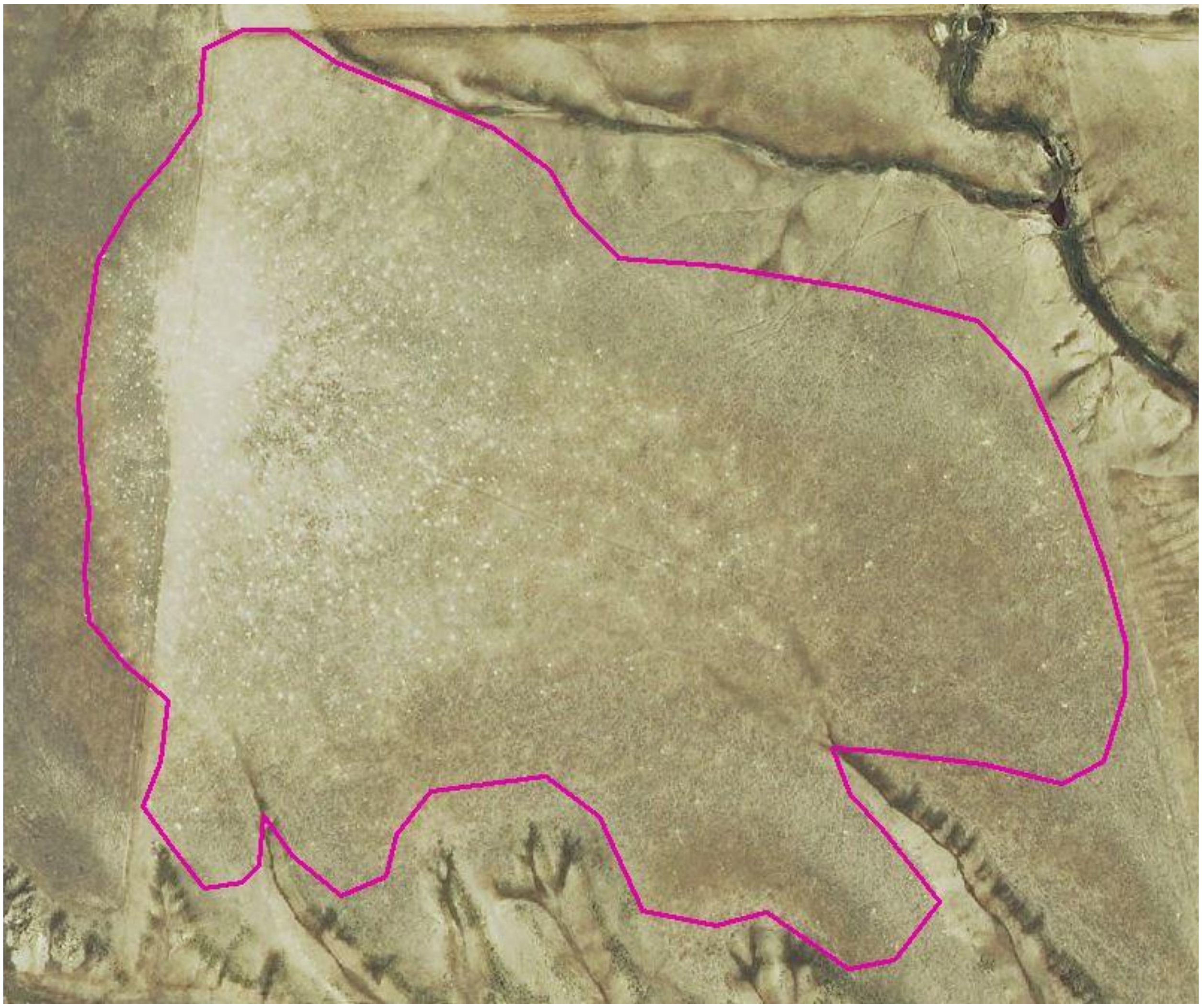

Figure A16. Prairie dog colonies often had similar patterns such as a concentrated area of mounds near the center with more dispersed mounds in the surrounding area. The wear patterns and trails between mounds were more visible near the center in this Colorado image. Ant colonies did not exhibit this pattern.

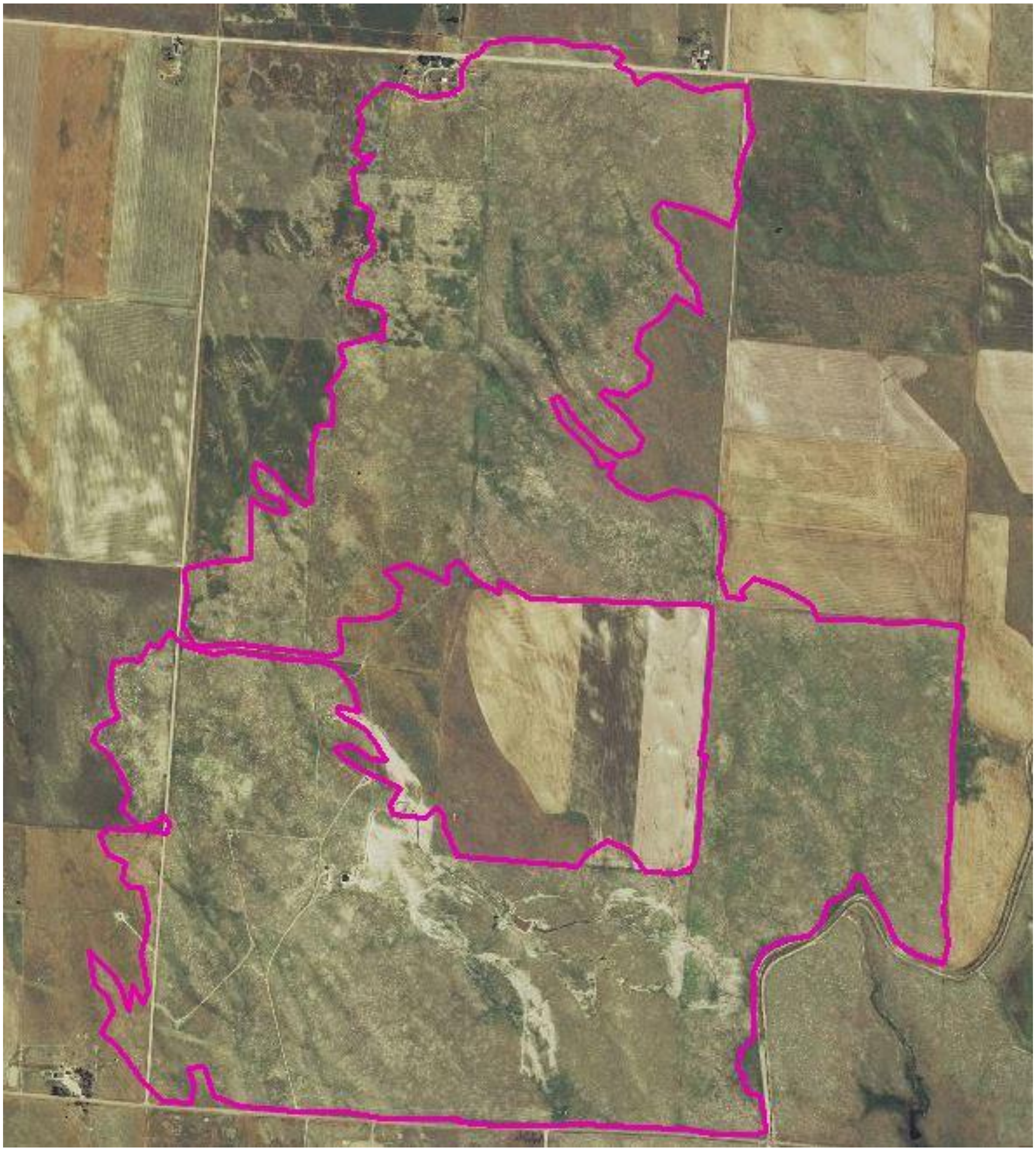

Figure A17. Odd, large shaped colonies often appear around areas of developed agricultural land. In this Colorado image, the observer digitized a feature that surrounds a smaller plot of farmland. These instances can occur due to land owners differences and whether or not they choose to remove prairie dogs from their land.

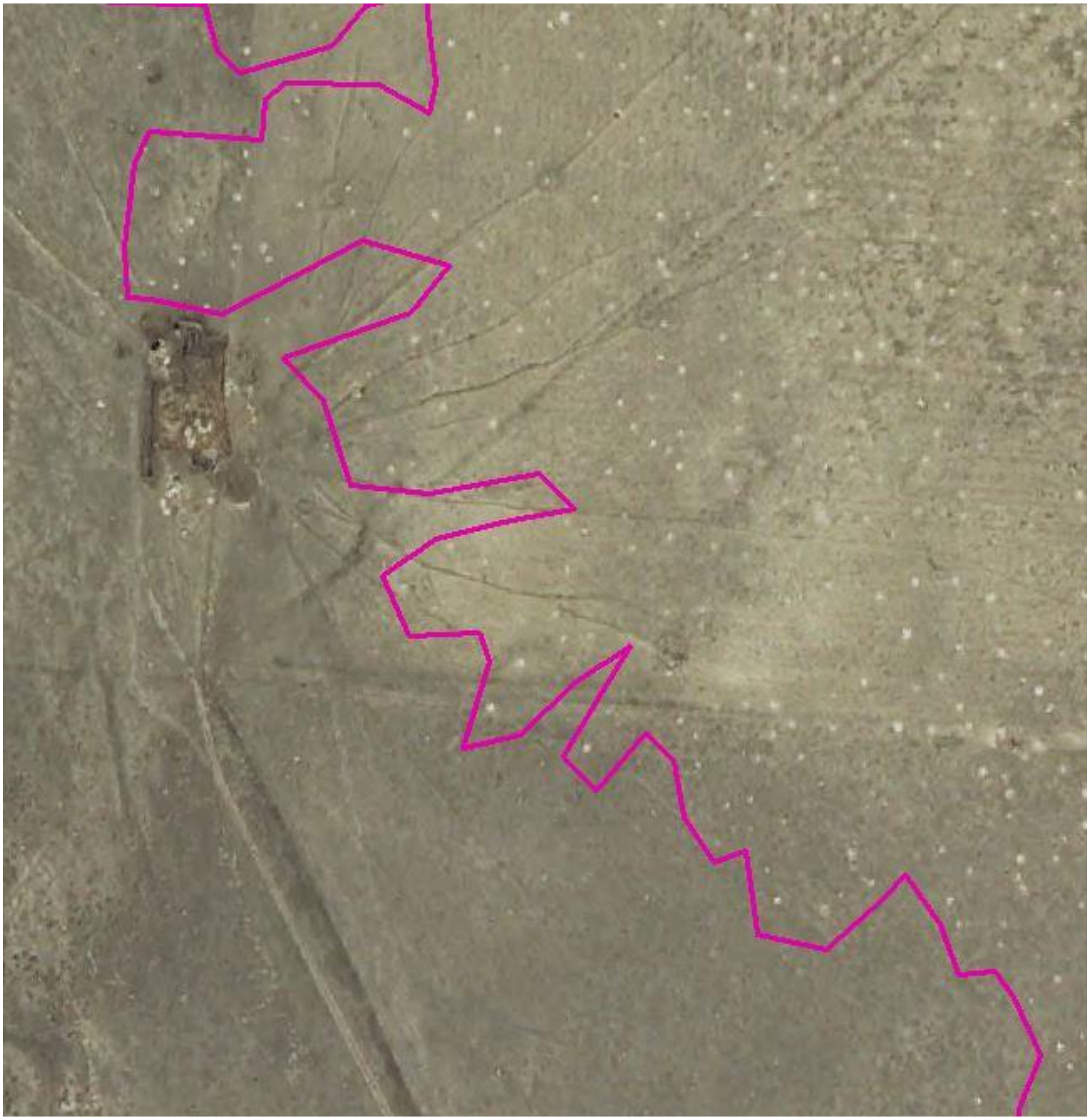

Figure A18. When digitizing, observers were instructed to connect the outermost mounds visible on the NAIP images, regardless of what might be visible using Google Earth.

Figure A19. Drought and landscape made digitizing difficult in some areas. In this image, observers used their best judgement to determine where the outermost burrows were on the NAIP imagery. Although observers were to digitize on the NAIP imagery, Google Earth helped determine the extent of the potential colony.

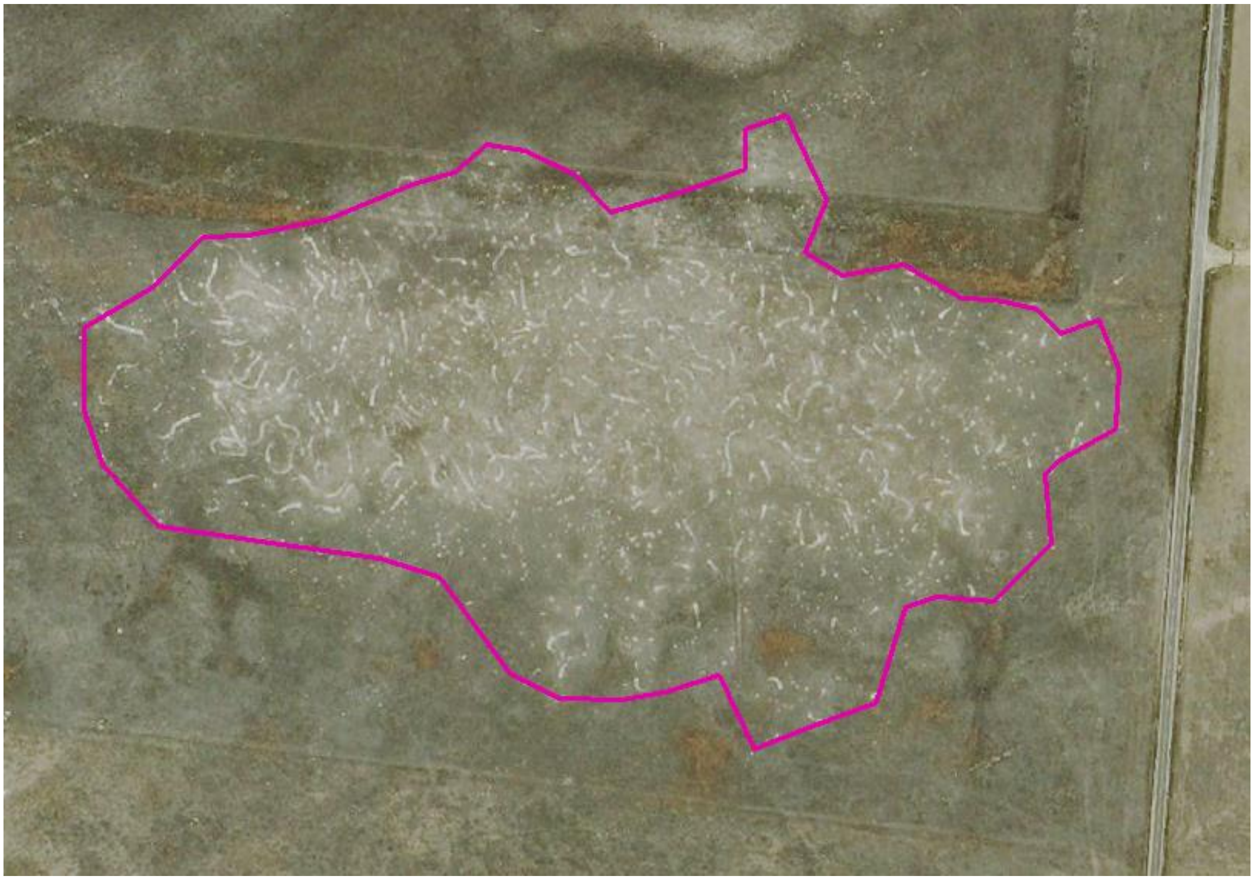

Figure A20. Unusual features were sometimes encountered. This feature was judged to be a potential black-tailed prairie dog colony, perhaps inhabited by black-footed ferrets with visible trenches.

Figure A21. This image shows a close-up in Google Earth of the potential black-footed ferret colony from the previous image, A20. Both images were from 2013.

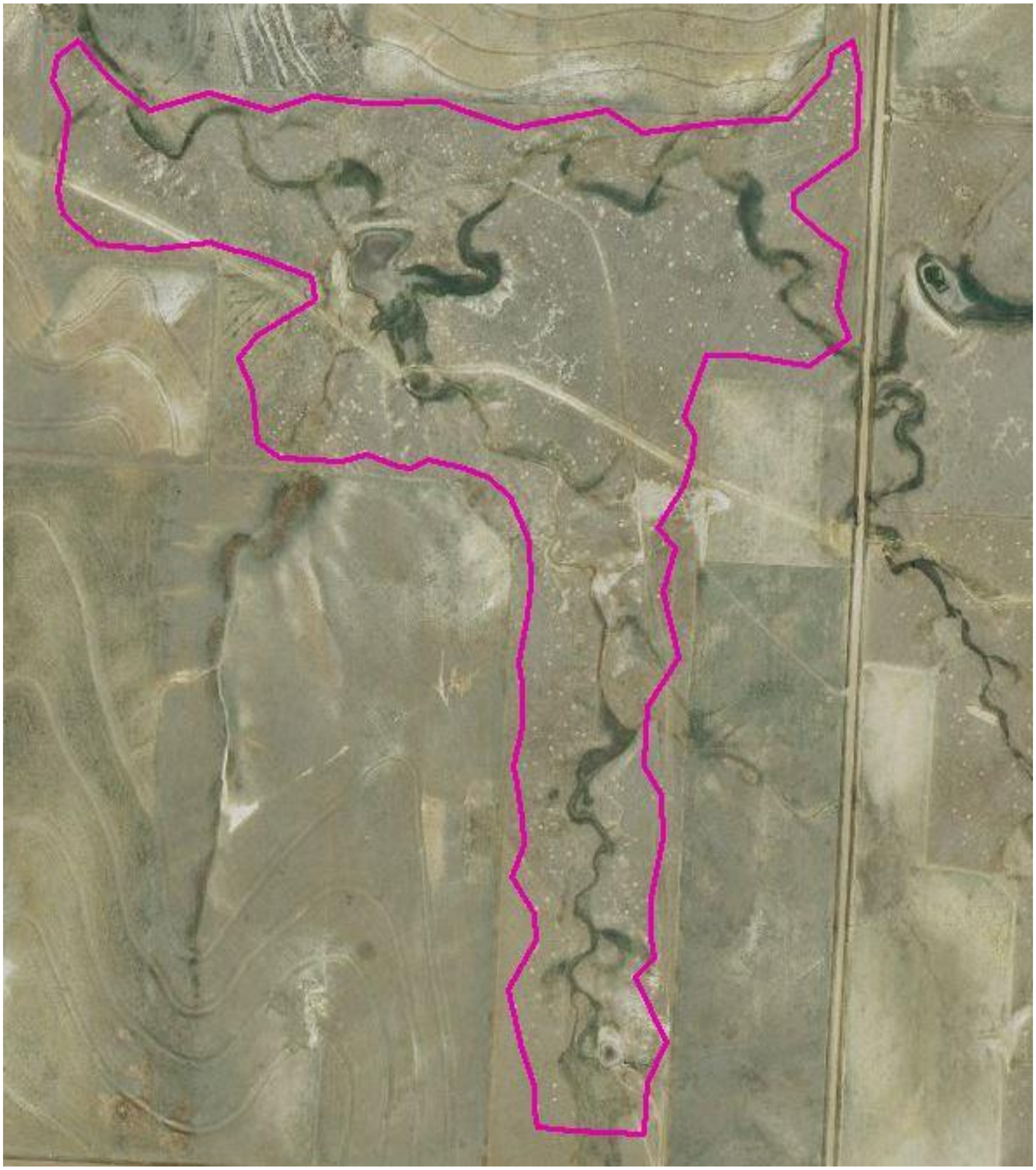

Figure A22. While digitizing colonies near riparian areas or bodies of water, observers were instructed not to include areas in the feature that prairie dogs would not use. In this image, the observer digitized this relatively large feature although it included some riparian areas probably not used by black-tailed prairie dog. To avoid over estimating the acreage of potential black-tailed prairie dog colonies, several smaller or more convoluted features of approximately the same area could have been digitized.

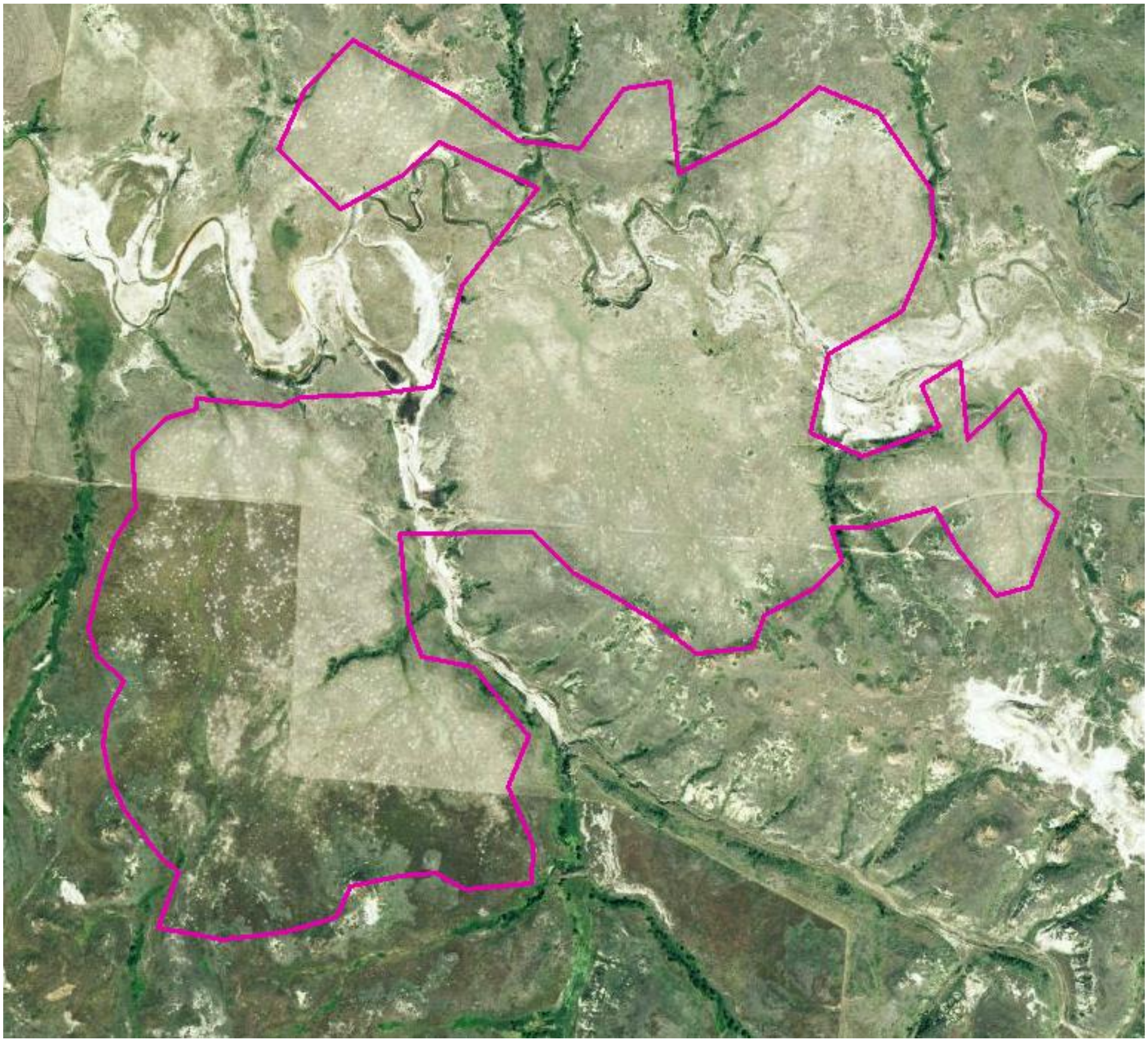

Figure A23. For difficult landscape features as here and in Figure A22, observers could consider splitting the colony into multiple parts. While prairie dogs may not feed or dig burrows in some parts of a feature, they may move across them. The above image contains a river and a ravine. Because the mounds go up to the feature and begin immediately again on the other side, the observer digitized this as a single colony.

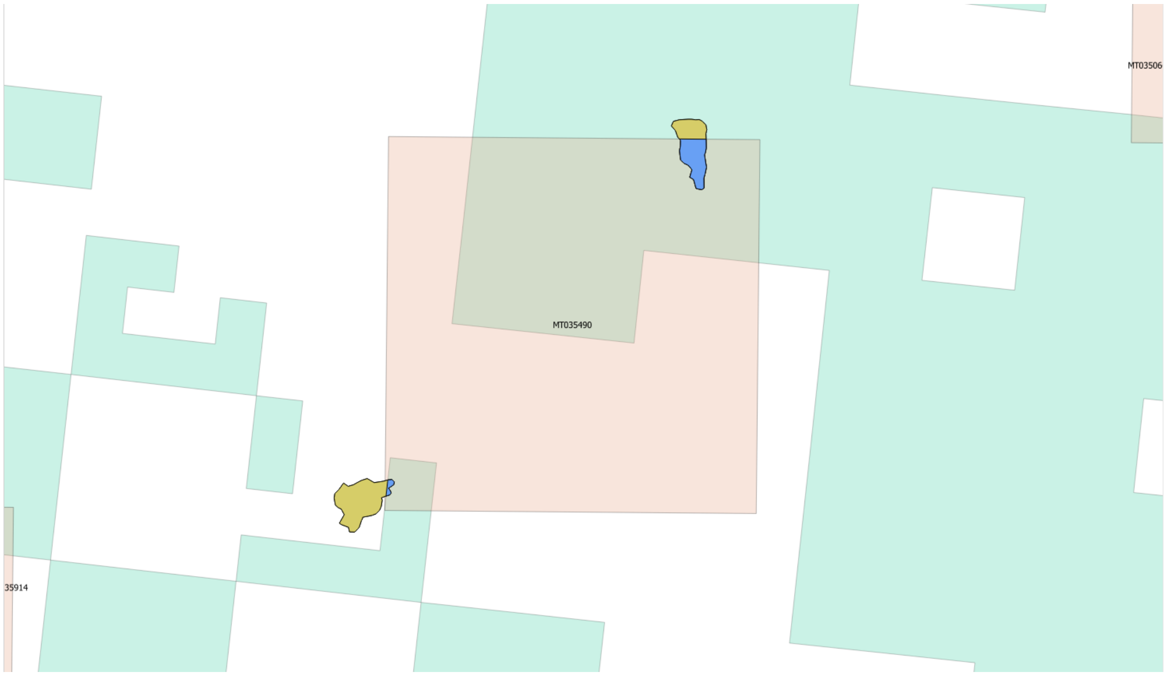

Figure A24. These two features overlapped BLM managed lands (green). The sampled cell (beige) had two digitized features with the centroid of the top feature in the sampled cell while the centroid of the bottom left feature was in a neighboring cell. The acreage on BLM land and in the sampled cell (blue) was averaged over sampled cells from the sampling frame for BLM land. The top feature was counted as associated with BLM land because it overlaps BLM land and its centroid was in the sampled cell.

APPENDIX B

Formozov-Malyshev-Pereleshin Analysis Methods

Formozov-Malyshev-Pereleshin formula for the transecting method

The Formozov-Malyshev-Pereleshin (FMP) formula estimates the probability P that a delineated feature boundary intersects with a grid-cell, or defined transect of interest based on simple probabilistic arguments (Stephens et al. 2006). Given a state containing T grid cells each 4 square miles in size and a total areal extent of $A = 4T$ square miles, the process of digitizing features results in two spatially related datasets. The first was the BAS sampling grid, consisting of t cells with four sides of equal length l, each oriented in one of the cardinal directions. For example, for all t western transects, with length l_w, the total length L_w over all western sides was $L_w = tl_w$.

The second spatial dataset contains the G digitized features. In practice, K_j line segments of length m_{jk} form the closed border of each jth feature, where the number of segments in each feature may vary. The perimeter of the jth feature was of length $M_j = \Sigma_k m_{jk}$, with M_j varying over the G features.

Suppose that one of the western transects of length l_{wi} of the ith cell, and a feature segment of length m_{jk}, were examined together. Given that all t cell transects were the same length l_w, the use of the cell index i is unnecessary. Now, assuming the two segments intersect, they either cross or connect in a “V,” via their endpoints. Assuming the latter, the resulting parallelogram with sides of length l_w and m_{jk}, with internal angles α and $\pi - \alpha$, forms the largest possible area these two intersecting segments could form, of extent $l_w m_{jk} \sin \alpha$. This area, when compared to the total study area $A = 4T$, was then the maximum probability $P(i, j, k, \alpha)$ that the two segments l_w and m_{jk} intersect. Specifically, let

$$P(i, j, k, \alpha) = \frac{l_w m_{jk} \sin \alpha}{A}$$

represent this angular-dependent probability. In reality, the angle α could vary, taking on any value between 0 and 2π, due to random orientation of the line segment m_{jk}. Assuming that α was distributed uniformly on [0, 2π], then the probability of intersection $P(i, j, k)$ of l_w and m_{jk}, averaged over angle α, is

$$P(i, j, k) = \frac{1}{2\pi} \int_0^{2\pi} \frac{l_w m_{jk} \sin \alpha}{A} d\alpha$$

$$= \frac{2l_w m_{jk}}{\pi A}.$$

Now, sum over all t western borders of length l_w and all K_j constituent segments m_{jk}, of the jth feature, to see that the probability P_j that the jth feature intersects any of the t western transects, equals

$$P_j = \sum_{i=1}^{t} \sum_{k=1}^{Kj} P(i, j, k)$$

$$= \sum_{i=1}^{t} \sum_{k=1}^{Kj} \frac{2l_w m_{jk}}{\pi A}$$

$$= \frac{2}{\pi A} \sum_{i=1}^{t} l_w \sum_{k=1}^{Kj} m_{jk}$$

$$= \frac{2}{\pi A} t l_w M_j$$

$$= \frac{2(2t)\ M_j}{\pi A},$$

after recalling that the sum of all t western transects of length $l_w = 2mile$ must equal L_w. The probability P_j of intersection of the jth feature and the entire western transects, with total length L_w, was proportional to L_w, the perimeter of the jth feature M_j , and the total study area A. The total transect length associated with each cardinal direction was equal for all four directions, i.e., P_j was the same in all four cardinal directions.

The study design suggests further simplification of P_j; recalling that each cell was 2×2 miles in size, and noting that $L_w = tl_w,\ A = 4T$ miles ^{2}, and that l_w = 2 miles, conclude that

$$P_j = \frac{2L_w M_j}{\pi A}$$

$$= \frac{2tM_j l_w miles^2}{4\pi T miles^2}$$

$$= \frac{tM_j}{T\pi}.$$

Note that P_j represents the probability that the jth feature intersects the western transects in all t sampled cells only *once*.

Given a probabilistic estimate, P_j, that the jth feature, b_j, crosses at least one of the individual T western transects, an estimate of both the total number of features N in the study region of area A, and total feature areal extent S, can be made via a Horvitz-Thompson estimator. The summation was over features, which cross the set of western transects. Consider the set of all western transects in a sample of the C grid cells.

Define G to be the number of digitized features that intersect the set of all western transects in a sample of the t grid cells. Finally then, to estimate the total number of features N_w, based on west-transect feature-extent crossings in a sample of grid cells, use a Horvitz-Thompson estimator to form

$$\hat{N}_w = \sum_{j=1}^{G} \frac{1}{P_j}$$

$$= \sum_{j=1}^{G} \frac{T\pi}{tM_j}$$

$$= \pi(T/t) \sum_{j=1}^{G} \frac{1}{M_j}$$

where the G indicates the summation was over all features which intersect the western transects in a sample of the C grid cells.

Similar calculations to estimate the total areal extent S suggest that

$$\hat{S}_w = \sum_{j=1}^{G} \frac{s_j}{P_j}$$

$$= \sum_{j=1}^{G} \frac{\pi T s_j}{tM_j}$$

$$= \pi(T / t)\sum_{j=1}^{G} \frac{s_j}{M_j}.$$

Intuitively, if the ratio of total number of grid cells (T) to the sampled number of grid cells (t) was increased by, for example, factor or 2 then P_j will decrease by a factor of 2 and the number of features (G) intersecting the western transects will increase by 2. In the long run,

$$\hat{S}_w = \sum_{j=1}^{2G} \frac{s_j}{2P_j}$$

will remain approximately the same.

Finally, this process was then repeated for the other three directions, so as to obtain, for both N and S , four directional estimates for each of the four cardinal directions. Sets of features with more of an east-west extent, rather than north-south, can expect to cross in higher numbers with respect to either the eastern or western transect, thus inflating N_e and N_w more readily than N_s and N_w. The estimation with respect to the four cardinal directions thus provides a guard against any feature anisotropy, or preferential alignment of features to one direction over all others. Given the resulting four estimates for each of N and S , we took the average over all four directions to obtain a final estimate for each, i.e., calculate

$$\hat{N} = \frac{\hat{N}_w + \hat{N}_e + \hat{N}_n + \hat{N}_s}{4}$$

and

$$\hat{S} = \frac{\hat{S}_w + \hat{S}_e + \hat{S}_n + \hat{S}_s}{4} .$$