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Monitoring black-tailed prairie dog colonies with high-resolution satellite imagery

John G. Sidle, Douglas H. Johnson, Betty R. Euliss, and Marcus Tooze

Abstract The United States Fish and Wildlife Service has determined that the black-tailed prairie dog (*Cynomys ludovicianus*) warrants listing as a threatened species under the Endangered Species Act. Central to any conservation planning for the black-tailed prairie dog is an appropriate detection and monitoring technique. Because coarse-resolution satellite imagery is not adequate to detect black-tailed prairie dog colonies, we examined the usefulness of recently available high-resolution (1-m) satellite imagery. In 6 purchased scenes of national grasslands, we were easily able to visually detect small and large colonies without using image-processing algorithms. The Ikonos (Space Imaging™) satellite imagery was as adequate as large-scale aerial photography to delineate colonies. Based on the high quality of imagery, we discuss a possible monitoring program for black-tailed prairie dog colonies throughout the Great Plains, using the species' distribution in North Dakota as an example. Monitoring plots could be established and imagery acquired periodically to track the expansion and contraction of colonies.

Key words black-tailed prairie dog, *Cynomys ludovicianus*, Great Plains, Ikonos, remote sensing, satellite imagery

The black-tailed prairie dog (*Cynomys ludovicianus*) is distributed throughout the Great Plains from southern Canada to northern Mexico (Figure 1). Most populations occur on private land. Numbers and sizes of colonies have declined greatly (Mulhern and Knowles 1997). Recently, the United States Fish and Wildlife Service (USFWS) decided that the black-tailed prairie dog warranted listing as a threatened species under the Endangered Species Act (USFWS 2000). Because the species is an official candidate for listing, many state agencies are establishing long-term management goals for black-tailed prairie dogs (W. Van Pelt, Arizona Game and Fish Department, unpublished report). The USFWS recommended "Candidate Conservation Agreements with Assurances" (CCAA, USFWS 1999) to implement black-tailed prairie dog conservation on private land. Federal agencies, such as the United States Department of Agriculture (USDA) Forest Service, are modifying management plans on national grasslands to expand black-tailed prairie dog colonies (USDA Forest Service 2001).

Size of black-tailed prairie dog colonies can change substantially over a few years because of plague (*Yersinia pestis*, Cully 1993), poisoning (Uresk and Schenbeck 1987, Fagerstone and Ramey 1996), or conversion of rangeland to cropland or other uses. State and federal agencies will be required to gauge the effectiveness of any black-tailed prairie dog CCAA through colony monitoring every 3–5 years (W. Van Pelt, Arizona Game and Fish Department, unpublished report). Accordingly, this monitoring effort needs to be accurate, logistically feasible, and cost-effective.

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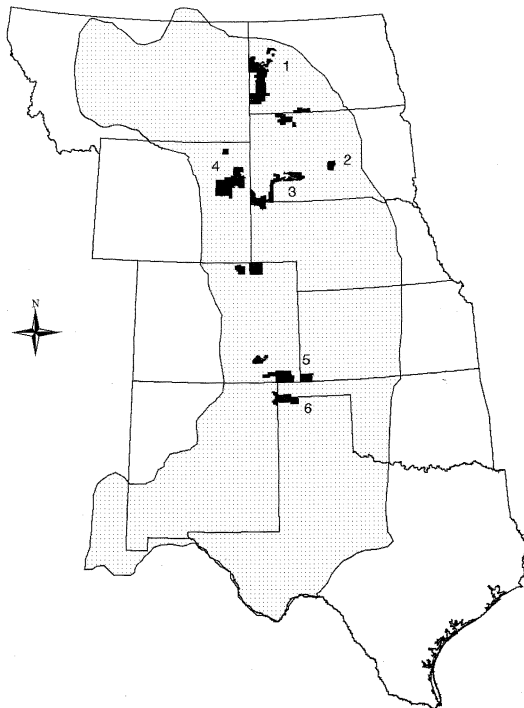
Figure 1. Ikonos satellite imagery was acquired of portions of numbered national grasslands located in the range of the black-tailed prairie dog: Little Missouri, North Dakota (1); Fort Pierre, South Dakota (2); Buffalo Gap, South Dakota (3); Thunder Basin, Wyoming (4); Cimarron, Kansas (5); and Rita Blanca, Oklahoma and Texas (6).

Various methods, often subjective, have been used to estimate the area covered by black-tailed prairie dog colonies in several states. Estimates have been based on available aerial photography, visits to known colonies, and visual estimates from weed- and pest-control staffs. For example, Cheatheam (1973) used large-scale (1:20,000) USDA aerial photography to inventory black-tailed prairie dog colonies in a large area of Texas. Ernst (2001) examined thousands of USDA Farm Services Agency 35-mm color slides to locate colonies in the Texas panhandle. Sidle (1999) and Sidle et al. (2001) carried out extensive aerial surveys during 1997–98 along thousands of kilometers of transects in the northern Great Plains to estimate black-tailed prairie dog colony areas in Nebraska, North Dakota, South Dakota, and Wyoming. At landscape scales, the global positioning system (GPS) has been used to monitor black-tailed prairie dog colonies on relatively small areas, such as tribal reservations, national parks, and national grasslands, with colony boundaries periodically described with GPS receivers. Large-scale aerial photography has also been used periodically to monitor colonies on small areas (Osborn 1942; Schenbeck and Myhre 1986; Uresk and Schenbeck 1987; R. G. Best, South Dakota State University, unpublished report).

Monitoring the status and trend of black-tailed prairie dog colonies on small areas does not pose a challenge. However, monitoring the species throughout its range (156.5 million ha) requires adequate and affordable techniques and an appropriate sampling design. Various ground and aerial surveys and examinations of recent aerial photography can provide information on locations of thousands of black-tailed prairie dog colonies. Conceivably, a system of monitoring plots could be established based on known colony locations for periodic examination. Nonetheless, collecting suitable large-scale aerial photography (at least 1:24,000; Tietjen et al. 1978; Dalsted et al. 1981; J. Pennell, United States Bureau of Reclamation, unpublished report) would be very expensive, and most satellite imagery cannot easily resolve black-tailed prairie dog colonies.

Recent availability of satellite imagery with 1-m resolution may allow use of the same remote-sensing platform to monitor black-tailed prairie dog colonies throughout the Great Plains. Because the diameter of black-tailed prairie dog mounds is 1–3 m (Cincotta 1989), we believed that such imagery could be useful in detecting and monitoring black-tailed prairie dog colonies. The 1-m spatial resolution of Ikonos satellite (Space Imaging™ Inc., Thornton, Colo.) data distinguishes them from the traditional range of lower-resolution satellite data. We evaluated Ikonos imagery for the monitoring of black-tailed prairie dog colonies and present a possible monitoring scheme. Use of company names,

Black-tailed prairie dog at Wind Cave National Park, South Dakota. All photographs by J. G. Sidle.

software, or trademarks does not imply endorsement by the United States Government.

Study area

About 17,000 ha of black-tailed prairie dog colonies occur on 1.4 million ha of USDA Forest Service national grasslands in the Great Plains from northern New Mexico and Texas to western North Dakota (Figure 1). National grasslands harboring black-tailed prairie dogs occur in short-grass and mixed-grass prairie in several ecological sections, including the Texas High Plains, Southern High Plains, Northwestern Great Plains, and North-central Great Plains (Bailey et al. 1994). We selected portions of national grasslands containing known black-tailed prairie dog colonies for satellite-imagery acquisition in different ecological sections. Black-tailed prairie dog colonies occur in numerous soil types and on various slopes (Stromberg 1975, Clippinger 1989). Soils at selected sites were primarily clay and loams. Slopes ranged from 0 to 15%, with 98% of the colonies occurring on 0 to 6% slopes (USDA soil survey publications for Morton County, Kansas; McKenzie County, North Dakota; Cimarron County, Oklahoma; Custer, Fall River, Pennington, and Stanley counties, South Dakota; and Campbell and Converse counties, Wyoming).

Methods

We acquired Ikonos panchromatic (1-m-resolution) satellite imagery of 6 selected areas totaling 315 km² on 5 national grasslands (Figure 1, Table 1). We also acquired multispectral images (4-m resolution) of 2 of those sites (Cimarron and Buffalo Gap

national grasslands). We purchased the Ikonos "Geo," the lowest-accuracy product, because image cost increases significantly with increasing horizontal accuracy requirements. We rectified the images with digital ortho-quarter quads (DOQQ) available from the United States Geological Survey at low cost ($212 for our project). These products were accurate to 1:12,000 map standards and provided digital terrain-corrected imagery developed under the National Aerial Photography Program. Using Imagine software (ERDAS® Inc., Atlanta, Ga. 30329, USA; ERDAS Inc. 1991), we removed geometric distortion from the image by aligning DOQQ and Ikonos image features. We applied a third-order polynomial rectification using the DOQQ as the target image to geo-rectify the Geo imagery (Wilkie and Finn 1996). With enough ground control points, image-scale problems due to topography can be reduced (Schowengerdt 1983).

We also used Imagine software to examine each Ikonos image. Because the Great Plains is platted into 259-ha (640-ac) sections, and roads or section lines were visible, we examined each image one quarter-section (65 ha = 160 ac) at a time. To determine colony area, we drew boundaries of the black-tailed prairie dog colonies by connecting the outermost burrows.

We verified our interpretations by conducting aerial surveys of the 6 sites at 1.60-km (1-mi) intervals. We searched for all black-tailed prairie dog colonies identified on the imagery and any colonies we may not have found on the imagery. We also visited most colonies on the ground. We used the GPS to outline the colonies on Buffalo Gap National Grassland for comparison with imagery. We calculated a correlation coefficient to compare GPS and imagery measurements. Finally, we also compared recent large-scale aerial photography of colonies on Buffalo Gap National Grassland (J. Pennell, United States Bureau of Reclamation, unpublished report) with Ikonos imagery to gauge the adequacy of Ikonos imagery.

Results and discussion

We easily identified black-tailed prairie dog colonies on Ikonos panchromatic imagery of 5 national grasslands. Aerial

Table 1. Selected areas of national grasslands for which geo-referenced 1-meter panchromatic imagery was acquired during 2000 to detect black-tailed prairie dog colonies.

National grassland	Image centroid[a]	Area (km²)	Image cost[b]	Acquisition date
Buffalo Gap, SD[c]	43.755 N 102.307 W	65.5	681	29 May
Buffalo Gap, SD	43.424 N 103.033 W	42.7	444	21 May
Cimarron, KS[c]	37.170 N 101.871 W	31.1	324	20 May
Fort Pierre, SD	44.216 N 100.134 W	38.4	399	3 June
Rita Blanca, OK	36.529 N 102.749 W	61.3	634	20 May
Thunder Basin, WY	43.519 N 105.010 W	76.0	790	21 May
Total		315	3,272	

[a] Latitude and longitude of the center of image.

[b] Cost ($US) includes a 20% discount for federal government orders.

[c] Four-meter, multi-spectral imagery also was purchased for these 2 areas for the same price and on the same date.
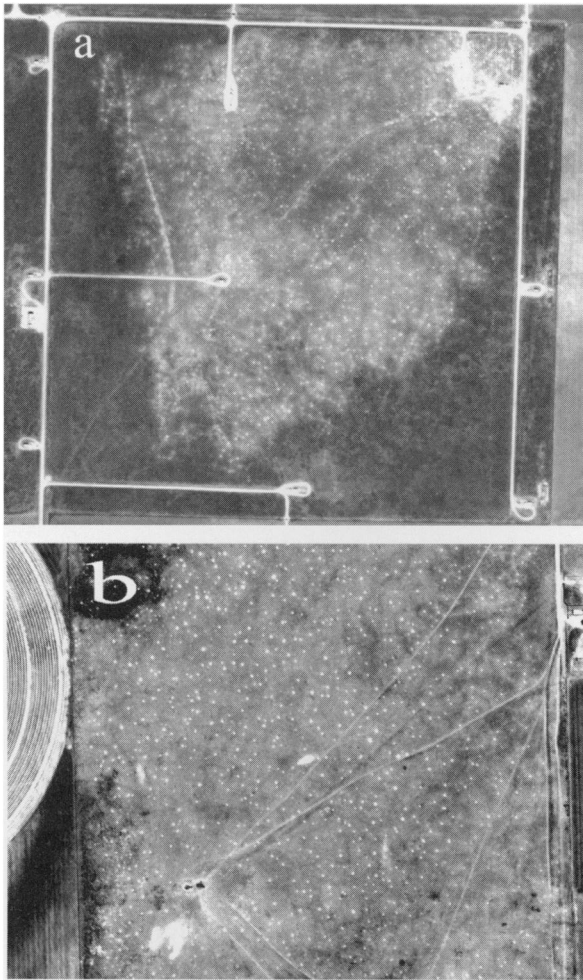
Figure 2. Ikonos panchromatic images (1-m resolution) of a black-tailed prairie dog colony on the Cimarron National Grassland, Kansas (a) and a colony within the administrative boundary of the Rita Blanca National Grassland, Oklahoma (b). The white dots are burrow mounds. The Cimarron image shows a colony and oil-well facilities in a 64.7-ha (quarter-section) pasture. The Rita Blanca image is a close-up of part of a colony. Livestock trails lead to a windmill and stock tank. The far left side of the image shows part of a field watered by a center-pivot irrigation system. Grazing by black-tailed prairie dogs and livestock gives a light tone to the colonies and further defines colony boundaries in both images.

and ground surveys did not reveal additional colonies. Individual burrow mounds appear on imagery as white-colored dots (Figure 2). Some mounds on the Little Missouri National Grassland were black because of prairie dog excavation of lignite coal seams. Areas impacted by prairie dog herbivory also were visible, giving additional definition (Whicker and Detling 1993).

We used the panchromatic band to try to enhance the spatial resolution of the multispectral data for Cimarron and Buffalo Gap national grasslands. Such enhancements are designed to make the standard true-color or false-color infrared band combinations more spatially interpretable than the standard 4-m resolution product. However, we did not observe any imagery enhancement.

Black-tailed prairie dog colonies exhibit spectral, spatial, and textural characteristics that were most evident in 1-m data. Black-tailed prairie dog mounds generally are bare soil surrounded by vegetation (grass and forbs). The mounds have a characteristic spacing and textural pattern. Because these mounds generally are 1–3 m in diameter, they are resolvable by a 1-m system. Secondly, the panchromatic band integrates light information across red and infrared portions of the spectrum. This spectral portion is ideal for distinguishing between vegetated and nonvegetated areas.

The area of black-tailed prairie dog colonies determined from the imagery was similar to the area determined with GPS receivers in the field. On Buffalo Gap National Grassland Ikonos images, we determined 198.4 and 1,514.2 ha of black-tailed prairie dog colonies on the Fall River and Wall ranger districts, respectively, and determined 197.6 and 1,514.7 ha, respectively, using GPS receivers. On other national grasslands, the latest GPS data were up to 3 years old and identified 63.59 ha in 1997 on the Little Missouri National Grassland, compared with 64.03 ha on the 2000 Ikonos imagery. On the Cimarron and Rita Blanca national grasslands, black-tailed prairie dog colony area measured in fall 1999 was similar to that determined from the 2000 Ikonos images. Overall, the correlation between Ikonos and GPS determinations was $r = 0.99998$ ($n = 57$). The average error was 0.52 ha, compared with an average colony size of 56.81 ha.

Colonies observed on 1997 color infrared aerial photography (1:12,000) of Conata Basin, Buffalo Gap National Grassland (J. Pennell, United States Bureau of Reclamation, unpublished report), could be seen on the 2000 Ikonos imagery of Conata Basin, although sizes of some colonies had changed. Although aerial photography was clearer than Ikonos imagery, the Ikonos imagery was adequate to see and describe black-tailed prairie dog colony boundaries. Therefore, we believe there is no need for the higher ground resolutions provided by large-scale aerial photography. For applications where discrete imaging plots are required across millions of square kilometers from North Dakota

and Montana to Texas and Mexico, the ability of satellite sensors to "point" anywhere reduces the costs typically associated with aircraft, aerial photography, film processing, scanning, and other steps.

Use of DOQQs for rectification (3 hrs/scene) and the low-cost Geo product could greatly reduce costs of any monitoring program. For example, the Geo product for the 76-km² Ikonos image of Thunder Basin National Grassland cost $790 versus $3,900 for the best ortho-rectified image. Therefore, developing a methodology to use the lowest-cost imagery will more than double ground coverage available for the same cost. Several factors support use of non-ortho-rectified imagery in the Great Plains. Black-tailed prairie dog colonies occur on relatively continuous, flat regions exhibiting little elevation change or slope. The actual elevation change relative to the height of the sensor above the earth is minimal. Therefore, imagery error due to slope or elevation change across a black-tailed prairie dog colony is very limited.

Our attempts to use satellite imagery were not wholly novel. Some investigators have tried using current lower-spatial-resolution systems with limited success (Assal 2001; G. Wolbrink et al., South Dakota State University, unpublished report; L. DeLay, New Mexico Natural Heritage Program, personal communication). Visual interpretation depends on spatial resolution, and because black-tailed prairie dog burrow mounds simply are bare patches of soil, often in intensively grazed areas, these features are difficult to model and detect with lower-spatial-resolution systems such as Landsat (28.5-m resolution), SPOT (10-m), and IRS (5-m). The utility of the poorer resolution systems is questionable because bare soil and grassland occur in many other areas and are difficult to attribute to black-tailed prairie dogs without extensive ground-truthing.

Monitoring design

In North Dakota, black-tailed prairie dogs occur west of the Missouri River over an area of 5.07 million ha. North Dakota, like many western and midwestern states, is platted into 93.3-km² townships. One-fourth of a township is 23.3 km², and there are 2,234 quarter-townships in the North Dakota black-tailed prairie dog range (Figure 3). Thus, the size of a quarter-township was similar to the smallest Ikonos image available at the time of this study (about 25 km²).
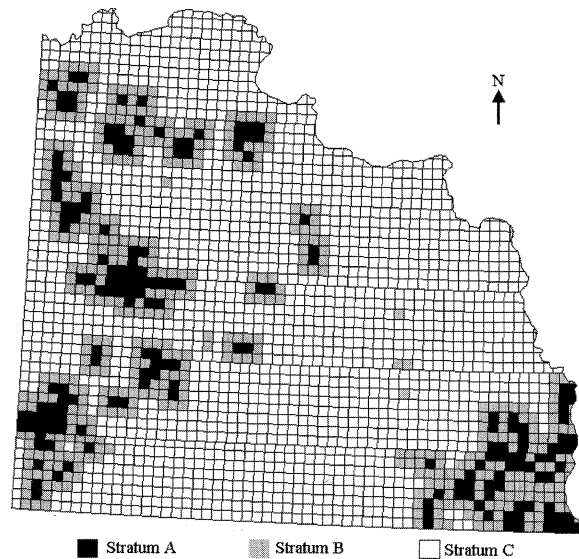

Figure 3. Stratification of quarter-township (23 km²) plots in the range of the black-tailed prairie dog in North Dakota. Stratum A comprises all plots where an active colony was observed in 1997–98. Stratum B includes plots adjacent to a stratum A plot as well as any plot where an inactive colony was observed in 1997–98. The rest of the black-tailed prairie dog range composes stratum C.

We suggest a monitoring design based on the Ikonos imagery using quarter-townships as monitoring units. The area to be sampled could be stratified based on known occurrences of black-tailed prairie dog colonies, as follows. The quarter-township plots in North Dakota could be stratified based on observed prairie dog colony activity in 1997–98 (Sidle 1999, Sidle et al. 2001, Figure 3). Stratum A would comprise all plots where an active colony was observed in 1997–98. Stratum B would include plots adjacent to a stratum A plot and any plot where an inactive colony was observed. The rest of the prairie dog range would compose stratum C. In North Dakota, there would be 182 plots in stratum A, 438 stratum B plots, and 1,614 stratum C plots.

Ikonos imagery of all 2,234 plots (at $250/plot) would cost in excess of $558,000 in 2000. However, sampling from each stratum would greatly reduce costs. Although it would be most important to monitor stratum A most intensively, it would be necessary to include samples from the other strata. Doing so would ensure statistical unbiasedness by providing an opportunity to encounter newly established or currently unknown black-tailed prairie dog colonies. For an optimal allocation of samples in a stratified design, number of samples/stratum should be proportional to the
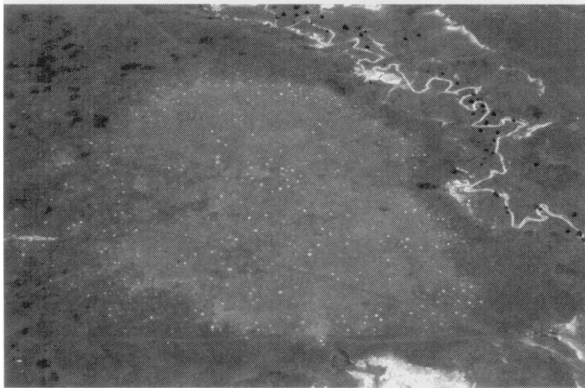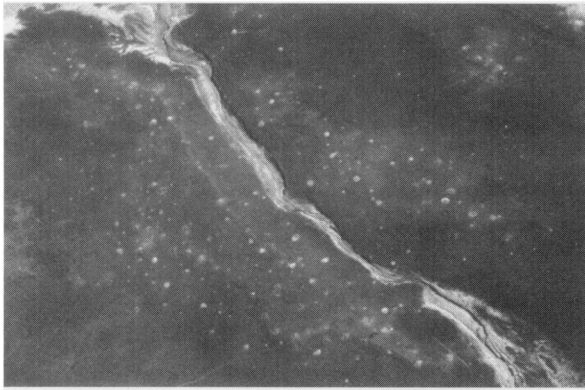
Aerial views of black-tailed prairie dog colonies, Conata Basin, South Dakota.

Aerial view of a black-tailed prairie dog colony near Scottsbluff, Nebraska.

standard deviation within the stratum times the total number of plots in that stratum (Cochran 1977). Although we do not know the standard deviation of counts in strata other than A, it is expected that nearly all plots in stratum C will have zero values, so the standard deviation within stratum C should be very small. In stratum B, more plots would have nonzero values, but the standard deviation should also be small.
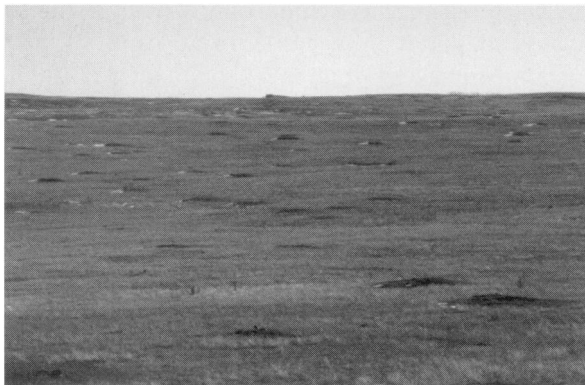
Ground view of a black-tailed prairie dog colony, Wind Cave National Park, South Dakota.

For example, stratum A could be sampled at a 100% rate (182 plots), stratum B at a 20% rate (88 plots), and stratum C at a 5% rate (80 plots). Over time, a partial replacement design (Cochran 1977) could prove to be the best alternative to detect new colonies. Also, some amount of ground-truthing (low-level aerial surveys, field visits) would be needed to verify prairie dog colony activity. At a minimum, wildlife managers would want to know whether a town is active or inactive. A sample of plots could be visited on the ground to determine activity, and if necessary, repeated visits could be made for population estimates (Menkens et al. 1990, Severson and Plumb 1998).

For our North Dakota example, the current total cost of images for those 350 plots would be $87,500. Because monitoring the black-tailed prairie dog involves the collaboration of many agencies, sharing of the satellite-imagery cost by Bureau of Indian Affairs, National Park Service, Natural Resource Conservation Service, North Dakota Department of Agriculture, North Dakota Game and Fish Department, USDA Forest Service and Wildlife Services, United States Fish and Wildlife Service, United States Geological Survey, and other relevant agencies would legitimately spread the monitoring cost. In all likelihood, the cost will be reduced further as more private companies launch high-resolution sensors and offer competition to the Ikonos system.

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