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Image-based monitoring to measure ecological change in rangeland

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High-resolution, image-based methods can increase the speed and accuracy of ecological monitoring while reducing monitoring costs. We evaluated the efficacy of systematic aerial and ground sampling protocols to detect stocking-rate differences across 130 ha of shortgrass prairie. Manual (SamplePoint) and automated (spectral) image-analysis methods were compared for both aerial and ground data. Vegetative cover changes due to grazing were detectable from 1-mm ground sample distance (GSD, a measure of resolution) digital aerial photography with as few as 30 samples yielding enough data to predict bare ground within ± 5%. We found poor agreement between automated and manual image-analysis methods, but good agreement between manual analyses of imagery from the air (100 m above ground level [AGL]) and from the ground (2 m AGL). We conclude that cover measurements made using SamplePoint from 1-mm GSD images (from 2 or 100 m AGL) can detect ecologically important changes in key indicators such as bare ground. The costs of ground and aerial methods differ markedly, and we suggest that aerial imagery is most cost effective for areas larger than 200 ha.

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Image-based data collection has been one of the "holy grails" of ecological investigation. As early as 1924, Cooper described a camera stand for use in vegetation analysis, signaling that ecological imaging had moved past the landscape perspectives of late 19th and early 20th century photographers such as WH Jackson (Johnson and Jackson 1987) and HL Shantz (McGinnies *et al.* 1991), to the vertical (nadir) perspective that, due to uniform resolution across the image, is useful for measurements. Cooper's paper was followed a series of reports, spread over 80 years, on high-resolution imaging for ecological analysis (see Table 1 of Booth *et al.* 2004), and a 30-year effort to use satellite and low-resolution aerial imaging for that purpose (Knipling 1970). Despite these long-standing efforts, image-based methods have yet to replace conventional point, plot, transect, and ocular estimates in most ecological tool boxes. Image-based assessments hold the promise of cost-effective data collection across large areas of interest (eg rangeland pastures, watersheds, landscapes), allowing uniform, high-density sampling in place of judgment-based choices of representative areas. This will bring greater statistical power and precision (repeatability), and a greater capability for detecting differences, to ecological investigations and to long-term monitoring efforts (Booth *et al.* 2006a; Booth and Cox 2006; Luscier *et al.* 2006; Seefeldt and Booth 2006).

In this study, aerial and ground imaging were tested with manual and automated image-analysis methods for detecting ground-cover differences in shortgrass-prairie pastures stocked at different rates for 3 years. The resolution of the ground and aerial images was 30 000 times that of Landsat, avoiding the need to deduce vegetative cover from the spectral mixtures of low-resolution pixels using the usual indices (ie Normalized Difference Vegetative Index, Soil Adjusted Vegetative Index) or to make accurate atmospheric corrections of reflectance signals (Wyliea et al. 2002).

Methods

Site description

The Central Plains Experimental Range (CPER) is located 40 km northeast of Fort Collins, Colorado, in the northern portion of the shortgrass prairie (40°49' N, 107°47' W). The characteristics of the site have been described previously by Lauenroth and Milchunas (1991). Average annual precipitation is 320 mm, of which 70% occurs between April and August. Vegetation is dominated by blue grama grass (*Bouteloua gracilis*), threadleaf sedge (*Carex filifolia*), fringed sagewort (*Artemisia frigida*), and plains prickly pear cactus (*Opuntia polyacantha*). Three enclosed, adjacent rangeland pastures on the CPER were used for this study. Elevation within the 130-ha study area ranged from 1652 to 1681 m, with a general south or east aspect. All were grazed with steers at a moderate stocking rate (May to October, 10 to 25 animal-days per hectare [ADH]) for 14 years prior to the study (Hart and Ashby 1998; M Ashby pers comm). For 3 years prior to sampling, the northern square-shaped 63-ha pasture was grazed with 10 steers at an average of 20 ADH (moderate; 35–45% utilization), while the southern square-shaped pasture was split diagonally, with a 34-ha pasture grazed with 10 steers at 39 ADH (heavy; 70–80% utilization) and an ungrazed 33-ha pasture. Grazing began in late May, and continued for 3 to 5 months, based on production. The range in elevation and slope among the pastures was 20 m and 0–7° for the ungrazed and heavily-grazed pastures, and 26 m and 0–9° for the moderately-grazed pasture.

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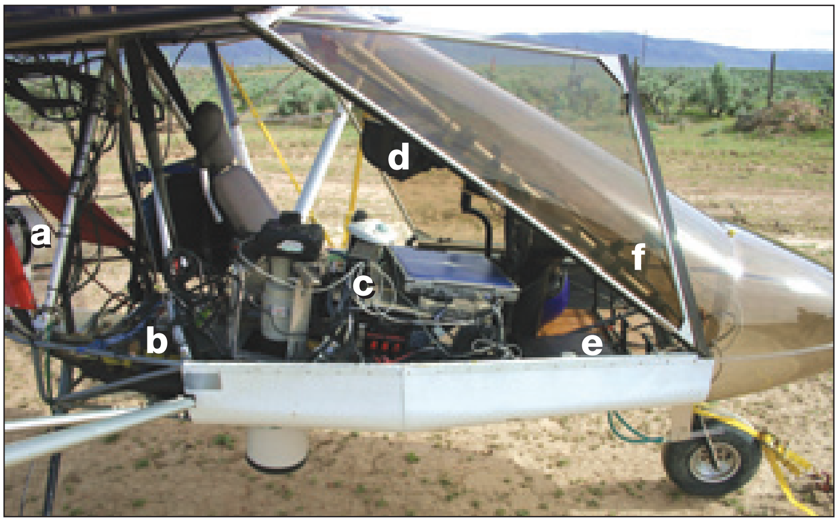

Figure 1. *Sport aircraft at a Nevada site with remote sensing equipment as used over the Central Plains Experimental Range in Colorado. (a) Ballistic parachute capable of safely landing the entire aircraft in an emergency; (b) 12V battery and AC/DC inverter for powering camera, laser altimeter, and laptops; (c) aluminum equipment module supporting the Canon 1Ds digital camera and 840-mm lens, Trackair navigation box, light meter, laser rangefinder used as an altimeter, 24V power supply for Trackair system, trackball mouse and laptop computer for displaying laser-measured altitude and storing digital images; (d) LCD monitor; (e) navigation laptop computer; and (f) global positioning system receiver.*

Aerial sampling

In late May of 2004, we took 200 color (red, green, blue [RGB]) 1-mm ground sample distance (GSD; a measure of digital image resolution defined as the linear dimension of a pixel on the ground) digital images (Canon 1Ds 11.1 megapixel camera with 840-mm [equivalent] lens mounted in a sport aircraft; 225-kg empty weight; Figure 1). The aircraft was equipped with a navigation and camera-triggering system and a laser range-finder for measuring altitude above ground level (AGL; Booth and Cox 2006a). The navigation system was powered by Tracker software (Oldenzaal, Netherlands) on a laptop computer interfaced with (1) a central navigation box, (2) a WAAS-enabled GPS (the Wide Area Augmentation System improves the accuracy of Global Positioning Systems for aircraft en route), and (3) a 15-cm in-cockpit LCD display. Raw images with a 3 x 4-m field of view were systematically captured from 100 m AGL at 80-m intervals, via automatic triggering, using planned GPS coordinates in a sampling grid that covered the study area. Images were stored on an onboard laptop. We captured 90 aerial and ground (described below) images in the moderately-grazed pasture and 55 each in the ungrazed and heavily-grazed pastures.

Ground sampling

Two days after the aerial survey took place, we took 200 color (RGB) 1-mm-GSD images (Olympus E20, 5-megapixel camera mounted on an aluminum camera frame with a 1-m^2 base that positioned the camera for nadir images 2 m AGL; Booth *et al.* 2004). Images were acquired by a single person who located the aerial photo center points on the ground using a Garmin eTrex Venture WAAS-enabled GPS (Olathe, Kansas). Images were cropped to 1 m^2 prior to their analysis.

Cover measurement

Ground-cover measurements from TIF images were used for detecting stocking-rate differences. We measured cover manually from all images of both the 2 m and 100 m AGL datasets using SamplePoint software (Booth *et al.* 2006a). This software facilitates point sampling of digital images in a manner similar to the method advocated by Wells (1971), but because the sample point is always a single pixel of the image, where the image GSD is $\leq$1 mm, the analysis has a potential accuracy of 92%, including errors due to pixel mixing, which are inherent in image-analysis methods (Booth *et al.* 2006a). The program loads the images from a database and applies a user-defined number of sample points over each image in either a grid or random pattern; we used a 100-point grid. As the software guides the user from one point to the next, the user can classify each point by clicking one of thirty user-defined buttons located under the image, at which point the classification is saved to the database and the next classification point automatically appears. The software allows image zooming to permit viewing of the context or detail of an image pixel. Our seven ground-cover classes included brown grass, green grass, cactus, shrub (consisting primarily of rabbitbrush, snakeweed, and saltbush), litter, cow manure, and bare ground.

We also measured cover using VegMeasure (Johnson *et al.* 2003), a spectral reflectance-based program that employs binary classification algorithms utilizing the RGB color model. VegMeasure is known to have a lower accuracy for rangeland cover types (ie around 82% where circumstances favor good spectral separations), but it has the advantage of speed (Booth *et al.* 2006 a, b). We calibrated the Veg-Measure Hue Selector algorithm separately for 100-m and 2-m images by randomly selecting 20 images from the dataset, measuring bare ground for each image by classifying 100 points per image in Corel Photo Paint (Ottawa, Canada), and adjusting the upper and lower thresholds within the algorithm so that VegMeasure returned the same bare ground value for each image, as outlined in Booth *et al.* (2006b). The average upper and lower thresholds were used to batch-process all images in the dataset.

Statistical analysis

Means testing for both 2-m and 100-m images for each ground-cover characteristic by pasture was completed using PROC MIXED in SAS V 9.1 (Nashville, TN). This accounted for some of the heterogeneity in variance arising from unequal sample sizes among different-sized pastures. We then performed F-protected ($P < 0.05$) t-tests. Correlation tests and paired t-tests comparing the different methods and acquisition altitudes were run using Microsoft Excel 2003 (Redmond, WA). Confidence intervals were generated for randomly-selected subsamples (n = 6 to n = 90) of the 2- and 100-m dataset to test the effect of sample numbers on statistical power using Statistics Analyzer (Robert Berryman Consulting, Boulder, CO). Sampling adequacy was assessed using bare ground because it is an important ecological indicator and is a nearly ubiquitous ground-cover class characteristic. ESRI ArcGIS 9.0 (Redlands, CA) was used for spatial analyses.

Results

Differences detected among grazing treatments

Brown grass, green grass, bare ground, litter, and cow manure ground-cover classes all had cover differences among pastures ($P < 0.05$) when measured from either the 100-m or 2-m AGL images (Figures 2 and 3). Shrub cover was similar among pastures as measured from 2-m images. Among these six cover classes, mean separation was in agreement between the 100-m and 2-m datasets only for bare ground. For either dataset, the heavily grazed pasture showed more bare ground than the ungrazed and moderately grazed pastures (Figure 3). The difference indicates that image-based monitoring will detect differences among grazing treatments on shortgrass prairie.

Among the cover classes, cactus alone did not vary between pastures for either dataset ($P > 0.25$; Milchunas *et al.* 1989; Rebollo *et al.* 2002). Slope, aspect, elevation, and distance to water were ruled out as factors significantly influencing observed treatment differences, since none of these variables were well correlated with any cover class ($r < 0.3$, n = 200). Milchunas *et al.* (1989) reported greater plant cover in grazed swales compared to uplands. The divergent findings may be due to the different objectives and sampling designs (ie hillslope catenas versus systematic pasture sampling).

Cover measurements for bare ground and cow manure differed between the ungrazed and heavily grazed pastures for both image datasets. This supports the use of bare ground as an effective indicator of grazing and, when measured over time, of rangeland condition (ITT 1996; USDI–BLM 1997; Booth and Tueller 2003). The temporal aspect of assessing condition ("health") is fundamental, since studies have shown that moderate and heavy grazing on shortgrass prairie increases the horizontal spread of the vegetation (Milchunas *et al.*1989; Hart and Ashby 1998). Cover for brown and green grass and litter were different among the three grazing treatments when measured from 100-m AGL images. From either 2 or 100 m AGL, green grass and litter cover in the heavily-grazed pasture exceeded that in the ungrazed pasture (Figure 3). This is counterintuitive, but results from the accumulation of brown grass in the canopy of the ungrazed pasture (Figure 2). When measured from 2-m AGL images, the 3.5% average difference between ungrazed and moderately grazed pastures was not significant (Figure 3). Separation of brown and green grass from litter is a fine-detail measurement. From Figure 3, it is evident that the cover measurements are in good agreement for brown grass, but differ reciprocally for green grass and litter (ie green-grass cover from 100-m data is high relative to that measured from 2-m data, and litter cover from 100-m data is low relative to that measured from 2-m data). We attribute these 2-m versus 100-m dataset differences to motion blur in the 100-m data. Blur increases the amount of judgment exercised in analysis and results in a bright-color bias (for green in this case), as previously described by Booth *et al.* (2006 a,b).

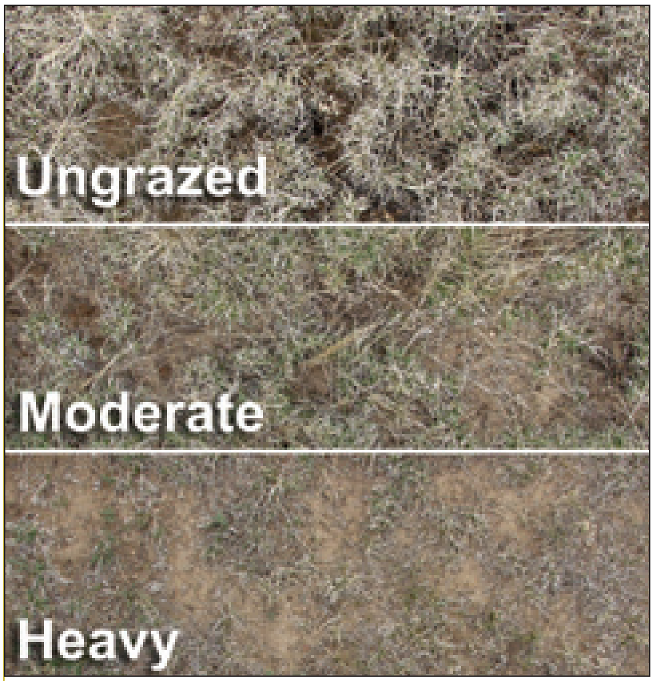

Figure 2. *Bare ground differences by pasture are illustrated in the above 100 x 33-cm (ground distance) panels taken from images with bare ground equal to the mean value for the pasture represented (10% ungrazed, 12% moderately grazed, and 18% heavily grazed). Images were acquired from 2 m above ground level and have a ground sample distance of 1 mm. Note that dead organic matter (mostly brown grass) not in contact with the soil surface was not defined as litter. Brown grass was the main constituent of the ungrazed pasture canopy (Figure 3) and overlaid much of the green grass, and the organic matter that fell to the soil surface. The heavily-grazed pasture therefore had litter and green-grass cover values greater than those measured for the ungrazed pasture (Figure 3).*

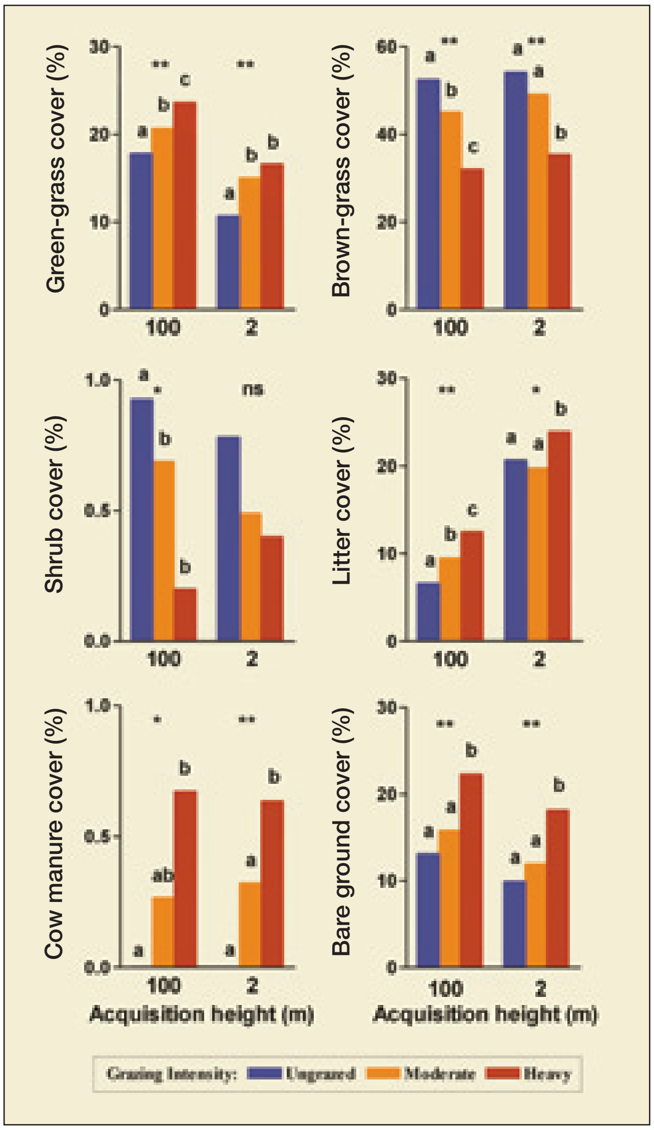

*Figure 3. Cover (%) means for every cover type showing significant differences (P < 0.05) among pastures as the result of a one-way ANOVA with F-protected t-test separation of data collected using SamplePoint from images captured from both 100 m and 2 m AGL. * = P < 0.05; ** = P < 0.0001.*

Appropriate sample size is a function of data variance and desired precision. Here, the variance in bare ground was highest in the heavily-grazed pasture, perhaps resulting from cattle travel patterns and congregating areas. Even with the higher variance of the heavily grazed pasture, the sample-adequacy analysis indicates that a sample size of approximately 30 images is sufficient to achieve a 95% confidence interval of less than 10% (precision of ± 5%) for bare ground (Figure 4). Thus, from this study, we conclude that a precision on the order of ± 3.5% can be expected from 55 samples, regardless of stocking rate. Note that these error rates are site-specific and, while they provide an illustration of analysis precision, local variation will determine the required number of samples to achieve a given precision. Repeated image-based surveys in this area, having at least 30 evenly-distributed images per pasture, should enable the detection of changes in bare ground greater than 5%, and should allow change-over-time analysis as a dependable indicator of trend in ecological health. Effective monitoring of a suite of ground-cover classes that include low-frequency classes requires greater sample numbers, as illustrated in this study.

Comparing all seven cover classes measured via SamplePoint from 2- and 100-m AGL images, we found (1) that the datasets were highly correlated (r = 0.86, n = 200), but (2) that 10 of 21 cover means (seven classes x three treatments) were 7% different, on average ($P < 0.05$, n = 10). Some of this 7% mean difference is probably due to coverage: 100-m AGL images captured 12 times the area captured by 2-m AGL images. Analysis of images from 100-m AGL showed slightly higher precision than from 2-m AGL, probably due to slight image "homogenization" through motion blur (Booth *et al.* unpublished), but the difference is minor (Figure 4). Thus, we conclude that cover measurements are affected by image-capture altitude, but that the effect is relatively small (< 7%).

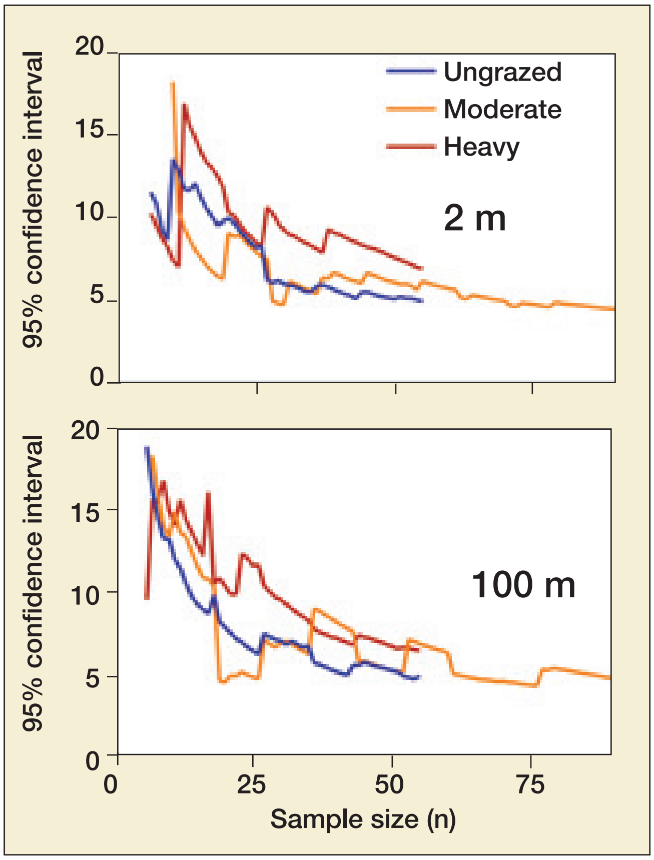

Figure 4. Ninety-five percent confidence interval for randomly-selected subsamples for each pasture and grazing treatment, plotted over sample size for both 2-m and 100-m datasets. This serves to illustrate the relationship between measurement precision and sample size, as well as to provide a predictive tool for estimating required sample sizes for a particular precision goal in future monitoring efforts for similar plant communities with similar physiography.

Manual and automated image analysis

SamplePoint bare-ground measurements from 2- and 100-m AGL images were better correlated (r = 0.50, n = 200) than were VegMeasure measurements (r = 0.35, n = 200). Both programs gave bare-ground means for each pasture that showed a significant difference between the 2- and 100-m AGL data ($P < 0.05$, n = 55 heavy and ungrazed; n = 90 moderate). VegMeasure comparisons had smaller P-values, and SamplePoint had a slightly smaller mean difference across all pastures (3.8%, n = 3) than did VegMeasure (4.9%, n = 3). Bare-ground cover differences between SamplePoint and VegMeasure analyses among pastures ranged from 1–7% for 100-m images and 3-7% for 2-m images. The study design does not allow a determination of method accuracy. SamplePoint has been shown to have a higher potential accuracy (92%) than VegMeasure (82%; Booth *et al.* 2006a). Therefore, we have more confidence in the SamplePoint results of this study, but a bare-ground cover difference of < 7% between methods may not warrant the increased time required for a SamplePoint analysis.

Costs

A major strength of image-based monitoring is the number of samples (images) that can be quickly acquired at relatively low cost (Table 1; Booth *et al.* 2004, 2006b; Booth and Cox 2006; Luscier *et al.* 2006). Since both 2-m and 100-m AGL image sets yielded similar results when analyzed by SamplePoint (r = 0.86, n = 200, and > 50% agreement on cover means), we conclude that either aerial or ground imaging will detect vegetative change due to grazing. For a small area, such as this 130-ha study, collecting and analyzing ground imagery was more cost effective (Table 1). Larger project areas require more travel time to photo locations. We infer that, at some extent not much greater than 130 ha, it will be more cost effective to collect and analyze aerial photographs. The size and accessibility of a project area is key to determining the most cost-effective option.

Table 1. Cost (in US$) for high-intensity monitoring via remote sensing of 130 ha of grazing land using aerial photography (100-m imagery) or ground photography (2-m imagery; n = 200)

Item	*100-m imagery*	*2-m imagery*
Determining plot coordinates	50	50
Writing flight plan	25	na
Flight costs	430	na
Ground image collection	na	200
Image cropping	na	100
SamplePoint image analysis	400	400
VegMeasure image analysis	50	50
Total	**$955**	**$800**

Notes: Costs assume US$25 hr^{-1} technician time and $125 hr^{-1} flight time. The flight cost includes both the pilot cost and ground technical support for a 2-hr flight, plus flight preparation.

Panel 1. Ongoing research

The aerial methods described here, with some modifications, are being tested over a range of applications and plant communities (short- and mixed-grass prairie, sagebrush steppe, cold desert, pinyon–juniper woodlands) and with a variety of cooperators. We currently use one, two, or three cameras to acquire simultaneous image resolutions between 1 and 30 mm GSD (depending on the indicators to be measured), and we are conducting cooperative work in Colorado, Idaho, Nevada, North Dakota, New Mexico, and Wyoming, covering 911 980 hectares of rangeland, 568 km of rangeland streams for riparian and aquatic assessments, and 73 km of public land pipeline right-of-way. Data evaluations for most of this work are ongoing. However, advantages of the aerial surveys that have been repeatedly demonstrated are:

(1) it is less expensive than conventional ground sampling for extensive areas,
(2) it makes the acquisition of large sample numbers practical,
(3) it reduces the sample-collection time to a period of days rather than months,
(4) it creates a permanent record for comparison to subsequent surveys, and
(5) it is a means for capturing details to detect ecologically important differences (eg increase or decrease of invasive species, willow regrowth with prescription grazing, shrub density as affected by fire interval, vegetation recovery after fire, plant density and ground cover between revegetated pipeline right-of-way and undisturbed rangeland).

Conclusions

Image-based monitoring using SamplePoint software with 1-mm GSD aerial or ground imagery is an effective and economical means for detecting ground-cover differences among grazing treatments across extensive areas (Panel 1). Object-based image analysis holds promise for the future (Luscier *et al.* 2006), but a manual SamplePoint analysis is a current, accurate option. Used over time, image-based monitoring can detect trends in ecological condition or "health", can assist in determining appropriate stocking rates, and can be used to monitor long-term ecological processes. A SamplePoint analysis can include multiple cover classes, thus providing a more complete picture of rangeland condition than a binary VegMeasure analysis. A probable instance of bright-color bias was detected in the 100-m AGL SamplePoint data, consistent with our earlier findings. In contrast, with conventional ground-cover measurements, image-based analyses allow such biases to be detected and measured, and allows images to be reanalyzed if needed. The most cost-effective approach (aerial versus ground) will depend on the size and accessibility of the area being monitored.

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SamplePoint analysis of all images, and L Griffith, who conducted much of the statistical analyses.

References

Booth DT and Tueller PT. 2003. Rangeland monitoring using remote sensing. *J Arid Land Res Manage* **17**: 455–78.

Booth DT, Cox SE, Louhaichi M, and Johnson DE. 2004. Lightweight camera stand for close-to-Earth remote sensing. *J Range Manage* **57**: 675–78.

Booth DT and Cox SE. 2006. Very large scale aerial photography for rangeland monitoring. *GeoCarto Int* **21**: 27–34.

Booth DT, Cox SE, and Berryman RD. 2006a. Point sampling digital imagery using "SamplePoint". *Environ Monit Assess* **123**: 97–108.

Booth DT, Cox SE, Meikle TW, and Fitzgerald C. 2006b. The accuracy of ground cover measurements. *Rangeland Ecol Manage* **59**: 179–88.

Cooper WS. 1924. An apparatus for photographic recording of quadrats. *J Ecol* **12**: 317–21.

Hart RH and Ashby MM. 1998. Grazing intensities, vegetation, and heifer gains: 55 years on shortgrass. *J Range Manage* **51**: 392–98.

ITT (Interagency Technical Team). 1996. Sampling vegetation attributes. Denver, CO: US Department of the Interior, Bureau of Land Management, National Applied Resources Science Center. Interagency Technical Reference, Report No BLM/RS/ST-96/002+1730.

Johnson DE, Vulfson M, Louhaichi M, and Harris NR. 2003. VegMeasure version 1.6 user's manual. Corvallis, OR: Department of Rangeland Resources, Oregon State University.

Johnson KL and Jackson WH. 1987. Rangeland through time: a photographic study of vegetation change in Wyoming, 1870–1986. Laramie, WY: Agricultural Experiment Station, University of Wyoming. www.rangelands.org/wy_photos/RangeThroughTime/RangeThroughTime.html. Viewed 6 Mar 2007.

Knipling EB. 1970. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. *Remote Sens Environ* **1**: 155–59

Lauenroth WK and Milchunas DG. 1991. Short-grass steppe. In: Coupland RT (Ed). Natural grasslands, introduction and western hemisphere. Ecosystems of the world 8A. Amsterdam, Netherlands: Elsevier.

Luscier JD, Thompson WL, Wilson JM, *et al.* 2006. Using digital photographs and object-based image analysis to estimate percent ground cover in vegetation plots. *Front Ecol Environ* **4**: 408–13.

McGinnies WJ, Shantz HL, and McGinnies WG. 1991. Changes in vegetation and land use in eastern Colorado: a photographic study, 1904 to 1986. Springfield, VA: USDA Agricultural Research Service. ARS-85.

Milchunas DG, Lauenroth WK, Chapman PL, and Kazempour MK. 1989. Effects of grazing, topography, and precipitation on the structure of a semiarid grassland. *Vegetatio* **80**: 11–23.

Rebollo S, Milchunas DG, Noy-Meir I, and Chapman PL. 2002. The role of a spiny plant refuge in structuring grazed short-grass steppe plant communities. *Oikos* **98**: 53–64.

Seefeldt SS and Booth DT. 2006. Measuring plant cover in sagebrush steppe rangelands: a comparison of methods. *Environ Manage* **37**: 703–11.

USDI–BLM (US Department of the Interior, Bureau of Land Management). 1997. Standards for healthy rangelands and guidelines for livestock grazing management. Cheyenne, WY: US Department of the Interior. Booklet BLM/WY/AE-97-023+1020.

Wells KF. 1971. Measuring vegetation changes on fixed quadrats by vertical ground stereophotography. *J Range Manage* **24**: 233–36.

Wyliea BK, Meyera DJ, Tieszenb LL, and Mannel S. 2002. Satellite mapping of surface biophysical parameters at the biome scale over the North American grasslands: a case study. *Remote Sens Environ* **79**: 266–78.