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Ground-Cover Measurements: Assessing Correlation Among Aerial and Ground-Based Methods

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Abstract Wyoming's Green Mountain Common Allotment is public land providing livestock forage, wildlife habitat, and unfenced solitude, amid other ecological services. It is also the center of ongoing debate over USDI Bureau of Land Management's (BLM) adjudication of land uses. Monitoring resource use is a BLM responsibility, but conventional monitoring is inadequate for the vast areas encompassed in this and other public-land units. New monitoring methods are needed that will reduce monitoring costs. An understanding of data-set relationships among old and new methods is also needed. This study compared two conventional methods with two remote sensing methods using images captured from two meters and 100 meters above ground level from a camera stand (a ground, image-based method) and a light airplane (an aerial, image-based method). Image analysis used SamplePoint or VegMeasure software. Aerial methods allowed for increased sampling intensity at low cost relative to the time and travel required by ground methods. Costs to acquire the aerial imagery and measure ground cover on 162 aerial samples representing 9000 ha were less than $3000. The four highest correlations among data sets for bare ground—the ground-cover characteristic yielding the highest correlations (r)—ranged from 0.76 to 0.85 and included ground with ground, ground with aerial, and aerial with aerial data-set associations. We conclude that our aerial surveys are a cost-effective monitoring method, that ground with aerial data-set correlations can be equal to, or greater than those among ground-based data sets, and that bare ground should continue to be investigated and tested for use as a key indicator of rangeland health.

Keywords Image analysis · Line intercept · Laser point frame · Point intercept · SamplePoint · Vegetation measurement · VegMeasure

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Introduction

The Green Mountain Common Allotment, south of Jeffery City, Wyoming, USA, is representative of public land that is increasingly cherished by society for unfenced solitude, wildlife populations, and recreational opportunities. On this and similar public lands there is ongoing debate over grazing and other public-land uses. The responsibility for proper adjudication of resource use, and the responsibility for assuring resource sustainability, lies with the responsible land-management agencies. Numerous ecological indicators are suggested for accomplishing assessments but none are more prominently considered, nor appear to have a greater demonstrated capability for statistically-adequate, economical sampling, than the measurement of ground cover and its inverse, bare ground (Booth and Tueller 2003; Booth and others 2005a; Kaiser 2005). Established correlations of bare ground with increased grazing and with watershed runoff, qualify it as a primary indicator of the ecological condition of grazed lands (BLM 1997; NRC 1994; Society for Range Management, Task Group on

Unity in Concepts and Terminology 1995). The evidence suggests that accurate bare-ground measurements from evenly distributed and statistically-adequate numbers of sample sites will support sustainable land management. Conventional field methods for measuring ground cover are labor intensive (Oosting 1956; Cook and Stubbendieck 1986), and there is growing recognition that these methods do not allow collection of sufficient data to accomplish monitoring objectives (West 1999).

Seefeldt and Booth (2006) found image analysis to be an effective means of ground-cover data collection when compared with conventional methods. They noted the reduction in cost per sample, the increased speed of sampling, the acquisition of a permanent image, the lower standard deviation associated with aerial sampling, and the ability of aerial methods to avoid aggravating problems of ground sampling, such as occurs when working in thick shrub stands. They, however, also noted the aerial technique they used was new and evolving, and recommended that aerial methods continue to be tested by correlating and comparing aerial data with ground sampling. This study was conducted to (1) test the utility of aerial acquisition as an image-based rangeland sampling method and, (2) to assess the correlation of ground-cover measurements from two nonimaging methods and from ground and aerially derived image measurements. The aerial imagery acquired in this study had twice the resolution of that acquired by Seefeldt and Booth (2006), effectively "sharpening" the sample point to increase accuracy (Cook and Stubbendieck 1986) when a pixel-based analysis was used (SamplePoint, Booth and others 2006c) in place of the digital grid used by Seefeldt and Booth (2006).

Study Area

The Green Mountain Common Allotment administered by the US Department of the Interior, Bureau of Land Management (BLM), Lander Field Office, is 209,222 ha of public land located south and west of US Highway 287 and east of Atlantic City, Wyoming, and includes the adjacent northern edge of Wyoming's Red Desert. The elevations of the plains in the allotment are 1940–1960 m with Green Mountain summit rising to 2768 m. There are 19 grazing leases with 47,279 animal unit months (AUMs). There are also numerous herds of wild horses (*Equus caballus*), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and pronghorn (*Antilocapra americana*). Greater sage grouse (*Centrocercus urophasianus*) is a species of concern. Environmentalists are concerned that grazing and drought have damaged the sage grouse habitat (Hadak 2002) and grazing lessees are concerned that reductions in grazing permits are unwarranted (Farquhar 2003).

Ground, aerial, and space imagery were obtained in June 2005, from the 9000-ha Hay Press Creek Pasture of the Green Mountain Common Allotment southwest of Jeffrey City, Wyoming (42° 27′ N, 107° 55′; W) between Green Mountain and the flood plain of the Sweetwater River. A LANDSAT 5 scene (30-m ground sample distance [GSD]) was obtained and analyzed using an unsupervised classification in ERDAS Imagine v8.7 (Leica Geosystems, Heerbrugg, Switzerland). The classification of the image showed 85% sagebrush-grassland (7526 ha), 12% riparian area (1096 ha), 2% Playa (161 ha), and 0.5% road (30 ha). The pasture is dominated with Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young).

Methods

Ground Sample Locations

Our study centered on 25 ground locations where ground data collection was GPS-paired with camera-trigger locations for 25 of the 162 aerial images whose acquisition is described below. The locations were selected nonrandomly to facilitate access, but were uniformly distributed across the pasture (Fig. 1) and were flagged after being located using a "DGPS Max" differentially-corrected global positioning system (DGPS)(CSI Wireless, Calgary, Alberta) with sub-meter accuracy (stationary). We emphasize that beyond demonstrating the utility of aerial surveys for obtaining large numbers of high-resolution images (objective 1), our study was about the correlations among data sets from the monitoring methods used at the 25 locations (objective 2). We are not attempting to describe the ecological health of 9000 ha with only 25 sample locations.

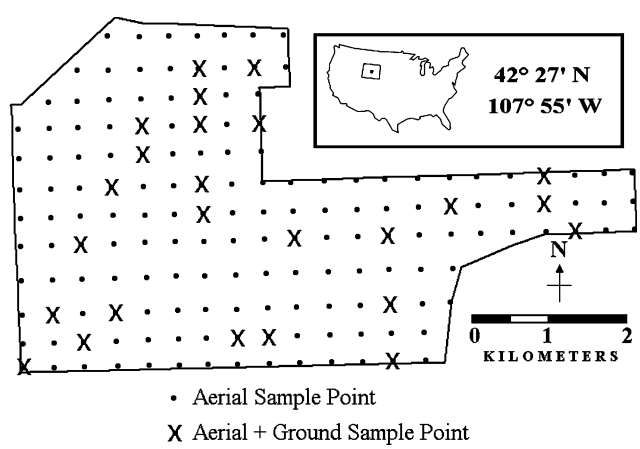

Fig. 1 Distribution of collected samples (images) within the 9,000-ha Haypress Pasture. Images were collected from 100-m AGL (aerial) and 2-m AGL (ground). Ground images were collected no further than 10 m from the aerial image center point

Remote Sensing

Ground Photography

We acquired 25 ground images using an Olympus E20, 5-megapixel, digital single lens reflex camera mounted on an aluminum camera frame with a 1-m^2 base (the base was centered on the flagged locations) that positioned the camera for nadir images 2-m above ground level (AGL) (Booth and others 2004; Seefeldt and Booth 2006). Images were saved as uncompressed color Tagged Image File Format (TIFF) files (red, green, blue [RGB] bands; sensor resolution = 0.9 mm GSD, 2 × 1.5-m field of view). Plots were shaded with a cotton sheet to eliminate shadows in the image.

Very Large-Scale Aerial Photography (VLSA)

We acquired 162 intermittently-spaced, color digital aerial images using a light airplane (225-kg empty weight, fixed wing, three-axis), a navigation and camera-triggering system, a digital camera, and a laser rangefinder (Booth and Cox 2006; Booth and others 2006a). The navigation system was powered by Tracker software (Track'Air B.V., Oldenzaal, The Netherlands) on a laptop computer interfaced with (1) a central navigation box, (2) a DGPS, and (3) a 15-cm in-cockpit LCD display. The navigation system was programmed to automatically trigger the camera at 800-m intervals along 12 east-west flight lines. We used a Canon 1Ds 11.1-megapixel single lens reflex, color (RGB) digital camera with a Canon 600 mm f/4.0 EF lens plus a 1.4x teleconverter to yield the equivalent of a 840 mm, f/5.6 lens (Canon USA, Lake Success, NY, USA). Shutter speed was manually set for 1/4,000th second with safety shift enabled to allow the shutter speed to slow in inadequate light. The camera was interfaced with a laptop PC (3.2-GHz, 40-GB-hard drive) running Canon Remote Capture software and images were stored directly on the hard drive. Images were initially saved as 10 MB RAW (non-lossy) files and later converted to 24-bit, 31 MB, 4064 × 2704-pixel Tagged Image File Format (TIFF) files for analysis. A Riegl LD-90 3100VHSFLP laser rangefinder (Riegl, Orlando, FL, USA) was used as an altimeter in conjunction with LaserLOG software (Booth and others 2006a) to continuously read and record the airplane's altitude AGL below 300 m. Altitude was displayed for the pilot on the screen of the laptop storing the images, while stored data were saved for later correlation with images. Planned flight altitude for the upland survey was 100 m AGL with an expected image resolution of 1 mm GSD (Comer and others 1998) and a 3 × 4-m field-of-view. The flight plan of 12 E–W flight lines totaling 121 km was created by extracting coordinates of user-defined points drawn on a digital raster graphic in ArcView GIS 3.3 (ESRI, Redlands, CA), then using Track'Air SnapXYZ flight planning software to enter the coordinates into a flight plan utilized in flight by Track'Air SnapShot software. Photo targets were planned on a 0.8-km grid covering the entire pasture. The DGPS was used to guide the pilot to the photo targets. Preliminary work established that use of the DGPS in the airplane resulted in an image field-of-view within 10 m of the target as located on the ground using stationary DGPS readings.

Image Analysis

SamplePoint (SP)

SamplePoint was developed USDA-ARS and was designed for point-classification of digital images. It allows accuracy comparable with the most accurate field-methods for ground-cover measurements (Booth and others 2006c). The program loads the images from a database and systematically identifies and locates a user-defined number of sample points in the image. We used 100 systematically-located points per image. The software takes the user from one point to the next so that the user can classify each point without worry of inadvertent double counting or missing a point. The sample point is always a single pixel of the image although the pixel GSD naturally depends on the resolution of the image loaded. Whatever the resolution; the pixel is the smallest possible contact point for digital analysis. SamplePoint identifies each sample point by four red, 1-pixel-thick lines, arranged in a crosshair pattern, that leads toward, but not over, the pixel of interest. The software also has 30 buttons below the image that allows users to identify designated ground-cover classes. When a user identifies a point by clicking one of the thirty buttons, the user's classification is saved to the database and the next classification point automatically shows up in the image window at the user-defined zoom level. Labels can be user-defined and we defined 16 categories: bare ground, litter, rock, biological crust, perennial grass, annual grass, perennial forb, annual forb, low sagebrush (*Artemisia arbuscula* Nutt. ssp. *arbuscula*), silver sagebrush (*Artemisia cana* Pursh), Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young), Greene's rabbitbrush (*Chrysothamnus greenei* (Gray) Greene), greasewood (*Sarcobatus vermiculatus* (Hook.) Torr.), spineless horsebrush (*Tetradymia canescens* DC.), plains pricklypear (*Opuntia polyacantha* Haw.), and unknown. The software allows a user to zoom in or out as needed to examine the context or detail of an image pixel. We used SamplePoint to analyze both the 2-m and 100-m AGL imagery and the respective data sets were designated SP-2 and SP-100.

VegMeasure (VM)

VegMeasure, a software program created at Oregon State University, uses rapid binary classification based on image spectral reflectances to batch process hundreds or thousands of images. It is a practical approach to analyzing the large numbers of images made possible through aerial remote sensing of this kind (Johnson and others 2003). We used VegMeasure v1.6.0 to measure plant cover using the green leaf algorithm (Louhaichi and others 2001). Bare ground was measured using the blue band and brightness algorithms (Johnson and others 2003). In each case the detection thresholds were calibrated using a 10% subsample of images analyzed using SamplePoint (Booth and others 2005b, 2006c). As with SamplePoint, we used VegMeasure to analyze both the 2-m and 100-m AGL imagery and the data sets were designated VM-2 and VM-100.

Nonimaging Ground-Cover Measurements

Ground-cover measurements from two conventional point-sampling methods were compared to the image-analysis methods. These two data sets were also compared to each other for grass, forb, shrub, litter, biological crust and rock cover, and percent bare ground.

Laser Point Frame (LPF)

The LPF (Van Amburg and others 2005) was custom built by the Colorado State University Agriculture Engineering and Research Center, Fort Collins, CO, and utilizes 10 lasers equally spaced 10 cm apart in a nadir orientation within an aluminum housing supported 33 cm above ground level by adjustable aluminum legs. Lasers have a 650-nm wavelength, with a maximum average radiant power of 3.5 mW, an operating voltage of 3–5 VDC, and a red-laser dot (ground contact) of 0.79 mm^2. One hundred first-hit points were classified within the same 1 m^2 quadrat used for ground photography. Use of point frames is described by the Interagency Technical Team (ITT 1996).

Point Intercept (PI)

The PI method was slightly modified from that described by the Interagency Technical Team (1996) and was the conventional method then used by the BLM Lander Field Office. A PVC frame, holding a vertically-oriented free-sliding steel pin (as opposed to a mirror-containing sighting device), was positioned at 50-cm intervals along a 30-m, E–W transect having the DGPS-flagged location as the east end. The first hit for each pin lowering was recorded for a total of 60 points. The point of the pin had a 0.8-mm diameter (0.50 mm^2 contact area).

Data Analyses

Ground-Cover Measurements

We compared means for grass, forb, shrub, litter, bare ground, rock, and crust cover, between data sets from the two nonimage field techniques using two-independent sample *t*-tests (SPSS v11, SPSS, Inc., Chicago, IL). Levene's homogeneity of variance test was used to check whether sample variances could be pooled or not. In addition, a MANOVA was performed to examine the effect of both ground measurement techniques on all seven cover means considered simultaneously. A clustered boxplot was used to graphically display differences between medians, 25th and 75th percentiles, min/max percent cover values, and outliers by method (LPF and PI).

Correlation Analysis

We computed the association between the data sets LPF, PI, SP-2, VM-2, SP-100, and VM-100 for bare ground (r_{bg}), litter + rock (r_{l+r}), live vegetation (r_{veg}), and the combination (bare ground + (litter + rock) + live vegetation; r_{all}) using correlation analysis of data for the 25 ground plots and associated aerial images. Live vegetation as assessed with LPF, PI, SP-2, and SP-100 includes non-green plant parts of green vegetation. VM-2 and VM-100 measurements are based on green reflectance. A *t*-test was used to determine if correlations between various cover values in the six different data sets were significantly different from zero ($p \leq 0.05$). To aid in assessing the relative correlation among data sets, correlation coefficients were ranked. A matrix of significant rankings was used to judge the relative association of each data set with the other data sets. Scatter diagrams showing the bare ground, live vegetation, and litter + rock cover values for SP-100 versus SP-2 and for VM-100 versus SP-2 were constructed. Superimposed over these data points was a 45 degree line to indicate perfect agreement between the cover values derived via the two indicated methods and a simple regression line with 95 percent confidence bands fit to the data to indicate the degree of bias.

The problem we address with correlation analysis is that of having no standard for measuring data-set accuracy. Data come from plots and transects, from ground versus aerial imagery, and in the case of VM analyses, from a method calibrated by another method to which it is being compared. Therefore, our measures of association must be considered within the context of data-set differences and similarities. The standard cautions about using correlation apply (i.e., correlation measures association by the degree to which two variables are linearly related and does not show causation or reflect non-linear association). Used conservatively, the correlation analysis is an important tool and is used here to assess the similarity among the various ground-cover-measurement data sets developed at the 25 sample locations.

Results and Discussion

Time Required for Ground and Aerial Assessments

Ground data collection at the 25 targets selected for study required 400 person hours and put 3 vehicles in the field per day over a 4-day period. Each vehicle traveled approximately 1129 km. Although ground photography required about 2 min at each site, travel time to sites was not less than 30 min between any two sites. There was an additional 16 hours for ground data processing. Collection of 162 VLSA photographs required 3 hours (Table 1). Image analysis of the 162 aerial photographs took 19.0 hours for SamplePoint (SP-100) using 16 categories (Table 2). The SamplePoint-calibrated VegMeasure (VM) analysis (with SamplePoint already done) required about 2 hours calibrating the software and 5 minutes to batch process the 162 images.

Table 1 Costs for VLSA image acquisition in upland survey of Hay Press Creek Pasture

Item	Rate ($/hr)	Time (hr)	Total ($)
Flight costs			
Air time	150	3	450
Ground time (pilot)	40	7	280
Ground time (support staff)	25	30	750
Other costs[a]			200
Total			1680

[a] This includes $5000 annual start up cost (insurance) pro-rated across 60 days of flying per year ($83 per day), and the cost of transporting the airplane to the work area from Fort Collins, CO

Table 2 Costs for image analysis of VLSA images of Hay Press Creek Pasture using SamplePoint and VegMeasure ($25/hour technician time)

Item	Time (hr)	Total ($)
File conversion, organization, color-correction	4	100
SamplePoint analysis	19	475
Total		575
File conversion, organization, color-correction	4	100
VegMeasure analysis	2	50
Total		150

Nonimaging Measurements Compared

Sample *t*-tests revealed significant differences between the LPF and PI measurements for bare ground (35 versus 27%, $p = 0.003$, $n = 25$) and grass cover (23 versus 32%, $p = 0.03$, $n = 25$) (Fig. 2). These same differences were detected in the vectors of all seven attributes between the LPF and PI field methods when considered simultaneously in a MANOVA ($F_C = 2.64$ with $\alpha = 0.024$) (Levene's test for homogeneity of variance was not violated in any case). Note that the LPF- and PI-measured cover for forbs and shrubs were closely aligned; being 2% for both methods for forbs and 14 versus 15% for shrubs (LPF and PI, respectively). Variability was highest with bare ground and lowest with forb and biological-crust cover.

Image and Nonimaging Measurements Compared

Among all data sets, bare-ground measurements ranged from 27 (PI) to 36% (SP-2). The difference is not significant as assessed by the 95% confidence limits (Table 3). There were differences among methods in measurements of vegetation with the PI data set having the highest value (49%), and VM-100 (33%) showing the lowest. The two VegMeasure analyses were not different due to wide confidence intervals associated with that data (Table 3). The LPF and PI data sets were different with the PI indicating significantly more green cover. This difference between data sets was also detected, as noted above, by the *t*-test analysis. There are also differences among data sets with

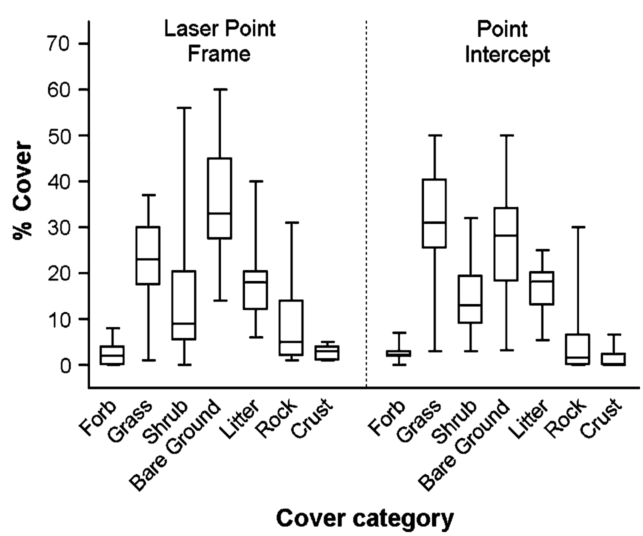

Fig. 2 Box and whisker plots showing the median, 25th and 75th % quartiles and range for each ground-cover characteristic as measured by either the LPF or the PI. Note that bare ground was more prevalent than other characteristics and forbs and biological crusts were the least prevalent

respect to the measurement of litter + rock cover percentages (Table 3).

Example scatter plots from the correlation analysis are given in Fig. 3. The highest linear correlation of ground cover measurements for the combined characteristics (bare ground, litter + rock, and vegetation, designated r_{all}) was for SP-2 with LPF ($r_{all} = 0.78$, Table 4). This linear association does not approach a ≥ 0.90 correlation that might have been postulated as a result of laboratory tests using two-dimensional models (Booth and others 2006b and c). Rather, the author's expectations (op. cit.) of reduced accuracy in a three-dimensional world appear justified. These two data sets had a relatively high correlation coefficient (r) for bare ground ($r_{bg} = 0.76$) and the highest ranked r for litter + rock ($r_{l+r} = 0.83$), and for live vegetation ($r_{veg} = 0.70$). Remembering that the LPF, SP-2, and VM-2 data are all from the same m^2 ground plots, one might have predicted similar correlations among all three of these data sets. That did not occur, and the next highest ranking associations across all characteristics among the ground data sets was for the LPF with PI ($r_{all} = 0.49$, ranked 5[th]) methods that did not cover exactly the same ground and thus can not be compared in the same manner as the SP-2 and LPF methods. No other ground-based data sets had significant r_{all} rankings.

The second most closely associated data sets ranked by r_{all} were PI with SP-100 ($r_{all} = 0.68$, ranked 2nd) and LPF with SP-100 ($r_{all} = 0.56$, ranked 3rd, Table 4). These are of particular interest for assessing how well the aerially-derived measurements compare with conventional ground-based measurements. PI with SP-100 had a high association for bare ground ($r_{bg} = 0.77$), was low for litter + rock ($r_{l+r} = 0.44$), and the relationship for vegetation was not significant. The LPF with SP-100 values were $r_{bg} = 0.54$, $r_{l+r} = 0.57$, and again vegetation was not significant. Thus, the bare ground linear association between the best-correlated aerial and ground data sets (PI with SP-100) was equal to the best-correlated ground data sets (SP-2 with LPF). The difference between the PI with SP-100 and LPF with SP-100 raises the question of whether transects better represent the 3 × 4-m area captured in aerial photographs than do single m^2 plots. The significant association found between ground and aerial data sets is likely to be partly due to the increased camera resolution used in this study as compared to that used by Seefeldt and Booth (2006).

The aerial data sets, SP-100 and VM-100, were 4th ranked with $r_{all} = 0.55$, and had the highest bare ground agreement ($r_{bg} = 0.85$), with lower values for litter/ rock and vegetation, areas where spectral separations can be less accurate (Booth and others 2005a). This correlation is not surprising given that both data sets are derived from the aerial imagery and that VegMeasure was calibrated using SamplePoint. These common factors are, however, no assurance of similarly accurate measurements.

From Table 4 it is evident that the different data sets are most closely associated for bare ground measurements, followed by litter + rock. Values for vegetation are, with three exceptions, not significant. Bare ground has five nonsignificant associations, litter + rock has seven, and green vegetation has 12. Similarly, when the distribution of r-values are considered, bare ground has eight values, litter + rock has three values, and vegetation has two values that are all ≥ 0.50 (Table 5). The low r-values for vegetation and the high number of nonsignificant values are evidence of high variability and suggest a problem in consistently and accurately assessing vegetation cover among the methods used to produce the data sets. The problem is not just between ground and aerial data sets. As can be seen in Table 4, with the exception of SP-2 with LPF, the ground to ground associations were no better

Table 3 Comparison of cover classification by Laser Point Frame, Point Intercept, SamplePoint, and VegMeasure[a] for the twenty-five 2-m and their associated 100-m AGL photographs

Method	% Bare ground	% Live vegetation			Total % live vegetation	% Litter + rock
		Shrub	Grass	Forb		
SP-2[b]	36 ± 4	9 ± 5	16 ± 3	9 ± 3	35 ± 4	28 ± 4
VM-2[a]	35 ± 7	NA	NA	NA	41 ± 6	24 ± 3
LPF	35 ± 5	14 ± 5	23 ± 3	2 ± 1	39 ± 4	24 ± 4
PI	27 ± 5	15 ± 3	31 ± 4	2 ± 1	49 ± 4	24 ± 3
SP-100	33 ± 5	19 ± 4	19 ± 3	6 ± 1	43 ± 3	24 ± 4
VM-100[a]	33 ± 6	NA	NA	NA	33 ± 5	34 ± 3

Means are shown with 95% confidence limits

[a] Since VegMeasure classification does not distinguish among components of green vegetation, these values are based on 3, rather than 6, cover categories

[b] SP-2 = SamplePoint used with 2-m AGL data; VM-2 = VegMeasure used with 2-m AGL data; LPF = Laser Point Frame; PI = Point Intercept; SP-100 = SamplePoint used with 100-m AGL data; VM-100 = VegMeasure used with 100-m AGL data

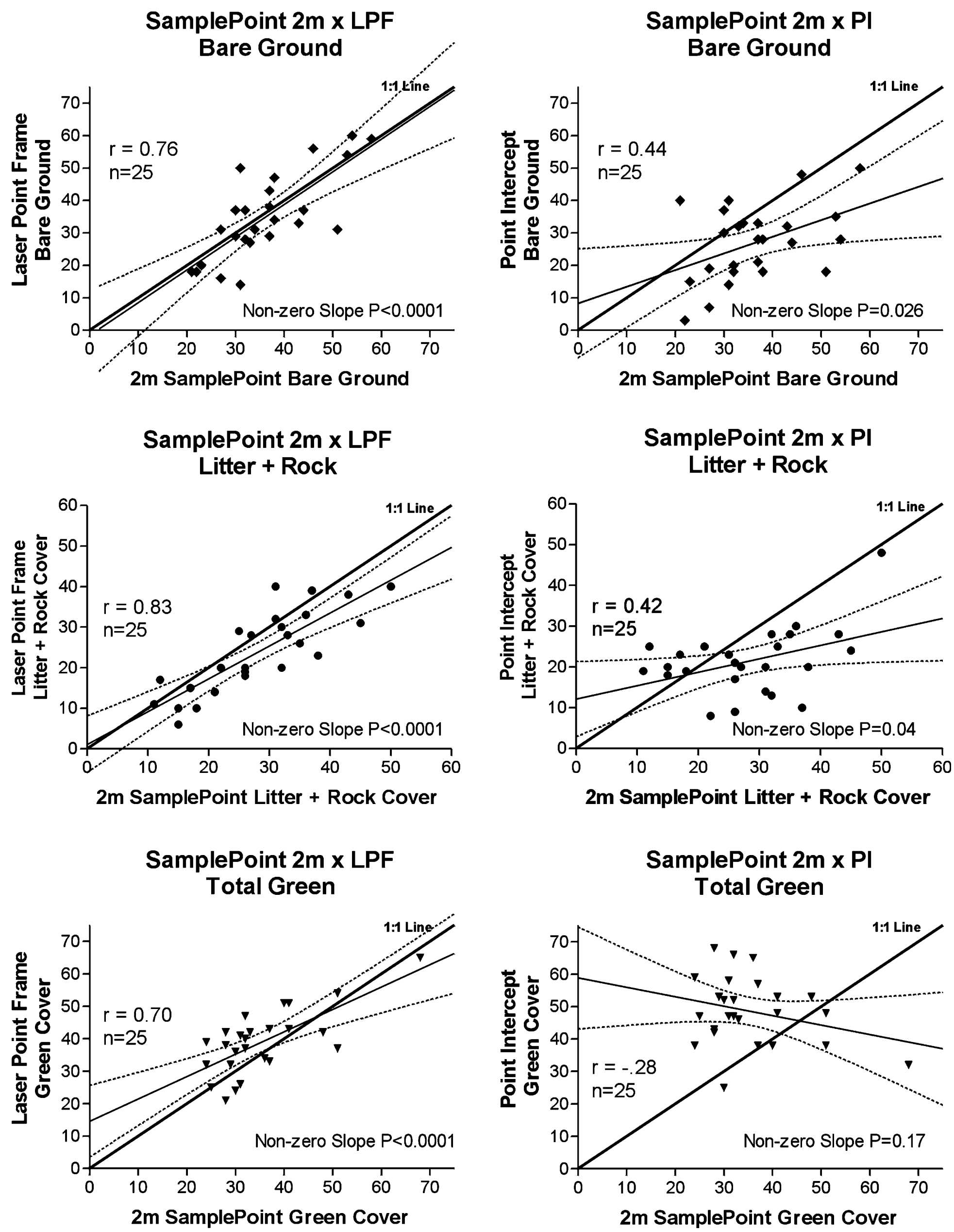

Fig. 3 Scatter plots showing six data-set correlation analyses for bare ground, litter + rock, and vegetation. Correlation line and 95% CI of the line are shown on each plot, along with a 1:1 perfect correlation line for comparison. Regression lines were tested for deviation from 0, with *p* - values (shown for each plot) less than 0.05 indicating a significant relationship between the two data sets

correlated than the ground to air associations (as was also evident in the *t*-test comparisons). Thus, this study adds further evidence to earlier suggestions that ecological monitoring focus on bare ground as a key indicator (Kaiser 2005). It also highlights (1) a need to better understand why ground-cover measurement methods do not give more highly-correlated results for vegetative cover and (2) we should not assume the ground data are always more accurate than remotely-sensed data since the method for collecting ground data will influence the correlation between the two (A. S. Laliberte, reviewer, personal communication, October 20, 2006).

VM-2 had no significant correlation with any data set. SP-100 had 13 significant correlations; SP-2, LPF, and VM-100 had 11; and PI had 10 (Table 4; see the data sets listed in column two and for each row for a given data set, count significant associations under r_{bg}, r_{l+r}, r_{veg}, and r_{all}; there are five data-set correlations x the four ground-cover labels). We speculate that the VM spectral analysis of high-resolution imagery (<1 mm) was complicated by the greater variety of colors that accompany an increase in detail, and that this decreased the association with other data sets. We contrast this outcome with the VM-100 data set where the same analysis method was used with aerial data. Although our aerial methods greatly reduce motion blur, blur can still be a factor causing a degree of homogenization among adjacent pixels. We speculate that the slight blur in the aerial imagery reduced the complexity

Table 4 Correlation coefficients generated by comparing data sets (column 1 with column 2)

Data sets compared		Bare ground		Litter + rock		Vegetation		BG + (L + R) + Veg	
1	2	r_{bg}	Rank	r_{l+r}	Rank	r_{veg}	Rank	r_{all}	Rank
SP-2	LPF	0.76	4	0.83	1	0.70	1	0.78	1
	VM-2	0.07	NS	0.11	NS	−0.03	NS	0.08	NS
	PI	0.44	10	0.42	6	−0.28	NS	0.26	NS
	SP-100	0.48	9	0.75	2	−0.24	NS	0.45	6
	VM-100	0.54	7	0.41	7	−0.30	NS	0.19	NS
LPF	VM-2	−0.17	NS	0.05	NS	−0.26	NS	0.07	NS
	PI	0.56	6	0.32	NS	−0.07	NS	0.49	5
	SP-100	0.54	7	0.57	3	−0.09	NS	0.56	3
	VM-100	0.57	5	0.40	8	−0.04	NS	0.29	NS
VM-2	PI	0.03	NS	0.05	NS	−0.09	NS	0.27	NS
	SP-100	0.15	NS	0.08	NS	0.11	NS	0.30	NS
	VM-100	−0.01	NS	0.24	NS	0.13	NS	0.01	NS
PI	SP-100	0.77	2	0.44	5	0.02	NS	0.68	2
	VM-100	0.76	3	0.16	NS	0.43	3	0.34	7
SP-100	VM-100	0.85	1	0.49	4	0.60	2	0.55	4

The data sets result from six sampling + analysis methods at 25 ground locations within the Hay Press Creek Pasture. The correlation coefficients, *r*, are ranked by ground-cover characteristic separately and combined. SP-2 and SP-100 = SamplePoint with 2- and 100-m AGL imagery, VM-2 and VM-100 = VegMeasure with 2- and 100-m AGL imagery, LPF = Laser point frame, and PI = Point intercept

r values have a significant (directional) *t*-statistic ($p < 0.05$) unless otherwise marked (NS)

Table 5 The distribution of *r*-values, without regard to sign or method, for bare ground (BG), litter + rock (L + R), and vegetation (Veg)

r	BG	L + R	Veg
≥.80	1	1	0
0.7 to 0.79	3	1	1
0.6 to 0.69	0	0	1
0.5 to 0.59	4	1	0
0.4 to 0.49	2	5	1
0.3 to 0.39	0	1	1
0.2 to 0.29	0	1	3
0.1 to 0.19	2	2	2
0 to 0.09	3	3	6

Values of *r* less than 0.4 (below dotted line) are not significant at $\alpha = 0.05$

of spectral analysis producing a data set that—while it may, or may not be accurate—had a higher degree of association with the other data sets.

The low association of VM-2 with other data sets is consistent with reports of the limitations of pixel-based image analysis methods for high-resolution images (Blaschke and Strobl 2001; Laliberte and others 2007a, b; Lobo and others 1998). The reports of these authors suggest more confusion is generated with a program classifying every pixel than with one that combines adjacent similar pixels into homogenous values—a situation not unlike our speculation that motion blur in the VM-100 data allowed a higher degree of association with the other data sets.

Rangeland technicians have been fully aware that the limited number of sample sites that can be visited and measured during a given year is inadequate for a statistical-science-based resource assessment of extensive areas. In practice, assessments continue to be judgments based on very limited sampling of selected “representative areas” because it simply has not been practical to do otherwise (West 1999). Further, the methods available to field technicians include the plot and transect methods as used in this study (ITT 1996), thus there can be spatial incongruence among datasets. This study acknowledges these realities and addresses them by examining the correlation among conventional and the new image-based methods that show potential for addressing the inadequacies of conventional rangeland monitoring.

Attempts at image-based monitoring are not new. Cameras were used to acquire vegetation data as early as 1924 (Cooper 1924; Rowland and Hector 1934). Improvements in equipment and technique have progressed through the past eight decades for ground (Claveran 1966; Wells 1971; Tueller and others 1972; Owens and others 1985; Bennett and others 2000) and aerial photography (Booth 1974; Abel and Stocking 1987; Ritchie and others 1992; Paruelo and Golluscio 1994; Pickup and others 1994; Tueller 1989, 1996; Everitt and others 1995a, b; Booth and

Tueller 2003; Booth and Cox 2006; Seefeldt and Booth 2006). The good correlation ($r \geq 0.50$) of aerial and ground data sets (except VM-2) are evidence that photography and innovative image analysis and data extraction methods offer the most likely path to the unbiased, economical monitoring needed for defendable ecological assessments of extensive areas like the Hay Press Creek Pasture of the Green Mountain Common Allotment.

Conclusion

One means of evaluating ground-cover measurements from aerial photography is to assess the correlation of aerially-derived measurements with those from ground-based methods. We conclude from our analysis of the 25 ground and aerial data sets obtained for the Hay Press Pasture, that correlation between aerial and ground data *can* be as well associated as between ground methods, particularly for bare ground. In this study bare ground was a more consistent indicator than was vegetation cover, thus supporting suggestions that bare ground be among a select few "key" ecological indicators used for monitoring rangelands (Kaiser 2005). We also conclude that there is a need to better understand the factors giving rise to a lack of association among methods and data sets (ground with ground/ground with aerial) for vegetation.

Capturing color digital images during the growing season is relatively quick and inexpensive, as was again demonstrated in this study, and is especially useful for large areas like the Hay Press Creek Pasture where aerial sampling allowed the acquisition of large sample numbers uniformly distributed over the area of interest. Even if conventional ground methods are considered more accurate sample by sample (i.e., site by site) than image-based methods, the overall assessment accuracy can be—and often is—called into question where sampling is limited by cost or seasonal time demands to a relatively few sample locations. The collection of color digital images for later analysis addresses both cost and the seasonal time demands. Most important, image data can be stored and re-analyzed in conjunction with data from subsequent surveys, thus greatly increasing the power to detect ecological change. The assessment of the Hay Press Creek Pasture of the Green Mountain Allotment demonstrates that photography and image analysis have evolved to better meet the ecological assessment requirements of public lands, and that among the 25 locations sampled by our various methods, data-set correlation was greater for bare ground than for the other measured variables.

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