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Measuring Plant Cover in Sagebrush Steppe Rangelands: A Comparison of Methods

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ABSTRACT / Methods that are more cost-effective and objective are needed to detect important vegetation change within acceptable error rates. The objective of this research was to compare visual estimation to three new methods for determining vegetation cover in the sagebrush steppe. Fourteen management units at the US Sheep Experiment Station were identified for study. In each unit, 20 data collection points were selected for measuring plant cover using visual estimation, laser-point frame (LPF), 2 m above-ground-level (AGL) digital imagery, and 100-m AGL digital imagery. In 11 of 14 management units, determinations of vegetation cover differed ($P < 0.05$). However, when combined, overall determinations of vegetation cover did not differ. Standard deviation, corrected sums of squares, coefficient of variation, and standard error for the 100 m AGL method were half as large as for the LPF and less than the 2-m AGL and visual estimate. For the purpose of measuring plant cover, all three new methods are as good as or better than visual estimation for speed, standard deviation, and cost. The acquisition of a permanent image of a location is an important advantage of the 2 and 100 m AGL methods because vegetation can be reanalyzed using improved software or to answer different questions, and changes in vegetation over time can be more accurately determined. The reduction in cost per sample, the increased speed of sampling, and the smaller standard deviation associated with the 100-m AGL digital imagery are compelling arguments for adopting this vegetation sampling method.

Since the beginning of range management as a discipline, evaluation and monitoring of expansive landscapes have relied more on judgment and experience than science (Stoddart and Smith 1955; NRC 1994). This is no longer acceptable. People on all sides of management issues are now calling for objective monitoring approaches (NRC 1994; Donahue 1999). The challenge is to develop cost-effective methods for detecting important vegetation change within acceptable error rates (Floyd and Anderson 1987; Brady and others 1995; Bråkenhielm and Quighong 1995).

Improvements in computers, image analysis software, cameras, and camera platforms are rapidly expanding our vegetation-monitoring capability. Some platforms and their sensors, such as Landsat, Hyperion, and Indian Remote Sensing, are too coarse to allow detection of any but the most profound vegetation changes. However, there are now platforms such as QuickBird (DigitalGlobe's satellite with 61 cm resolution) and new airplane imaging systems that substantially increase the resolution (Booth and Tueller 2003; Booth and Cox 2006; Booth and others 2003, 2006). The new aerial imagery offers the opportunity for objective measurement of vegetation in large, ecologically diverse, expansive landscapes that typify western rangelands.

The sagebrush steppe of the upper Snake River Plain is a variable mix of vegetation (Pehanec 1941). This diversity is a consequence of the variability in soil depth, aspect, elevation, fire history, rainfall, and herbivory. The resulting unevenness has presented a challenge to vegetation monitoring since the inception of science-based range management (Pehanec and Stewart 1940, 1941). Within this ecosystem, rangeland scientists recognized the importance of working at appropriate scales when analyzing vegetation (Ellison and Croft 1944). To date, these vegetation-measurement issues of variability and scale in the sagebrush steppe have not been resolved. Adequate techniques have not been designed for the monitoring of vegetation trends that are influenced by management,

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climate, fire, and other factors. Certainly, the lack of adequate techniques is not due to a lack of effort (e.g., see Pellant and others 1999, 2000; Pyke and others 2002; Bonham and others 2004). With recent technological advances in image access and image analysis software, it might be possible to develop new methods for measuring vegetation that are more precise and more cost-effective than the techniques currently in use. The objective of this research was to compare the utility of three new methods for measuring plant cover on the sagebrush steppe.

Materials and Methods

Study Philosophy

The assessment and comparison of ground-cover measurement techniques is hampered by the lack of a practical standard (Floyd and Anderson 1987). There is no extensive piece of vegetated rangeland where ground cover is a known entity, nor is there any cover-measurement technique with an established accuracy. Without a known population, it is impossible to determine technical accuracy. Therefore, accuracy was not assessed; rather, the results of the methods were compared to each other. Precision was determined using measurements of variability (standard deviation, uncorrected sums of squares, corrected sums of squares, coefficient of variation, and standard error). We could have compared techniques using repeated sampling on one small piece of land, but we questioned the appropriateness of that approach when evaluating aerial photography relative to other techniques. We chose instead to make our measurement over large areas more representative of rangeland pastures or allotments and to compare the techniques on the basis of the conclusions implied by multiple samples across the landscape rather than repeated samples of the same piece of land.

Site Description

The study was conducted from June to September 2003 at the US Sheep Experiment Station (USSES) Headquarters, a 12,000-ha property approximately 10 km north of Dubois, Idaho, in the Upper Snake River plain (44°14′44′ N latitude, 112°12′47′ W longitude). Climate is semiarid with cold winters that include several months of daily mean temperatures below freezing and warm summers with daily highs averaging 27°C. Annual precipitation measured at the station office for the last 69 years averaged 325 mm, but 2003 precipitation was only 235 mm. Soils are fine-loamy, mixed, frigid Calcic Argixerolls derived from wind-blown loess, residuum, or alluvium on slopes ranging from 0% to12% (Natural Resources Conservation Service 1995). The site ranges in elevation from 1600 to 1900 m and is in the northeastern part of the sagebrush steppe region (West 1983). Vegetation in the southwest half of the station is a mix of tall three-tip sagebrush (*Artemisia tripartita* Rydb. ssp. *tripartita*), bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) A. Love ssp. *Spicata*], and arrowleaf balsamroot [*Balsamorhiza sagittata* (Pursh) Nutt.]. Vegetation in the northeast half of the station is dominated by mountain big sagebrush [*Artemisia tridentata* Nutt. ssp *vaseyana* (Rydb.) Beetle], antelope bitterbrush [*Purchia tridentata* (Pursh) DC.], thickspike wheatgrass [*Elymus lanceolatus* (Scribn. & J.G. Sm) Gould ssp. *Lanceolatus*], Idaho fescue (*Festuca idahoensis* Elmer), and plains reedgrass (*Calamogrostis montanensis* Scribn.).

For over 80 years, land use has been spring and fall sheep grazing under USSES management. Detailed grazing, fire, and other histories have been kept for the location and are available with soil and vegetation maps in a USSES geographic information system (GIS) database (records on file at USSES). Using this information, the land area was divided into 14 management units on the basis of vegetation type, fire, and grazing history. Four of the management units used in this study were based on vegetation type: tall three-tip sagebrush with bluebunch wheatgrass (Vegtype 1), mountain big sagebrush with Idaho fescue (Vegtype 3), a transition zone between the first two types (Vegtype 5), and tall three-tip sagebrush without bluebunch wheatgrass (Vegtype 7) (Figure 1). Boundaries of the vegetation units are not shown in Figure 1 because of issues of scale and clarity. Five of the management units were based on fire types defined by year of fire: 1995, 1998, 1999, 2000, and 2002. The remaining five management units were based on grazing types defined as ungrazed and burned in 2000 (Control burned), autumn grazed and unburned (Autumn), autumn grazed and burned in 2000 (Autumn burned), spring grazed and unburned (Spring), and spring grazed and burned in 2000 (Spring burned) (Figure 1). All project areas were not grazed until after sampling.

Sampling began the third week of June 2003 and was completed in August. In the sagebrush steppe, grass and forb growth is largely completed by July 1 (Craddock and Forsling 1938). In April of 2003, a record high 89 mm of rainfall was received at USSES. Subsequent rainfall was 40, 7, 1, 4, 8, and 1 mm in the months from May to October. In this third year of drought, few plants produced seeds, and most plant species were senesced or dormant by the middle of June.

Sampling Methods

A variety of sampling methods were used to assess vegetation cover throughout the 14 management units. In all cases, foliar cover was determined. Foliar cover is the area of ground covered by the vertical projection of the aerial portions of the plants (Interagency Technical Reference 1999). In each management unit, 20 data collection points (plots) were located from a georeferenced map of the management areas. These points were evenly spaced on lines that traversed the management units, and global positioning system (GPS) coordinates were obtained for each using ArcView (ESRI ArcView 3.0). At each data collection point (Figure 1), the following sampling methods were used:

Laser-point Frame. The laser-point frame (LPF) utilizes 10 light-projecting laser diodes (VanAmburg 2003; VanAmburg and others 2005), rather than the metal pins used in conventional point frames (Levy 1927; Levy and Madden 1933). The 10 lasers are spaced 10 cm apart in a nadir orientation. The lasers have a 650-nm wavelength, with a maximum average radiant power of 3.5 mW and a diameter of 0.79 mm exclusive of the halo. The first object that intercepted the light from the laser was recorded. Plant cover was measured by tabulating laser "hits" on functional plant groups (grass, forb, shrub), bare ground, litter, and rock. Cover was measured at each data collection point by reading 100 points (10 × 10-cm spacing grid) in a 1-m^2 quadrat. No LPF measurements were taken in vegetation type 1 because the frame was not available.

Two-meter Above-ground-level Imagery (Camera Stand). At the same data collection point, although not at the same square meter area, 2-m above-ground-level (AGL) imagery was acquired using an Olympus E20, 5-megapixel, digital SLR camera mounted on an aluminum camera frame with a 1-m^2 base that positioned the camera for nadir images 2 m AGL over the base (quadrat) (Booth and others 2004) (Figure 2A). The camera was equipped with a 9–36-mm lens, equivalent to a 35–140-mm lens on a standard 35-mm SLR film camera. The focal length was set at about 10 mm. Shutter speed and aperture is automatic. Images were acquired as uncompressed color Tagged Image File Format (TIFF) files (red, green, blue bands; sensor resolution = 0.97 mm/pixel ground sample distance (Comer and others 1998)). Of the 280 data collection points, 11 digital images were lost due to battery, memory, or data transfer problems. The remaining 269 images were archived.

One Hundred-meter AGL Imagery. Our methods followed those previously described (Booth and Cox 2006; Booth and others 2003, 2006). We used an 11.1-megapixel Canon EOS 1DS digital color camera mounted in a 225-kg (empty weight), piloted fixed-wing airplane flown at 72 km/h ground speed 100 m AGL (2.1 mm/pixel resolution) (Figure 2B). The Canon was connected to a vibration-resistant computer (Image Labs, Bozeman, MT) via an IEEE-1394 (Fire Wire) interface cable, allowing images to be stored directly on a 24-gigabyte hard drive. We equipped the camera with a Canon 300-mm, autofocus, autoaperture, image-stabilizing lens. A 1.4 × teleconverter was also added to give the equivalent of a 420 mm/F2.8 lens. Shutter speed was manually set for 1/4000 s, and automatic override ("safety shift") was enabled. The camera was automatically triggered by an aerial survey system (Track'Air, Oldenzaal , The Netherlands) over each plot along the lines shown in Figure 1. The flight plan was created by using Didger II (Golden Software, Golden, CO, USA) to extract GPS coordinates for target areas from a digitized raster graphic of the study site. The coordinates were then entered into the flight plan creator in the Track'Air software, which resulted in the pilot being able to see where he was positioned on the flight line. All 280 data collection points were sampled, and the corresponding 6 × 8-mm field-of-view images were archived.

Image Analysis (2 and 100 m AGL). Plant cover was measured from the images automatically using a calibrated Green-Band algorithm in VegMeasure (Louhaichi and others 2003, Johnson and others 2001, 2003) as described by Booth and others (2005a, 2005b). Calibration of the software was accomplished by manually measuring, for each dataset (2 or 100 m AGL image), vegetation on images from four randomly selected data collection points in each management unit. Manual measurement consisted of using a partially transparent digital grid (Corel Photo Paint; Corel, Ottawa, ON, Canada) of 100 grid intersections per image in a manner similar to the dot-grid transparency technique advocated by Avery (1962) and Claveran (1966) and the microscope grid advocated by Wells (1971). At each grid intersection, the cover, including functional plant groups (grass, forb, and shrub), bare ground, litter, and rock, was recorded. Excel's random number generator was used to select the subsample images with the restriction that the images had to have >5% plant cover as determined by digital-grid analysis. Selected images with >5% vegetation were imported into VegMeasure, where a Green-Band threshold was selected for each image by finding the value that directed the software to calculate the same amount of bare ground as was found using the digital-grid technique. An average of the threshold values of calibrated images was then used to

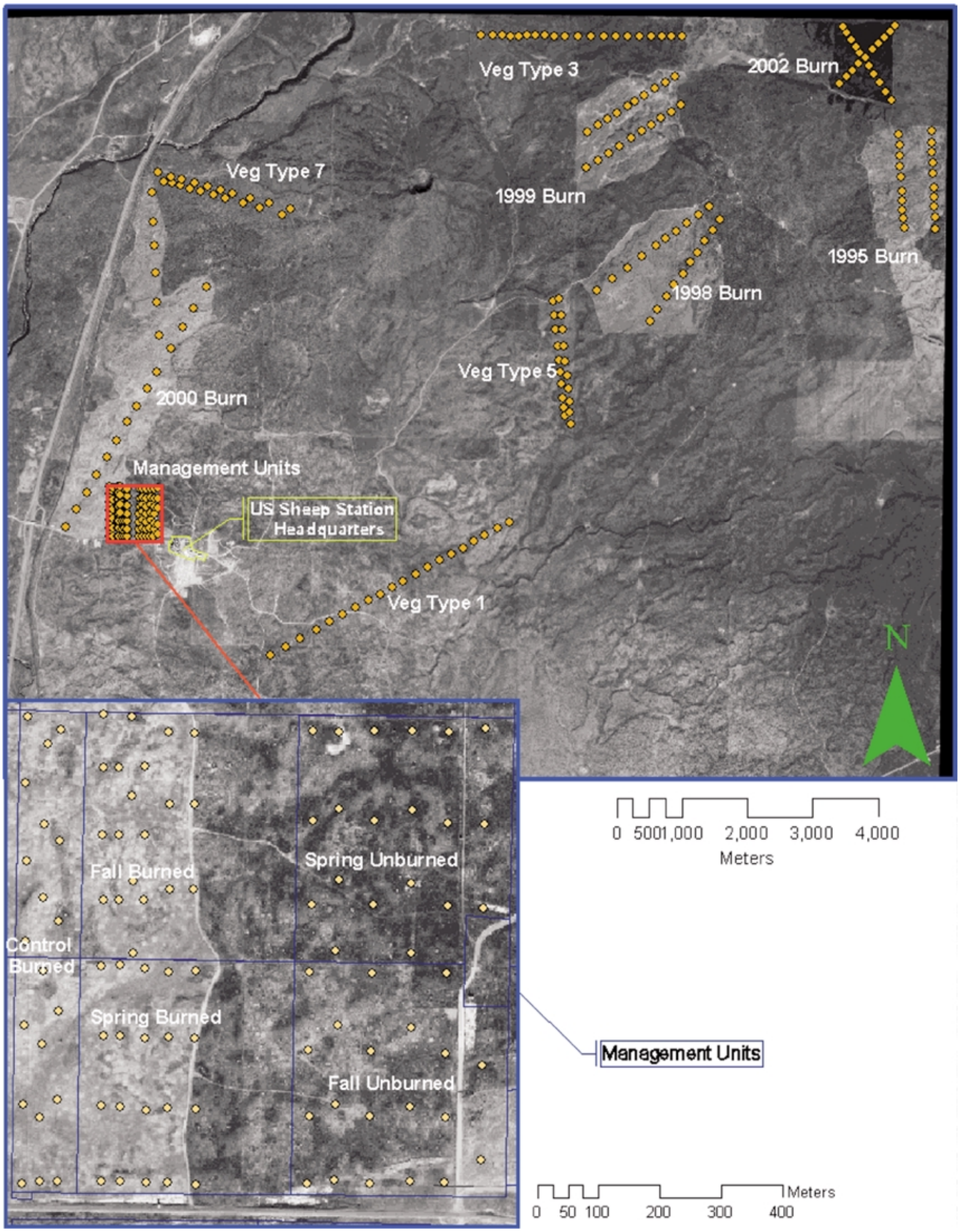

Figure 1. Location data collection points (dots) along flight lines and management units on the US Sheep Experiment Station spring–fall range. Boundaries of the vegetation units are not shown because of issues of scale and clarity.

batch process all images in that dataset (management unit by 2 or 100 m AGL photography). There are several methods that could be used to calibrate the image analysis software as well as several image analysis software packages. In trying to adapt this technology for potential users, a decision was made to work with the simplest method thought to give acceptably accurate results.

Figure 2. Digital image from 2 m AGL with 0.97 mm/pixel resolution (1 m^2) with example of zoom in detail (**A**) and digital image from 100 m AGL with 2.1 mm/pixel resolution (6 × 8 m) with example of zoom in detail (**B**).

Visual Cover Estimates. At each data collection point, five 0.5 × 2 m quadrats were used to estimate cover to the nearest 5%. Each quadrat was placed approximately 1 m from a center point, with a 0.5 m end closest to the center. The five quadrats were approximately equally distant from each other. In each quadrat, the percentage cover of grasses, forbs, shrubs, and other (a combination of bare ground, litter, and rock) was visually estimated. One person made all visual cover estimates to eliminate person-to-person variation. Because a person on the ground in a sagebrush stand has an oblique view (versus the nadir view of LPF and cameras), the estimates included understory canopy. This was adjusted to foliar cover by assuming (1) that sagebrush canopies were not covered and (2) that forb and grass canopies were evenly spaced throughout the quadrat. Thus, if sagebrush accounted for 50% of the cover, then 50% of the grass and forbs canopies were under the sagebrush. The estimate adjustment was: AC = SC + [GFC − GFC × (SC/100)], where AC is total adjusted canopy, SC is shrub canopy, and GFC is grass and forbs canopies. Only eight data collection points on vegetation type 1 were estimated because the other 12 were in a pasture that was being grazed, and one data collection point was missed in the spring grazed unburned unit.

Cost-Effectiveness

Costs of personnel, equipment, and transportation were recorded during the experiment. In addition, records were kept on the time required to collect and analyze data for each method in order to determine costs per sampling point.

Table 1. Determinations of vegetation cover in 14 management units in a sagebrush steppe community using 4 different methods

	Sampling method[a]			
Management unit	LPF %	2-m AGL %	100-m AGL %	Estimate
1995 burn	55 a (20)	49 a (20)	51 a (20)	47 a (20)
1998 burn	56 ab (20)	49 c (17)	62 a (20)	51 b (20)
1999 burn	47 a (20)	47 a (20)	47 a (20)	41 a (20)
2000 burn	37 bc (20)	38 b (19)	59 a (20)	31 c (20)
2002 burn	30 b (20)	47 a (20)	26 b (20)	40 a (20)
Spring burned	53 b (20)	29 c (20)	48 b (20)	64 a (20)
Autumn burned	43 bc (20)	42 c (20)	59 a (20)	49 b (20)
Control burned	38 b (20)	35 b (20)	56 a (20)	51 a (20)
Spring	42 b (20)	40 b (20)	58 a (20)	54 a (19)
Autumn	43 a (20)	34 b (17)	37 ab (20)	37 b (20)
Vegtype 1	—	52 b (20)	58 a (20)	51 b (8)
Vegtype 3	54 a (20)	57 a (20)	60 a (20)	50 a (20)
Vegtype 5	47 b (20)	41 b (16)	55 a (20)	54 a (20)
Vegtype 7	35 c (20)	50 a (20)	43 b (20)	31 c (20)

Note: Values given in percent.

[a]LPF = laser-point frame; 2 m AGL = image taken 2 m above ground level; 100-m AGL = image taken 100 m above ground level; Estimate = visual cover estimate. Within a row, means without a common letter differ at $P < 0.05$. Number in parentheses is the number of data collection points.

Statistical Analysis

The data were determined to be Normally distributed using a UNIVARIATE procedure (SAS Institute Inc., Cary, NC). At each data collection point, the data from the five quadrats were averaged before analysis.

A general linear models procedure was used to compare determinations of vegetative cover using LPF, 2 m AGL, 100 m AGL, and visual estimates for each management unit (SAS Institute Inc., Cary, NC). The summary statistics (mean, standard deviation, uncorrected sums of squares, corrected sums of squares, coefficient of variation, and standard error) that resulted from the analyses of each management unit were then compared using a general linear models procedure to determine whether there were differences in precision among the methods.

Results and Discussion

Eleven of the 14 management units had differences ($P < 0.05$) in mean vegetation-cover determinations among the four methods (Table 1). Differences in cover determinations sometimes varied widely within a management unit. For example, in the spring burned management unit, vegetation cover determinations ranged from 29% to 64%. The differences within the management units are a reflection of the variability associated with the sagebrush steppe vegetation community and the fact that our sampling quadrates did not overlap. When averaged over all management units, there were no differences in vegetation cover (Table 2) with the 100 m AGL measurements averaging 51% compared to 47% for visual estimate, 45% for LPF, and 44% for 2 m AGL.

Measures of variability among the cover determinations were different (Table 2). The 100 m AGL method had the lowest and the LPF had the greatest standard deviations and coefficients of variation. The 2 m AGL and the visual estimate methods were similar to each other.

There was a trend ($P = 0.12$) for the 100 m method to result in the highest determination of vegetation cover. This trend is likely due to a bias resulting from blunt contact points (Cook and Stubbendieck 1986, p. 59). The contact point for 100 m AGL imagery was 2.10-mm per pixel ground sample distance (GSD), a measure of spatial resolution (Comer and others 1998). This compares to 0.97 mm per pixel GSD for the ground photography and 0.89 mm diameter for the laser dot from the LPF. The initial visual estimate included the understory, which can be an important component of the ecosystem. Further research might determine that the understory vegetation canopy will be correlated to the top canopy layer measured using the other three methods. However, any correlation would be site-specific and dependent on grazing management, time of year, and climate.

Ground travel from one data collection point to another required 8–12 min and accounted for the majority of the time involved in the ground sampling

Table 2. Summary statistics for 4 sampling methods across the 14 management units in a sagebrush steppe community

	Summary statistics[a]						
Method	*N*	Mean	STD	USS	CSS	CV	SE
Estimate	14 a	46.6 a	9.4 bc	46,536 a	1,801 b	20.6 b	2.14 b
LPF	13 a	44.6 a	14.5 a	45,267 a	4,219 a	32.6 a	3.23 a
2 m AGL	14 a	43.6 a	9.6 b	39,485 a	1,701 b	22.5 b	2.19 b
100 m AGL	14 a	51.4 a	8.1 c	56,467 a	1,381 b	16.0 c	1.81 b

[a] *N* = number of management units; STD = standard deviation; USS = uncorrected sum of squares; CSS = corrected sum of squares; CV = coefficient of variation; SE = standard error. Within a column, means without a common letter differ at $P < 0.05$.

Table 3. Area, time, and cost associated with four sampling methods at individual sampling points to estimate vegetative cover in sagebrush steppe communities

	Sampling method[a]			
	LPF	2-m AGL	100-m AGL	Estimate
Area sampled (m^2)	1	1	48	1
Travel time (min)	8–12	8–12	< 1	8–12
Sample time[b] (min)	6–10	2–4	< 1	2–4
Points per hour	3–4	4–6	70	4–6
Data processing (min)	1	3–4	3–4	< 1
Total time (min)	15–23	13–18	4–5	10–16
Cost per point	$4.75	$3.87	$2.94[c]	$3.27
Sample dates	June 16–September 30	June 16–June 21	June 17	June 30–September 30
Missed points	20	11	0	15

[a] LPF = laser-point frame; 2 m AGL = image taken 2 m above ground level; 100 m AGL = image taken 100 m above ground level; Estimate = Visual cover estimate. [b] Sample time for one quadrat. [c] Includes cost of contractor at $140.00 per hour.

methods (Table 3). Although not included in the estimates, travel to and from the station office to the sample areas ranged from 2 to 30 min each way. One person can accomplish each method, although a second person is helpful for recording information when using the LPF. The visual estimate required 2–4 min per 0.5 m × 2 m plot and a few seconds to enter data into a spread sheet at the office (Table 1). Using the LPF, one person can read a plot in 6–10 min (VanAmburg and others 2005; Booth and others 2005a). Our LPF data were recorded using paper and pen (as opposed to a personal digital assistant) and therefore required an additional 1 min per plot to enter data into a spread sheet at the office. Two-meter AGL digital imagery required 2–4 min per plot to acquire the image and 3–4 min to calibrate VegMeasure and batch process the images with data automatically stored in a spread sheet (Booth and others 2005a). One hundred-meter AGL digital imagery took less than 1 min to travel to and acquire an image, but it took the same amount of time as 2 m AGL for calibration and processing of the image. Both 2 and 100 m AGL methods yielded permanent digital images. Except for the locations in the five grazing types, data collection points were 100–200 m apart in a flight line and a set of 20 points typically took 6 h of work for one person, including travel to and from the area (Table 3). The 100-m AGL method took 4 h for all 280 points (take-off to landing). Shrub size or density did not influence the execution of the 100 m AGL method, but all ground methods were made more difficult when large shrubs or high-density patches were encountered. The larger area sampled in a 100 m-AGL frame captured more of the inherent variability of sagebrush steppe vegetation.

Labor costs for the fieldwork were about $15 per hour per paid technician. Costs for the small equipment used include $1600 for the LPF (VanAmburg and others 2005), $1200 for the camera, and approximately $100 for a camera stand for the 2 m AGL digital imagery method. The latter method also requires a computer and software for image analysis. The aerial method is practical only by contracting with an appropriate service provider. Booth and Cox (2006) have discussed VLSA equipment and reported that aerial survey costs for a 70,800 ha rangeland watershed in Wyoming was approximately $6000 or $0.08 per hectare. The visual estimate method needed the least amount of equipment. Not including equipment costs, the LPF was the most expensive method on a per-plot basis, followed by 2 m AGL, visual estimate, and 100 m AGL (Table 3).

The digital image methods have a distinct advantage over the other two methods because the images can be stored for later comparisons or analyses needed for documenting change in vegetation as a response to management or disturbance. For the purpose of measuring plant cover, all three new methods are as good as or better than visual estimation for speed, precision, and cost. All three new methods rely on largely unbiased measures of vegetation cover, as opposed to visual estimates that are influenced by observer bias and person-to-person variability. The LPF and 2-m AGL methods are easy to teach and the equipment needed for these methods are readily available. Although untested at this point, the 48 m^2 image from the 100 m AGL method might be more useful for detecting spatial patterns in rangelands than the other methods. The 100 m AGL method is impractical for most managers because of the required skills and equipment. However, this technology is being transferred to the private sector through a Cooperative Research and Development Agreement between the Agricultural Research Service and Bitterroot Restoration Incorporated (copy of agreement on file with Booth). Evaluations conducted to date indicate that this service might be purchased at a cost less than the cost of sending people to a location on the ground (Booth and Cox 2005).

Conclusions and Recommendations

The reduction in cost per sample, the increased speed of sampling, the acquisition of a permanent image, and the lower standard deviation associated with the 100 m AGL digital imagery are compelling arguments for adopting new vegetation sampling methods. The aerial technique addresses several aggravating problems of ground sampling and one is tempted to recommend the technique for all areas of a size large enough to make contracting for aerial services a cost-effective approach. However, the technique is new and methods for image analysis are evolving. Therefore, we recommend that if aerial methods are used, conventional ground sampling also be used in a way that aerial and conventional ground methods can be correlated and compared.

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