Comparing Two Ground-Cover Measurement Methodologies for Semiarid Rangelands

Keith T. Weber GISP, GIS Director, GIS Training and Research Center, Idaho State University, 921 S. 8th Ave., Stop 8104, Pocatello, Idaho 83209-8104 webekeit@isu.edu (corresponding author)

Fang Chen, GIS Training and Research Center, Idaho State University, 921 S. 8th Ave., Stop 8104, Pocatello, Idaho, 83209-8104

D. Terrance Booth, Rangeland Scientist, High Plains Grassland Research Station, USDA Agricultural Research Service, 8408 Hildreth Road, Cheyenne, Wyoming 82009 Terry.Booth@ars.usda.gov

Mansoor Raza, GIS Training and Research Center, Idaho State University, 921 S. 8th Ave., Stop 8104, Pocatello, Idaho 83209-8104

Kindra Serr, Systems Administrator, GIS Training and Research Center, Idaho State University, 921 S. 8th Ave., Stop 8104, Pocatello, Idaho, 83209-8104, serrkind@isu.edu

Bhushan Gokhale, GIS Training and Research Center, Idaho State University, 921 S. 8th Ave., Stop 8104, Pocatello, Idaho 83209-8104

ABSTRACT

The limited field-of-view (FOV) associated with single-resolution very-large scale aerial (VLSA) imagery requires users to balance FOV and resolution needs. This balance varies by the specific questions being asked of the data. Here, we tested a FOV-resolution question by comparing ground-cover measured in the field using point-intercept transects with similar data measured from 50 millimeters per pixel (mmpp) VLSA imagery of the same locations. Particular care was given to spatial control of ground and aerial sample points from which observations were made, yet percent cover estimates were very different between methods. An error budget was used to calculate error of location and error of quantification. Budget results indicated location error (0.435) played a substantial role, compared to quantification error (0.216); however, significant quantification error was present. We conclude that 1) while the georectification accuracy achieved in this project was actually quite good, the level of accuracy required to match ground and aerial sample points represents an unrealistic expectation with currently available positioning technologies, 2) 50-mmpp VLSA imagery is not adequate for accurate ground-cover measurement, and 3) the balance between resolution and FOV needs is best addressed by using multiple cameras to simultaneously acquire nested imagery at two or three VLSA resolutions. We recommend ground-cover be measured from 1-mmpp imagery and that the imagery be nested in lower resolution, larger FOV images simultaneously acquired.

KEYWORDS: aerial imagery, GIS, remote sensing, VLSA

INTRODUCTION

Ground-cover is the vegetation, litter, rocks and gravel that cover bare soil and thereby reduce the risk of erosion (Branson et al. 1972). Quick and accurate assessments of ground-cover are not only useful to land managers for assessing soil stability (NRC 1994), but are also highly important for the sustainable management of millions of hectares of rangelands worldwide. In the past, the evaluation and monitoring of expansive landscapes has relied heavily on judgment and experience (NRC 1994; Stoddart and Smith 1995). However, conventional field surveys and sampling techniques may be nearly impossible or simply impractical to implement across vast areas like the US Intermountain West. As a result, many people on all sides of management issues are calling for increasingly quantitative and expedient monitoring approaches (Donahue 1999) such as those available through remote sensing. New measures are needed that are cost-effective and provide timely information within acceptable error rates (Floyd and Anderson 1987; Brady et al. 1995; Brakenhielm and Quinghong 1995; Sivanpillai and Booth 2008).

High spatial resolution satellite and aerial remote sensing have been used to conduct many studies across large landscapes. Blumenthal (2007) used high resolution imagery to study and measure infestations of invasive terrestrial weeds. Anderson et al. (1996), Bradley and Mustard (2006), Everitt et al. (1995 and 1996), and Lass et al. (2005) suggested that satellite and aerial imagery can be used to obtain accurate identification of invasive weeds. Sivanpillai and Booth (2008) used various remote sensing techniques to determine percent cover of vegetation over the 9,000 ha Hay Press Creek Pasture near Jeffrey City, Wyoming. Most recently, advancements in digital camera development and lens technologies have improved image sharpness to 1 millimeter per pixel (mmpp) (Booth et al. 2006). This has allowed for the differentiation of plant functional groups and even plant species with aerial photography (Booth et al. 2007; Booth et al. 2010).

One problem with Very-Large Scale Aerial (VLSA) imagery is the trade-off between spatial resolution and aerial extent. For example, achieving a spatial resolution of 1-mmpp commonly limits resulting scenes to 4 x 3 m (12 m^2). In addition, accurate georectification (+/- 0.5 pixel; Weber 2006) of the imagery is quite difficult due to current limitations of positioning technologies such as the NAVSTAR GPS (+/- 1 cm under survey conditions). For these reasons, an alternative solution was sought that could deliver high spatial resolution imagery (50-mmpp), with relatively large individual scene sizes (0.5 km x 0.5 km), and accurate georectification.

The objectives of this study were to use VLSA imagery (50-mmpp spatial resolution) to: 1) compare individual point observations read in the field with observations read from aerial imagery to better understand the current capabilities and uncertainty associated with the use of VLSA imagery and, 2) compare percent ground-cover measurements derived from field observations with percent ground-cover measurements derived from aerial photography to better understand the management implications of VLSA imagery for range scientists.

METHODS

Study Area

The study was conducted in the sagebrush-steppe rangelands of southeast Idaho, US, approximately 30 km south of Pocatello, Idaho, at the O'Neal Ecological Reserve (Figure 1). This 50-ha site contains sagebrush-steppe upland areas located on lava benches. The Reserve receives < 380 mm of precipitation annually (primarily in the winter) and is relatively flat, with a mean elevation of approximately 1,400 m (1,401-1,430 m). The dominant plant species is big sagebrush (*Artemisia tridentata* Nutt.) with various native and non-native grasses, including Indian rice grass (*Oryzopsis hymenoides* [R. & S.] Ricker.) and needle-and-thread (*Stipa comata* Trin. & Rupr.) present throughout the Reserve.

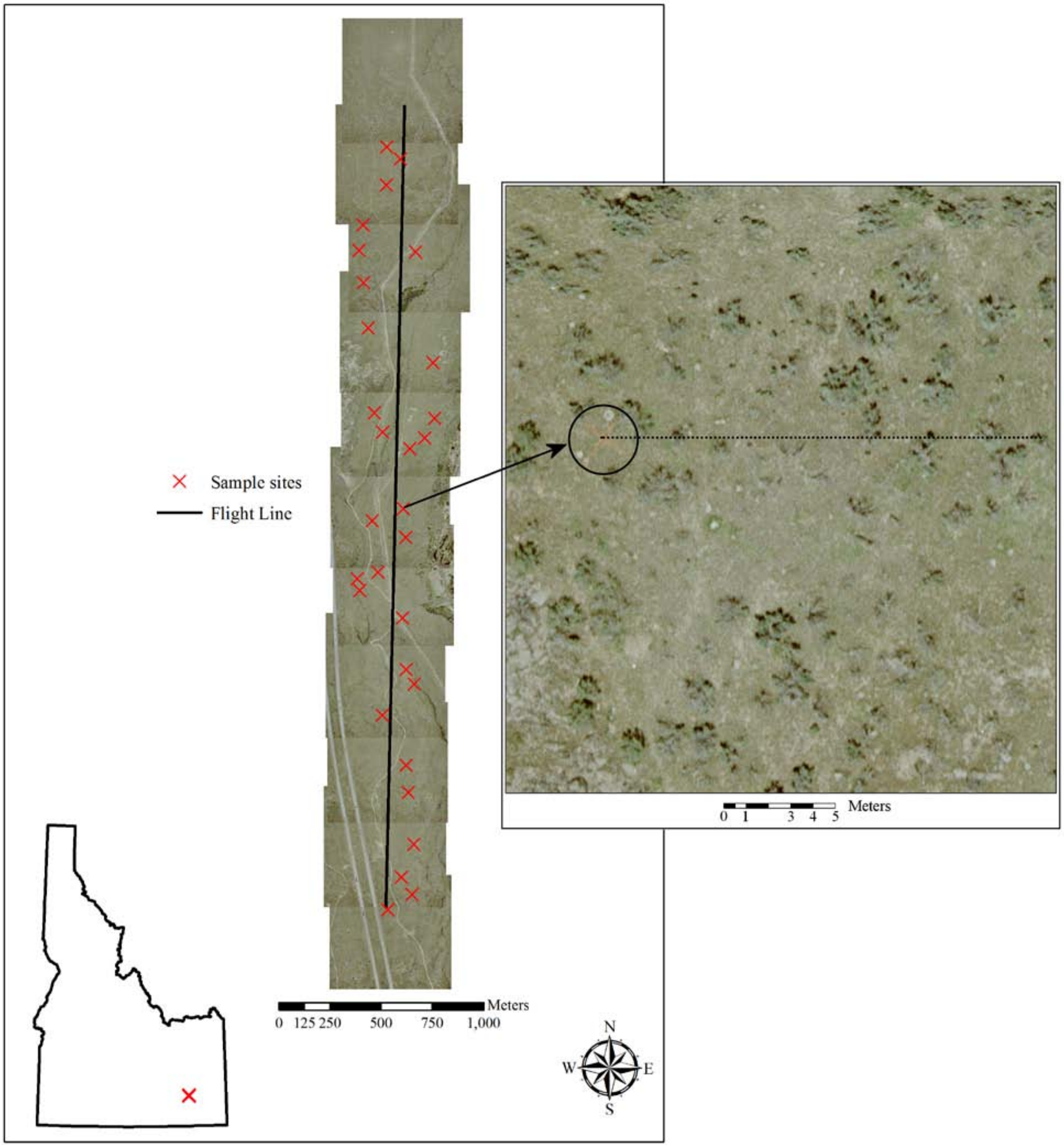

Figure 1. The flight line and 50-mmpp VLSA imagery collected at the O'Neal Ecological Reserve in 2009. Inset shows an example of the imagery and illustrates the red-X painted on the ground (circled). The black dots extending west to east indicate the location where point observations and corresponding API observations were made.*Aerial Photography Acquisition*

VLSA natural-color digital photography (50-mmpp) was acquired by Valley Air Photo (Boise, Idaho) on May 22nd, 2009. All imagery tiles were collected +/- 2 hours of solar noon (1230 hrs MST) to minimize shadow at a mean above-ground elevation of 450 m (1:3000 flight scale; $\bar{x}$ flight speed = 240 km/h). Aerial image tiles were collected using a Zeiss RMK Top 15 Pleogon A3 wide-angle lens having a calibrated focal length of 152.812 mm, an angular field of view (FOV) of 28.34 m (diagonal), and continuous aperature of f/4 to f/22 resulting in <3 pm of distortion. The imagery was then scanned at 12 µ resolution and resampled to 50-mmpp. All imagery tiles were delivered in uncompressed TIFF format and georeferenced to Idaho Transverse Mercator (NAD 83).

Field Sampling

Percent cover was determined using point-intercept transects (Gysel and Lyon 1980; ITT 1996). The location of transect starting points (n = 30) was randomly generated using Hawth's tools within ArcGIS 9.3.1 and based on the following criteria: all points were 1) >70 meters from an edge (road, trail, or fence line) and 2) <750 meters from a road. All transects were read in an east-west direction from the starting point. Prior to acquisition of the aerial imagery, starting points were navigated to using a Trimble GeoXH GPS receiver (+/-0.20 m @ 95% CI after post processing). A large cross (mean arm length = 2.0 m and mean arm width = 0.1 m) was painted on the ground using red surveyor's spray paint to ensure the starting point would be readily visible in the imagery (Figure 1). The physical marker served two purposes; 1) it was easy for field personnel to revisit each site, and 2) it ensured the same starting point was used for both field observation and VLSA image interpretation.

During the week of aerial imagery acquisition, field personnel revisited each sample location and placed a 20-m flexible tape upon the ground from the starting point (indicated by the painted marker) and in the designated direction (directly east or west) with the aid of a compass. Photographs were taken using a Sony digital camera in each cardinal direction. Ground-cover type was determined by looking straight down at the transect tape and recording the cover feature in the upper most canopy directly indicated at the designated observation point. Observation points began at 10 cm from the starting point (observation point one) and continued every 20 cm thereafter (observation points 2-100). Ground cover at each observation point was classified as either shrub, rock (if the rock was over 7.5 cm in surface diameter), bare ground, invasive weed, grass, forb, litter, standing dead herbaceous material, standing dead woody material (e.g., a dead tree or sagebrush shrub still intact at the ground), or microbiotic crust. A total of 100 observations were made at each transect and recorded in a GPS-based field form. Percent cover was calculated in the laboratory and results of this sampling effort are henceforth referred to as FIELD observations.

Aerial Photography Interpretation (API)

A personal geodatabase point feature class was created where each point represented the location of an observation along the transect used for field data collection. These features were overlaid on the VLSA imagery (50-mmpp) within ArcGIS 9.3.1 to ensure the starting point for each transect feature was correctly aligned with the painted starting point visible in the imagery. Each set of transect points contained 101 points, with one point representing the starting point followed by 100 observation points consistent with FIELD observation protocols. Each point vector feature was effectively equivalent to a 25 cm^2 region in the field, as each point feature was used to extract the value of the pixel at the coincident geographic location. Each pixel, in turn, represents a region (25 cm^2), within which all ground features are mixed, or generalized, and displayed as one "color" within the imagery. In theory, the value of the color displayed in the imagery will be most representative of the feature occupying the majority of each pixel given that all feature categories have similar albedo and reflectance. While the location of the vector point features may not have been precisely at the same location as the point observed in the field, following this procedure allowed for the best co-registration possible. Three independent observers trained in GIS, aerial photo interpretation, and/or range science identified the cover type (bare ground, shrub, or grass) found immediately beneath each point feature at each observation point (n = 100) along each transect (n = 30). These observations were recorded in separate spreadsheets which were then compiled together and contained the observations made by each person in separate columns of the same spreadsheet (n = 9000 observations). Each observer worked independently throughout this process following an initial briefing and did not have access to FIELD observations for these transects.

Data Analysis: Point-observation scale

The spreadsheet was reviewed and a new column created containing the consensus (MAJORITY) cover type (bare ground, shrub, or grass) found for each observation point record. In addition, FIELD observation data were imported as a separate column within the spreadsheet and related to the corresponding observation using the unique combination of transect and observation point identifiers. The MAJORITY column was reviewed and if no consensus was reached for an observation point, that row of data was deleted and not used in subsequent processing or analysis (note: copies of these data were made and no original data was permanently deleted during this study). Corresponding FIELD observations were also removed to eliminate incorrect cross-referencing. The cover types (bare ground, shrubs, and grass) were then assigned a numeric value of 1, 2, and 3 respectively, throughout both the MAJORITY and FIELD observation columns.

Since FIELD data were collected for 10 cover types instead of the three used during the aerial photo interpretation, all rows of data that did not contain bare ground, shrub, or grass entries (1, 2, or 3) were deleted. The remaining data (n = 2465 records or 82% of original records) were rearranged in a new text file to conform to ESRI's ASCII raster format. The header of this file indicated the raster layer would contain 30 rows (one for each transect) and 100 columns (one for each observation). For those rows (transects) that did not contain a full complement of 100 columns (observations) due to the data reduction processes described above, the value of zero (0) was used as a no-data indicator to thereby maintain the consistency of the files for analysis. Two ASCII raster files were created, one describing aerial photography interpretation (API) observations and the other describing FIELD observations. These files were imported into Idrisi Taiga and displayed for visual inspection. The ERRMAT module of Idrisi Taiga was used to assess agreement between API and FIELD observations.

Data Analysis: Transect-scale

Percent cover measurements for bare ground, shrubs, and grasses were calculated for both FIELD and MAJORITY observations along the transects. Single-factor ANOVA was used to compare percent cover measurements for each cover type and assess the significance of agreement between the two cover measurement methodologies.

Analysis of Georectification Accuracy

The georectification accuracy of the VLSA imagery was independently assessed by comparing the X,Y location of 10 readily identifiable features visible in the imagery (utility poles, distinctive trees, etc.) with the X,Y location of the same feature visible in 150-mmpp imagery acquired in 2005 for the same study area. The latter reference imagery (Gregory et al. 2010) was orthorectified using the X,Y, and Z of visible ground control points (GCP's) strategically located throughout the flight path (+/- 2.0 cm). The 2005 aerial imagery was therefore considered a high-quality reference image relative to its horizontal positional accuracy.

RESULTS AND DISCUSSION

Ground-cover types at the point-observation scale were very different between FIELD and API observations using the 50-mmpp aerial imagery as user's, producer's, and overall accuracies were < 50% (Table 1). The shrub cover type had the lowest producer's accuracy (9%) and was the cover type least documented using API techniques (compare 9% API observations with 26% field observation rates). Bare ground had the lowest user's accuracy rate (26%) and was most commonly misclassified as the grass cover type. The Kappa Index of agreement (KIA) was 0.008 indicating any agreement between the observations was likely due entirely to chance.

Table 1. Comparison of field-based land cover point observations with point observations made using aerial photography interpretation (API).

	Accuracy (%)	
Land cover type	Producer's	User's
Bare ground	48	26
Shrub	9	28
Grass	44	46

Overall accuracy = 35%
Kappa Index of Agreement = 0.008

The results of ANOVA tests comparing percent cover of each cover type at the transect-scale indicated a fairly similar disagreement between observational methodologies (Table 2). All comparisons were statistically different ($P < 0.0001$) save for the comparison of the grass cover type ($P = 0.81$).

Table 2. Results of ANOVA tests comparing FIELD and aerial photography interpretation (API) measurements of percent cover at the transect-scale (*n* = 30).

Land cover type	P-value
Bare ground	< 0.001
Shrub	< 0.001
Grass	0.811

The georectification accuracy of the VLSA imagery as provided by the vendor was 3.17 m (SE = 0.49) relative to the reference imagery. The VLSA imagery and location of each transect were corrected to ensure accurate coregistration using the GPS-acquired location of each start point and the location of each cross painted on the ground at each start point that was visible in the VLSA imagery. While the georectification of the VLSA imagery as delivered by the vendor was not able to achieve an accuracy ≤ 50% of a pixel (i.e., 0.025 m), this level of accuracy represents an unrealistic expectation with currently available positioning technologies. From an applications-based perspective the georectification accuracy achieved in this project was actually quite good.

What is more interesting and perhaps more central to the focus of this paper is the high degree of disagreement between FIELD and API observations. In all cases, agreement between these data were very poor and any agreement at all was attributable only to chance. This suggests that while the identification of landscape features common to semiarid sagebrush-steppe ecosystems (bare ground, shrubs, and grasses) can be made using aerial imagery, the spatial resolution of 50-mmpp is not adequate for accurate ground-cover measurement (cf., Booth and Cox 2009). However, error of location (Pontius 2000; Weber et al. 2008) may explain some of the disagreement. For example, if the tape measure used to identify the transect and its subsequent observation points was not tight, or if the tape was blown by the wind during observation, or not perfectly aligned in an east-west direction, or the observers eye was not perfectly positioned at nadir over the observation point, the probability of agreement between discrete observations would decrease as the observation locations would not be the same. In addition, errors or slight deviations in compass trend could also have been a source of variation between FIELD and API observations. In these cases, the error of location would be more pronounced at the extremes of the transect. In other words, if the rate of agreement was better at the first observations relative to the last observations, a measurable error of location would be demonstrated. To test for this type of error, the rate of agreement between first observations (FIELD and API) and last observations (FIELD and API) was determined. The results of this comparison revealed that 17 of 30 (57%; $R^2 = 0.108$) first observations made in the field agreed with the first observations made from VLSA imagery, whereas only 8 of the last observations agreed (27%; $R^2 = 0.005$). An error budget was estimated following Pontius (2000) using the VALIDATE module of Idrisi to calculate error of location and error of quantification. This result indicates error of location (0.435) played a substantial role, compared to quantification error (0.216), in the cumulative error budget associated with this study.

An additional source of potential error relates to parallax within the VLSA imagery especially along those transects furthest from the flight line. To minimize, albeit not eliminate, this error and yet retain a random sampling design, all transect observations were read toward the flight line.

Accurately measuring percent cover from 50-mmpp imagery was also problematic. The sample “point” on the 50-mmpp imagery is actually a small plot on the ground (25 cm^2), an area large enough to contain all of the ground-cover types to be identified; thus, the 50-mmpp resolution was considered too coarse to measure percent bare ground (Booth and Cox 2009) and illustrates again, the importance of matching resolution with task (Congalton et al. 2002). FIELD data were collected as point observations since small-plot sampling (e.g. 2.9 $cm^{2;}$) has been previously demonstrated to show only poor relationships with plant cover (Cook and Stubbendieck 1986, reviewing the method of Parker 1951). Cook and Stubbendieck (1986) also review evidence that cover measurements obtained using blunt-point sampling apparatuses result in biased data. These findings imply a 1-mmpp (sharp) digital sample point will provide a more accurate cover measurement than a point 50 times more blunt. Since percent cover is ultimately derived from individual transect observations and, given the heterogeneity exhibited in the vegetation of semiarid ecosystems (Norton 2008), it is understandable that percent cover measurements did not agree. These results call into question the feasibility of such comparisons as the ability to replicate observations is extremely difficult even though the individual methodologies used may be applicable and sound.

This study compared the agreement between two cover measurement methodologies (i.e., FIELD and API) and did not test the accuracy of either method as this requires a true answer be known. While one may argue or assume that field observations represent the truth, this argument is only correct if the observations were repeatable (i.e., have high precision) and without other bias (e.g., observer bias). Furthermore, a true accuracy test would require API observations be made at the identical point observed in the field. While all attempts were made to eliminate discrepancies between actual observation points, the inherent uncertainty present in these studies suggests the results are best viewed in terms of agreement between methodologies and not a test of accuracy.

Management Implications

Properly comparing methods to characterize ground cover in semiarid rangelands is very difficult. While both field-based and API observations have their place, API observations using VLSA imagery is becoming more common and more reliable. VLSA image interpretation presents several advantages: 1) cover can be measured anywhere within the imagery regardless of difficulty of access or proximity to roads, 2) measurements are repeatable (though observer bias is still present [Booth et al. 2006, Cagney et al. submitted]), and 3) the acquired aerial imagery represents an historical record of the rangelands that may be used for numerous other management applications in addition to cover measurement.

The proper design of any API-based ground cover assessment is critical to its success and a primary consideration relates to the granularity of observations. For instance, complete species differentiation using only aerial imagery, even with a 1-mmpp spatial resolution is not always possible. At present, the 50-mmpp imagery does not provide sufficient clarity to resolve or differentiate shrubs, grasses and bare ground, and cover assessments of plant functional groups, like that used in this study, requires a spatial resolution < 50-mmpp (Booth and Cox 2009; Booth et al. 2010). While 1-mmpp imagery may be more difficult to coregister, there are techniques to accomplish reliable coregistration, such as the nested imagery technique described by Moffett (2009; 2010). This will help reduce error of location (a large part of the total error budget) and could be applied to either 1-mmpp or 50-mmpp imagery in a similar way. However, the part of the error budget is the error of quantification and here only the 1-mmpp imagery will provide an improvement. Additional research is required to refine these spatial resolution guidelines.

The trade-off between spatial resolution and aerial extent is being addressed by using multiple cameras for simultaneously acquiring nested imagery at two or three resolutions, such as 1-, 10-, and 20-mmpp (Booth and Cox 2009, Booth et al. 2010). The utility of this approach is evident by the limited increase in operational cost to obtain multi-resolution data compared to single resolution data (the added cost is largely the cost of examining the additional images) and in the efficiency demonstrated by Booth et al. (2010) where the larger FOV was most valuable for assessing an area infested with a noxious weed, and where identification of the weed was confirmed using nested 1-mmpp imagery.

CONCLUSIONS

We tested agreement between ground cover measurements from point-intercept transects and 50-mmpp VLSA imagery. Both individual observation-point and transect-scale percent cover measurements were compared, with results indicating very poor agreement between methodologies. This does not necessarily indicate that either method was incorrect however. While it may be possible to improve agreement between observations as well as percent cover measurements using a revised study design and collection of higher spatial resolution imagery (< 50-mmpp), it is more important to appreciate that 1) VLSA imagery can be used to measure ground-cover in semiarid rangelands and 2) like all other cover-measurement or estimation methodologies, the use of VLSA imagery and API has limitations (e.g., species cannot be identified at the spatial resolution used in this study) as well as advantages; 1) ground-cover can be measured anywhere within the imagery regardless of difficulty of access or proximity to roads, 2) measurements are repeatable (though observer bias is still present), and 3) the acquired aerial imagery represents an historical record of the rangelands that may be used for numerous other management applications in addition to cover measurement .

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