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Comparing Two Ground-Cover Measurement Methodologies for Semiarid Rangelands

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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 with the use of point-intercept transects with similar data measured from 50-mm-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. These results indicated location error (43.5%) played a substantial role with significant quantification error (21.6%) also present. We conclude that 1) although 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 species identification or cover assessments of plant functional groups, and 3) the balance between resolution and FOV needs is best addressed by using multiple cameras to acquire nested imagery at multiple VLSA resolutions simultaneously. We recommend ground cover be measured from 1-mmpp imagery and that the imagery be nested in lower-resolution, larger FOV images simultaneously acquired.

Key Words: 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 useful for assessing soil stability (National Research Council [NRC] 1994) and are 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 (Stoddart and Smith 1955; NRC 1994). 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 Quighong 1995; Sivanpillai and Booth 2008).

High-spatial-resolution satellite and aerial remote sensing have been used to conduct numerous studies across large landscapes. Blumenthal et al. (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, 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 mm per pixel (mmpp) (Booth et al. 2006a), resulting in the ability to differentiate plant function groups and many plant species (Booth et al. 2007, 2010).

One consideration 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 4×3 m (12 m^2). In addition, accurate georectification ($\pm$ 0.5 pixel; Weber 2006) of the imagery is quite difficult due to current limitations of positioning technologies such as the NAVSTAR GPS ($\pm$ 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$\times$0.5 km), and accurate georectification.

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

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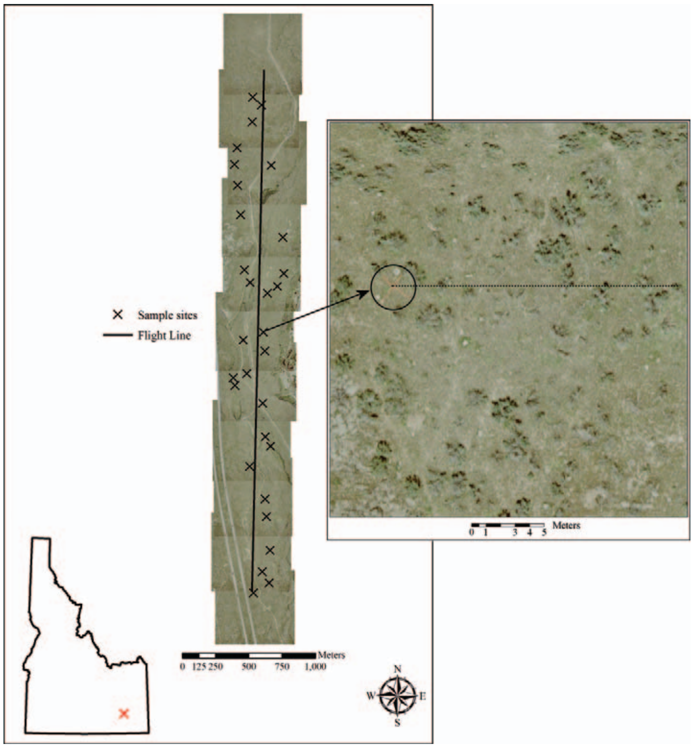

Figure 1. The flight line and 50-mmpp VLSA imagery collected at the O'Neal Ecological Reserve in 2009. Inset shows an example of the imagery and illustrates the red X painted on the ground (circled). The black dots extending west to east indicate the location where point observations and corresponding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

scientists' understanding of the management implications of VLSA imagery.

METHODS

Study Area

The study was conducted in the sagebrush-steppe rangelands of southeast Idaho, approximately 30 km south of Pocatello, Idaho, at the O'Neal Ecological Reserve (Fig. 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 elevation ranging from 1401 to 1430 m. The dominant plant species is big sagebrush (*Artemisia tridentata* Nutt.), with various native and nonnative grasses, including Indian rice grass (*Oryzopsis hymenoides* [R. & S.] Ricker.) and needle-and-thread (*Stipa comata* Trin. & Rupr.).

Aerial Photography Acquisition

VLSA natural-color digital photography (50-mmpp ground sample distance [GSD] [25-cm^2 aerial extent of each pixel]) was acquired by Valley Air Photo (Boise, Idaho) on 22 May 2009. All images were collected ± 2 h of solar noon (1230 hours MST) to minimize shadow, and were acquired at a mean height of 450 m aboveground (mean flight speed = 240 km/h ground speed). Images were collected using a Zeiss RMK Top 15 camera with Pleogon A3 wide-angle lens having a calibrated focal length of 152.812 mm, an angular field of view (FOV) of 93° (diagonal), and continuous aperture of f/4 to f/22. The imagery was then scanned at 12-μm resolution and resampled as a 50-mmpp orthorectified image product. Based upon these characteristics, percent source image distortion was 0% at nadir and up to 10% at the corners of each image. All images were delivered in uncompressed TIFF format and georeferenced to Idaho Transverse Mercator (NAD 83).

The georectification accuracy (root means square error [RMSE]) of the imagery as reported in the vendor-supplied geospatial metadata was ± 3.17 m (SE = 0.49). The VLSA imagery and location of each transect were corrected to ensure accurate coregistration with the use of 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.

Field Sampling

Percent cover was determined with the use of 30 point-intercept transects each with 100 observations (Gysel and Lyon 1980; Interagency Technical Team [ITT] 1996). The location of transect starting points was randomly generated with the use of Hawth's tools within ArcGIS 9.3.1 and based on the following criteria: all points were 1) > 70 m from an edge (road, trail, or fence line) and 2) < 750 m 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 at 95% confidence interval [CI] after postprocessing). A large cross (mean arm length = 2.0 m and mean arm width = 0.1 m) was painted on the ground with the use of red spray paint to ensure the starting point would be readily visible in the imagery (Fig. 1). In addition to the physical markers being used to coregister the image, the markers served two other 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. To minimize, albeit not eliminate, lens distortion error (Booth et al. 2006b) and yet retain a random sampling design, all transect observations were read, toward the flight line and hence, toward a point of decreasing distortion. Ground-cover type was determined by looking straight down at the transect tape and recording the cover feature in the uppermost 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). Observation points were measured on the graduated side of the tape measure and had a width of 1 mm. 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 geodatabase of points was created where each point represented the location of an observation along the transect used for field data collection. These points 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. Thus, each set of API transect points contained 101 points, with 1 point representing the starting point followed by 100 observation points consistent with field observation protocols.

Although the location of the image sample points (pixels) may not have been precisely at the same location as the field point, following the procedure described in this article allowed for the best coregistration possible. Three independent observers trained in GIS, aerial photo interpretation, and/or range science identified the ground-cover class (bare ground, shrub, or grass) found immediately beneath each image sample point at each field observation point ($n=100$) along each transect ($n=30$) ($n=9\,000$ total observations from the three observers). Each observer worked independently throughout this process following an initial briefing, and did not have access to field observations for these transects.

Data Analysis: Scale of Point Observations

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 with the use of 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 record (row of data) was not used in subsequent processing or analysis. The cover types (bare ground, shrubs, and grass) were then assigned a numeric value of 1, 2, or 3, respectively, throughout both the majority and field observation columns.

Because field data were collected for 10 cover types instead of the 3 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 (note: no cover types were grouped or combined). The remaining data ($n=2\,465$ 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 (1 for each transect) and 100 columns (1 for each observation). For those rows (transects) that did not contain a full complement of 100 columns (observations) because of the data reduction processes described above, the value of zero (0) was used as a no-data indicator to 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. The Kappa index of agreement (KIA) was used to compare measurements by cover class and assess overall agreement between the two cover measurement methodologies.

Data Analysis: Transect Scale

Percent cover measurements for bare ground, shrubs, and grasses were calculated for both field and majority observations with transects used as the experimental unit ($n=30$). Limits of agreement (LOAs) by cover class were determined following Bland and Altman (1986).

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 with the use of the X, Y, and Z of visible ground control points (GCPs) strategically located throughout the flight path (horizontal position accuracy of GCPs $= \pm 2.0$ cm RMSE).

RESULTS AND DISCUSSION

To achieve reliable classification of imagery, coregistration between imagery and field observation data must not exceed 50% of the size of a pixel's shortest dimension (Weber 2006). When dealing with square pixels, the shortest dimension is moot, and so a guideline for georectification accuracy has become 50% of the size of a pixel. Although the georectification of the VLSA imagery as delivered by the vendor was not able to achieve an accuracy $\leq 50\%$ of a pixel (i.e., ± 25 mm), $\leq 50\%$ of a pixel at this and even higher spatial resolutions represents an unrealistic expectation with global navigation satellite system (GNSS) technologies currently available. From an applications-based perspective, however, the georectification accuracy achieved in this project was very good.

Ground-cover classes at the point-observation scale were different between field and API observations. The 50-mmpp aerial imagery users', producers', and overall accuracies were $< 50\%$ (Table 1). Although the shrub cover class had the lowest producer accuracy rate (9%), bare ground had the lowest user 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 observations was no better than chance.

Categorical KIA was similar with agreements of 0.019, –0.005, and 0.015 for bare ground, shrub, and grass classes. Agreement of each individual observer ($n=3$) with field observations was quite low with resulting KIAs of 0.007, 0.003, and –0.003.

Transect-scale percent cover measurement revealed a lack of agreement within cover classes as indicated by the broad range of measures (limits of agreement [LOA] were 56%, 53%, and 64% for bare ground, shrub, and grass cover classes). As suggested by Bland and Altman (1986), such a broad range of

Table 1. Comparison of field-based point observations with point observations made with the use of aerial photography interpretation (API) (n=2 465).[1]

Ground cover type	Bare ground	Shrub	Grass	Total	User's accuracy (%)
Bare ground	300	352	506	1158	26
Shrub	57	68	118	243	28
Grass	268	305	491	1 064	46
Total	625	725	1 115	2 465	
Producer's accuracy (%)	48	9	44	Overall accuracy (%)	35

[1]Kappa index of agreement=0.008.

measures should be considered unacceptable and indicative that the two measurement methods are not interchangeable. In this study, the broad LOAs are attributable in large part to resolution effects, suggesting that 50-mmpp aerial imagery does not allow the viewer to resolve ground cover to the same degree as field-based observations. What is most interesting about these results and perhaps more central to the focus of this article is the high degree of disagreement between field and API observations (cf. KIA=0.008). In all cases, agreements between these data were very poor and any agreement was attributed only to chance. This suggests that although the identification of ground-cover classes common to semiarid sagebrush-steppe ecosystems (bare ground, shrubs, and grasses) can be made with the use of aerial imagery, the spatial resolution of 50-mmpp is not adequate for accurate ground-cover measurements (cf. Booth and Cox 2009).

Error of location (Pontius 2000; Weber et al. 2008) helps to explain some of the disagreement further. 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 observer's 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%) first observations made in the field agreed with the first observations made from VLSA imagery, whereas only 8 of the last observations agreed (27%). An error budget was estimated following Pontius (2000) with the use of the VALIDATE module of Idrisi to calculate error of location and error of quantification. This result indicates error of location (43.5%) played a substantial role, compared to quantification error (21.6%), in the cumulative error budget associated with this study.

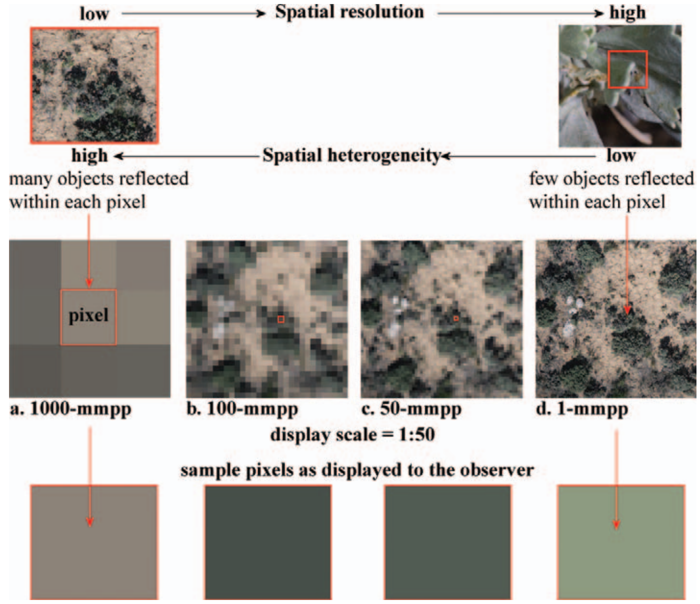

Figure 2. What is the ground-cover type (vegetation, bare ground, litter, rock) at each pixel outlined in panels a–d above? The inherent difficulties of using lower-spatial-resolution imagery for ground-cover measurement are demonstrated above by an image displayed at various spatial resolutions. The figure illustrates digital-image characteristics: (1) the smallest unit of a digital image is the pixel (picture element); (2) nadir image resolution is measured by the ground sample distance of one pixel (GSD; the linear distance on the ground captured by a pixel); (3) the area captured within a single pixel is always blended (mixed) and displayed to the observer as one color regardless of size, number of ground-cover characteristics, or their reflected spectra. As GSD increases (i.e., image resolution decreases), more mixing occurs. As illustrated above, the 1-mm GSD image (**d**) provides sufficient spatial resolution to eliminate most mixed-pixel effects.

Accurately measuring percent cover from 50-mmpp imagery was also problematic. Each observation point identified one pixel in the image. Each pixel on 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 (Fig. 2). Within this area all ground cover is mixed, or generalized, and displayed as one color on the computer monitor (i.e., whereas a given color can be described by its red, green, and blue components, the digital-camera-sensor element output as viewed by the human eye is one color). In theory, the value of the color displayed in the imagery should be representative of the feature occupying the majority of space captured by a pixel.

Small plots, such as the Parker method of small-plot sampling (i.e., 2.9 cm^2), gave poor relationships with plant cover (Cook and Stubbendieck 1986, reviewing the method of Parker 1951) and thus has not been considered an accepted means for measuring ground cover. Cook and Stubbendieck (1986) also review evidence that cover measurements obtained with the use of blunt-point sampling apparatuses result in biased data. Thus, 50-mmpp imagery has pixels covering too large an area to measure percent bare ground accurately (Fig. 2; Booth and Cox 2009) and illustrates again the importance of matching resolution with task (Congalton et al. 2002).

We 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. Although 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. Although all attempts were made to eliminate discrepancies between actual observation points, the inherent uncertainty suggests results are best viewed in terms of agreement between methodologies and not a test of accuracy.

Comparing various methods used to characterize ground cover in semiarid rangelands is difficult. It is important, however, as range science increasingly embraces geospatial technologies. Comparisons demonstrating cross-validation between methodologies are critical to bridge the transition between management and monitoring practices that were once entirely dependent upon field observations to one more dependent upon remotely sensed VLSA imagery. This, however, is also difficult, as performing a reliable cross-validation is dependent upon adequate coregistration, which in turn is currently limited by the precision of GNSS positioning technologies available in the field (i.e., ± 1 m). To our knowledge, this is the first article to measure errors of location (43.5%) and quantification (21.6%) in a cumulative error budget to build an improved understanding of the complex relationship between rangeland field and aerial survey methodologies. Our results provide important insights for further progress in using ground and aerial data together.

Although both field-based and API observations have their place, API observations with VLSA imagery are 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. 2006a; Cagney et al. 2011]), 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.

This study 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, as the role of locational error cannot be overlooked especially in heterogeneous environments where ground-cover classes readily change across even short distances (e.g., 25 mm). Although it may be possible to improve agreement between observations as well as percent cover measurements with the use of a revised study design and collection of higher spatial resolution imagery ($<$ 50-mmpp), it is more important to appreciate that 1) based upon other studies where higher-spatial-resolution imagery was used, VLSA imagery can be used to measure ground cover in semiarid rangelands, 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, and 3) it is critical to match resolution with task appropriately. Finally, we conclude that this study's measures of error of location (43.5%) and quantification error (21.6%) between rangeland ground and aerial survey methodologies defines the current limitations of using ground and aerial data together.

MANAGEMENT IMPLICATIONS

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 by only aerial imagery, even with a 1-mmpp spatial resolution, is not always possible. The 50-mmpp imagery used in this study does not provide sufficient clarity to resolve or differentiate shrubs, grasses, and bare ground, and cover assessments of plant functional groups requires a spatial resolution $<$ 50-mmpp (Fig. 2; Booth and Cox 2009; Booth et al. 2010). Although 1-mmpp imagery may be more difficult to coregister, there are techniques to accomplish reliable coregistration, such as the nested imagery technique described by Moffet (2009) and Moffet et al. (2011). This will aid in reducing 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, error of quantification can only be improved with the use of finer-resolution imagery (e.g., 1 mmpp). Additional research is required to define spatial-resolution guidelines better.

A trade-off between spatial resolution and aerial extent exists and is being addressed with the use of multiple cameras to acquire nested imagery at two or three resolutions (e.g., 1, 10, and 20 mmpp [Booth and Cox 2009; Booth et al. 2010]) simultaneously. The utility of this approach is evident by the limited increase in operational costs to obtain multiresolution data compared to single-resolution data acquisition (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 with the use of nested 1-mmpp imagery.

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