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Using Unmanned Aerial Vehicles to Assess Vegetative Cover and Identify Biotic Resources in Sagebrush Steppe Ecosystems: Preliminary Evaluation

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USING UNMANNED AERIAL VEHICLES
TO ASSESS VEGETATIVE COVER AND IDENTIFY BIOTIC RESOURCES IN SAGEBRUSH STEPPE ECOSYSTEMS: PRELIMINARY EVALUATION

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ABSTRACT

The Idaho National Laboratory (INL), in conjunction with the University of Idaho, is evaluating novel approaches for using unmanned aerial vehicles (UAVs) as a quicker and safer method for monitoring biotic resources. Evaluating vegetative cover is an important factor in understanding the sustainability of many ecosystems. In assessing vegetative cover, methods that improve accuracy and cost efficiency could revolutionize how biotic resources are monitored on western federal lands. Sagebrush steppe ecosystems provide important habitat for a variety of species, some of which are important indicator species (e.g., sage grouse). Improved methods are needed to support monitoring these habitats because there are not enough resource specialists or funds available for comprehensive ground evaluation of these ecosystems. In this project, two types of UAV platforms (fixed wing and helicopter) were used to collect still-frame imagery to assess cover in sagebrush steppe ecosystems. This paper discusses the process for collecting and analyzing imagery from the UAVs to (1) estimate total percent cover, (2) estimate percent cover for six different types of vegetation, and (3) locate sage grouse based on representative decoys. The field plots were located on the INL site west of Idaho Falls, Idaho, in areas with varying amounts and types of vegetative cover. A software program called SamplePoint developed by the U.S. Department of Agriculture, Agricultural Research Service was used to evaluate the imagery for percent cover for the six vegetation types (bare ground, litter, shrubs, dead shrubs, grasses, and forbs). Results were compared against standard field measurements to assess accuracy.

INTRODUCTION

Evaluating vegetative cover is an important factor in maintaining the sustainability of many biotic resources. Cover data provide important information relative to ecological structure and processes such as nutrient cycling (National Research Council, 1994; Carroll et al., 1999; Pyke et al., 2002; Pellant et al., 2005; Crawford et al., 2004), fuel management, and desertification (Mouat and Hutchinson, 1995). Data collection for these evaluations on federal lands in the western United States is a monumental task, however. There are not enough natural resource specialists or funds for ground surveys to be conducted on many of these lands.

Manned fixed-wing and helicopter aircraft have traditionally been used to support monitoring activities on large areas of federal lands; however, the safety of staff flying in the vehicles has become a major concern. Information compiled for 1990–2002 from the National Transportation Safety Board aviation accident database and synopses compiled by the Idaho Fish and Game Department (Zager, 2006) show that flying aircraft for wildlife and fisheries applications is dangerous. For fixed-wing aircraft in 11 western states, there have been at least 19 accidents during this period, with an average of 2.6 fatalities per year. For helicopter applications, there have been 1.3 survey-related incidents per year resulting in one fatality every 4 years. In 2005, four biologists from Montana Fish and Game were involved in a fixed wing aircraft accident while conducting vegetation and biotic surveys; three were killed. Flying fixed wing aircraft slow and low has the highest potential to result in an accident with fatalities. Remote sensing systems are another option; however, these systems have potential issues with cost, accuracy at the sub-meter level, and weather conditions (e.g., cloud cover).

UAVs are an emerging technology that has application for the management of biotic resources on federal lands. UAVs are aerial platforms that can be flown using remote controlled or autonomous navigational systems. These platforms can carry a variety of sensors to capture imagery of the resources on the ground. However, UAVs do have payload limitations so sensors and cameras need to be relatively light [< 6.8 kg (15 lb)].

This study examined the use of UAVs to monitor biotic resources. The objectives of the study were to

1. Determine the accuracy of estimates of percent cover for six vegetation types (grasses, forbs, shrubs, dead shrubs, litter, and bare ground) derived from fixed-frame imagery acquired from UAVs within a variety of sagebrush steppe communities.
2. Determine how accurately fixed-frame imagery will identify the presence and sex of bird decoys (by identifying color differences) within vegetative cover of different densities.

BACKGROUND

The INL landscape is dominated by a sagebrush steppe ecosystem that has the unique aspects of a high elevation, cold desert ecosystem (Rickard et al., 1988; Whitford, 1986). Ecosystems like these often go through transitions from grasslands to shrub lands with numerous vegetative states including extensive grass, mixtures of grasses, forbs and sparse shrubs, and dense shrub cover (Walker, 1993). Activities such as grazing, burning, exotic weed infestation, and planting of non-native species (such as crested wheatgrass) can cause major changes to vegetative cover and have significant potential management implications (Knick and Rotenberry, 1995).

The typical native vegetation at the INL consists of a shrub overstory with an understory of perennial grasses and forbs. The most common shrubs are Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*) and basin big sagebrush (*Artemisia tridentata* subsp. *tridententa*), which may be dominant or co-dominant with the Wyoming big sagebrush on sites with deep soils or accumulations of sand on the surface (Anderson et al., 1996; Mahalovich and McArthur, 2004). Communities dominated by big sagebrush occupy much of the central and southern portion of the INL. Green rabbitbrush (*Chrysothamnus viscidiflorus*) is the next most abundant shrub. Other common shrubs include gray rabbitbrush (*Ericameria nauseosa*), winterfat (*Krascheninnikovia lanata*), spiny hopsage (*Grayia spinosa*), and prickly phlox (*Leptodactylon pungens*) (French and Mitchell, 1983).

One of the most observed features of a given community is its physical structure (Smith, 1990). Vegetative cover is an important part of a landscape's structure and is used to assess the condition of rangelands (Society for Range Management, 1995; Pyke et al., 2002; Pellant et al., 2005) and plays an important role in understanding the desertification process (Mouat and Hutchinson, 1995). Sagebrush communities are regarded by many as steppe or shrub steppe because of the importance of grasses (Daubenmire, 1970; Brown, 1982), which make up an important component of cover. Grasses on the INL are a mixture of native species, those introduced to support revegetation activities, and exotics that have migrated onto the INL. The most common native grasses include thickspike wheatgrass (*Elymus lanceolatus*), bottlebrush squirreltail (*Elymus lanceolatus*), Indian ricegrass (*Achnatherum hymenoides*), needle-and-thread grass (*Hesperostipa comata*), and Nevada bluegrass (*Poa nevadensis*). Forbs are another important cover component because of their importance to wildlife (Connelly et al., 2000; Pedersen et al., 2003) and nutrient cycling (Smith, 1990). Litter and the amount of dead shrub are important factors for both fuels assessment for fire and as a deterrent against erosion from wind and rain (Pyke et al., 2002; Pellant et al., 2005). Bare ground has been identified by a group of rangeland scientists as one of the most important indicators for assessing long-term sustainability of western lands (Maczko et al., 2004).

Total vegetative coverage is the proportion of ground occupied by a perpendicular projection to the ground from the outline of the aerial parts of the member of a plant species (Brower et al., 1990). Typically, coverage can be visualized as expressing the proportion of ground covered by the different cover types, as viewed from above. For this reason, UAVs provide a good platform for coverage measurements.

In general, suitable sagebrush steppe habitat is dominated by a canopy of sagebrush. The absolute and relative amount of sagebrush, grasses, and forbs on a specific site varies with the subspecies of sagebrush, the ecological site potential, and the condition of the habitat. Sagebrush sites best suited to sage grouse have shrub canopy cover between 15 and 25%. Beyond these values, as shrub cover increases, the preference displayed by grouse declines (Nevada Wildlife Federation, 2002). Sagebrush cover may reach 30–40% or more with decline in herbaceous production and no recruitment of herbaceous seedlings. In the case of Wyoming big sagebrush, understory production begins to decline when sagebrush cover is between 12 and 15%, depending on specific site features. The continued increase in brush cover eventually leads to the elimination of understory plants (Nevada Wildlife Federation, 2002).

Fire, both natural and human-caused, also plays an important role in the amount of cover and type of cover present in a sage steppe community (Pedersen et al., 2003). Environmental conditions such as pre- and post-fire conditions have a large effect on the response of a sagebrush steppe community to fire (Bunting et al., 1987). The type of cover in more arid big sagebrush communities has been greatly influenced by annual grasses, particularly cheatgrass (Bunting, 2002). The importance of the forb component varies across the big sagebrush steppe communities. Forb richness increases with increasing moisture; consequently, mountain big sagebrush steppe has a diverse array of associated forbs (Bunting, 2002).

METHODS

This study focused on developing a more accurate method for assessing percent cover for monitoring rangelands. Cover is usually determined using one of a variety of field methods such as line-transect or quadrant sampling [Brower et al., 1990; U.S. Department of the Interior, Bureau of Land Management (USDI-BLM), 1997]. The accuracy of conventional ground-cover methods compared against emerging automated methods has been recently evaluated (Booth et al., 2006; Booth and Tueller, 2003). Results indicate that conventional techniques have significantly greater correlation (≥ 92% agreement of measured to known) than measurements from algorithms from a software system called VegMeasure (Johnson et al., 2003) (70%). The critical factor influencing accuracy of a point-sampling method was the area of the contact point for the given method (Booth et al., 2006). This supports findings from other researchers that point sampling with minimal contact points resulted in the greatest measurement accuracy (Cook and Stubbendieck, 1986).

The present study collected field values at the subplot level and used these as the standards for comparison against data collected from the two different UAV platforms. For this study, accuracy was evaluated by comparing the average difference between the field values and the values obtained from the two UAV approaches. Because the UAV technology is fairly new and equipment is limited, this project relied on acquiring images from missions that were flown by INL's UAV program for other projects; thus, timing for the flights was not a controllable factor.

Study Plot Selection and Design

Data collection using the UAV platforms occurred on INL lands during the spring and summer of 2005. During this period, field plots were established within an area where a UAV runway has been established and a permit to fly under the Federal Aviation Administration–Certification of Authorization (FAA-COA) has been obtained. The FAA-COA is needed in all situations where an autopilot system is used for navigation. Plots were established in seven different locations around the runway, selected based on vegetation that represented diversity of both sagebrush- and grass-dominated communities typical for sagebrush steppe ecosystems. Figure 1 shows the locations of the seven plots, UAV runway, and the study area on the INL. The plots were selected near the runway to accommodate the flight restrictions of the helicopter UAV.

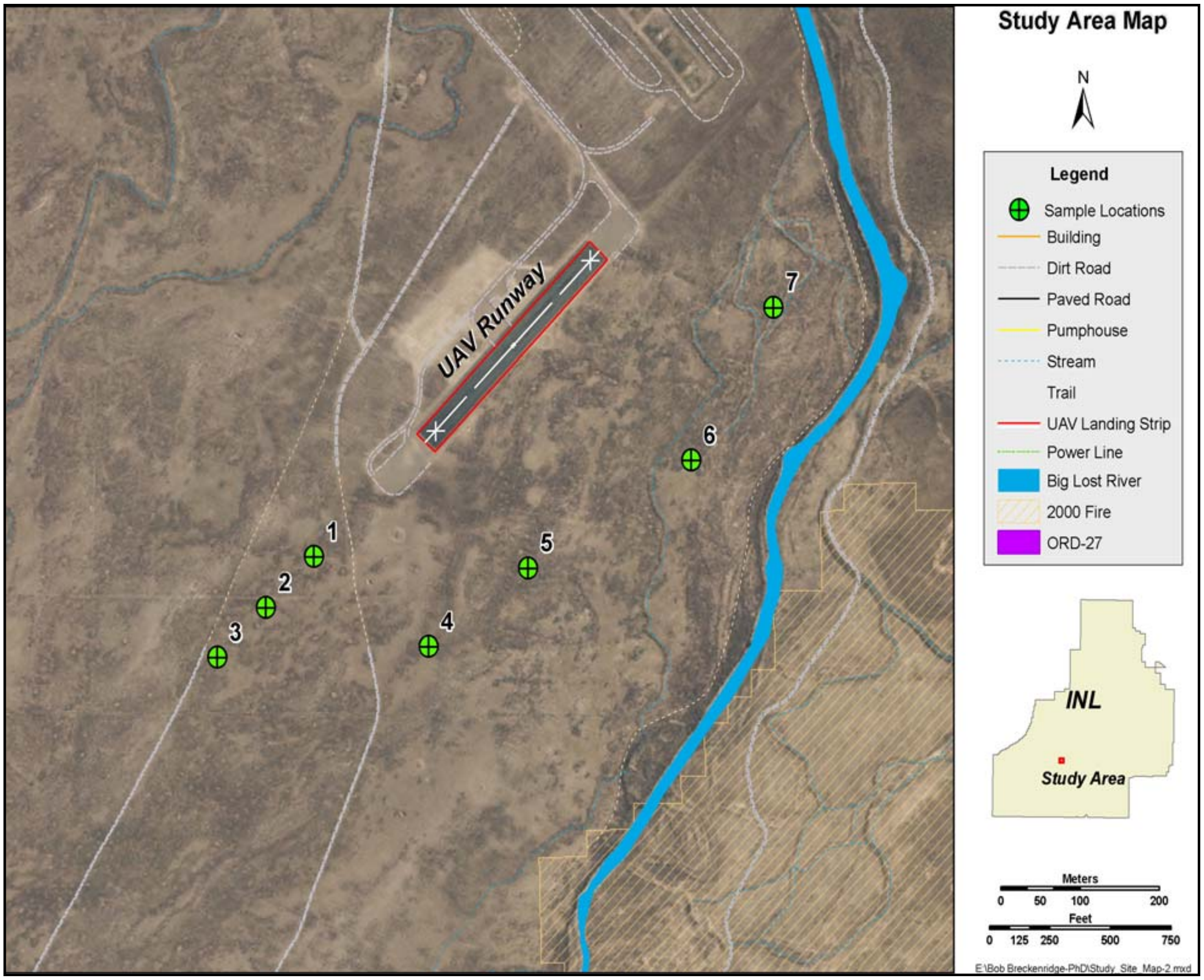

Figure 1. Location of INL UAV runway and seven field plots.

Field plots were established in the early spring by locating the northwest corner of each plot and laying out four 3 × 4-m subplots at each of the seven plot locations. Each corner of a subplot was marked by a 30.4-cm plastic paint bucket lid (from a 5-gal bucket) mounted on a 1.2-m (2.5 × 5.1-cm) wooden stake with two screws. Orange lids were always used on the north end of the plots and subplots to make it easier to ensure orientation and identify images during analysis. Multiple lids were placed in the northwest corner of each plot to equal the plot number (i.e., Plot 7 had seven lids, see Figure 2). Plot numbers were sprayed on the lids using a special, highly-visible paint for plastics so that they could be viewed from UAV flights at different heights Above Ground Level (AGL).

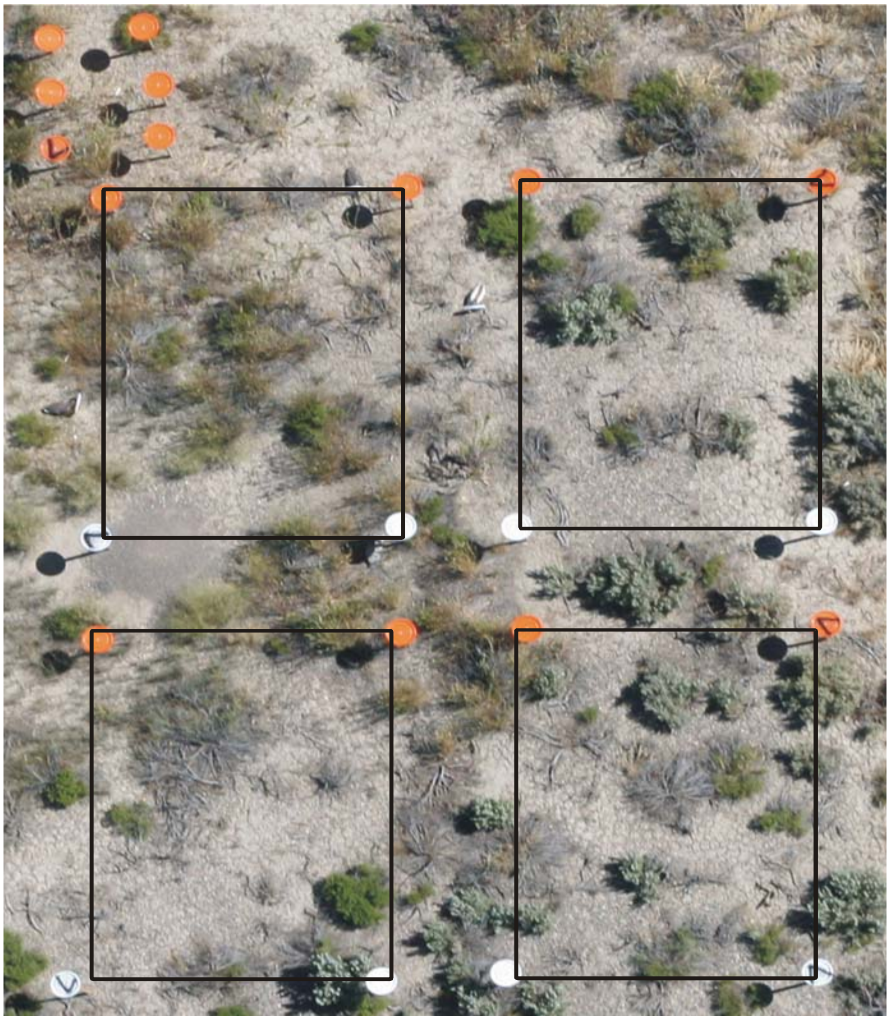

Figure 2. Sample plot design for UAV image collection and analysis study. This image was taken at 76 m AGL from a fixed wing platform and shows the layout of Plot 7 with the four 3 × 4-m subplots identified and three male and one female decoys.

To simulate sage grouse on a lek site, duck decoys were "dressed" using 25.4-cm white plastic paint lids. The 25.4-cm size was selected after consulting with a wildlife biologist to gain insight about the size of a sage grouse's white chest during strutting on a lek. The decoys posture was either standing or laying. On a real lek, several male sage grouse will often strut for one or more hens. The plots had between 0 and 7 decoys oriented in a manner that would be typically be found on a natural lek site. Decoys were staked to the ground to minimize movement during strong winds.

The paint lid and decoy setup proved to be very stable and an effective manner to view the plots from UAV platforms. Even with spring gusts of up to 97-km/hr, none of the decoys blew away and only three of the over 40 lids needed to be re-attached from May through July.

Image Acquisition

Imagery was acquired using two different UAV platforms. The first method used an APV-3 fixed wing airplane with about a 3-m wing span made by RnR Products. This aircraft flew using an autonomous navigation system and carried an 8-megapixel, full-size camera equipped with through-the-lens video feed connected to the ground base station through a remote frequency connection. The plane flew at 76, 153, and 305 m (250, 500, and 1,000 ft) AGL. Because of concerns with turning operations, the plane was not flown below 76 m. Manual controls were used during take-off and landing. During image acquisition, the plane was controlled with an autopilot system tied into a global positioning system (GPS); a portable computer on the ground with pre-programmed flight information controlled the plane through a remote frequency link. Fixed wing flights lasted about 80 min, and over 700 images were collected. The limiting factor for the fixed wing platform was storage capacity for the imagery. The platform could be flown for 4–8 hr depending on how the engine and camera power system were configured.

The second platform was an X-Cell model helicopter made by Miniature Aircraft carrying a micro 4-megapixel, digital single-lens reflex camera mounted on an aluminum frame located under the nose of the helicopter. The camera captured nadir images when the helicopter was in a stable hovering position (Nadir images are those taken directly overhead a field plot). Images were acquired by an operator using a remote control trigger system. Imagery was collected at heights of 10–15 m AGL.

To locate the helicopter over a plot, two methods were tried. First, a through-the-lens video system was mounted onto the camera and the operator on the ground viewed the plot using a 25-cm portable screen. This method proved not to be effective because the field of view for the video was too restricted, making it difficult to locate the plot. Also, the video screen was difficult to read when working out in the direct sunlight. The second method proved to be very effective and quick. This approach used two observers with flags located at adjacent sides of each plot. The flag persons would signal the location of the helicopter by holding the flag left, right, or straight up (meaning the UAV was located over the center of the subplot). The operator of the camera relayed location information to the UAV pilot and used the flag information to ensure the UAV was centered over the subplot when acquiring pictures. Some experience was needed by both the camera and UAV operator to center the helicopter over the subplot once the winds were over 16 km/hr. The helicopter was flown in winds up to 25 km/hr without problem.

The helicopter had a flight-time limitation of about 15 min because of its fuel capacity. The best approach was to lay a 1 × 2-m mat down in a clear area near the plot and use this as the take-off and landing area. After flying each plot, the pictures were downloaded from the camera to a portable computer and the operators immediately ensured that good images were acquired from each of the four subplots. On average, 30 images were collected over each plot during flights that averaged 5 min.

Field Data Collection

Cover values in the field were measured manually using a point frame method (Floyd and Anderson, 1982). Field values were collected within one day of the helicopter flights and within one week of the fixed wing flight during the second week of July. For sampling plants, rectangular plots have been found to yield better results than other shapes; a rectangle with sides in a 1:2 ratio works well (Brower et al., 1990). The subplots were sampled using a point frame method with a rectangular design (0.5 × 1 m). For each sample location, a 1 × 1-m area was sampled by flipping the frame over after reading the first frame. Sampling points were identified by establishing a 1 × 1-m grid over each of the 3 × 4-m subplots. The grids were numbered starting at the northwest corner and continuing across the north and west sides, creating twelve 1-m^2 sampling locations. A random number generator was used to select 6 of the 12 locations to read with the point frame. Thus, 50% of each subplot was read. For two of the subplots in Plot 1, 100% of the plots were read in the field. This information was used for quality checks.

Three different observers read the plots by looking through the cross hairs of the point frame and identifying the aerial cover as shrub, dead shrub, litter, bare ground, grass, or forb. Vegetation types were called out to a second worker who recorded the data into a handheld portable data recorder with a preformatted Microsoft Excel spreadsheet. To improve quality control, the three observers were also calibrated with an experienced range specialist for a day.

Image Manipulation and Processing

Images were downloaded from the UAV cameras into a portable computer at the end of each flight. The clearest and most nadir images were selected for analysis. Each image was rotated to the same directional orientation and cropped to the smallest rectangle possible without removing any information inside the plot using Corel PHOTO-PAINT 10. This was done by rotating the image and lining up the longest side of the rectangle with a horizontal axis. The cropped images were then imported into ERDAS Imagine, an image processing software package. The images were manipulated to match each other through the use of the Image Geometric Correction subroutine. This was accomplished by selecting one image from each plot as the base image or template. The other images for the plot were tied to the first by establishing points on the ground that could be identified in each image. The rotated, cropped, and matched images were then imported into image analysis software called SamplePoint.

SamplePoint, a software program developed at the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS) in Cheyenne, Wyoming, was used to measure vegetation cover on the image (Booth et al., in press). For the SamplePoint method, images were processed using a computer-based ocular process to identify the cover type on the fixed frame photos. For the helicopter imagery, a 10 × 10 grid (100 points) was overlaid on each subplot image and the cover was identified at each grid point as one of seven types (shrub, dead shrub, litter, grass, forb, bare ground, or unknown). To evaluate the effect of different observers, three observers read each of the helicopter images. For the fixed wing imagery, an analysis was conducted at the subplot level using the 10 × 10 grid; however, there was too much distortion in the image to make an accurate assessment. Thus, the fixed wing imagery was read at the total plot level using a 16 × 16 grid that allowed for about 64 points to be read in each subplot. One observer read all the fixed wing imagery.

Training the three observers was an important part of the quality control process. Each observer conducted an analysis of an image. Summary statistics were generated and the three observers discussed results and differences. The three observers had different levels of field experience in working with evaluating rangelands from high to medium and low. During the initial training runs, there was a noted difference in results and the average time for reading a 100-point image was 45 min. The team conducted 2 weeks of training and reviewed 12 images. After the eighth image was reviewed, there was fairly good convergence on results. The time required to read an image was reduced significantly to about 7 min. At the conclusion of the training, there was still some difference among observers but most of this was attributed to difficulty in identifying grasses from forbs and litter.

If the vegetation types at a point could not be determined (due to shadow) or the vegetation fell outside of the corners of the plots, it was recorded as "unknown." Data from each image were normalized to account for unknown values so that the remaining six cover types sum to 100% for each image.

Data Analysis

An assumption made for this study is that the field method of estimating percent cover is most representative of the true values and would be considered the standard against which the other imagery values were compared. This standard value may not be the true value, but it is likely to be known with the least error.

Data from both the field and image analysis processes were assessed to determine how well the two techniques agreed on cover categories as defined by a modified cover class method (Daubenmire, 1968). The modified cover classes were altered slightly to provide discrete breaks between classes as shown in Table 1.

Table 1. Modified cover classes for evaluating cover types.

Cover category (%)	Cover class
0–1	1
1.01–5	2
5.01–25	3
25.01–50	4
50.01–75	5
75.01–95	6
95.01–100	7

Decoy evaluation data from the helicopter and fixed wing UAVs were recorded using an ocular method. Imagery was evaluated to determine if decoys randomly placed around subplots could be identified. Data from the helicopter and fixed wing imagery (76 m AGL) were recorded and compared against field values for decoy location and sex for each subplot.

RESULTS AND DISCUSSION

Helicopter Imagery

Table 2 shows the results of the comparison between the field and helicopter values averaged for all plots. Examining the data qualitatively, the helicopter imagery from early July shows a high degree of agreement with the field values for bare ground, dead shrub, grasses and litter. Shrub cover is often overestimated by the imagery approach and forbs were both underestimated and overestimated. If is likely that forbs were hard to identify because the imagery was acquired a bit past there peak growing season. Also, the initial analysis of forbs among the three observers showed great differences. Training did help reduce uncertainty, but there is still a difference between the most skilled observer and the team, with the skilled observer being slightly more accurate.

Table 2. Comparison summary for helicopter UAV July imagery results against field values as classified into modified cover classes. Correct = classified into the same category; +/− shows % of values classified as one or two classes above or below correct class. Values are given for one observer and a team of three observers.

Cover type	Number of observers	Error in cover class estimate			
		−2(%)	−1(%)	Percent correct	+1(%)
Bare ground	1			100%	
	3			86%	14%
Dead shrub	1			100%	
	3			100%	
Forbs	1	14%	28%	44%	14%
	3	14%	58%	28%	
Grasses	1			100%	
	3			100%	
Litter	1			86%	14%
	3			100%	
Shrubs	1			71%	29%
	3			86%	14%

Fixed Wing Imagery

Results for the comparison between the field values and imagery values from the fixed wing platform are presented in Table 3. There is good agreement for bare ground and dead shrub. Accuracy is fair for assessing litter and shrub. Accuracy is poor for assessing grasses and forbs; however, accuracy may be improved if these two classes were combined.

Table 3. Comparison summary of fixed wing UAV July imagery results against field values as classified into modified cover classes. Correct = classified into the same category, +/− shows % of values classified as one or two classes above or below correct class. One observer read the fixed wing imagery.

Cover type	Number of observers	Error in cover class estimate			
		−2(%)	−1(%)	Percent correct	+1(%)
Bare ground	1			100%	
Dead shrub	1			100%	
Forbs	1	43%	43%	14%	
Grasses	1	14%		58%	28%
Litter	1		14%	71%	14%
Shrubs	1			71%	29%

Ground cover has been identified as one of the most important indicators of rangeland health (USDI-BLM, 1997) and bare ground has been identified as the one key ground cover measurement for evaluating long-term sustainability of rangeland systems (Maczko et al., 2004). Both the helicopter and fixed wing UAV imagery showed very good comparison to the field values for bare ground for the seven plots. The UAV methods using available technology show promise for measuring bare ground.

Fixed wing imagery was used to evaluate how well imagery from three different AGLs could be used to identify decoys. For the 76-m AGL imagery, both the male and female decoys could be identified by a skilled observer. An example of how the decoys looked for Plot 7 is shown in Figure 2. This image has four male decoys and one female. Three of the four male decoys are fairly easy to see, one is in the shadows. The female decoy blends in with the native vegetation. The fixed wing imagery from early June was obtained at 153 and 305 m AGL. Because vegetation was much greener than in the July imagery and the imagery was collected one day after a rain event, the decoys showed well. For the 153-m AGL imagery, all the male decoys and 60% of the female decoys could be detected. For the 305-m AGL imagery, over 90% of the male decoys were detected but only 10% of the female decoys could be identified. Thus, the fixed wing imagery at 76, 153, and 305 m AGL provided a good platform to identify decoys roughly the size of male grouse if they were in full strutting display on a lek. Females decoys were easy to identify at 76 and 153 m AGL, but difficult to identify at 305 m AGL.

The UAV methods may have an advantage over conventional field methods relative to the time required to set plots and collect and analyze data. Table 4 is a summary of the times required to collect data from both the UAV methods and field methods. These are the typical times that the researchers needed to complete tasks but do not include the times required for training. The time for collection of field data could in general be reduced by experienced field crews, but it would be very difficult to reduce the time to below that required to collect the imagery with the UAVs. For the fixed wing system, the actual flight time was 75 minutes to collect imagery for the seven plots. Over 700 images were collected during the fixed wing flight. For the helicopter, the total flight time was 40 min and more than 210 images were collected. The remainder of the time was spent on set-up, safety checks, and data transfer. One of the most difficult tasks with the UAV process was selecting the best image for analysis.

Table 4. Comparison of time required for collection of UAV and field data sets.

Activity	UAV time requirement (hr)	Field method time requirement (hr)
Set up 7 plots	5	4
Collect imagery from either helicopter or fixed wing platform, set-up to takedown time	8	
Collect field data using point frame method and sampling 50% of all 7 plots		36
Image processing Fixed wing, 30 min/plot × 7 plots Helicopter, 12.5 min/subplot × 28 subplots)	 3.5 5.8	
Analyze data (30 min/plot × 7 plots)	3.5	3.5
Report on cover class data as percents (30 min/plot × 7 plots)	3.5	3.5
Totals **Fixed wing** **Helicopter**	 **23.5** **25.8**	**47**

RECOMMENDATIONS AND CONCLUSIONS

Results from collecting cover data using UAV technologies show these platforms can be effective for collecting high resolution, near earth imagery. These platforms can fill an important niche between the field worker and satellite systems. They are highly mobile, can cover vast remote areas with ease, and reduce the time spent in the field to collect data.

Agencies considering UAVs as a possible data collection alternative will need to evaluate the results from this study against their technical and legal requirements. The systems tested showed promise for selected cover types under the conditions and constraints of this study. Two things are relatively certain that will influence the future use of UAVs: (1) technology (including the UAV platform, camera system, and image processing systems) will continue to improve by weighing less and storing more data, and (2) high quality reliable data will be required for making and defending management decisions. Considering these factors, along with the concerns of safety, increasing cost for field workers, and reduced availability of trained workers, UAVs may provide cost-effective options for collecting future data for management of rangelands.

There are a number of recommendations that have been developed as a result of this study:

1. Fixed wing UAVs provide an excellent platform for collecting data over large areas; however, there are limitations about how long they can fly and collect images. Research should focus on establishing the optimum AGL for collecting rangeland data from UAVs and identifying the best total system (platform, camera, and navigational instruments). The fixed wing UAV was initially flown at 153 and 305 m AGL; these elevations produced marginal imagery. 76 m AGL provided imagery that was of good quality, but better imagery could probably be collected at 30–60 m AGL with platforms designed to fly that low.
2. A study comparing UAV collected data against several conventional field methods currently being used by the BLM, USDA Forest Service, and other rangeland scientists would improve the usefulness of the data. Greater involvement with land management agency scientists will improve the understanding of the current challenges and will enhance data collection, which should then be better accepted by the agencies.
3. This study was constrained by borrowing flight time and equipment from another program; thus, the optimum phenological times were not used for collecting the best data for analysis of forbs and grasses. If agencies and scientists want to know data about specific species, a study would need to focus on flying UAV platforms at various times during the growing season and identifying the best time for collecting cover data.
4. Image processing using SamplePoint was reasonable for this study. However, for UAV or any other near-earth image collection systems to become useful, the software needs to be developed to a point that is automated and reliable. Future research that moves a system like SamplePoint toward automation would improve the usefulness of image analysis systems for rangeland management.
5. The helicopter imagery method did a better job of doing a more complete census of the subplot for shrub cover and may be more accurate. This study did not test this hypothesis but it would be a good topic for future study.
6. Additional research needs to be conducted to see if a live sage grouse would react to a UAV flying over a lek in a similar manner to a raptor that might be preying on the grouse.

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