RESEARCH ARTICLE

Using Unmanned Aerial Vehicles for Rangelands: Current Applications and Future Potentials

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High resolution aerial photographs have important rangeland applications, such as monitoring vegetation change, developing grazing strategies, determining rangeland health, and assessing remediation treatment effectiveness. Acquisition of high resolution images by Unmanned Aerial Vehicles (UAVs) has certain advantages over piloted aircraft missions, including lower cost, improved safety, flexibility in mission planning, and closer proximity to the target. Different levels of remote sensing data can be combined to provide more comprehensive information: 15–30 m resolution imaging from space-borne sensors for determining uniform landscape units; < 1 m satellite or aircraft data to assess the pattern of ecological states in an area of interest; 5 cm UAV images to measure gap and patch sizes as well as percent bare soil and vegetation ground cover; and < 1 cm ground-based boom photography for ground truth or reference data. Two parallel tracks of investigation are necessary: one that emphasizes the utilization of the most technically advanced sensors for research, and a second that emphasizes the minimization of costs and the maximization of simplicity for monitoring purposes. We envision that in the future, resource management agencies, rangeland consultants, and private land managers should be able to use small, lightweight UAVs to satisfy their needs for acquiring improved data at a reasonable cost, and for making appropriate management decisions.

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High resolution aerial photographs have important rangeland applications, such as monitoring vegetation change, developing grazing management practices, determining rangeland health and condition, and assessing remediation treatment effectiveness (Rango and Havstad, 2003). Unmanned Aerial Vehicles (UAVs) have several advantages over piloted aircraft for acquiring high resolution images. These advantages include a less expensive remote sensing platform, improved safety for operators, and a more rapid deployment capability than piloted aircraft.

Most applications of UAVs in rangeland areas, which make up 50% to 70% of the world's land surface (Holechek, Pieper, and Herbel, 1995), only require simple high resolution photography and thermal infrared imagery that can be provided with existing sensors over selected sites. Unmanned Aerial Vehicle flight requirements over rangeland are also simple, with slow flight speeds, low altitudes, and flight durations of two to six hours usually being adequate. Such capabilities should be sufficient to satisfy the need for high resolution photography of remote rangeland areas. Satellite and piloted aircraft missions (both high and low altitudes) have provided excellent data for rangeland applications, but a major gap exists between these large area coverages and boom-mounted vertical ground photography of small areas; UAVs can fill this gap. Because the large area coverage can provide landscape level views, high resolution satellite data can be used to identify rangeland areas (in the case of rangeland health assessments) that need more detailed observations; UAVs then can be uti-

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lized to provide greater detail on cover and pattern within specific areas.

According to Newcome (2004), a UAV is defined (by the Department of Defense) as "A powered aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry . . . payload." Several terms have been used to describe a UAV, including pilotless airplane, robotic aircraft, drone, remotely piloted vehicle, unmanned aircraft, automatically piloted vehicle, and remotely operated aircraft (Newcome, 2004). Since the first automatically controlled flight of an unmanned aircraft in 1916, the UAV field has been dominated by military applications, but civilian science applications recently have received more emphasis, particularly at the UAVs for Land Management and Coastal Zone Dynamics Workshop sponsored by the National Aeronautics and Space Administration (NASA, 2005). Characteristics of certain UAVs make them very appropriate for rangeland applications.

As a technology, the earliest aerial photographs were taken from balloons and kites in the 1800s and from piloted aircraft and low altitude compressed air rockets in the early 1900s. Unmanned Aerial Vehicles were developed concurrently with piloted aircraft, starting in the early 1900s. Photography from UAVs came later, because of an initial emphasis on robotic control of the vehicle and relatively small payload capabilities. The first reported UAV adapted for photography was developed in 1955, when the Radioplane company modified its OQ-19 Shelduck target drone to fly film cameras (Newcome, 2004). From this point on, UAV size decreased, while at the same time, model airplanes were improving and gradually became more capable of lifting heavier payloads. There is some confusion between the definition of a model airplane and that of a small UAV. They are probably best distinguished by the UAV autonomous flight capability and georeferencing of images, both of which require an on-board global positioning system (GPS); UAVs can also accommodate a larger payload than most model airplanes. In addition to cameras (including video cameras), some UAVs are able to carry multispectral radiometers, thermal radiometers, and even hyperspectral devices.

Background

There has been limited application of UAVs for rangeland research. Walker (1993) used a modified model airplane to fly a lightweight film camera to obtain high resolution vertical photographs over small areas at archeological sites, as well as at other natural resource areas. Quilter and Anderson (2001) used a radio-controlled airplane fitted with a 35 mm camera to obtain images over small research plots that had been treated or harvested to simulate shrub utilization by grazing. This approach showed promise for a quick and accurate assessment of the effects of grazing. Hardin and Jackson (2005) report on the use of off-the-shelf model airplane components to fly a 35 mm camera and a GPS to accurately geolocate high resolution rangeland images. This system was used to map squarrose knapweed (*Centaurea virgata* Lam. spp. *squarrosa*) invasion in Utah. These approaches proved to be economical and amenable to field work in rangelands. Modified model airplanes seem suitable for rangeland work, especially in the early research stage, but commercially available UAVs with well-developed guidance systems are required for widespread use and the capability to produce comparable images on a repetitive basis. The MLB-Bat 3 (Horcher and Visser, 2004) and the Lockheed-Martin APV-3 (Johnson et al., 2003) are examples of UAVs with well-developed guidance systems that have been used in natural resource studies similar to rangeland applications.[1] The MLB-Bat 3, an off-the-shelf system, has been tested by the US Forest Service (2005) and has been found to be capable of the two- to six-hour flight time previously mentioned.

UAV Requirements for Rangeland Management Applications

Unmanned Aerial Vehicles for use in rangeland applications have modest requirements, which should reduce their cost relative to UAVs used for applications requiring high-cost airframes, heavy payload capability, and the ability to stay aloft for several days to weeks (e.g., for forest fire management, pollution and air quality assessment, coastal ocean observations, cloud and precipitation assessment, and severe storm monitoring applications). We believe that most imaging requirements can adequately be served from relatively low altitudes and slow airspeeds, for which the moderately expensive UAVs are designed (e.g., the MLB-Bat 3). These kinds of flights result in high resolution images required for distinguishing rangeland plant species, as well as possessing the capability for measuring patch and gap sizes and describing spatial patterns at multiple spatial scales across a variety of ecosystems. The capability to fly at a variety of altitudes to obtain images of different spatial resolutions with the same sensor is an additional advantage.

Unmanned Aerial Vehicle data acquisition clearly has many advantages over acquiring data from piloted aircraft. These include the fact that UAV flight plans are more flexible when conditions in the target areas change. The UAV is generally stationed near the study area, whereas most piloted aircraft are at much greater distance from the rangeland under study. Data are usually not available until several weeks after the mission from a piloted research aircraft, whereas the UAV photography can be displayed immediately upon landing, if necessary. Research aircraft usually have a crew of two or more. The availability of the piloted research aircraft is sometimes limited because of multiple demands on the aircraft. This logistical problem also limits the use of piloted aircraft for target-of-opportunity events (which can be over in a matter of hours in arid rangelands). Of course, there are also elevated risks with piloted missions. In sum, both capital and operational costs are much higher for piloted missions than UAV missions.

Although they are less expensive and easier to operate, smaller airframes do have several disadvantages. Distortion in the images is common due to motor vibrations affecting camera stability. These can be minimized with sponge or foam insulation capable of dampening the motor vibration (Walker, 1993) or the use of an electric motor than can be switched off during photography to achieve a high degree of image sharpness (Veisze, 1997). Slow airspeeds, fast camera shutter speeds, and the use of wooden propellers can also be used to minimize blur in aerial photographs (Hardin and Jackson, 2005).

In rangelands, UAV takeoffs can be problematic because of rough surfaces, including some dirt roads that may also be too narrow for the wingspan of certain UAVs. This can be solved by short distance catapult launches or even launches by hand, if the UAV is sufficiently light. Landing of the UAV is also critical, and GPS guidance can be used to bring the UAV in for short distance landings on smooth playa surfaces, dirt roads, or even moderately uneven vegetated fields; this is already accomplished by certain UAVs, e.g., the MLB-Bat 3 (see MLB Company, 2006). Portability of the UAV system is an associated requirement, so that UAV takeoff and landing locations can be close to rangeland study areas.

Unmanned Aerial Vehicle flight duration capability should be two to six hours, so that the optimum sun angles during the day for photography (occurring from about 1000 to 1500 hours) can be used for the imagery. Sufficient payload capability should be available so that multiple lightweight sensors can be flown simultaneously. In addition to a camera, these sensors could include multiband radiometers for spectral vegetation index computations and thermal infrared sensors. The thermal sensors can be used to collect data for input to evapotranspiration models, mapping of surface temperature variability, and possible identification of preferred routes followed by cattle during grazing and accessing watering points. The UAV can also be available for target-of-opportunity flights in rangeland areas, such as assessment of remediation treatment effectiveness immediately after runoff events. After routine missions or target-of-opportunity events, the data can be processed immediately upon landing of the UAV, if necessary. For operational use in rangeland, the UAV system should be self-contained and easy to use, yet still available at low to moderate expense to various government agencies. A modified model airplane airframe with GPS and digital camera costs up to $2,500 (low cost), whereas a moderate-cost UAV such as the MLB-Bat 3, including catapult launcher, ground control system, digital camera, video camera, and one airframe, costs $48,000 as of this writing (MLB Company, 2006).

Challenges for the Effective Use of UAVs

There are currently unresolved issues with regard to access to airspace and safe operations required by the Federal Aviation Administration (FAA). The FAA is still in the process of determining how UAVs will be regulated. Current opportunity exists to influence these regulations, and rangeland applications may be in a favorable situation because they require operation at low altitudes over nearly uninhabited areas. At the moment, radio-controlled model airplanes are exempt from FAA regulation, but they must be operated at less than 400 ft (122 m), can only be used for non-commercial purposes, and cannot employ autonomous flight capabilities. True UAVs must fly either outside of the National Airspace System (e.g., in military operation areas or in special use airspace) or, if the flights are planned to be in the National Airspace System, the agency in charge must apply to FAA for a Certificate of Authorization so that the flights can take place. Currently, development of our UAV techniques for rangeland applications is being done outside the National Airspace System or under a Certificate of Authorization. Future flights must abide by FAA regulations specific to UAVs as they are enacted in the next few years.

The transition from a radio-controlled model airplane to a "modified model airplane" useful for rangeland science applications requires the development of a self-contained remote guidance and data collection system that can be used in operational activities. The development of the system need not go too far into the realm of "sophisticated" UAVs with great altitude, flight duration, and payload capabilities. The system must remain simple and relatively inexpensive (e.g., less than $2,500) to be effectively utilized, for example, by local governments; these are the aspects of the model airplane heritage that need to be retained.

To be useful on rangeland, the UAV system must possess the capability for completely autonomous flight over numerous flight lines. The UAV must then locate the landing site and proceed to that point and land on its own. For efficiency of operation, the landing site may not be the takeoff location in many cases. The payload capability must improve, but only so that two to four lightweight sensors can be flown simultaneously. In the case of aerial photographs, a spatial resolution of 5 cm or less is required. The capability to fly at low altitudes will ensure that this resolution is acquired. Development or acquisition of simple data analysis software is needed to assure rapid processing after routine flights for next day planning and also target-of-opportunity flights for real-time decision making and management response. With the UAV system, keeping pace with new technological developments must be considered on the one hand, and on the other, we need to know when we have all the capability needed for the application. This requires the development of two parallel tracks: one emphasizing the development of the most technically advanced sensors for research, and a second emphasizing the minimization of costs and the maximization of simplicity for monitoring purposes.

UAV Experiments at the Jornada Experimental Range

Site Description

Several UAV studies have been conducted on the United States Department of Agriculture/Agricultural Research Service's Jornada Experimental Range (JER) in south central New Mexico (Havstad et al., 2000). The JER was established in 1912 and encompasses 783 km^2 of desert grassland in the northern portion of the Chihuahuan Desert. Since the late 1800s, grasslands at the JER have experienced invasion by shrubs. Rangeland scientists at the JER have conducted research to see if the displacement of grassland by shrubland can be reversed or at least halted. The conditions at JER are representative of other arid rangelands in the southwestern United States and around the world. The suitability of new methods for rangeland health monitoring and measurement have been developed and tested at the JER (Herrick et al., 2005). The next step in these assessments is to more fully include remote sensing as an integral component, so that the use of UAVs is a viable approach to monitoring and measurement. In addition to acquisition of long-term rangeland datasets at the JER, the site has also been used numerous times as a NASA remote sensing validation site (e.g., Privette et al., 2000), and the JER has been the site of a temporally repetitive remote sensing project now totaling 12 consecutive years, called JORNEX (Rango et al., 1998).

Data Acquisition and Analysis

Two different UAVs were tested at the JER, the Rmax helicopter (length 3.6 m) and a small propeller-driven modified model airplane (fuselage length 1.25 m, wingspan 1.53 m) (Figures 1a and 1b). The Rmax helicopter acquired data in 2000 and 2002 at several altitudes from 10 to 100 m, at a number of JER test sites being used for JORNEX (Rango et al., 1998). The data were acquired at nadir and at a range of angles to study the surface bidirectional reflectance distribution function. In 2005, the modified model airplane was able to acquire data in coordination with satellite (ASTER, QuickBird), low altitude aircraft, and a ground-based boom mounted camera system. In addition, there are historic aerial photographs available over the same area of study (Rango and Havstad, 2003). The multilevel dataset acquired in the years 2003 to 2005 (some earlier satellite data were utilized) over a playa study site with various shrubs, subshrubs, and tobosa grass (*Pleuraphis mutica*) is an excellent example of some of the capabilities of UAVs. The 2003 QuickBird satellite data, with a panchromatic resolution of approximately 61 cm, is comparable to the spatial resolution of the historic aerial photographs (Laliberte et al., 2004). With QuickBird, it has been possible to distinguish shrubs from grass and bright or bare soil (Laliberte et al., 2004). Eighty-seven percent of all shrubs greater than 2 m^2 were detected with QuickBird, and 29% of shrubs smaller than 2 m^2 were detected. Various categories of grass and bare soils could also be delineated after the shrubs had been masked out of the QuickBird data (Laliberte, Fredrickson, and Rango, 2006). Because the 61 cm resolution from space is very similar to a variety of existing aerial photographs, QuickBird is an important resource for supplementing an aerial photography database. The major problem with QuickBird and aerial imagery is that the resolution of the data is not sufficient to answer the ques-

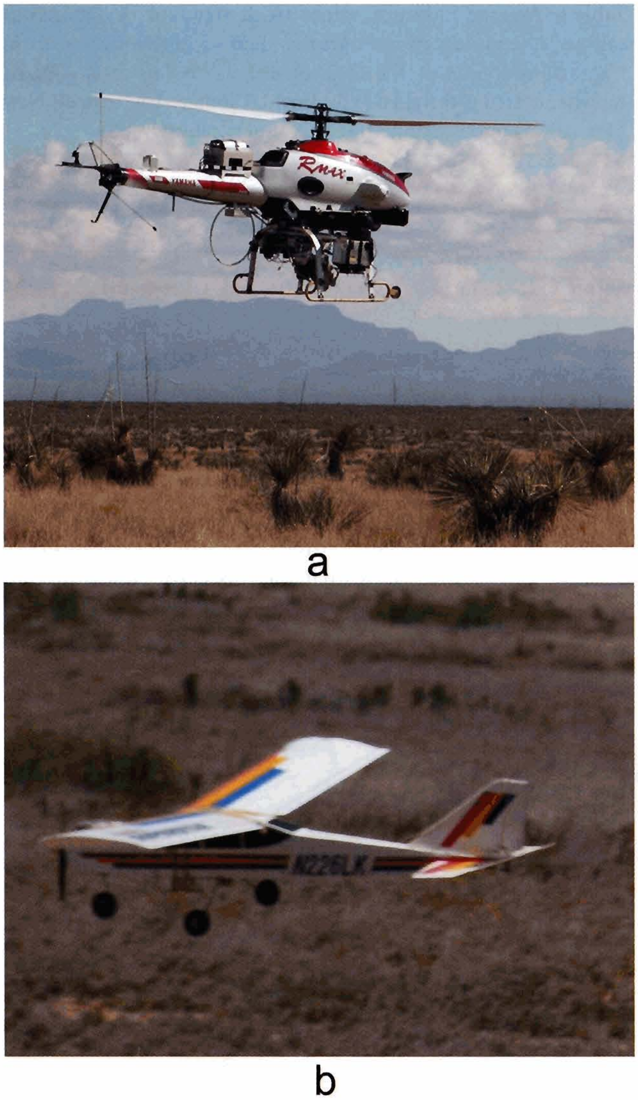

Figure 1. (a) Yamaha Rmax helicopter Unmanned Aerial Vehicle and (b) modified model airplane Unmanned Aerial Vehicle during operation at the Jornada Experimental Range, Las Cruces, New Mexico.

tions being asked by ecosystem modelers and agencies charged with evaluating rangeland health.

Critical management questions currently revolve around the characteristics of spatial arrangement, namely, the pattern and size of patches of vegetation and gaps between patches or individual plots (Herrick et al., 2005; Holm et al., 2002). These spatial characteristics, which are highly correlated with erosion risk and wildlife habitat quality, cannot be resolved by QuickBird (Figure 2a). Aerial photographs from about 5,000 ft (1,515 m) taken by an ARS research aircraft (Figure 2b) are not suitable for resolving the patterns of patches and gaps either. The UAV image taken at an approximate altitude of 60 m with a simple 2-megapixel Aiptek Pencam SD digital camera (Figure 2c), however, provided a large increase in detail at a resolution of 5 cm for displaying gaps and patches. Figure 3 shows a comparison of the UAV data (Figure 3a) with higher resolution boom color photography (Figure 3b) taken approximately 2.8 m above the surface with an 8-megapixel Canon Powershot Pro 1 digital camera and $<$ 1 cm resolution. Even though the UAV photograph does not have the detail of the boom photograph, it can be used to help determine the shrub canopy cover gap sizes for the UAV digital photograph seen in Figure 4a (discussed in more detail later).

Unmanned Aerial Vehicle photography can be used to create vegetation indicators, listed in Table 1, that are difficult, if not impossible, to generate from satellite data. Shrub canopy cover and the percentage of the soil surface falling in large intercanopy gaps are extremely expensive to measure on the ground. Although we can estimate average foliar cover (percent of ground covered by vegetation) within a satellite pixel, it is nearly impossible to detect changes in canopy cover (percent of ground falling within the perimeter of a plant canopy). While foliar cover is more useful for erosion prediction and is more closely correlated with plant biomass, canopy cover is often more useful for many wildlife studies because it is more sensitive to changes in the total area in which plants modify visibility and microclimate (Winter et al., 2006). The proportion of the soil surface falling in intercanopy gaps is impossible to generate from most satellite imagery because the best resolution commonly available is 61 cm (QuickBird). Studies have shown that a relatively limited number of shrubs less than 2 m^2 in area can be detected with QuickBird (Laliberte et al., 2004), and it is necessary to delineate shrubs before detecting intercanopy gaps. Plant communities with large gaps are more susceptible to wind erosion, even if they have similar foliar and canopy cover. Ludwig et al. (2000) have used 20-cm resolution aerial videography images from piloted aircraft to measure arrangement and size of vegetated and bare soil patches to describe landscape function.

For each of the four quadrants of the image shown in Figure 4a, we conducted our measurements on five randomly selected 20-m transects located a minimum of 2.5 m apart, drawn on a printed and enlarged UAV image with a scale of 1:75. We estimated canopy cover of woody vegetation by recording the number of points that fell within a woody plant canopy. There were a total of 40 points per transect (every 50 cm). All gaps less than 20 cm long were included as canopy cover. A continuous line intercept method was used to quantify the proportion of the soil surface exposed in large intercanopy gaps (Herrick et al., 2005). We recorded all gaps greater than 20 cm and calculated the proportion of the soil surface covered by gaps greater than 50 cm. As shown in Table 1, canopy cover was highest and large gaps lowest in the SE quadrant, although the quadrant had a statistically significant effect only regarding canopy cover ($p < 0.05$; $n = 5$ transects). The data can also be used to rapidly characterize variability among different parts of the landscape, which is another important indicator of wildlife habitat suitability. Although both gap and canopy cover indicators reflect some variability, canopy cover had a much higher average coefficient of variation (40.1% for canopy cover versus 8.7% for large intercanopy gaps; n =4 quadrants).

The use of the software eCognition, an object-oriented image analysis program (Definiens, 2003), allows classification of the mixed rangeland in Figure 4a into four primary cover types—bare soil, mesquite (*Prosopis glandulosa*), broom snakeweed (*Gutierrezia sarothrae*), and grass, as shown in Figure 4b. At Jornada, this is the first time that we have been able to classify subshrubs (broom snakeweed)

Table 1. Average indicator values (with standard deviations) of canopy cover and gap sizes greater than 50 cm along the 20 m transects for each of the four quadrants in Figure 4a (mixed rangeland at the Jornada Experimental Range, Las Cruces, New Mexico), using Unmanned Aerial Vehicle photography

	Quadrant, Figure 4a			
	NW	NE	SW	SE
Shrub and sub-shrub canopy cover (%)	24 (7)	12 (11)	15 (5)	30 (8)
Gap > 50 cm (%)	83 (10)	82 (13)	82 (5)	69 (7)

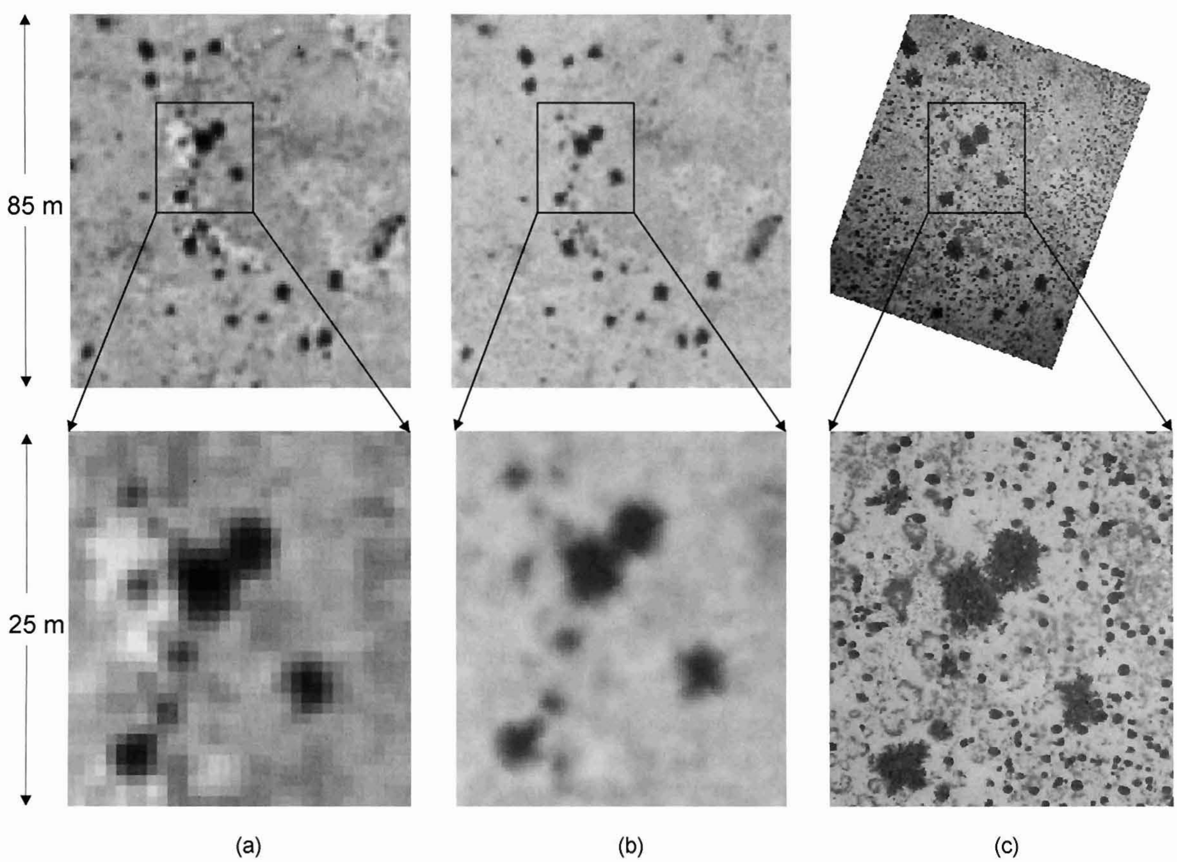

Figure 2. Comparison of (a) satellite (QuickBird) pan sharpened 61 cm resolution, (b) Agricultural Research Service aircraft 24 cm resolution, and (c) Unmanned Aerial Vehicle 5 cm resolution imagery over a playa study site at the Jornada Experimental Range, Las Cruces, New Mexico.

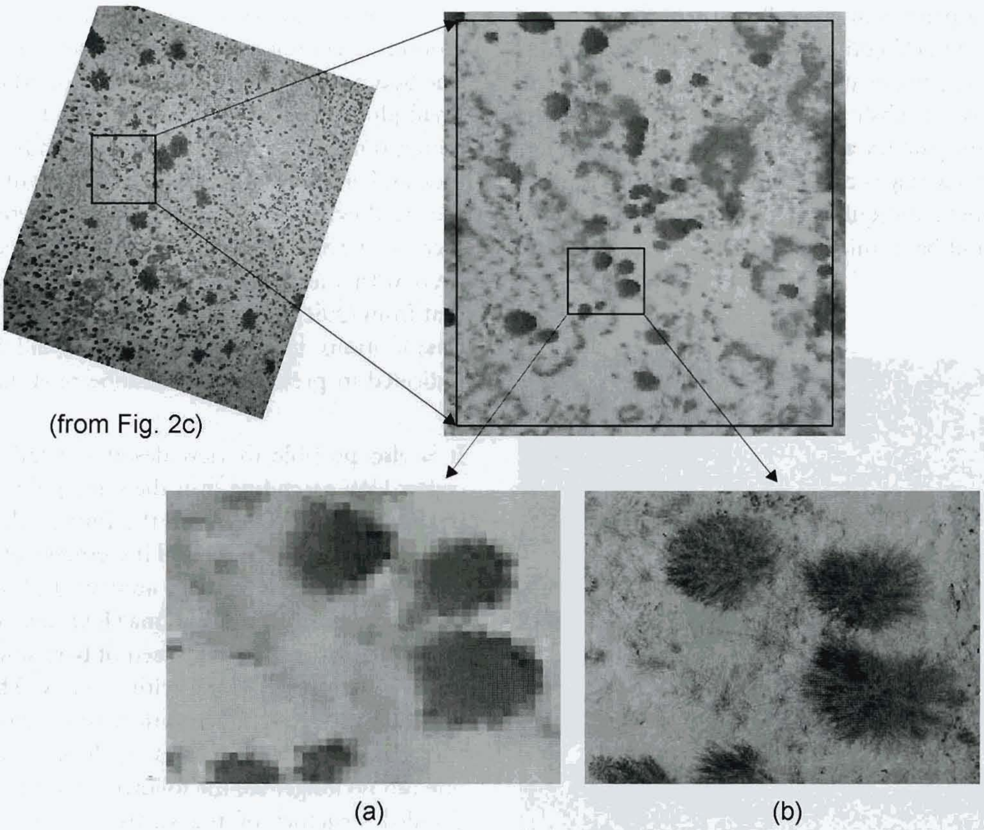

Figure 3. Comparison of (a) an enlarged Unmanned Aerial Vehicle photo and (b) a ground-based boom photo of a 2 m × 3 m plot at the playa study site at the Jornada Experimental Range, Las Cruces, New Mexico. Figure 3a is an enlargement of a portion of Figure 2c.

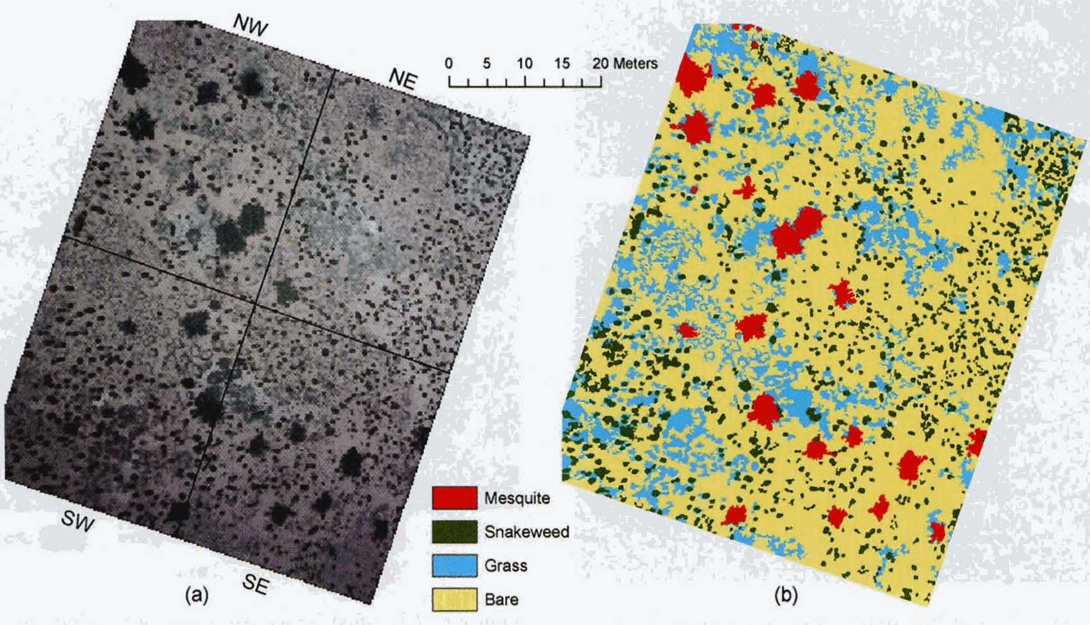

Figure 4. Modified model airplane Unmanned Aerial Vehicle photograph (from Figure 2c) over mixed rangeland at the Jornada Experimental Range, Las Cruces, New Mexico, (a) divided into quadrants for analysis of canopy cover and gap size and (b) classified image, using eCognition software.

and detect small patches of grass. Because of the increased UAV resolution and eCognition's capability to segment the image into homogeneous patches, the distinctive shape of the small snakeweed subshrubs can be easily identified and patterns of grass patches are now evident. In Figure 4b, ground cover percentages calculated using the UAV imagery are as follows: mesquite, 4.46%; snakeweed, 11.36%; grass, 17.98%; and bare soil, 66.20%. These values are similar to other studies at Jornada that have used detailed ground vegetation measurements (see Rango et al., 2005). The boom photography is used as ground truth in specific small plots, whereas the UAV can cover much larger areas than ground-based photography, depending on flight altitude and amount of overlap between flight lines. The UAV can be flown over sequential and adjacent flight lines to increase the area covered, if necessary, at relatively low cost. Even with the best resolution satellite coverage, such as that from QuickBird, only mesquite shrubs and bright soil classifications in this UAV scene would be possible, as indicated in previous work (Laliberte et al., 2004).

It is also possible to view desert vegetation from a helicopter UAV ascending over the same point. As an example of this option, images from the Rmax helicopter UAV are shown in Figure 5, in vertical increments of about 20 m up to 58 m. The area studied, another JER site, features an important remnant black grama (*Bouteloua eriopoda*) grassland area that is also comprised of bare soil, mesquite, and yucca (*Yucca* spp.), along with shadow. The photographs illustrate the reduction in information content as resolution is degraded with increasing altitude. At 58 m altitude, one can no longer see the following features visible at 17 m: detailed structure of the stems and leaves of grass and shrubs, small pebbles on the soil, and the delineation of shadows (Figure 5a); however, gap and patch patterns can still be distinguished at 58 m (Figure 5c). The classification of this scene is shown in Figure 6, where the percent cover

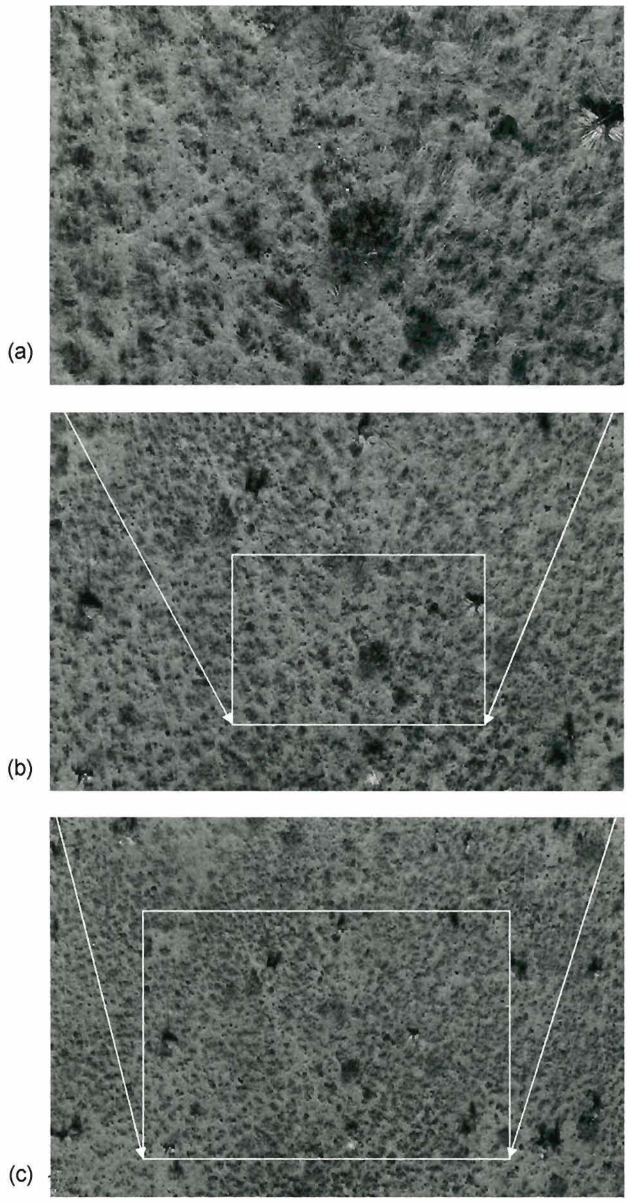

Figure 5. Comparison of helicopter Unmanned Aerial Vehicle photography at three altitudes: (a) 17 m, (b) 37 m, and (c) 58 m. The study site is above black grama grassland at the Jornada Experimental Range, Las Cruces, New Mexico.

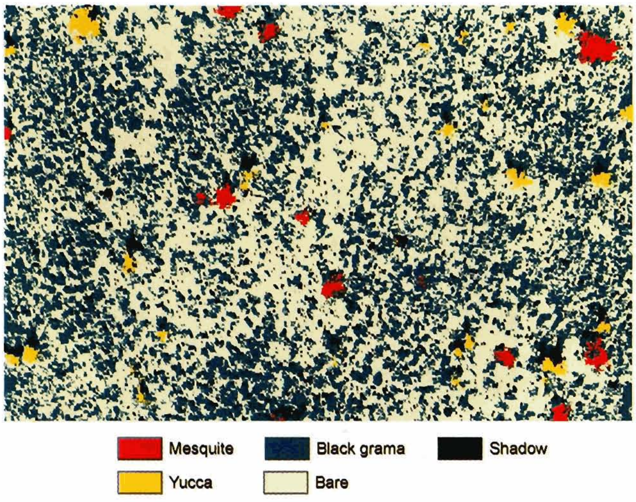

Figure 6. Classified image from helicopter Unmanned Aerial Vehicle (see Figure 5c) over the black grama rangeland at the Jornada Experimental Range, Las Cruces, New Mexico, using eCognition software.

is as follows: mesquite, 1.23%; black grama, 39.00%; yucca, 1.47%; bare soil, 55.29%; and shadow, 3.00%. These figures are also similar to other studies at Jornada, in terms of ground cover (see Rango et al., 2005).

Discussion

Several levels of remote sensing can provide quantitative data for rangeland monitoring and health assessments. The 15–30 m resolution data, initially available from Landsat ETM and later from Terra ASTER, can be used to define landscape units of relatively uniform topography and soils, e.g., ecological sites (Bestelmeyer et al., 2004). With an understanding of the vegetation states that may occur in a particular land unit, Landsat and often finer resolution imagery can be used to classify vegetation states differing in their potential for degradation or recovery. Areas needing more detailed analysis can be examined with the QuickBird imagery or aerial photography with resolutions of less than 1 m in order to determine the pattern of states currently existing in the area of interest. The likelihood that changes in these states are occurring can be evaluated using several key indicators of rangeland health derived from remotely-sensed UAV data with about 5 cm resolution, including gap and patch sizes, percent bare soil, and vegetation ground cover by plant structural group (e.g., grass versus shrub). The 5 cm UAV resolution would seem to be an improvement over the 20 cm aerial videography resolution used by Ludwig et al. (2000) for determining landscape metrics. In selected smaller areas, ground-based boom photography with resolutions of less than 1 cm may be useful to determine fine detail in vegetation patterns for monitoring purposes, as well as to serve as ground truth for the coarser resolution, remote sensing data discussed above. This level of resolution is also useful to determine foliar ground cover, which is more closely correlated with water erosion than canopy cover. Resolution requirements are likely to vary considerably among rangeland types and specific applications.

There is a need for a real-time remote sensing capability to rapidly monitor various management treatments after storms that can be met by a UAV with autonomous flight capabilities, such as the MLB-Bat 3 and, most recently, the modified model airplane. Treatments such as water ponding dikes (Rango et al., 2006) need to be checked immediately following storm events for assessment of the amount of water being provided and for determination of leaks through the dike system, which needs maintenance in order to keep treatment effectiveness at a high level. The UAV can also be used immediately following a storm event to delineate which landscape units produce enough surface runoff to merit the construction of additional treatments. Typically, ground visits to these locations immediately after a storm are problematic for several days, because of impassable roads.

For federal land management agencies, such as the Bureau of Land Management (BLM), which manage millions of acres of public land, the use of remote sensing is likely to become an efficient tool to aid the decision-making process. Current ground-based point measurements over such large areas is challenging due to high labor costs and has resulted in severe undersampling in many areas and periods. Landscape surveys, monitoring, and determination of rangeland health over the vast extent of public lands with remote sensing will become more and more an essential component of operations as the demand for up-to-date assessments and the cost of day-to-day operations each continue to grow, while federal operating budgets continue to decline. The use of UAVs can provide an affordable and effective complement for extending the utility of point monitoring approaches. The operation of UAVs for data acquisition could be handled by BLM personnel, and data analysis could be performed by in-house personnel or in close association with contractors trained in use of the remote sensing software.

Conclusion

Rangeland scientists and managers need to utilize remote sensing data for many reasons, one being the enormous size rangeland areas cover in the United States and around the world. At the same time, restrictions in budgets dictate that any remote sensing method needs to be as simple and affordable as possible. Because rangeland management agencies need a remote sensing overview as well as extreme detail in selected locations, a stratification of remote sensing observations is suggested. Landscape units can be covered by 15–30 m resolution data from ASTER or Landsat. Determination of the pattern of vegetation states in landscape units can effectively utilize less than 1 m resolution satellite data (QuickBird) or aerial photography. For many of the details needed in assessing rangeland health, UAVs with about 5 cm resolution or better seem adequate in the cases we have considered. Higher resolution photography can be obtained from ground-based cameras on booms for the most detailed type of ground truth data. Eventually, resource management agencies, rangeland consultants, and private land managers should be able to use small and lightweight UAVs to acquire improved data at a reasonable cost, which can be used to enhance management decisions.

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Note

1. Mention of specific products by name in this article does not imply endorsement by the US Government and is included only for the reference of a reader.

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