INL/EXT-10-17983

Improving Rangeland Monitoring and Assessment: Integrating Remote Sensing, GIS, and Unmanned Aerial Vehicle Systems

Robert P. Breckenridge

May 2007

The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance

INL/EXT-10-17983

Improving Rangeland Monitoring and Assessment: Integrating Remote Sensing, GIS, and Unmanned Aerial Vehicle Systems

A Dissertation
Presented in Partial Fulfillment of the Requirements for the
Degree of Doctor of Philosophy
with a
Major in Environmental Science
in the
College of Graduate Studies
University of Idaho

Robert P. Breckenridge

May 2007

Major Professor: Maxine Dakins, Ph.D.
Associate Professor, Environmental Science

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Work supported by the
U.S. Department of Energy
Office of Nuclear Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Abstract

Creeping environmental changes are impacting some of the largest remaining intact parcels of sagebrush steppe ecosystems in the western United States, creating major problems for land managers. The Idaho National Laboratory (INL), located in southeastern Idaho, is part of the sagebrush steppe ecosystem, one of the largest ecosystems on the continent. Scientists at the INL and the University of Idaho have integrated existing field and remotely sensed data with geographic information systems technology to analyze how recent fires on the INL have influenced the current distribution of terrestrial vegetation. Three vegetation mapping and classification systems were used to evaluate the changes in vegetation caused by fires between 1994 and 2003. Approximately 24% of the sagebrush steppe community on the INL was altered by fire, mostly over a 5-year period. There were notable differences between methods, especially for juniper woodland and grasslands. The Anderson system (Anderson et al. 1996) was superior for representing the landscape because it includes playa/bare ground/disturbed area and sagebrush steppe on lava as vegetation categories. This study found that assessing existing data sets is useful for quantifying fire impacts and should be helpful in future fire and land use planning. The evaluation identified that data from remote sensing technologies is not currently of sufficient quality to assess the percentage of cover. To fill this need, an approach was designed using both helicopter and fixed wing unmanned aerial vehicles (UAVs) and image processing software to evaluate six cover types on field plots located on the INL. The helicopter UAV provided the best system compared against field sampling, but is more dangerous and has spatial coverage limitations. It was reasonably accurate for dead shrubs and was very good in assessing percentage of bare ground, litter and grasses; accuracy for litter and shrubs is questionable. The fixed wing system proved to be feasible and can collect imagery for very large areas in a short period of time. It was accurate for bare ground and grasses. Both UAV systems have limitations, but these will be reduced as the technology advances. In both cases, the UAV systems collected data at a much faster rate than possible on the ground. The study concluded that improvements in automating the image processing efforts would greatly improve use of the technology. In the near future, UAV technology may revolutionize rangeland monitoring in the same way Global Positioning Systems have affected navigation while conducting field activities.

Page Intentionally Blank

Acknowledgments

I would like to sincerely thank the following people for their help: Drs. Stephen Bunting and Lee Vierling, Academic Faculty of the University of Idaho, Rangeland Ecology & Management, for valuable technical consultation and reviews; Drs. Jerry Harbour (National Training Center) and Don Crawford (University of Idaho) for technical guidance and assistance; Randy Lee, Sera White, Shane Cherry, Ron Rope, Ryan Hruska, and Paul Wichlacz (INL) and Marilynne Manguba (The Nature Conservancy) for assistance in collecting field data, acquiring GIS coverages, and teaching me to read imagery and reviews; Anthony Piscitella, Chase Eckersell, and Katherine Schoellenbach (students) for assistance in collecting field data and reading imagery; Mark McKay and Matt Anderson for serving as the UAV pilots; Jackie Hafla, Sue Vilord, Amy Forman, and Roger Blew (Stoller Corporation) for technical guidance and assistance; Terry Booth and Sam Cox (USDA-ARS) for developing and assistance in using SamplePoint; Dr. Larry Blackwood for guidance with statistical analysis; Tess O'Sullivan, program manager for science and conservation at Lava Lake Foundation for providing GIS coverages; Angie Smith (INL) for editorial support; Drs. Bruce Wiersma and Paul Kearns for the initial push to pursue a terminal degree; and the staff in the Ecological Sciences Department and management in the Science and Technology division at the INL for providing opportunity and encouragement to pursue this program.

I would especially like to thank Dr. Maxine Dakins for her guidance and vision in helping me design a successful program, for her editorial assistance at every stage of each manuscript, and her endless support and encouragement throughout this project.

.

Page Intentionally Blank

Table of Contents

List of Tables

List of Illustrations

Improving Rangeland Monitoring and Assessment: Integrating Remote Sensing, GIS, and Unmanned Aerial Vehicle Systems

Introduction

The Society for Range Management defines rangeland as “land on which the indigenous vegetation is predominantly grasses, grass-like plants, forbs, or shrubs and is managed as a natural ecosystem” (Glossary Update Task Group 1998). The definition further states that “rangelands include natural grasslands, savannas, shrub lands, many deserts, tundras, alpine communities, marshes and meadows.” Rangelands and grasslands comprise approximately 70% of the earth’s land surfaces (Sustainable Rangeland Roundtable 2006) and 34% of the total area in the conterminous U.S. (Vogelmann et al. 2001). In the western U.S., rangelands comprise most of the land west of the 95^o meridian (Mitchell 2000).

Scientists and land managers measure the amount and type of cover on rangelands to assess current conditions and, if measured over time, trends in conditions. Cover will be defined in this manuscript as the presence or absence of vegetation on the land surface at the study locations. Land managers need this information to make correct decisions and measure progress toward sustainability. Measurements of vegetation characteristics have been made for over a century, and the techniques developed to measure those characteristics are numerous (Brower et al. 1990; Bonham 1989). Few of the available techniques and results can be compared to each other, however, even for measuring the same characteristics of vegetation such as percent cover. Even when using the same methods and data, experts disagree about the health and sustainability of rangelands in the American west. According to Bonham (1989), this occurs because the objectives to obtain the measures differ. To be useful in monitoring rangeland sustainability, these methods must be comparable over space and time.

Early methodology for rangeland monitoring was developed by Dyksterhuis (1949) and measured the weight or coverage of each species in a plot and classified these as climax species or not (Hunt et al. 2003). Rangeland condition was calculated from the percent climax vegetation present into four groups ranging from excellent to poor. This method, with minor modifications, was used for many years for monitoring federally-owned grazing lands (Hunt et al. 2003). Additional developments in rangeland science have resulted in a change from the single climax community to a focus on multiple end-state communities with "state and transition models" (Laycock 1991; Friedel 1991). This focus is changing the objectives of studies being requested by rangeland managers. Many of the current managers want some method using a remote sensing platform that would classify an area based on the successional status of the species present. The National Research Council suggested that criteria for management of rangelands should be related to ecosystem health (National Research Council 1994).

Developing approaches that advance rangeland monitoring and assessment with science and technology is critical. This is especially a concern for land managers responsible for very large areas. Because many of the rangelands that require monitoring are in remote places, safety and labor and travel costs present major challenges to managers. Having a sufficient and well trained work force is another need that is becoming crucial as many of the traditionally-trained rangeland scientists approach retirement age. Designing approaches for monitoring these large areas is vitally important to managers that need timely and legally defensible information to make decisions about use and management of rangelands.

Environmental scientists in both federal agencies and non-government organizations (NGOs) are realizing the importance of developing comparable and consistent measurement techniques among organizations. Several federal agencies have joined forces to develop consistent approaches for interpreting indicators of rangeland health (Pellant et al. 2005). In a second group, over 75 federal agencies, NGOs, tribes, and producers have joined together to focus on developing a consistent set of criteria and indicators for monitoring and assessing the economic, social, and ecological sustainability of rangelands (Sustainable Rangeland Roundtable 2006). Among the common indicators identified by both groups are the measurement of vegetation and the percentage of bare ground. Both groups have also identified the need to analyze how emerging technologies using remote sensing platforms, electronic data capture and analysis, and high speed computing can help collect, analyze, and report information to management for making decisions at the local, regional, and national levels.

Remote sensing systems provide an option for collecting information for rangeland management, and large-scale aerial imagery collected with near earth remote platforms may hold promise for identifying many species by either color or patterns and shapes of the plant clumps or crowns. Hunt el al. (2003) identified that traditional remote sensing satellite platforms are being complemented with very-large-scale aerial imagery collected from ultralight airplanes equipped with high end digital cameras and GPS receivers. Booth et al. (2006) reported on using an ultralight airplane to collect high resolution imagery and identified how a software system called "SamplePoint" could be used to automate image analysis and obtain cover data for monitoring rangelands.

Sufficient information over extended time periods is becoming available from ground and remote sensing methods to allow scientists and managers to begin to understand that creeping environmental problems often start small, but can result in the destruction of major areas and sometimes entire ecosystems. Creeping problems from development and land conversion around the Aral Sea Basin have been touted as one of the worst human-made environmental catastrophes of the twentieth century (Glantz 1999). Once the fourth largest inland body of water on the planet, the Aral Sea now ranks in sixth place and the sea's surface area has been reduced by half. Other problems include reduced inflow, declining water quality, salt and dust storms, salinization of water and soils, vegetation changes, and escalating human health effects.

Degradation of rangelands plagues all regions of the world. One sixth of the world's population is threatened by the effects of rangeland degradation and 76% and 73% of the rangelands of North America and Africa, respectively, are degraded (Mouat and Hutchinson 1995). Destruction of the land's productive capacity brought on by degradation and desertification costs the world more than $42 billion each year (Mouat and Hutchinson 1995). Developing improved methods for evaluating the degradation of these lands is an urgent need, not just for the world's human health but also for the health of these ecosystems.

Bahre (1991) reported that Euro-American settlers, starting in 1870, brought unprecedented changes to the Arizona borderlands, one of the most ecologically diverse areas of the U.S. He used a combination of field data, comparative photographs, and historical records to demonstrate that most of the change followed human disturbance such as cattle grazing, wildfire suppression, and land conversion to agriculture. His analysis suggests that Euro-American settlement has brought unprecedented changes to the lands and vegetation dynamics.

In the study area of this dissertation, the Idaho National Laboratory (INL) on the upper Snake River Plain of southeastern Idaho, fire and human disturbance have had a notable impact on the natural rangelands. For example, about 24% of the INL burned between 1994 and 2003. The sagebrush steppe shrub communities declined by 21–23% during this 10-year period, with most of this change occurring between 1996 and 2000. This is significant because it can take up to a century for full post-fire recovery of big sagebrush community, which is critical habitat for state species of concern and federal endangered species. However, public and grazing access to the interior core of the INL has been very limited since 1949 and therefore, the sagebrush steppe ecosystem in these areas has remained relatively undisturbed. Because of this restricted access, it is possible to manage these lands to provide unique research and conservation opportunities (Sperber et al. 1998).

This dissertation comprises three manuscripts; each is a stand-alone document but with a common theme of advancing the science to support improved monitoring of rangelands. The first manuscript evaluates how effective existing satellite imagery is for assessing land conversion due to fire and agriculture in selected areas of the Upper Snake River Basin. It seeks to determine if available vegetation classification systems are adequate for making assessments at the community level. The conclusion from the first manuscript is that improved methods are needed for assessing community level information and for evaluation of the percent change of vegetation cover. The second manuscript formally introduces a novel approach for collecting information about vegetation cover on rangelands using unmanned aerial vehicles (UAVs), in this specific case a helicopter. It evaluates the feasibility of using the UAV technology, outfitted with a digital imagery collection system, to collect data and evaluates the image processing technique. The data from the UAV system were compared to field data collected using a point-frame method to determine if this approach might be a viable method to gather information needed for rangeland monitoring and assessment. The third manuscript extends this analysis to include the evaluation of a fixed-wing UAV platform and compares data collected from these systems to the helicopter and field data. The fixed-wing platform used a much different data collection system. The system has an autopilot that could be programmed to collect data at predetermined locations. The field plots were designed so that both vegetation cover and the presence or absence of sage-grouse like decoys could be evaluated. The primary objectives of manuscripts two and three were to assess the feasibility of using UAV technologies to serve as a near earth platform for collecting imagery for evaluation of vegetation cover in a quicker manner than current approaches.

The analysis reported in this dissertation demonstrates that there can be substantial value in using UAV technologies and image processing approaches to improve collection of vegetation cover in rangeland systems. During the study, a number of interesting observations were made that should build a strong basis for convincing scientists and managers that UAV technology could have a role in revolutionizing the future of rangeland monitoring for both vegetation and selected wildlife species. The integrated approach of teaming UAV technologies with image processing software is just in its infancy. The emerging possibilities for this integrated approach for collection of data to improve evaluation of rangelands on an almost real-time basis are broad and exciting (Dakins 1994).

References

Bahre, C. J. 1991. *A Legacy of Change: Historic Human Impact on Vegetation in the Arizona Borderlands*. Tucson, Arizona: The University of Arizona Press.

Bonham, C. D. 1989. *Measurements for Terrestrial Vegetation*. New York: John Wiley & Sons, Inc.

Booth, D. T., S. E. Cox, and R. D. Berryman. 2006. Point sampling digital imagery with 'SamplePoint.' *Environmental Monitoring and Assessment* 123(1–3): 97–108.

Brower, J. E., J. H. Zar, and C. N. vonEnde. 1990. *Field and Laboratory Methods for General Ecology (Third Edition)*. Dubuque, Iowa: Wm. C. Brown Publishers.

Dakins, M. E. 1994. Modeling for risk-based environmental remediation decision making. PhD diss., State University of New York.

Dyksterhuis, E. J. 1949. Condition and management of rangeland based on quantitative ecology. *Journal of Range Management* 2: 104–115.

Friedel, M. H. 1991. Range condition assessment and the concept of thresholds: A viewpoint. *Journal of Range Management* 44: 422–426.

Glantz, M. H., ed. 1999. *Creeping Environmental Problems and Sustainable Development in the Aral Sea Basin*. Cambridge: Cambridge University Press.

Glossary Update Task Group, Society for Range Management, ed. 1998. *Glossary of Terms Used in Range Management, 4th Edition*. Denver: Society for Range Management.

Hunt, E. R., Jr., J. H. Everitt, J. C. Ritchie, M. S. Moran, D. T. Booth, G. L. Anderson, P. E. Clark, and M. S. Seygried. 2003. Applications and research using remote sensing for rangeland management. *Photogrammetric Engineering & Remote Sensing* 69(6): 675–693.

Laycock, W. A. 1991. Stable states and thresholds of range condition on North American rangelands: A viewpoint. *Journal of Range Management* 44: 427–433.

Mitchell, J. E. 2000. *Rangeland Resource Trends in the United States: A Technical Document Supporting the 2000 USDA Forest Service RPA Assessment*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado. General Technical Report RMRS-GTR-68.

Mouat, D. A., and C. F. Hutchinson, eds. 1995. *Desertification in Developed Countries, International Symposium and Workshop on Desertification in Developed Countries: Why Can't We Control It?* Dordrecht, The Netherlands: Kluwer Academic Publishers.

National Research Council. 1994. *Rangeland Health: New Methods to Classify, Inventory and Monitor Rangelands*. Washington, D.C.: National Academy Press.

Pellant, M., P. Shaver, D. A. Pyke, and J. E. Herrick. 2005. *Interpreting Indicators of Rangeland Health, Version 4*. U.S. Department of the Interior, Bureau of Land Management, National Science and Technology Center, Denver, Colorado. Technical Reference 1734-6, BLM/WO/ST-00/001+1734/REV05.

Sperber, T. D., T. D. Reynolds, and R. P. Breckenridge. 1998. *Developing the Scientific Basis for Long-Term Land Management of the Idaho National Engineering and Environmental Laboratory*. Idaho National Laboratory. INEEL/EXT-98-00221.

Sustainable Rangeland Roundtable. 2006. About SRR. http://sustainablerangelands.warnercnr.colostate.edu/about.html.

Vogelman, J. E., S. M. Howard, L. Yang, C. R. Larson, B. K. Wylie, and N. Van Driel. 2001 Completion of the 1990s national land cover data set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. *Photogrammetric Engineering & Remote Sensing* 67:650–662.

Chapter 1: Synthesizing Old and New: Joining Existing Remote Sensing and GIS Data to Assess Fire Issues in Sagebrush Steppe Ecosystems

Abstract

Changes in land use are impacting some of the largest remaining intact parcels of shrub-steppe ecosystems in the western United States and are fragmenting the landscape and habitats, creating major problems for land managers. The Idaho National Laboratory (INL) is part of the sagebrush steppe ecosystem, one of the largest ecosystems on the North American continent. Scientists at the INL and the University of Idaho have integrated existing field and remotely sensed data with geographic information systems technology to analyze how recent fires on the INL have influenced the current distribution of terrestrial vegetation. Three different vegetation mapping and classification systems were used to evaluate the changes in vegetation from fires between 1994 and 2003. Twenty-four percent of the sagebrush steppe community on the INL was altered by fire, mostly over a 5-year period. There were notable differences between methods, especially for juniper and grasslands. One method was superior in representing the landscape because it includes playa/bare ground/disturbed area and sagebrush steppe on lava as vegetation categories. This study found that assessing existing data sets is useful for quantifying fire impacts and should be helpful in future fire and land use planning. It also demonstrates how different mapping and classification methods can influence the outcome from fire impact assessments.

Introduction

Shrub-steppe is a vegetation community characterized by large, dry, mainly treeless open areas and is dominated by sagebrush (*Artemisia* ssp.), other shrubs, grasses, and forbs. In the early 1800s, Lewis and Clark found vast expanses of shrub-steppe land (Rickard et al. 1988). Rapid development and exploration of the west from 1880 to 1920, however, resulted in the rapid loss of sagebrush lands and habitat (Rickard et al. 1988). Today, sagebrush steppe is one of the most endangered land types on the continent (Knick et al. 2003), and cheatgrass (*Bromus tectorum*) and other aggressive, alien annuals are now a permanent part of the flora (Mack 1981).

The Idaho National Laboratory (INL) lies within the largest sagebrush steppe region in North America. The INL is an 890-mi^2 (2305-km^2) (note: units in the first manuscript are in both English and metric to enhance use by land managers) federal facility managed by the U.S. Department of Energy (DOE) and is located west of Idaho Falls (see Figure 1-1), Idaho, in a semi-arid section of the Upper Snake River Basin. Figure 1-1 also shows the remaining intact sagebrush communities in the region (INSIDE Idaho 2006) and other land holdings in eastern Idaho that support conservation management. Public and grazing access to the interior core of the INL has been very limited since 1949 and therefore, the sagebrush steppe ecosystem on the site has remained relatively undisturbed. Because of the restricted access, it is possible to manage these lands to provide unique research facilities and conservation opportunities (Sperber et al. 1998).

Considerable effort has been expended to collect or generate field data for the INL for a variety of specific plant and animal studies to evaluate impacts on air, water, wildlife, and cultural resources from DOE operations (Sperber et al. 1998; Stoller 2005; DOE-Idaho Operations Office [DOE-ID] 2003; DOE-ID 1997). However, little effort has been spent on evaluating the data at the landscape level to determine its application in supporting landscape-level management decisions and to understand how change is altering the ecosystem. If the data from these existing studies were evaluated, integrated, and supplemented, they could be analyzed and used to evaluate future land use options.

The overarching objective of this paper is to assess the feasibility and utility of integrating existing data sets with conceptual models to evaluate how terrestrial vegetation and land cover in sagebrush steppe ecosystems have changed because of disturbance. The specific study objectives are to

1. assess the feasibility of merging existing field data with remote sensing data to evaluate how terrestrial vegetation has changed because of recent fires and land use changes, and
2. compare the utility and limitations of three different vegetation mapping techniques and classification systems for quantifying changes to INL terrestrial vegetation as a result of recent fires.

This information is critical for evaluating status and trends in vegetation cover and availability of habitat for sagebrush steppe species and can be very useful for assessing future land management options.

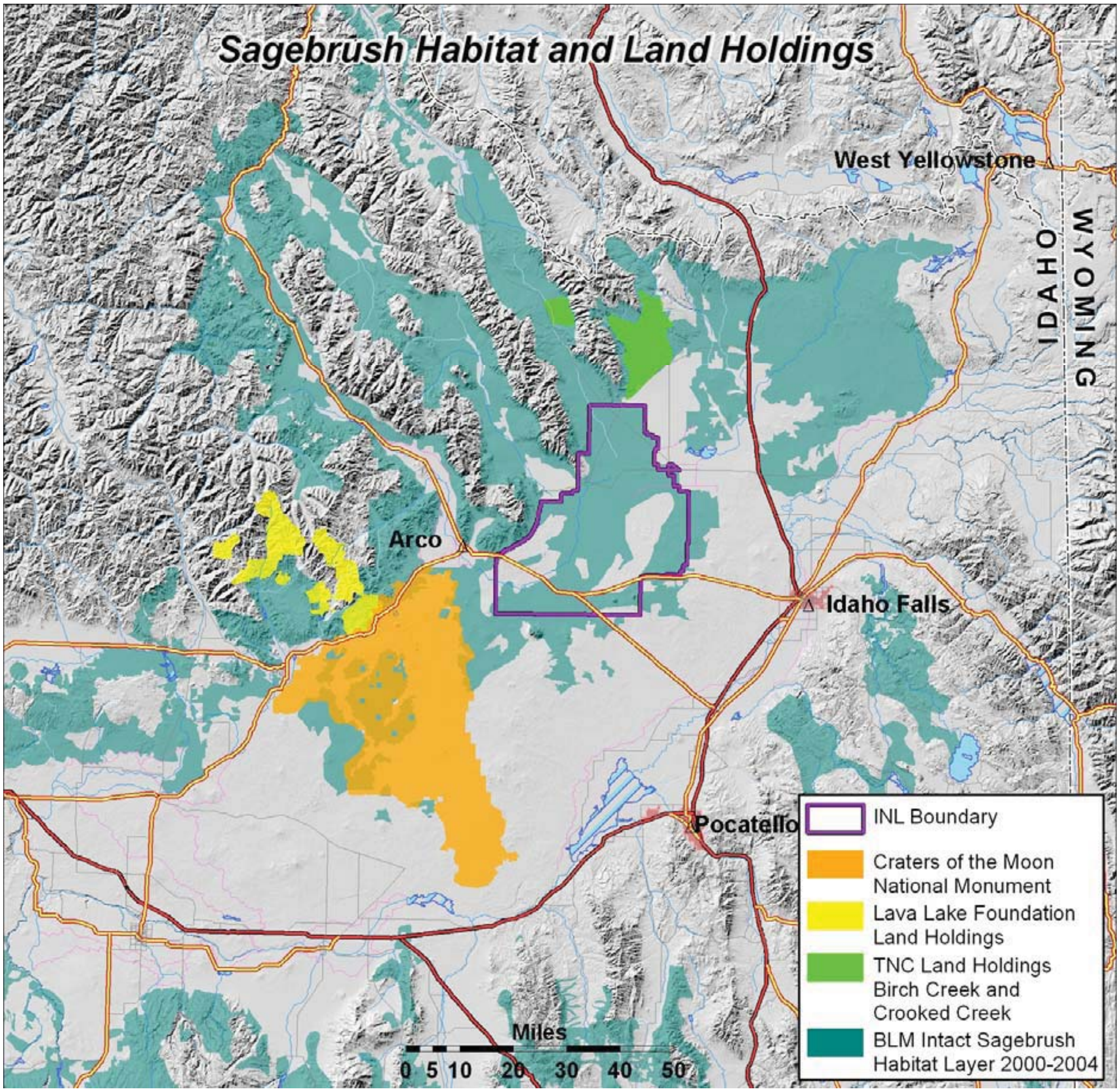


Figure 1-1. Regional map showing the location of the INL, the remaining intact sagebrush communities in the region, and other land holdings in eastern Idaho that support conservation management. (TNC stands for The Nature Conservancy; BLM is the Bureau of Land Management.)

Study Area

The INL is situated along the northwest edge of the Eastern Snake River Plain at an average elevation of 5,000 ft (1,500 m). The landscape consists of flat, gently rolling high desert terrain with vast sagebrush flats; outcroppings of basalt are also common (DOE-ID 1997). Isolated buttes on INL land reach 6,572 ft (1,994 m). Individual mountain peaks just north and west of the site approach 11,000 ft (3,300 m).

The climate of the INL is a cold desert characterized by large daily and seasonal fluctuations. The average annual temperature is 42°F (5.6°C) with a frost-free period of about 90 days. There are often 2–3 months of winter with below-freezing temperatures. Summer temperatures can often reach 86–95°F (30–35°C). Mean annual precipitation on the INL is about 8.6 in. (21 cm) (based on a 44-year average from 1950 to 1994 [Anderson et al. 1996].) In an average year, melting snow and spring rains typically account for most of the annual recharge of soil moisture. On average, 40% of the annual precipitation falls during April (0.71 in. [1.8 cm]), May (1.3 in. [3.2 cm]), and June (1.4 in. [3.6 cm]), followed by lows in July (0.32 in. [0.8 cm]) (Anderson and Holte 1981). This precipitation pattern with wet winters and springs and then dry, hot summers is ideal for developing late summer range fires.

The typical native vegetation on the INL consists of a shrub overstory with an understory of perennial grasses and forbs (French and Mitchell 1983). The most common shrub is Wyoming big sagebrush (*Artemisia tridentata*, ssp. *wyomingensis*). Basin big sagebrush (*Artemisia tridentata*, ssp. *tridententa*) 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). Other common shrubs include green rabbitbrush (*Chrysothamnus viscidiflorus*), gray rabbitbrush (*Ericameria nauseosa*), winterfat (*Krascheninnikovia lanata*), spiny hopsage (*Grayia spinosa*), and prickly phlox (*Leptodactylon pungens*) (French and Mitchell 1983).

Grasses on the INL are a mixture of native species and exotics that have either been introduced to support revegetation activities or have been established inadvertently. 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*). Bluebunch wheatgrass (*Pseudoroegneria spicata*) is common at slightly higher elevations to the southwest and along the eastern side of the INL.

The INL supports a high diversity of forbs. Common native forbs include tapertip hawksbeard (*Crepis acuminata*), Hood's phlox (*Phlox hoodii*), hoary false-yarrow (*Chaenactis douglasii*), paintbrush (*Castilleja angustifolia*), globemallow (*Sphaeralcea munroana*), buckwheats (*Eriogonum ssp.*), evening-primrose (*Oenothera caespitosa*), lupines (*Lupinus*), bastard toadflax (*Comandra umbellata*), milkvetches (*Astragalus*), and mustards.

Fire Dynamics

Fire is an important factor in the development and maintenance of sagebrush steppe communities (Bunting et al. 1987; Wright 1971; Wyoming Interagency Vegetation Committee 2002). Understanding fire dynamics is critical for assessing impacts to vegetation and associated wildlife. Fire can serve an important role by increasing nutrient availability, creating space for seedling establishment, and enhancing habitat and landscape complexity (Bunting 1996). It is estimated that fire frequency on most Wyoming big sagebrush steppe ecosystems is greater than 100 years (Wright and Bailey 1982).

The vast majority of shrubs (including rabbitbrush), perennial grasses, and forbs can survive wildfires, especially fires that occur in late summer or fall when plants are dormant (Colket 2003). The notable exception is sagebrush, which must re-establish itself from seed rather than underground root systems. Over the course of several years after a fire, sagebrush seeds are distributed by the wind from unburned areas. Seedling sagebrush begin to grow and, after about 5 years, produce seeds. The maturing sagebrush compete with other plants for nutrients and water and a balance is established. As the plant community flourishes, the fuel load increases along with the likelihood of another fire (Colket 2003). Recovery of big sagebrush after fire or other disturbance requires long periods of time; for the INL, this is often a decade to become established (Colket 2003) and several decades to become mature (Wright and Bailey 1982; Bunting et al. 1987; Wambolt et al. 2001). Full post-fire recovery of big sagebrush communities on the INL requires nearly a century (Colket 2003). Numerous burned areas can be seen from satellite imagery of the INL (Figure 1-2).

Non-native annuals such as cheatgrass change the fire and recovery cycle (Anderson and Holte 1981). Cheatgrass seed quickly germinates after a fire and competes with native plants for nutrients and water. Cheatgrass also goes to seed and dries by early summer, creating a

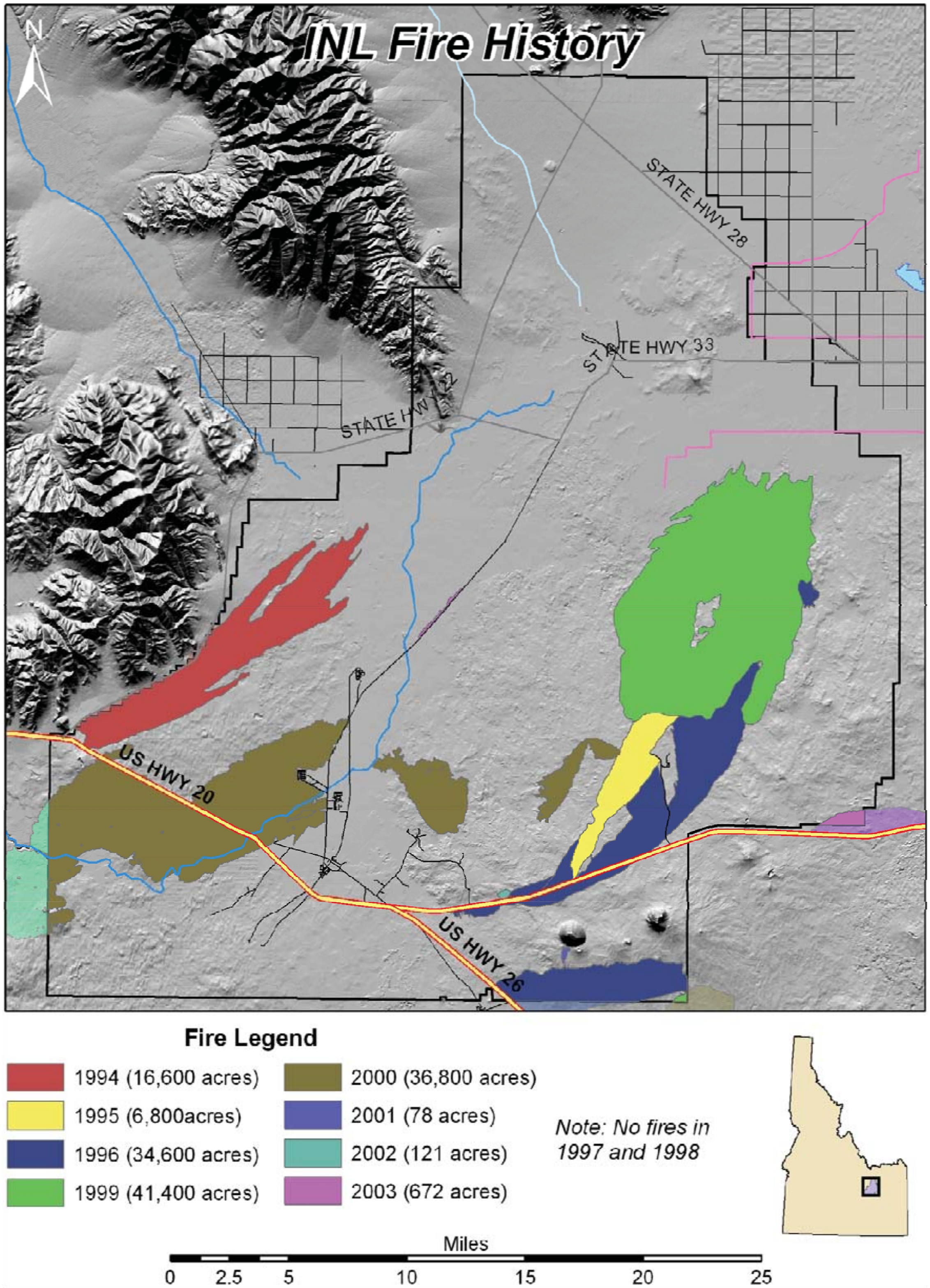


Figure 1-2. Fire history on the INL between 1994 and 2003.

high fuel load. Areas dominated by cheatgrass may burn every three to five years (DOE-ID 2003), which is too little time to re-establish sagebrush.

Increased grazing around the borders of the INL and recent large fires have accelerated the establishment of exotics (Anderson and Inouye 1999; Anderson and Holte 1981; Colket 2003). In addition to cheatgrass, native species are being replaced with stands of Russian thistle (*Salsola kali*) and fan weed (*Thlaspi arvense)* (Anderson et al. 1996). These exotics alter the plant communities in the region, which in turn affects wildlife habitat (Connelly and Braun 1997; Connelly et al. 2000). Of particular concern is the habitat for sage grouse (*Centrocercus urophasianus*), which has been impacted by agricultural conversion, fire, invasion of exotic annuals, and fragmentation (Braun 1998; Schroeder et al. 1999).

It should be noted that the INL is currently restricted from using prescribed fire through a moratorium imposed in May of 2000 by the Deputy Secretary of Energy (DOE 2000). The INL will not use prescribed fire until DOE has established appropriate policies for addressing use, limitation, planning, approval, and notification requirements.

Methodology

Selecting Indicators of Rangeland Condition

An important initial step in evaluating how land conversion impacts ecosystems is to identify relationships at the overall system level. Conceptual models are useful tools that can be developed from the individual plot to the ecosystem scale to allow scientists to better understand the interrelationships within a complex environmental system (Deaton and Winebrake 2000). Once the key interactions are understood, indicators for evaluating the health of rangelands can be selected. Selecting key indicators for monitoring is important because there are not enough resources to monitor all the components of an ecosystem that managers and scientists need (Pyke et al. 2002).

A number of scientists and land management teams have studied ecological components in detail and have selected indicators to interpret rangeland health (Pyke et al. 2002; Pellant et al. 2005; Breckenridge et al. 1995). Others have discussed using conceptual models to link individual ecological indicators at the plot level and expand them to the landscape level (Turner et al. 2003). Figure 1-3 is a generic conceptual model that identifies important indicators to monitor when evaluating the condition of semi-arid rangeland (Breckenridge et al. 1995). The model was used to

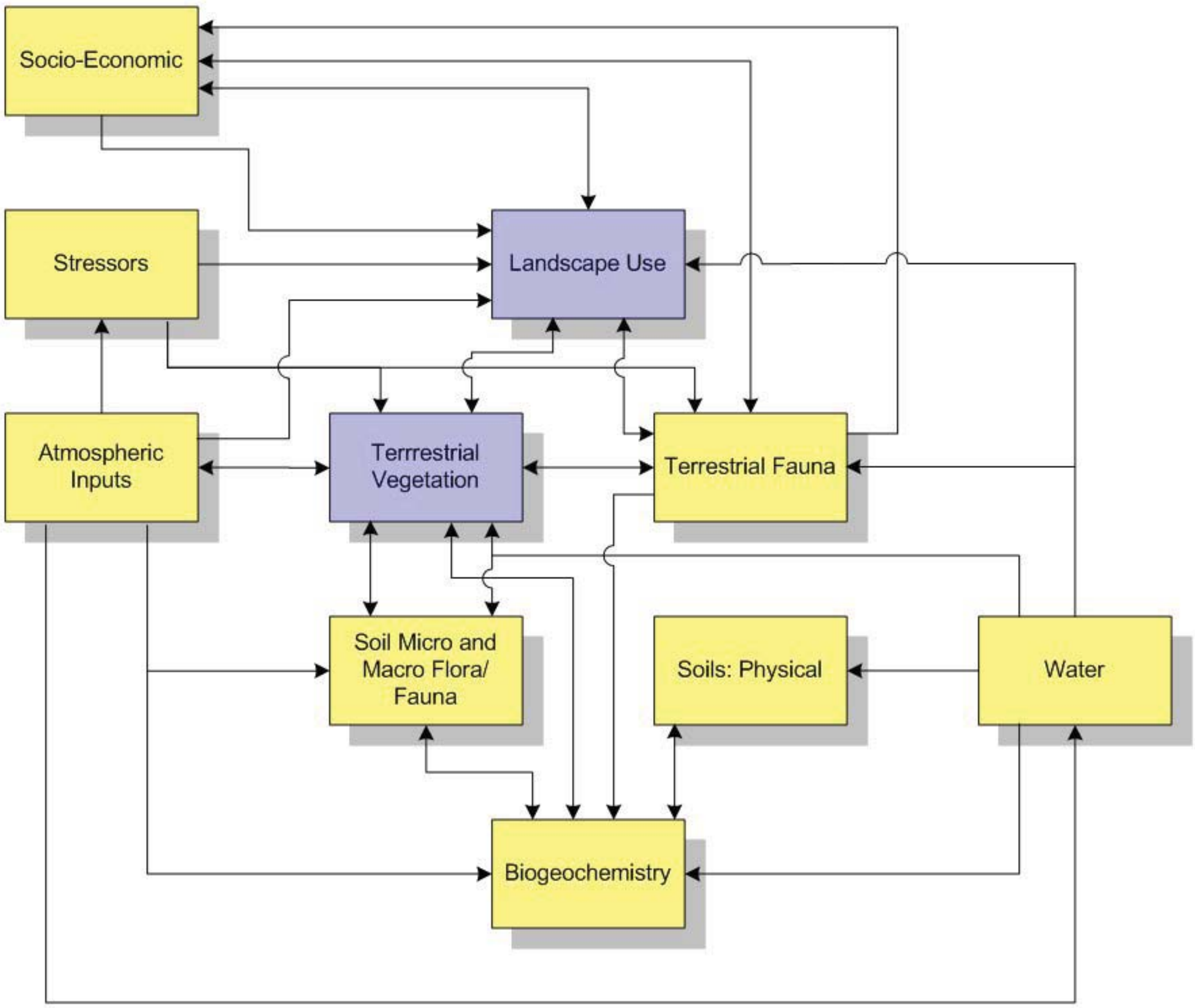


Figure 1-3. INL conceptual model for semi-arid ecosystem components showing. Purple-colored boxes show the critical indicators for this study. Arrows show interactions between components.

select indicators that (a) could be measured using existing remote imagery (Frohn 1998) and supported with field data to determine status and trends in ecosystem condition and (b) could be useful in evaluating how fire and land use change impact biotic habitat for sagebrush obligate species. The two critical indicators selected from Figure 1-3, which became the focal point for this study, were terrestrial vegetation type and landscape use.

Evaluation and Integration of Available Data Sets and Imagery

To evaluate change in terrestrial vegetation and landscape use over time across the vast area of the INL, data with moderately high spatial resolution, reasonable temporal (annual or monthly) availability, and affordable cost was desired. Existing imagery available for the INL was first identified and spatial coverage was assessed. Both Ikonos and aerial photography imagery provided very high resolution but the images covered only selected parts of the INL. Costs associated with acquiring and working with the very high resolution data were also prohibitive. The other limitation, with the exception of Landsat, was temporal revisit time. The Landsat data collection system has the best long-term data imagery for doing evaluations over extended periods of time. To evaluate change over a reasonable time period and examine areas both inside and outside the INL boundaries, Landsat 7 imagery was selected because it provided the best combination of spatial and temporal resolution.

Evaluation of Land Use Change

Land use on and around the INL plays a major role in influencing landscape dynamics. The evaluation of land use change considered the usefulness of available data for quantifying the effects of land conversion from rangeland to production agriculture. The study examined how land use change over several decades can contribute to environmental problems of habitat and forage loss for sagebrush-dependent species and increase the potential for the introduction of exotic weeds and agriculture chemicals into the ecosystem (Crowley and Connelly 1996).

Data from the Landsat Pathfinder North American Landscape Characterization (NALC) program were used for this assessment (U.S. Environmental Protection Agency [EPA] 2007). An accuracy assessment was conducted on the NALC data and an overall classification accuracy of about 75% was obtained (Kepner et al. 2004). The existing data from Landsat Multi-Spectral Scanner scenes for July 16, 1973; July 5, 1985; and July 16, 1992; were used to evaluate land use change on lands bordering the INL. Efforts were focused on the northern and eastern boundaries of the INL because these are the areas where the greatest change in land use was suspected. These particular scenes were used because they provided the appropriate temporal coverage for this analysis (approximately 10-year increments) and had relatively the same anniversary dates of collection. Before analysis, the 1973 and 1992 scenes were co-registered to the 1985 scene to ensure proper alignment for change analysis.

Land use change was evaluated by manually digitizing polygons associated with non-rangeland uses (agricultural and urban development) between the three NALC scenes in ArcInfo (from

Environmental System Research Institute [ESRI], version 6.0). The differences in area values between dates were evaluated through simple geo-processing functions such as Intersect and Union. This method was used in place of traditional, spectrally-based classifiers because of confusion between fallow agricultural land, cleared land for urban development, and undisturbed rangeland.

Evaluation of Fire on Terrestrial Vegetation

An evaluation of the impact of fire on vegetation was performed using a geospatial layer representing fires between 1994 and 2003 and three different terrestrial vegetation classification systems: Gap Analysis Program (GAP) (Scott et al. 2002), McBride (McBride et al. 1978), and Anderson (Anderson et al. 1996).

GAP was selected because it is a landscape scale, joint state and federal effort, and is a scientific method to assess the extent of protection for native plant species (Jennings and Scott 1997). The GAP system uses Landsat imagery and produces vegetation information for each 30-m pixel. Assessed accuracy results from the Idaho GAP analysis for the southern part of Idaho showed a total percent correct ranging from 65.5% to 79.3% with an overall percent correct of 69.3% (Scott et al. 2002).

The McBride and Anderson classification systems were selected because they are slightly different systems developed specifically for management of INL lands. A complete accuracy assessment was never done for these two systems because of funding limitations but the systems were considered accurate enough to be used for large-scale, general land management and new facility siting decisions.

The McBride system used a mosaic of aerial photos taken in 1953 and 1954 to identify and map vegetation communities. Accuracy checks were conducted by performing ground reconnaissance to determine the species of plants most characteristic of each area delineated on the aerial photos. Where this evaluation indicated a sufficient difference between two vegetation types, the area was designated according to the three most prominent plant species. These evaluations were qualitative and were checked with some transects. There was good agreement between the transect data and the qualitative rapid assessments (McBride et al. 1978).

The Anderson system was developed using two Landsat satellite images with contrasting vegetation conditions: one during spring growth (May 8, 1987) and the other from late summer (August 17, 1989) (Kramber et al. 1992). Aerial photography from 1976 and field sampling in July and August of 1990 were used to improve accuracy and develop a successive refinement for the classification data based on plot data, field notes, and field experience from scientists with long-term knowledge of INL vegetation (Anderson and Inouye 2001).

In processing the Landsat satellite imagery two ratio images were created: a normalized Normalized Difference Vegetation Index (NDVI) image (Bands 3 and 4) (Rouse et al. 1974, Frohn 1998) and a mineral composite image (Bands 5 and 6). The ratio images were created using ERDAS IMAGINE's Interpreter/Spectral Enhancement/Indices functions (version 8.4). The ratio approach was used to evaluate if

1. the terrestrial vegetation in the burned areas was affected by the fire and whether its characteristics were different from the characteristics of the undisturbed vegetation outside the impacted area.

2. soil properties associated with the burned areas were different from soil properties in non-burned areas either because of effects on the soil from the fire itself or because the loss of vegetation allowed the soil properties to be detected more easily.

Global positioning system (GPS) ground positions collected after each fire season were used to develop fire boundaries between 2001 and 2003. The fire boundaries layer was produced using a combination of satellite imagery and ground data collected with backpack and helicopter GPS units. The GPS and satellite-derived boundaries were combined into one Shapefile using the merge command in ArcGIS (version 9.1).

Evaluation of the impact of fire on the terrestrial vegetation for each of the three classification systems was derived by intersecting the fire polygon features (from ArcGIS) with each of the three vegetation classification systems. Changes to terrestrial vegetation were determined by comparing the ratios from the 1994 imagery and GIS coverages to the 2003 images and coverages. For the vegetation coverage by plant community, new layers were calculated using a Visual Basic script within ArcMap (version 7.0) to update the area field.

The vegetation categories used in the analysis differed slightly between the three classification systems. The three systems also have some limitations with accuracy. Thus, the vegetation categories were collapsed into three main plant communities: shrub-dominated communities, grass-dominated communities (perennial and annual), and juniper-dominated communities. For the Anderson system, categories of sagebrush steppe on basalt (defined as lava by Anderson et al. [1996] and in this paper) and playa/bare/disturbed areas were included because the imagery was of good enough quality (30-m pixels) and there were sufficient field checks to differentiate these areas.[a]

Results and Discussion

Evaluation of Land Use Change

The evaluation of the Landsat imagery for change as described in the Methods section showed a total of 42,105 acres (17,039 ha) of land was converted from native rangeland to agriculture along the north and eastern boundaries of the INL from 1973 to 1992. Many of these areas went into production agriculture for potatoes, alfalfa, or grain. The availability of Landsat on a 10-year increment proved very valuable in assessing change over the 19-year time frame. Some of the lands converted to agriculture were irrigated using new center-pivot systems that show up easily as circles on the imagery (Figure 1-4). Lands adjacent to these areas are important habitat for sage-grouse, antelope, and other sagebrush obligate species. The conversion to production agriculture has changed yearly food supplies for wildlife from those found in native rangelands (where winter seed sources are available) to those associated with alfalfa and grain production (little winter food source and shelter from snow and wind). The main impact of the conversion is loss of winter habitat and spring nesting areas for birds (Crowley and Connelly 1996).

Landscape alterations from conversion to production agriculture provide challenges in addition to habitat loss. The production agriculture fields become an attraction to wildlife feeding on alfalfa; this group of wildlife is often impacted by chemical contamination (Hoffman et al. 2003) or planting and harvesting equipment (Crowley and Connelly 1996). Increased development around the INL boundaries will increase the importance of the site as a refuge for wildlife species and will need to be factored into future management decisions.

The conversion to center pivot irrigation has an additional impact of reducing groundwater levels, which can influence the moisture available to nearby riparian and wetland areas (Sperber et al. 1998). These impacts were not evaluated in this study but should be the subject of future studies.

---

[a] E-mail communication from R. Rope, INL, to R. Breckenridge, "INL vegetation map cover classes," December 15, 2006.

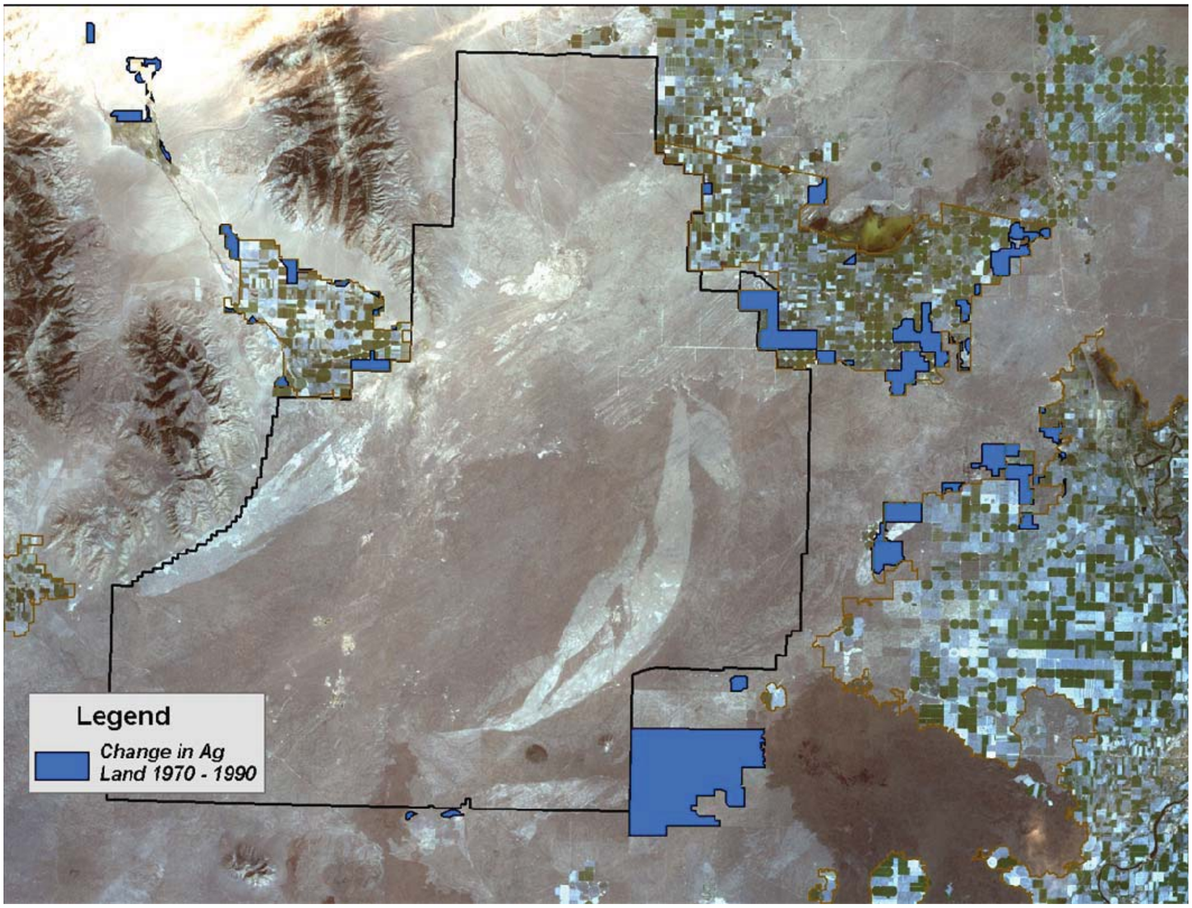


Figure 1-4. Land use change due to conversion of rangeland to production agriculture around INL between 1973 and 1992 is shown in dark blue. The light blue and green are mostly existing agriculture lands, burned areas, or areas with high reflectance (e.g., playas or sinks). Brown areas are rangelands, sagebrush steppe on lava, or mountains.

Evaluation of Fire on Terrestrial Vegetation

The frequency of fire in sagebrush steppe ecosystems can vary significantly depending on moisture (Colket 2003). This has been true at the INL, where the area impacted by fire varied from a low of zero acres in 1997 and 1998 to a high of 41,400 acres (16,754 ha) in 1999. To analyze these fluctuations, the average precipitation data from the National Oceanic and Atmospheric Administration (NOAA) station located on the INL (unpublished data) were compared with acreage burned (Figure 1-5). One interesting relationship is that large burned acreages occur one to several years following years with above-average annual precipitation. During 1995, the annual precipitation exceeded the annual average (9.5 in. [24 cm] vs. 8.6 in. [22 cm]); in 1996, 34,600 acres (14,000 ha) burned. This is more than double the average acreage burned over the 10-year period (15,230 acres/yr [6,163 ha/yr]). In 1998, the annual rainfall was 10.97 in. [27.8 cm]; in 1999, the burned acres totaled 41,400 acres (16,800 ha), which is 2.7 times the average. These results are consistent with observations made by Swetnam and Betancourt (1990), Miller and Rose (1999), and Colket (2003), who noted that widespread big sagebrush mortality, increased herbaceous biomass associated with high precipitation in the mid 1990s, and the pairing of dry years after wet years likely enhanced the continuity of fuels, resulting in several large wildfires at the INL.

The GAP analysis (Figures 1-6 and 1-7) indicated that almost all the fire occurred in shrub-dominated communities (136,424 acres [55,209 ha]). The McBride classification system (Figures 1-8 and 1-9) also indicated that the largest amount fire occurred in shrub-dominated communities (124,751 acres [50,485 ha]). For the Anderson classification analysis (Figures 1-10 and 1-11), the majority of fire occurred in shrub-dominated communities on and off lava for a total of 129,555 acres [52,429 ha].

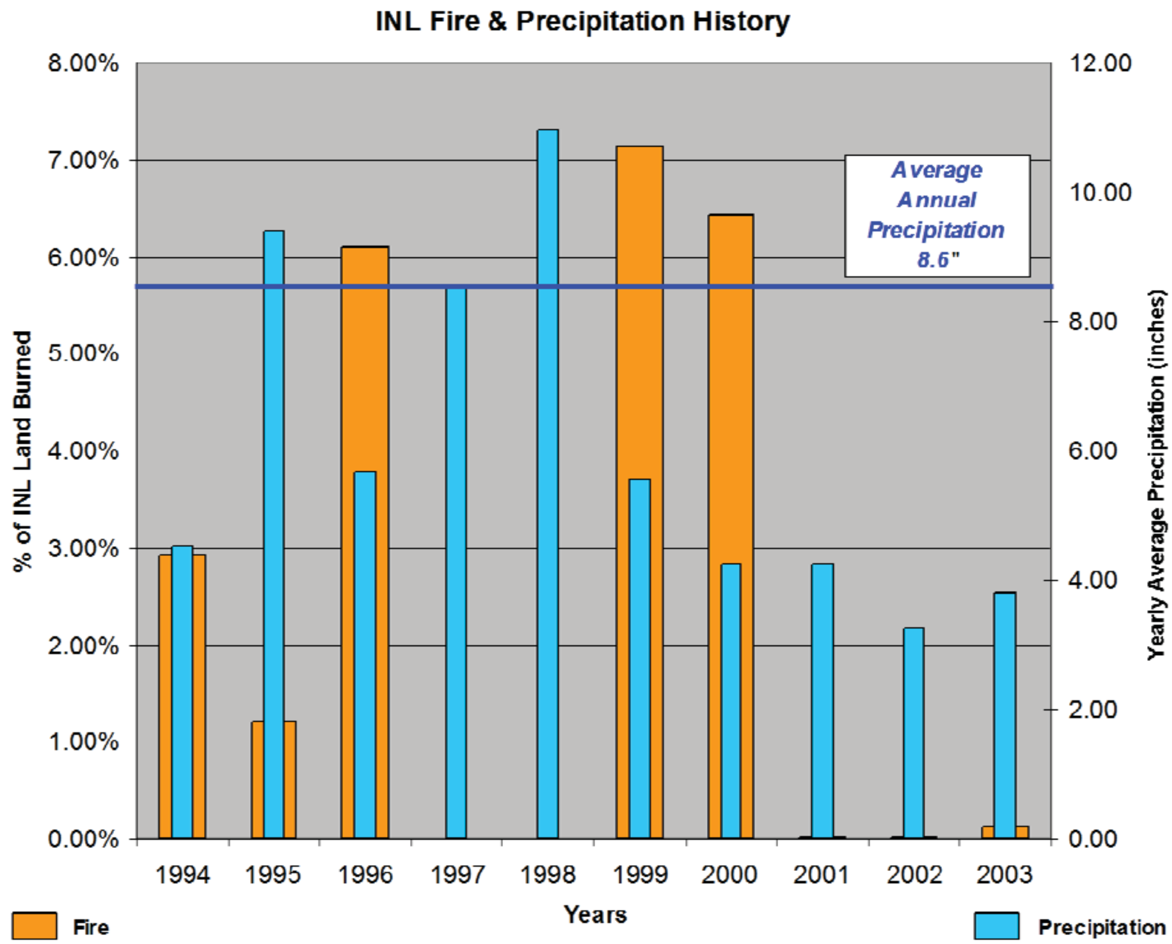


Figure 1-5. INL fire and precipitation history from 1994 to 2003.

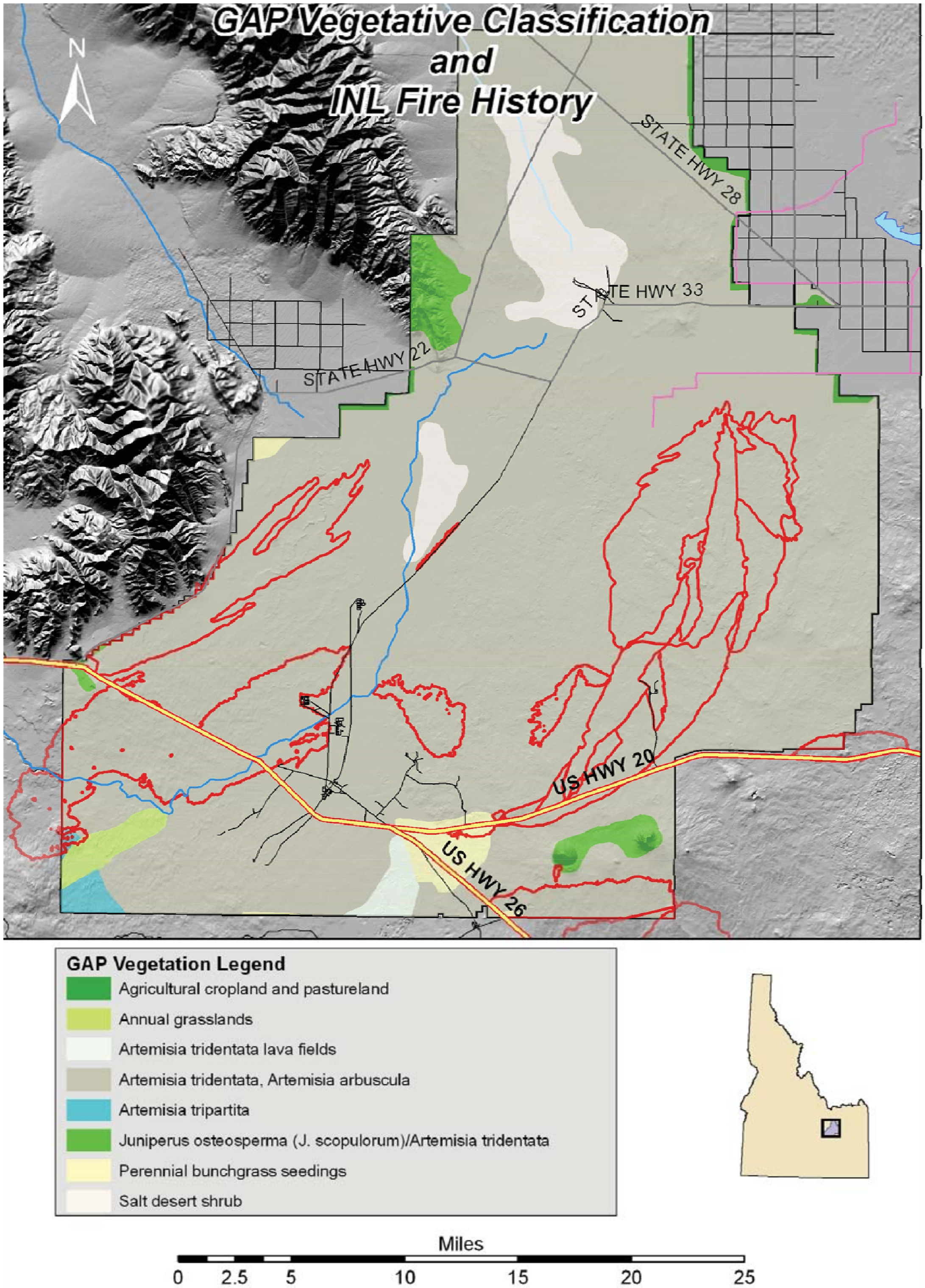


Figure 1-6. Occurrence of fire on the INL within different terrestrial vegetation classes using GAP analysis. Areas outlined in red are recent burns.

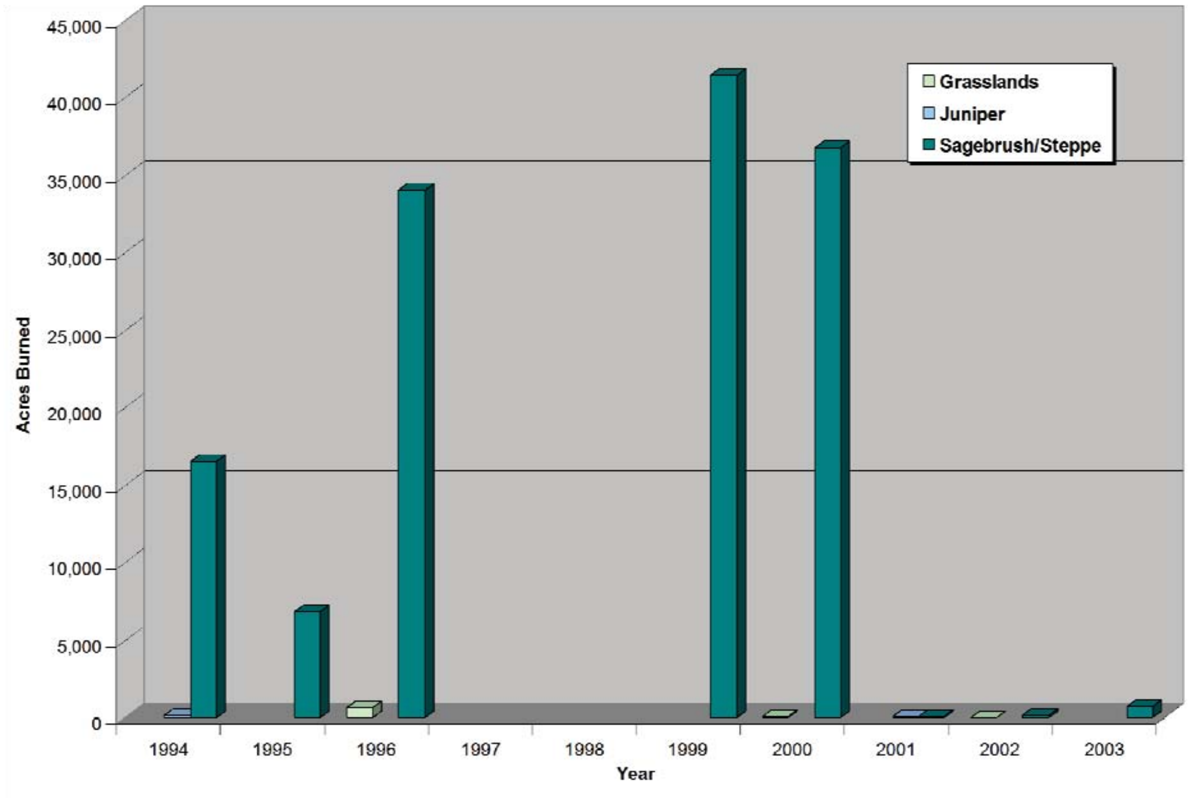


Figure 1-7. Analysis of the occurrence of fire on the INL within different terrestrial vegetation classes using GAP classification system.

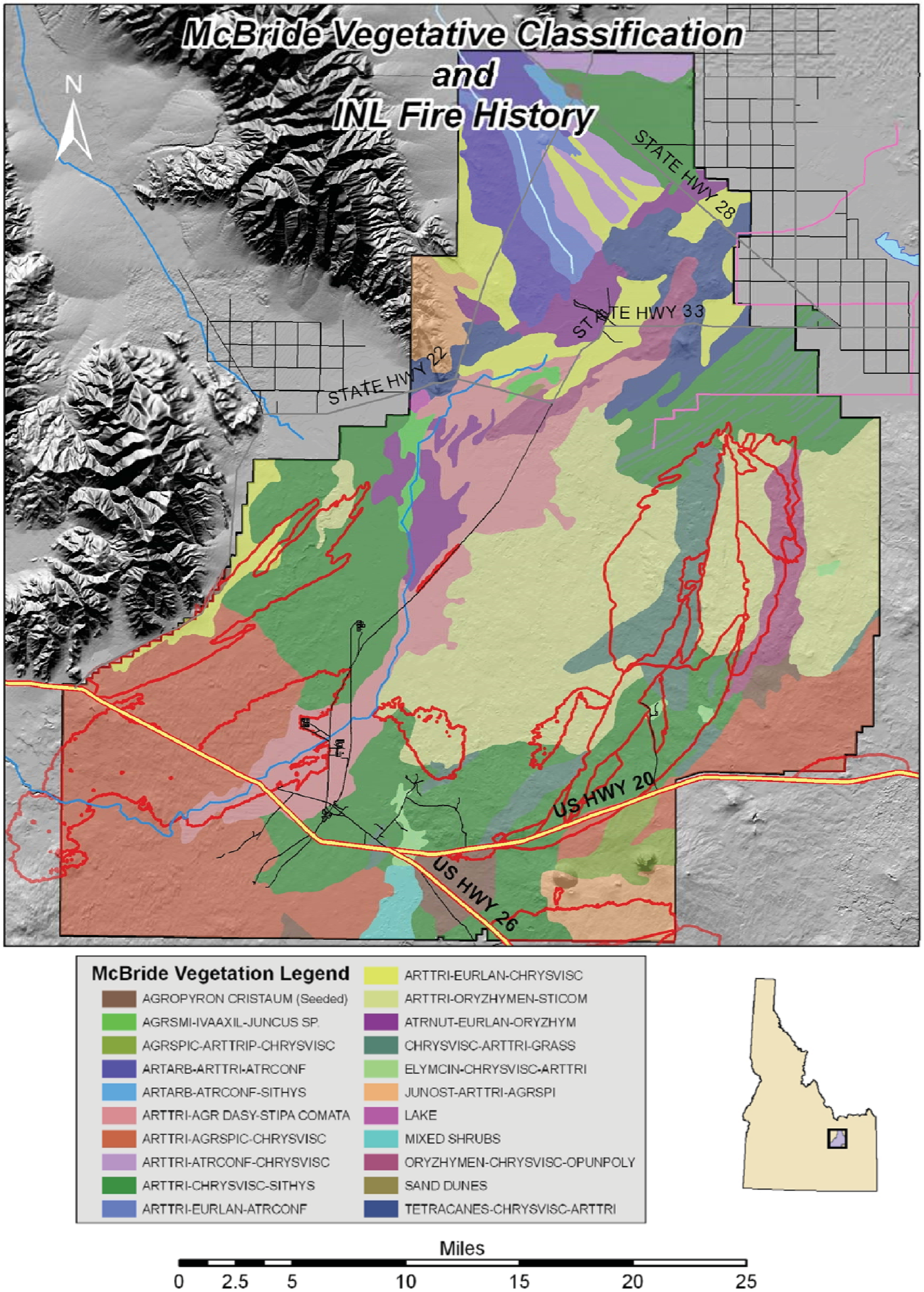


Figure 1-8. Occurrence of fire on the INL within different terrestrial vegetation classes using McBride classification system. Areas outlined in red are recent burns.

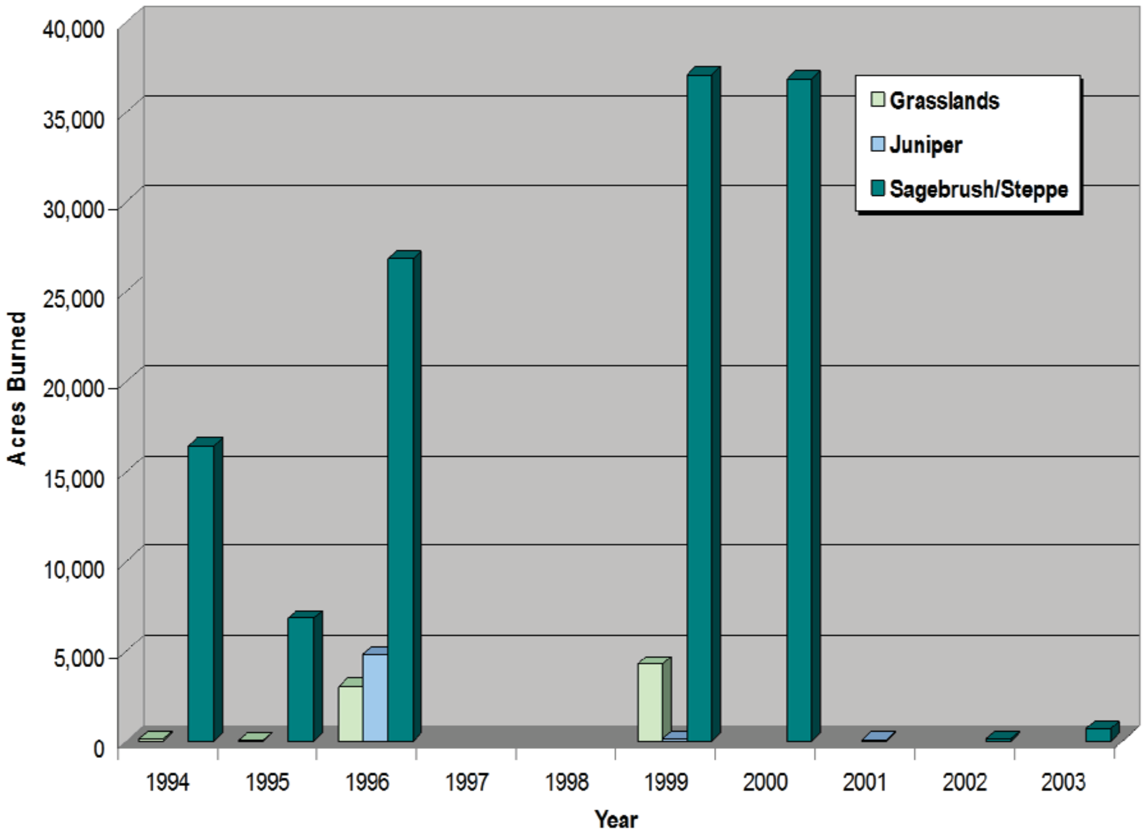


Figure 1-9. Analysis of the occurrence of fire on the INL within different terrestrial vegetation classes evaluated using McBride classification system.

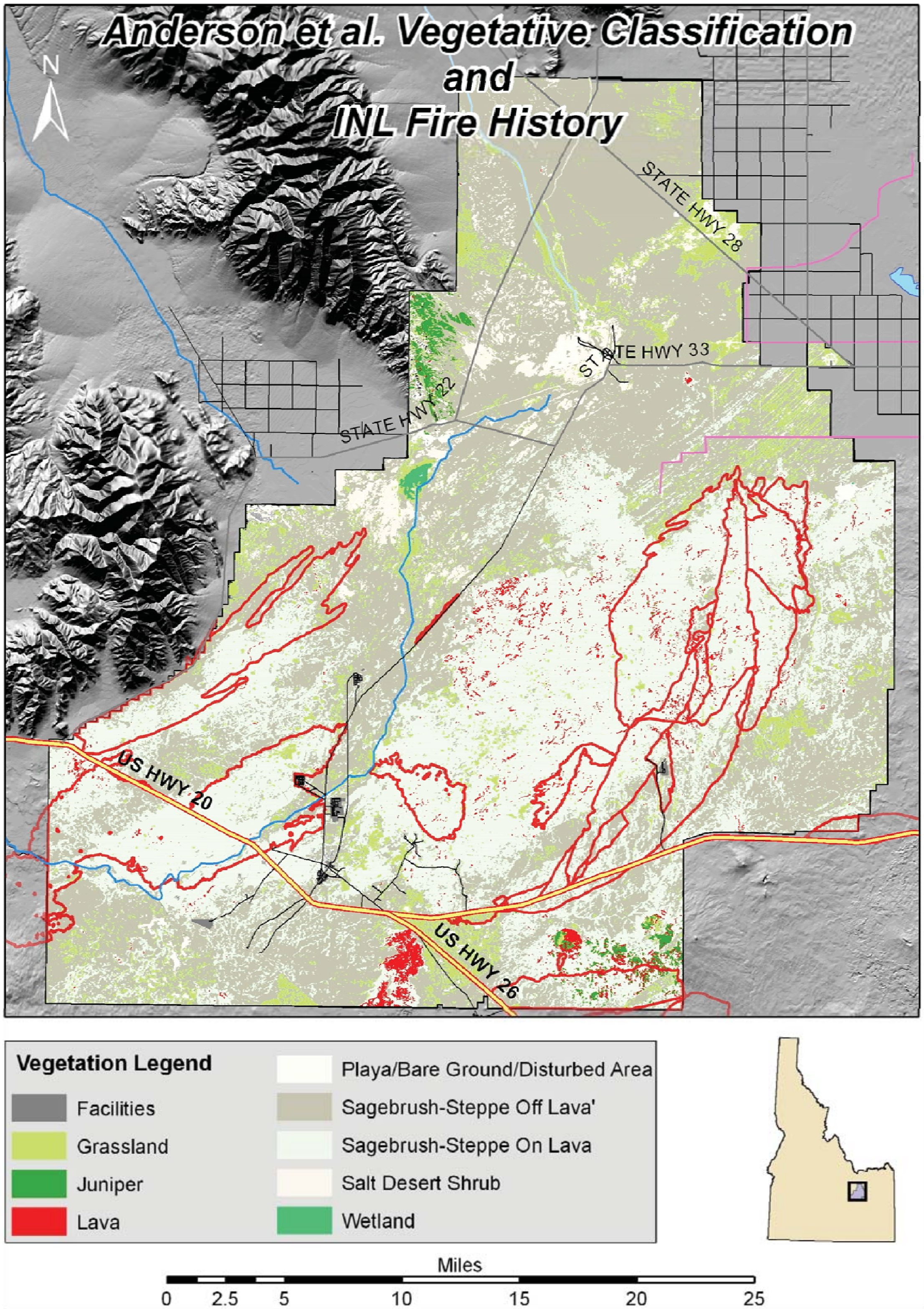


Figure 1-10. Occurrence of fire on the INL within different terrestrial vegetation classes evaluated using Anderson classification system. Areas outlined in red are recent burns.

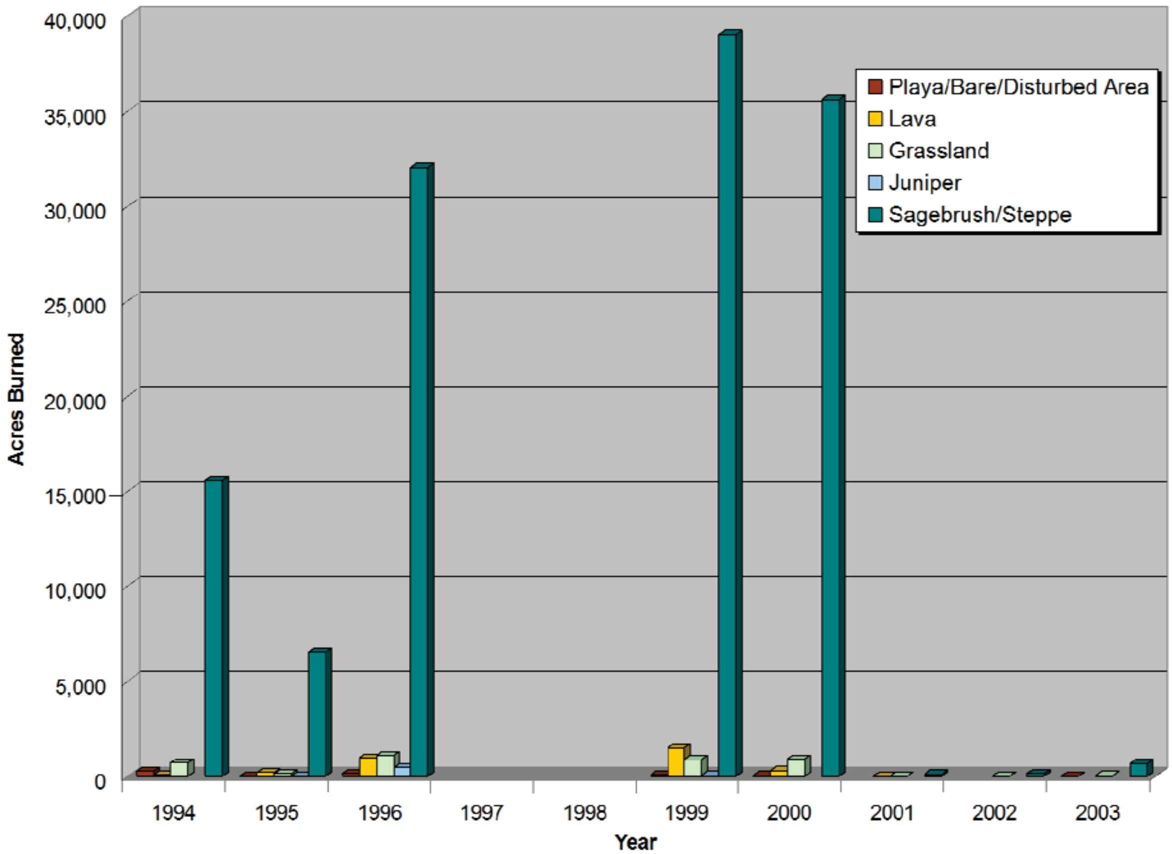


Figure 1-11. Analysis of the occurrence of fire on the INL within different terrestrial vegetation classes as evaluated using Anderson classification system.

Table 1-1 shows the relative number of acres for each vegetation category impacted by fire for the three classification systems. The data show good comparison for the total number of acres burned from 1994 to 2003 (between 137,116 and 137,234 acres [55,498 and 55,537 ha]). A key point to note is that all three systems show that the sagebrush steppe shrub communities lost 21–23% during the 10-year period. It is important to note that most of this change occurred over a 5-year period between 1996 and 2000. This large amount of change in such a short period can have significant impacts to wildlife species (Connelly et al. 2000) and should be considered in future wildlife management strategies.

Table 1-1. Comparison of the occurrence of fire on the INL within terrestrial vegetation classes using Gap, McBride, and Anderson land cover classification systems.

Vegetation Classification System	**Sagebrush/ Steppe Shrub Communities**	**Native Grassland**	**Seeded Grassland**	**Juniper**	**Playa/ Bare Ground/ Disturbed Area**	**Lava**	**Totals Acres Burned 1994–2003**
McBride	124,751	6,942	437	4,985			**137,115**
Gap	136,424	44	637	129			**137,234**
Anderson	129,555	3,685		466	469	2,955	**137,130**

The main difference between the classification systems is that GAP reported only a small amount of juniper and native grasslands burned. This is because GAP was originally designed for regional landscape-scale assessments and has been criticized for its accuracy for mapping vegetation cover at local or field levels (Short and Hestbeck 1995). Scott et al. (2002) noted that when using the GAP data, particular attention should be paid to sample size because larger error was noted with smaller islands of vegetation. This is the case for some of the grasslands that occur on the INL.

The McBride approach reported the greatest amount of juniper and native grasslands burned. The scale of the aerial photos used by McBride was not identified (estimated to be 1:40,000), but analysis of available photos taken about the same time show scales much greater than the 30-m pixel resolution used for the GAP and Anderson assessments,[a] which could account for the discrepancy.

The Anderson approach reported what seems to be a more balanced distribution of how the land cover changed because it included bare ground and disturbed areas and sagebrush-steppe on lava cover categories. The Anderson system combined native and seeded grasslands because there are several situations where different perennial native and seeded species occur within the same area. The spectral signature of the native and seeded species was very similar. This is due to the fact that the

---

[a] E-mail communication from R. Rope, INL, to R. Breckenridge, "INL vegetation map cover classes," December 15, 2006.

seeded areas were planted with crested wheatgrasses (*Agropyron desertorum* or *Agropyron cristatum*) that are native to the steppes of Asia. Many of the seeded grassland areas were planted to control the spread of halogeton (*Halogeton glomeratus),* an aggressive annual weed that was introduced to North America from Asia. The plantings of crested wheatgrasses are stable. The main ecological difference between these and the native grasslands is that because they are quite stable, they effectively resist invasion by native species (Anderson et al. 1996). Although there are concerns with the accuracies of all three approaches, the Anderson classification system used the most recent available imagery and matched most closely with the ground reconnaissance, which was done by scientists with an extensive (over 30 years) knowledge base of the INL vegetation. This was especially true in areas where the vegetation was a mosaic or where it was sparse around playas and disturbed areas. Based on this assessment, the Anderson classification system is recommended for assessing the impact of fire on vegetation cover and related habitat types for the INL.

One shortfall of all three approaches is that the spatial resolution is too coarse to identify the amount of bare ground within a vegetation cover class. These data, if available, could be used as an indicator of rangeland health (Pellant et al. 2005). A ground-based analysis of vegetation dynamics for 94 permanent plots evaluated over 35 years on the INL (Anderson and Inouye 1999) has documented that, in general, the amount of bare ground is often about 24%. Future analysis of vegetation dynamics on the INL should address trends in bare ground within a vegetation cover type because it is an important indicator in assessing ecosystem condition (Pellant et al. 2005). The Anderson system at least identified some of the larger bare ground/playa areas. Knowing the locations of larger bare ground areas as well as playa and lava-dominated areas is important for planning fire breaks. By taking advantage of areas that do not have vegetation that will carry a fire, the amount of fire line that needs to be cut (usually with bulldozers) can be reduced and impact to landscape can be reduced. Identifying some of the larger bare areas adjacent to good cover is important because these are sometimes used as leks by sage grouse during their mating ritual in the spring. For the future, until a verified classification system is developed, it is recommended that fire management plans and land cover change from fire be evaluated using the Anderson system.

Conclusions and Recommendations

The analysis presented here shows how integrating GIS technology and existing field and remotely sensed data can help to better understand relationships between annual rainfall and fire alteration of terrestrial vegetation and habitat, and can provide a useful data set for developing fire management plans. Understanding how fire has impacted terrestrial vegetation at the landscape level will allow fire and wildlife managers to make better decisions about how to manage future fires (i.e., how and where to use natural fire breaks), how to identify potential critical habitat, and how to determine where and if prescribed fire can be a viable tool to meet management objectives.

Fire management is an important consideration in conducting landscape-level assessments (Bunting et al. 1987; Turner et al. 2003). At the landscape level, much of the ungrazed core and northern portions of the INL have not been impacted by recent fires. This factor should be considered in any long-term land management strategy for the INL. The fire and precipitation history from 1994 to 2003 (Figure 1-5) for the INL suggests that larger fires often occur following years with near or above annual rainfall. This may be because there is an abundance of soil moisture resulting in an increase in fine fuel (grasses and forbs) following wet years. Interestingly, years with rainfall notably below the long-term average did not show an increase in fire occurrence either during the dry year or the year following the dry year (Figure 1-5). These results provide important information for decision makers developing fire management policy directed at protection of human life and facilities, preservation of antiquities, and conservation of critical habitat (DOE-ID 2003).

As with fire management, land conversion is important to consider in landscape assessments. In the 1970s when the first imagery was collected over the INL, there was limited interest in conserving sagebrush steppe at the ecosystem level. Today, the areas in southern Idaho that are under conservation or protective management are extensive (see Figure 1-1); however, land conversion and development pressures are increasing. Without a more extensive evaluation of how land conversion is impacting the regional landscape, it will be difficult to establish an integrated approach to ensure the critical parts of the sagebrush steppe ecosystems are linked and connective corridors are maintained.

When the INL was established by Congress, it was designated a federally-funded research and development center. As such, the INL can take the lead role in bringing together state and federal agencies, universities, tribes, and non-governmental organizations to merge common interests and disparate data sets to better manage sagebrush steppe lands. Some specific recommendations that could be adopted include:

1. Develop a long-term integrated research strategy that includes all INL-related researchers and data users, lists needs and gaps in existing data sets, and tasks the appropriate entities to develop plans to fill data needs and improve long-term management through data integration. This needs to be done in a timely manner with near- and long-term actions that focus on near-term improvement to provide the greatest benefit to the overall ecological system (e.g., enhance the

mix of vegetation cover to benefit wildlife, identify and focus attention on high-value landscape areas, and identify critical migratory and connective corridors).

2. Develop a centralized web-based digital repository of all environmental information for the INL and surrounding lands and develop data standards that are consistent, allow easy access, and are based on future use requirements.

3. Conduct additional data analyses that integrate the landscape and vegetation analysis conducted in this paper with existing studies that have evaluated biotic resource changes on the INL (e.g., Stoller 2005) to assess how critical species (e.g., sage grouse and pygmy rabbit) populations have changed as a result of fire and landscape alteration.

4. Develop improved methods for analysis of vegetation cover to improve accuracy for assessing change. These methods should complement the remote sensing imagery identified in the document but improve the near earth identification of percent cover of vegetation classes and bare ground. The improved methods would provide timelier and better data to assess how vegetation and landscapes are changing, with more focus on vegetation cover and percent cover.

References

Anderson, J. E., and K. E. Holte. 1981. Vegetation development over 25 years without grazing on sagebrush-dominated rangeland in Southeastern Idaho. *Journal of Environmental Management* 34:25–29.

Anderson, J. E., K. T. Ruppel, J. M. Glennon, K. E. Holte, and R. C. Rope. 1996. *Plant Communities, Ethnoecology, and Flora of the Idaho National Engineering Laboratory*. Environmental Science and Research Foundation. ESRF-005.

Anderson, J. E., and R. S. Inouye. 2001. Landscape-scale change in plant species abundance and biodiversity of a sagebrush steppe over 45 years. *Ecological Monographs* 71:531–566.

Anderson, J. E., and R. S. Inouye. 1999. Long-term vegetation dynamics in sagebrush steppe at the Idaho National Engineering and Environmental Laboratory. Environmental Science and Research Foundation, Idaho Falls, Idaho, 58 p.

Braun, C. E., 1998. Sage-grouse declines in western North America: What are the problems? *Proceedings of the Western Association of State Fish and Wildlife Agencies* 78:139–156.

Breckenridge, R. P., W. G. Kepner, and D. A. Mouat. 1995. A process for selecting indicators for monitoring conditions of rangeland health. *Environmental Monitoring and Assessment* 36:45–60.

Bunting, S. C., 1996. The use and role of fire in natural areas. In *National Parks and Protected Areas: Their Role in Environmental Protection*, edited by R. G. Wright. Cambridge, Massachusetts: Blackwell Science, pp. 277–301.

Bunting, S. C., B. M. Kilgore, and C. L. Bushey. 1987. *Guidelines for Prescribed Burning Sagebrush-Grass Rangeland in the Northern Great Basin*. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Research Station. Ogden, Utah. General Technical Report INT-231.

Colket, E. C., 2003. *Long-Term Vegetation Dynamics and Post-Fire Establishment Patterns of Sagebrush Steppe*, Master's thesis, University of Idaho, Moscow.

Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage-grouse *Centrocercus urophasianus* populations in western North America. *Wildlife Biology* 3:229–234.

Connelly, J. W., K. P. Reese, R. A. Fischer, and W. L. Wakkinen. 2000. Response of a sage grouse breeding population to fire in southeastern Idaho. *Wildlife Society Bulletin* 28:90–96.

Crowley, C., and J. W. Connelly. 1996. *Sage-grouse Population and Habitat Trends in Southeastern Idaho and Southwestern Montana*. Idaho Department of Fish and Game, Pocatello.

Deaton, M. L., and J. J. Winebrake. 2000. *Dynamic Modeling of Environmental Systems*. New York: Springer.

DOE. 2000. "Moratorium on Prescribed Fires," Secretarial Memorandum, June 5.

DOE-ID. 2003. *Idaho National Engineering and Environmental Laboratory Wildland Fire Management Environmental Assessment*. U.S. Department of Energy Idaho Operations Office. DOE/EA-1372, April.

DOE-ID. 1997. *Idaho National Engineering and Environmental Laboratory Comprehensive Facility and Land Use Planning*. U.S. Department of Energy Idaho Operations Office. DOE/ID-10514, December.

EPA. 2007. Some Landsat views of the United States. EPA, Office of Research and Development, Las Vegas, Nevada. http://members.aol.com/landsatcd/MOREHTML/nalc.html. Accessed May 4, 2007.

French, N. R, and J. E. Mitchell. 1983. *Long-term Vegetation Changes in Permanent Quadrants at the Idaho National Engineering Laboratory Site*. College of Forestry, Wildlife and Range Sciences, University of Idaho. Bulletin Number 36.

Frohn, R. C. 1998. *Remote Sensing for Landscape Ecology: New Metric Indicators for Monitoring, Modeling, and Assessment of Ecosystems*. Boca Raton, Florida: CRC Press.

Hoffman, D. J., B. A. Rattner, G. A. Burton Jr., and J. Cairns Jr. 2003. *Handbook of Ecotoxicology, Second Edition*. Boca Raton: CRC Press.

INSIDE Idaho. 2006. Interactive numerical & spatial information data engine. INSIDE Idaho. http://inside.uidaho.edu/default.htm. Accessed May 4, 2007.

Jennings, M., and J. M. Scott. 1997. Official description of the gap analysis program. U.S. Geological Survey, National Biological Information Infrastructure. http://gapanalysis.nbii.gov/portal/server.pt/gateway/PTARGS_0_2_1021_200_458_43/ http%3B/gapcontent1%3B7087/publishedcontent/publish/public_sections/gap_home_sections/descriptionofficial/highlights_content.html.

Kepner, W. G., C. J. Watts, C. M. Edmonds, J. K. Maingi, S. E.Marsh, and G. Luna. 2004. A landscape approach for detecting and evaluating change in a semi-arid environment. *Journal of Environmental Monitoring and Assessment* 64:179–195.

Knick, S. T., D. S. Dobkin, J. T. Rotenberry, M. A. Schroeder, W. M. Vander Haegen, and C. Van Riper III. 2003. Teetering on the edge or too late? Conservation and research issues for avifauna of sagebrush habitats. *The Condor* 105:611–634.

Kramber, W. J., R. C. Rope, J. E. Anderson, J. Glennon, and A. Morse. 1992. Producing a vegetation map of the Idaho National Engineering Lab using Landsat thematic mapper data. American Society for Photogrammetry and Remote Sensing/American Congress on Surveying and Mapping Annual Meeting Technical Paper, Vol. 1:217–226.

Mack, R. N. 1981. Invasion of *Bromus tectorum* L. into western North America: An ecological chronicle. *Argo-Ecosystems* 7:145–165.

McBride, R., N. R. French, A. H. Dahl, and J. E. Detmer. 1978. *Vegetation Types and Surface Soils of the Idaho National Engineering Laboratory Site*. Radiological and Environmental Sciences Laboratory, U.S. Department of Energy, Idaho Falls, Idaho. IDO-12084.

Miller, R. F., and J. A. Rose. 1999. Fire history and western juniper encroachment in sagebrush steppe. *Journal of Range Management*. 52:550–559.

Pellant, M., P. Shaver, D. A. Pyke, and J. E. Herrick. 2005. *Interpreting Indicators of Rangeland Health, Version 4*. U.S. Department of the Interior, Bureau of Land Management, National Science and Technology Center, Denver, Colorado. Technical Reference 1734-6, BLM/WO/ST-00/001+1734/REV05.

Pyke, D. A., J. E. Herrick, P. Shaver and M. Pellant. 2002. Rangeland health attributes and indicators for qualitative assessment. *Journal of Range Management* 55:584–497.

Rickard, W. H., L. E. Rogers, B. E. Vaughan, and S. F. Liebetrau. 1988. *Shrub-Steppe Balance and Change in a Semi-arid Terrestrial Ecosystem*. Amsterdam: Elsevier.

Rouse, J. W., H. Haas, J. A. Schell and D. W. Deering, 1997, “Monitoring Vegetation in the Great Plains with ERTS,” *Proceedings,* Third Earth Resources Technology Satellite -1 Symposium, Greenbelt: NASA SP-351, 310-317.

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Sage-grouse (*Centrocercus urophasianus*). In *The Birds of North America, No. 425*, edited by A. Poole and F. Gill. Philadelphia: The Birds of North America, Inc.

Scott, J. M., C. R. Peterson, J. W. Karl, E. Strand, L. K. Svancara, and N. M. Wright. 2002. *A Gap Analysis of Idaho: Final Report*. Idaho Cooperative Fish and Wildlife Research Unit. Moscow, Idaho.

Short, H. L., and J. B. Hestbeck. 1995. National biotic inventories and gap analysis. *BioScience*. 45:535–539.

Sperber, T. D., T. D. Reynolds, and R. P. Breckenridge. 1998. *Developing the Scientific Basis for Long-Term Land Management of the Idaho National Engineering and Environmental Laboratory*. Idaho National Laboratory. INEEL/EXT-98-00221.

Stoller, 2005. *Idaho National Engineering and Environmental Laboratory Site Environmental Report Calendar Year 2004*. Environmental Surveillance, Education and Research Program for DOE-ID. DOE/ID-12082(04), ISSN 089-5469, STOLLER-ESER-93, October.

Swetnam, T. W., and J. L. Betancourt. 1990. Fire-southern oscillation relations in the southwestern United States. *Science* 249:1017–1020.

Turner, M. G., R. H. Gardner, and R. V. O’Neill. 2003. *Landscape Ecology in Theory and Practice: Pattern and Processes*. New York: Springer-Verlag.

Wambolt, C. L., Walhof, K. S., and M. R. Frisina. 2001. Recovery of Big Sagebrush communities after burning in south-western Montana. *Journal of Environmental Management* 61:243–252.

Wright, H. A. 1971. Effects of fire on bunchgrasses of the sagebrush-grass region of southern Idaho. *Ecology* 46:680–688.

Wright, H. A., and A. W. Bailey. 1982. *Fire Ecology: United States and Southern Canada*. New York: John Wiley & Sons.

Wyoming Interagency Vegetation Committee. 2002. *Wyoming Guidelines for the Managing Sagebrush Communities with Emphasis on Fire Management*. Wyoming Game and Fish Department and Wyoming BLM, Cheyenne, Wyoming.

Chapter 2: Using Unmanned Helicopters to Assess Vegetation Cover in Sagebrush Ecosystems

Abstract

The Idaho National Laboratory (INL), in conjunction with the University of Idaho, is evaluating whether unmanned aerial vehicles (UAVs) are faster than the point-frame field method and safer than manned aerial vehicles for monitoring biotic resources. Evaluating vegetation cover is an important factor in understanding the sustainability of many ecosystems. Methods that improve accuracy and cost efficiency could dramatically improve how biotic resources are monitored on both public and private lands. This will be of interest to land managers because there are rarely enough resource specialists or funds available for comprehensive ground evaluations. In this project, unmanned helicopters were used to collect still-frame imagery to assess cover during May, June, and July in a sagebrush steppe ecosystem. The images were used to estimate percent cover for six types (shrub, dead shrub, grass, forb, litter, and bare ground). The field plots were located on the INL site west of Idaho Falls, Idaho. A software program called SamplePoint was used to evaluate the imagery and the results were compared against standard field measurements to assess accuracy. The helicopter imagery evaluation showed a high degree of agreement with field values for litter, bare ground, and grass, and reasonable agreement for dead shrubs. Shrub cover was often overestimated and forbs were generally underestimated. The helicopter method took 45% less time than the field method to set plots and collect and analyze data. This study demonstrated that UAV technology provides a viable method for monitoring selected cover types for rangelands with less time and lower cost, but field validation should always be included as a quality check.

Introduction

One of the most observed features of an ecological community is its physical structure (Smith 1990), of which vegetation cover is an important part (Bonham 1989). Vegetation cover is a measure used to assess the condition of rangelands (Society for Range Management 1995; Pyke et al. 2002; Pellant et al. 2005). Evaluating cover is an important factor in understanding the sustainability of many biotic resources. Cover data provide important information about ecological structure and processes like 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). Collecting data to evaluate cover on federal, state, and private lands in the western United States is a monumental task, however, and there are not enough natural-resource specialists or funds to conduct ground surveys on many of these lands.

Manned aircraft have historically been used to support monitoring activities on large areas of public lands, but 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 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 (National Transportation Safety Board 2007; Zager 2006). 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 fatal accidents.

One alternative to manned aircraft is remote-sensing systems. These systems have few safety concerns but do have other potential issues such as cost, accuracy at the sub-meter level, and weather conditions (e.g., cloud cover). Unmanned aerial vehicles (UAVs) are an established technology that can collect near-earth data to improve biotic resources management on public and private lands. UAVs can be flown using remote-controlled or autonomous navigational systems and can carry various 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, specifically an unmanned helicopter, to monitor biotic resources. The objectives of the study were to:

- Assess the feasibility of using a UAV helicopter to collect imagery useful in assessment of selected cover values in rangelands
- Compare the relative accuracy of the cover values collected and processed from UAV technology with cover values from field measurements
- Compare the level of effort for collecting cover data from UAV and field methods.

One Intermountain West entity studying UAVs is the Idaho National Laboratory (INL), a federal facility operated by the U.S. Department of Energy. The laboratory is located west of Idaho Falls, Idaho, in a semi-arid section of the Upper Snake River Basin. Within the INL's boundaries is a large protected sagebrush steppe ecosystem. Because public and grazing access to the central part of the INL has been restricted for over 50 years (Anderson et al. 1996), the core of the sagebrush steppe ecosystem on the site has been relatively undisturbed and is therefore a unique research facility. This study used the INL's sagebrush steppe ecosystem as the research site.

Sagebrush communities are regarded by many as steppe or shrub steppe because of grasses, which make up an important component of cover (Daubenmire 1970; Brown 1982). Forbs are another important cover component because of their forage value to wildlife (Connelly et al. 2000; Pedersen et al. 2003) and nutrient cycling (Smith 1990). The amounts of dead shrub and litter are important factors for both fire-fuel assessment and as deterrents against wind and rain erosion (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).

In general, suitable sagebrush steppe habitat is dominated by a canopy of sagebrush. The absolute and relative amounts of sagebrush, grasses, and forbs on a specific site vary with the subspecies of sagebrush (*Artemisia ssp.*), the ecological site potential, and the habitat's condition. Sagebrush cover may reach 30–40% or more with a decline in herbaceous production and no recruitment of herbaceous seedlings. In the case of Wyoming big sagebrush (*Artemisia tridentate ssp. wyomingensis)*, understory production begins to decline when sagebrush cover is between 12 and 15%, depending on site-specific features. The continued increase in brush cover eventually leads to the reduction of understory plants (Nevada Wildlife Federation 2002).

Fire, both natural and human-caused, also plays an important role in the amount and type of vegetation cover present in a sagebrush steppe community (Pedersen et al. 2003; Colket 2003). Environmental conditions, such as pre- and post-fire conditions, have a large effect on a sagebrush steppe community's response 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 (*Bromus tectorum*)[a] (Bunting 2002). The importance of the forb component varies across the big sagebrush steppe communities. Forb richness increases with increasing moisture; consequently, big sagebrush steppe has a diverse array of associated forbs (Bunting 2002).

Methods

Study Area

The INL's landscape is dominated by a sagebrush steppe ecosystem with 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 vegetation states, including extensive grasses, mixtures of grasses, forbs and sparse shrubs, and dense shrub cover (Walker 1993; Colket 2003). Activities like grazing, burning, exotic-weed infestation, and planting of non-native species (e.g., crested wheatgrass [*Agropyron cristatum*]) can cause major changes in vegetation cover and have significant 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 and Basin big sagebrush (*Artemisia tridentata* ssp. *tridententa*), which may be dominant or co-dominant with the Wyoming big sagebrush on sites with deep soils or surface accumulations of sand (Anderson et al. 1996; Mahalovich and McArthur 2004). Communities dominated by big sagebrush occupy much of the INL's central and southern portion. 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). Grasses on the INL are a mixture of native species, non-native species introduced to support revegetation activities (e.g., crested wheatgrass), and invasive species such as cheatgrass (*Bromus tectorum*) that have migrated onto the INL. The

[a] The scientific names used are taken from a list of common plants of the INL (Forman and Hafla 2005).

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*) (Anderson et al. 1996). The most common introduced grasses are crested wheatgrass used for revegetation activities and cheatgrass that has advanced because of grazing and fires.

Study Design

This study evaluated the feasibility of using UAV technology and image processing software to generate cover values on rangelands. Vegetation canopy cover is defined as the proportion of ground occupied by a perpendicular projection to the ground from the outline of the aerial parts of a plant (Brower et al. 1990). Typically, cover can be visualized as expressing the proportion of ground covered by the different vegetation types as viewed from above. For this reason, UAVs may provide a good platform for collecting aerial coverage measurements.

Cover is usually determined using one of several field methods like line-transect or quadrant sampling (Brower et al. 1990; U.S. Department of the Interior, Bureau of Land Management [USDI-BLM] 1997; Bonham 1989). The accuracy of conventional ground-cover methods compared with emerging automated methods has recently been evaluated (Booth et al. 2006a; Booth and Tueller 2003). Results indicate that conventional techniques have significantly greater correlation (≥ 92% agreement of measured to known) than measurements from algorithms in a software system called VegMeasure (70% agreement) (Johnson et al. 2003). The critical factor influencing the accuracy of the point-sampling method was the area of the contact point for the given method (Booth et al. 2006a). This supports findings of others that point sampling with minimal contact points yields the greatest measurement accuracy (Cook and Stubbendieck 1986).

Cover type, as used in this study, is defined as the material located above the soil surface. This material can be either live or dead vegetation or, in cases where there is nothing present, the cover type is bare ground.

Field values for this study were collected at the subplot level and used as the standards for comparison with data collected from a UAV helicopter. Accuracy was evaluated by analyzing the paired differences between the field values and the values obtained from the helicopter for the seven study plots. Because the helicopter technology is fairly new and equipment is limited, this project relied on acquiring images during missions flown by the INL’s UAV program for other projects; thus, timing for the flights was not a controllable factor.

Study Plot Selection and Design

Data collection occurred on the INL lands during the spring and summer of 2005. Field plots were established within an area where a UAV runway had been established and a permit to fly under the Federal Aviation Administration–Certification of Authorization (FAA-COA) had been obtained. (The FAA-COA is needed in all situations where an autopilot system is used for navigation.) Plots were established in seven locations around the runway (Figure 2-1). The plots were selected near the runway to accommodate the helicopter's flight restrictions. The specific locations selected represent the diversity of vegetation in both sagebrush- and grass-dominated communities typical of sagebrush steppe ecosystems.

Field plots were established in the early spring by locating the northwestern corner of each plot and laying out four 3 × 4-m (10 × 12-ft) subplots within each of seven plot locations. Each corner of a subplot was marked by a 30.4-cm (12-in.) plastic paint bucket lid (from a 20-L [5-gal] bucket) mounted on a 2.5-cm × 5.1-cm × 1.2-m (1-in. × 2-in. × 4-ft) 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 orange lids were placed in the northwest corner of each plot to equal the plot number (i.e., Plot 7 had seven lids, including the lid on the subplot corner [Figure 2-2]). Plot numbers were sprayed on the lids using a special, highly-visible paint for plastics so that they could be viewed in the UAV helicopter imagery at different heights above ground level (AGL). The AGL designation is used with UAV flights because it provides a better representation of the height of the actual flight above the ground; elevation can vary in uneven terrain. The paint lid setup proved to be very stable and was an effective way to view the plots from the helicopters. Even with spring gusts of up to 97 km/hr (60 mi/hr), only three of the over 40 lids needed to be re-attached from May through July.

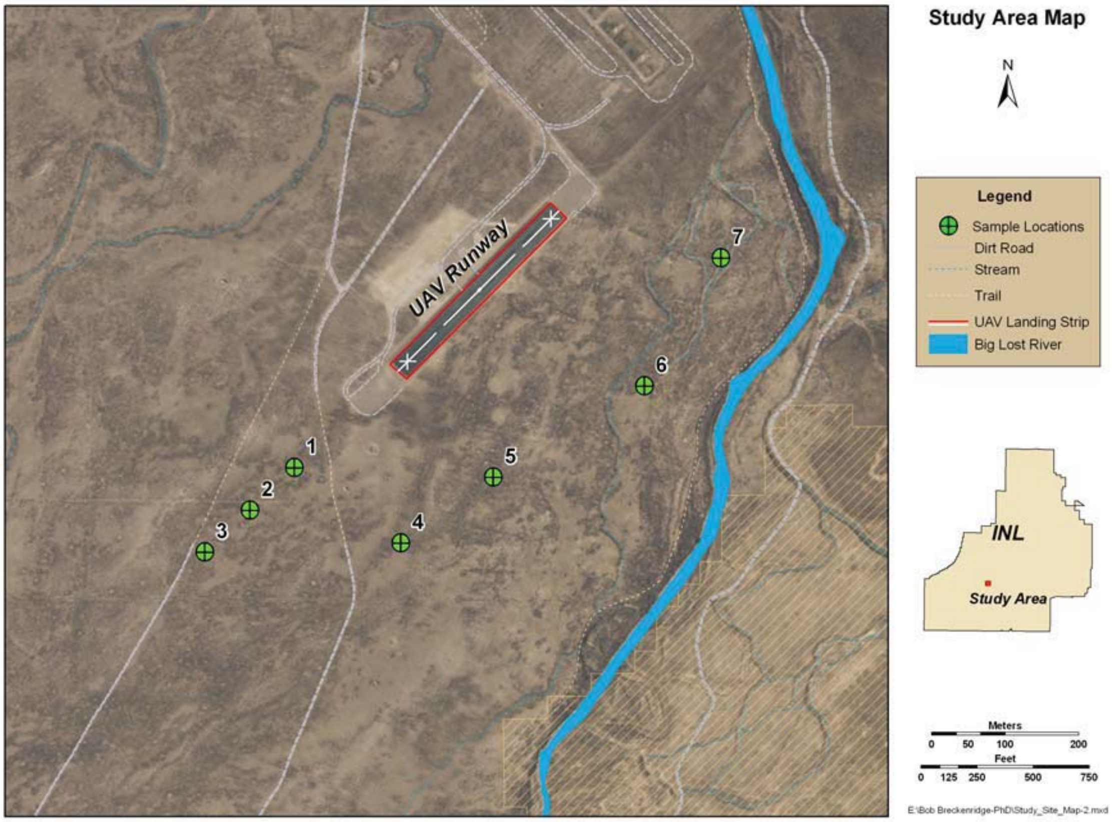


Figure 2-1. Map showing the location of the Idaho National Laboratory unmanned aerial vehicle runway, seven study plots, and study area on the Laboratory site.

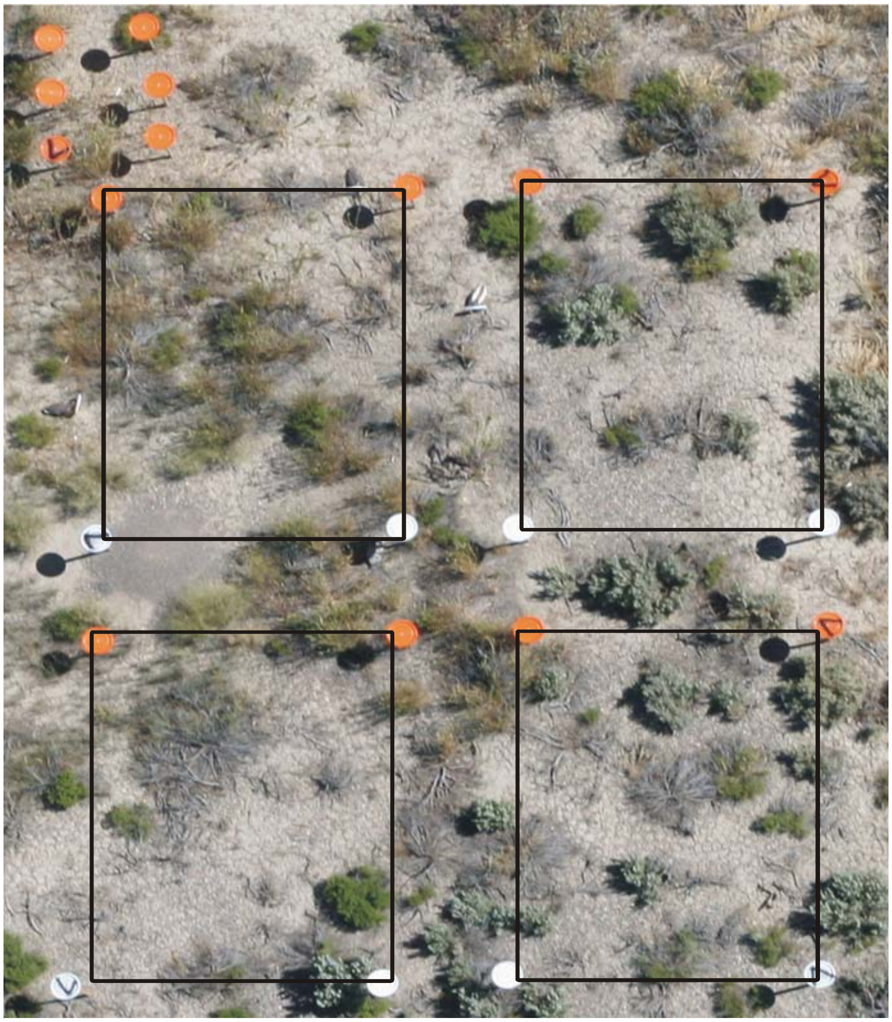


Figure 2-2. Sample plot design for unmanned vehicle image collection and analysis. This image shows the layout of Plot 7 with the four 3 × 4-m subplots.

Note: The number of orange lids in upper left (NW) corner identifies the plot number (in this figure, Plot 7).

Image Acquisition

Because our imagery collection was dependent on other UAV projects, images were collected in both June and July. The original plan was to use a helicopter that has a gyro-stabilizer system designed to allow clear images to be taken even in moderate winds. However, the original helicopter was designed and built at a location near sea level. When it was tested at an INL site with an elevation of about 1500 m (5000 ft), the helicopter did not have sufficient lift to fly. Imagery was acquired using an X-Cell model helicopter made by Miniature Aircraft carrying a micro 4-megapixel, digital, single-lens reflex camera. The camera was 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 taken directly overhead a field plot). An operator acquired images by using a remote-controlled trigger. Because UAV helicopter technology is relatively new, there was very limited information from other studies on the optimum height (AGL) for collecting imagery. During preliminary testing, the UAV was flown at heights of 6–30 m (20–100 ft) AGL. Imagery was collected at average heights of 11–15 m (32–50 ft) AGL, which allowed the entire subplot to be collected in one picture frame.

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 (10-in.) 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 in direct sunlight.

The second method proved to be effective and quick. This approach used two observers with flags located at adjacent sides of each plot. The flag persons signaled the location of the helicopter by holding the flag left, right, or straight up (meaning the helicopter was located over the center of the subplot). The camera operator relayed location information to the helicopter pilot and used the flag information to ensure the helicopter was centered over the subplot when acquiring pictures. Some experience was needed by both the camera and helicopter operators to center the helicopter over the subplot when winds exceeded 16 km/hr (10 mi/hr). We were able to fly the helicopter in winds up to 25 km/hr (15 mi/hr) but landing was difficult and required a high degree of skill by the operator.

The best approach for developing a field heliport was to lay down a 1 × 2-m (3 × 6-ft) exercise mat in a clear area near the plot and use this as the take-off and landing area. After each flight, 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. The helicopter had a flight-time limitation of about 15 min because of its fuel capacity. On average, 30 images were collected over each plot during flights that averaged 5 min.

As part of our protocol, we followed a pre- and post-flight checklist and checked battery and fuel levels on the helicopter following each flight and replenished as needed. During one helicopter flight in June, we experienced difficulty with the electrical controls because of a faulty battery pack. We had just replaced a battery pack on the control system and had the helicopter reaching an elevation of about 8 m (26 ft) when the battery pack went dead and we lost control of the helicopter, resulting in a crash landing. The camera was not damaged, but the helicopter sustained about $700 in damages. Thus, we were only able to collect imagery from four plots during June.

Field Data Collection

Training of field personnel by an experienced plant science researcher was conducted until field values were of high quality and a high level of reproducibility was achieved. Field cover type values were collected immediately following the second flights during the second week of July 2005. Entering the plots earlier would have impacted the vegetation cover. The subplots were sampled manually using a point-frame method (Floyd and Anderson 1982). The frame had a rectangular design of 0.5 × 1 m (1.6 × 3 ft). A rectangle with sides in a 1:2 ratio was used because this shape has been found to yield better results than other shapes for sampling plants (Brower et al. 1990). For each sample location, a 1 × 1-m (3 × 3-ft) area was sampled by flipping the frame over after reading the first frame. The point frame approach used two sets of thin fly-fishing backing line superimposed 5 cm (2 in.) apart. The frame was typically located about 1.2 m (4 ft) above the ground and the observer looked down between the two sets of strings and aligned them like crosshairs in a rifle scope. On average, the method sampled a spot on the ground that was < 0.5 cm in size, however, in theory a point has no area. One hundred points were read for each frame.

Locations to be sampled in the subplots were established by overlaying the 1 × 1-m (3 × 3-ft) grid over each of the 3 × 4-m (10 × 12-ft) subplots. The grids were numbered starting at the northwest corner and continuing across the north side and then down the west side, creating twelve 1-m^2 (10.8 ft^2) sampling locations. A random-number generator was used to select six of the 12 locations to read with the point frame. Thus, 50% of each subplot was read.

Image Manipulation and Processing

Images were downloaded from the UAV helicopter camera into a portable computer after each flight. The clearest and most nadir images were selected for analysis. Each image was rotated using Corel PHOTO-PAINT (version 10) to the same directional orientation and cropped to the smallest rectangle possible without removing any information inside the plot. This was done by rotating the image and lining up the longest side of the rectangle with a horizontal axis. Evaluation of the images was not done at the pixel level (usually assessments were on a 4–6 pixel spot); thus, evaluating re-sampling techniques during rotation was not a major concern. The cropped images were then imported into ERDAS Imagine (version 8.6), an image-processing software package. The images were aligned with the Image Geometric Correction subroutine. One image from each plot was selected 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 images (Booth et al. 2006b). A 10 × 10 grid (100 locations) was overlaid on each subplot image (see Figure 2-3). The zoom feature was used, if necessary, to zoom in to a 1-pixel level, but this was usually too fine. On average, when it was necessary to zoom in to differentiate between cover types, the zoomed image covered about a 4-pixel area (about 2 cm [0.8 in.] on the ground). In cases where the grid point fell on an obvious target (e.g., a large area of bare ground or the top a shrub), it was not necessary to use the zoom feature. At every grid point, the cover type was identified as one of eight types (shrub, dead shrub, grass, forb, litter, bare ground, shadow, or outside). If the cover type at a grid point could not be determined because of shadows or the vegetation fell outside the corners of the plots, it was recorded as either shadow or outside and considered as "unknown." We used two categories for unknowns because we wanted to assess the impact of shadows separately from locations that fell outside the plots. The largest shadow and outside values were, respectively, 11% and 21%. The average shadow and outside values, respectively, were 1.8% and 6.4%. It was assumed that the distribution of cover types for the unknown areas is similar to that of the known cover values.. Data from each image were normalized to account for "unknown" so that the remaining six vegetation types summed to 100% for each image. Because the total percentages for the six cover types needed to sum to 100%, the data were not independent; this could affect some of the results.

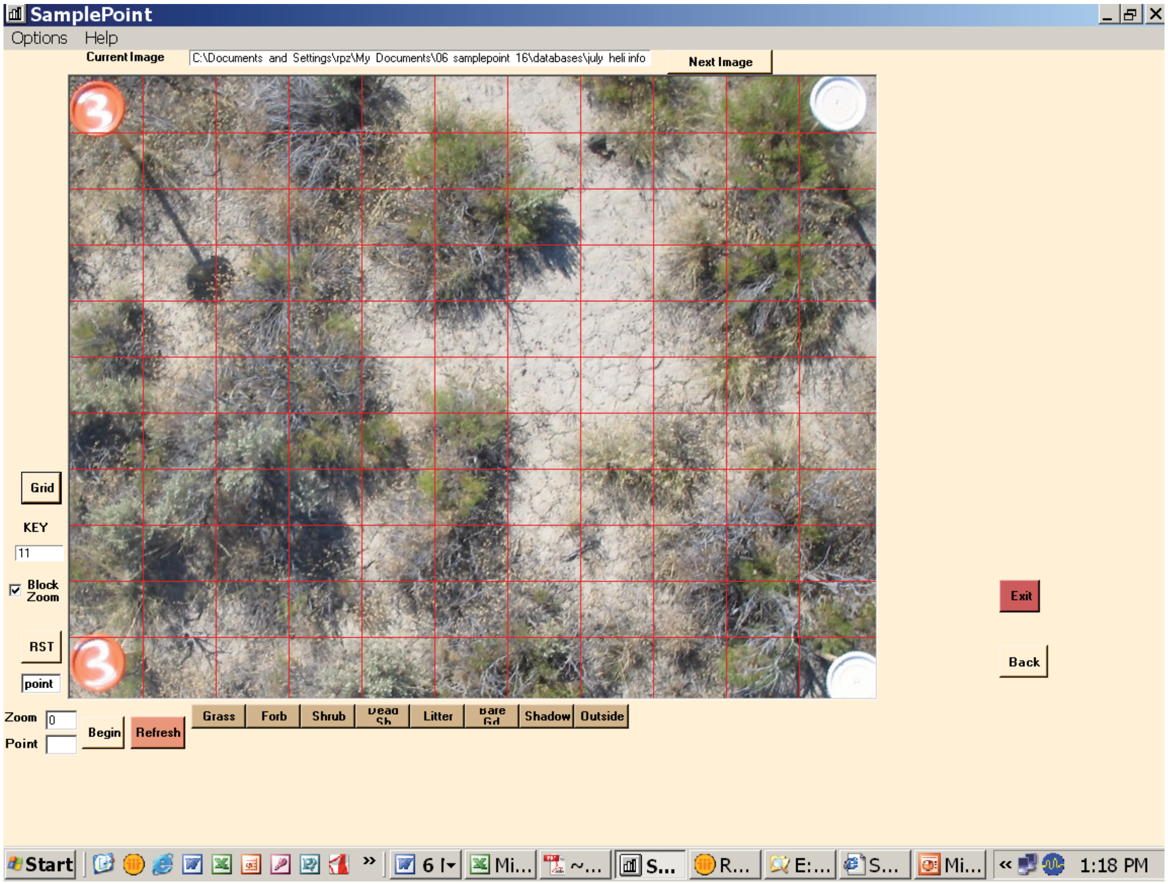


Figure 2-3. Screen shot from SamplePoint software with a 10 × 10 grid for analysis of imagery from helicopter subplots (3 × 4 m [10 × 12 ft]). Note: zoom factor = 0 (much higher level zoom available as needed).

Imagery was read using the SamplePoint program by either one or a combination of three observers. The three observers had different levels of training and will be discussed as Observer 1 (H) who had a high level of training, Observer 2 (M) with a moderate level of training, and Observer 3 (L) with a relatively low level of training. When data from all three observers were combined, this is reported as multiple observers.

Training the three observers was an important part of the quality-control process. First, each observer analyzed an image. Summary statistics were generated and the three observers discussed results and differences. During the initial training runs, there was a noticeable difference in results and the average difference in time for reading a 100-point image between the highly trained observer and lowest trained observer 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 both results and the time required to read an image.

Data Analysis

Multiple analyses were conducted to assess how well the UAV imagery method compared to the field method for assessing percent cover for the six vegetation types. An assumption made for this study is that the field method of estimating percent cover is most representative of the true values and is considered the standard against which the imagery values are compared. Prior to conducting the statistical analyses, a quality check was performed on the data to ensure all data fields had been properly entered and values were correct.

Statistical assessments were conducted to evaluate how well the imagery-collection method compared to the field method. Relative accuracy in measurement is assessed by considering the two component parts of measurement error: precision and accuracy (also called bias) (Blackwood and Bradley 1991). Precision was measured first by comparing variances between the methods; accuracy was then assessed by using paired *t*-tests. Before running the statistical tests, the assumptions were checked by examining the normal probability plots and histograms for the plot data. The distribution of the data appeared to satisfy the assumption of normality.

Once the normality assumption was verified, the variance caused by the measurement method (field or imagery) was separated from other sources of variability (e.g., among vegetation types). Grubbs (1948, 1973) specifies an applicable model that identifies the different sources of variance (Blackwood and Bradley 1991). Under Grubbs' model, and assuming a bivariate normal distribution for the paired data, Maloney and Rastogi (1970) have shown that Pitman's test (Pitman 1939) applied to the observed variance in measurement (i.e., the sum of the field and imagery variances) is also a test of the relative precision of the two methods.

The precision between the two methods is evaluated by testing the hypothesis that the difference in the variances, by vegetation type, for the paired field and imagery data for all seven plots are equal to zero. This can be stated by the following Pitman's test (Pitman 1939).

$H_o: \sigma^2_I - \sigma^2_F = 0$

is equivalent to

$H_o: \rho_{sd} = 0$

where

I = imagery values

F = field values

σ^2 = variance

ρ_{sd} = the correlation coefficient for the variables

Sum = *imagery + field*

Difference = *imagery - field values.*

This was performed by calculating the significance of the correlation (using a correlation matrix) between the sums and differences of the imagery and field values. In evaluating results, $p \leq 0.05$ was considered to be significant.

The above test considers only the relative precision of the two methods. Grubbs (1973) and Maloney and Rastogi (1970) suggest a separate paired t-test to determine the relative accuracy of the imagery and field methods. The advantage of using this approach is that it follows the scientific method and there are easily accessible methods to test for precision and accuracy (Blackwood and Bradley 1991). Therefore, a single sample paired *t*-test was used to test that the mean of the differences between the field and imagery was equal to zero.

Statistical analyses were conducted on the UAV imagery and field data using a statistical software package called Statistica (version 7.1).

Results

Scatter plots were used to compare the results of the UAV and field methods for the six cover types. The scatter plot for bare ground, Observer 1 (H), flown at 11 m (35 ft) AGL, is shown in Figure 2-4. All of the scatter plots for June and July for Observer 1 (H) and the three observers combined are provided in Appendix A. The scatter plots show that data varied from the perfect fitted line between the imagery and field values; thus, additional statistical evaluations were undertaken to determine the precision and accuracy between the methods.

Tables 2-1 through 2-4 show the mean values for the imagery and field data and the results of the statistical evaluations for both precision and accuracy of the June and July data collections. In presenting and discussing results we will address the July results first since we did not collect the field data until July to minimize impact to the field plots; thus, these two data sets are more temporally correlated. The June data will then be presented and discussed. However, note that there was almost a month of growth between the imagery and field values, and for some of the early season forbs, senescence occurred in the phenology of the plant communities.

Evaluation of Precision between Methods

For the July helicopter data, there was a significant difference in precision for Observer 1 (H) for shrub ($p = 0.008$) and bare ground ($p = 0.045$) (Table 2-1). The other four cover types had p-values that were not significant. For Observer 2 (M) in July, there was no significant difference between variances, suggesting there was no difference between field and imagery methods. For Observer 3 (L), there was a significance difference ($p = 0.031$) for dead shrub (Table 2-3). For the combination of the three observers in July (Table 2-4), there was a significant difference for shrub ($p = 0.001$). For the other five cover types, there was no significant difference between the two methods in terms of precision. The conclusion from the evaluation of the variances is that while there are limited cases where there are statistically significant differences in variances between methods, there was not enough consistency to indicate a difference in precision between the two measurement methods.

The June helicopter data for Observer 1 (H), showed there was a significant difference in variance for grass ($p = 0.00$) (Table 2-1). For the other two observers (M) and (L) for the June evaluation (Tables 2-2 and 2-3), there was no significant difference between methods. For the combined evaluation of all three observers, there was also a significant difference for bare ground ($p = 0.009$).

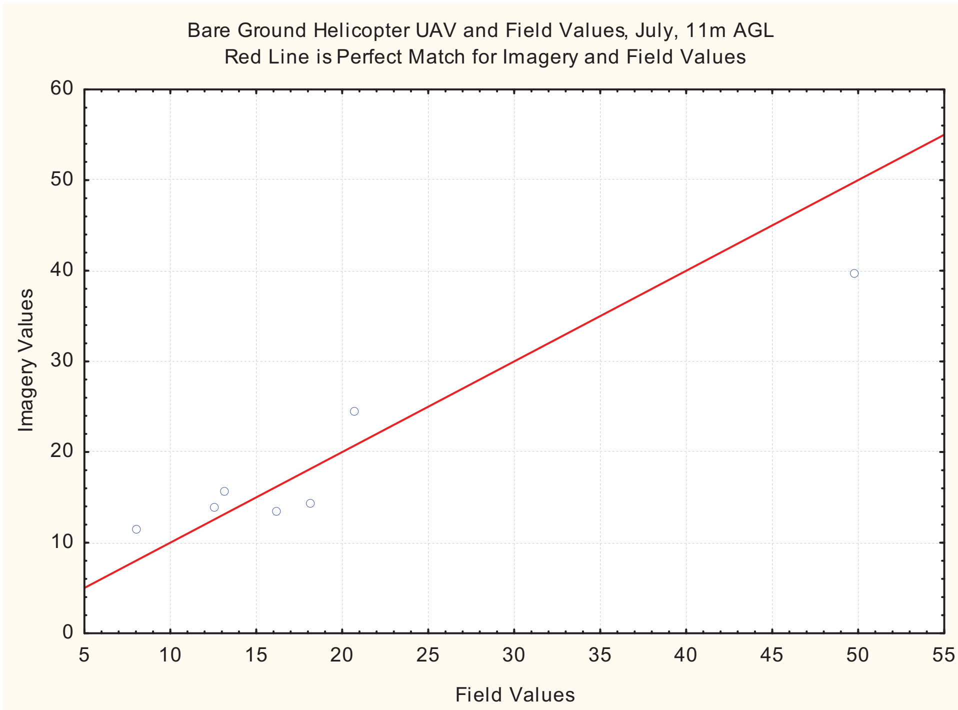


Figure 2-4. Perfect-fit line (in red) for imagery and field values for seven field plots to compare bare ground values for Observer 1 (H) flown in July at ≈11 m (35 ft) AGL.

Table 2-1. June and July field and imagery values for Observer 1. (Note: Values in red are significant $p = 0.05$).

Cover Type	June						July					
	n[a]	Mean Imagery Values (Standard Deviation)	Mean Field Values (Standard Deviation)	Test of Equality of Variances p-value	Mean Difference IV – FV (Standard Deviation)	Test of Means of Differences p-value	n	Mean Imagery Values (Standard Deviation)	Mean Field Values (Standard Deviation)	Test of Equality of Variances p-value	Mean Difference IV – FV (Standard Deviation)	Test of Means of Differences p-value
Shrub	4	12.2 (3.0)	10.1 (3.0)	0.988	2.2 (3.6)	0.319	7	22.0 (11.2)	12.7 (4.8)	0.008	9.2 (7.4)	0.017
Dead shrub	4	6.2 (3.9)	7.7 (4.4)	0.780	-1.5 (2.4)	0.302	7	8.5 (3.6)	10.1 (5.0)	0.372	-1.6 (3.7)	0.299
Grass	4	26.3 (17.9)	31.2 (10.5)	<0.001	-4.9 (7.4)	0.275	7	28.0 (13.1)	27.0 (13.6)	0.890	1.0 (7.4)	0.735
Forb	4	21.3 (16.5)	26.9 (15.7)	0.803	-5.7 (4.2)	0.073	7	12.6 (18.7)	20.5 (14.5)	0.274	-7.9 (9.1)	0.061
Litter	4	9.5 (2.6)	9.5 (3.1)	0.581	0.0 (5.5)	0.990	7	9.9 (1.9)	9.9 (3.5)	0.171	0.0 (3.0)	0.962
Bare ground	4	24.5 (9.4)	14.5 (5.4)	0.246	10.0 (5.5)	0.037	7	19.0 (10.0)	19.8 (13.9)	0.045	-0.8 (5.1)	0.690

a. "n" indicates the number of observations.

Table 2-2. June and July values for field and imagery collection for Observer 2. (Note: Values in red are significant at p = 0.05).

Cover Type	June						July					
	n[a]	Mean Imagery Values (Standard Deviation)	Mean Field Values (Standard Deviation)	Test of Equality of Variances p-value	Mean Difference IV – FV (Standard Deviation)	Test of Means of Differences p-value	n	Mean Imagery Values (Standard Deviation)	Mean Field Values (Standard Deviation)	Test of Equality of Variances p-value	Mean Difference IV – FV (Standard Deviation)	Test of Means of Differences p-value
Shrub	4	15.0 (5.1)	10.1 (3.0)	0.133	4.9 (2.5)	0.028	7	17.4 (6.9)	12.7 (4.8)	0.264	4.7 (4.3)	0.028
Dead shrub	4	4.7 (3.4)	7.7 (4.4)	0.743	-3.0 (5.1)	0.032	7	10.1 (5.7)	10.1 (5.0)	0.490	0.04 (2.3)	0.962
Grass	4	22.2 (11.2)	31.2 (10.5)	0.897	-9.1 (6.7)	0.074	7	28.7 (16.0)	27.0 (13.6)	0.489	1.7 (7.8)	0.584
Forb	4	9.4 (13.0)	26.9 (15.7)	0.579	-17.6 (6.7)	0.014	7	6.9 (16.2)	20.5 (14.5)	0.686	-13.7 (8.9)	0.007
Litter	4	5.2 (5.4)	9.5 (3.1)	0.468	-4.3 (5.2)	0.195	7	7.5 (3.8)	9.9 (3.5)	0.888	-2.4 (3.7)	0.137
Bare ground	4	43.6 (2.9)	14.5 (5.4)	0.428	29.1 (4.9)	0.001	7	29.4 (11.2)	19.8 (13.9)	0.303	9.5 (6.1)	0.006

a. "n" indicates the number of observations.

Table 2-3. Data for June and July for field and imagery collection for Observer 3. (Note: Values in red are significant at p = 0.05).

Cover Type	June						July					
	n[a]	Mean Imagery Values (Standard Deviation)	Mean Field Values (Standard Deviation)	Test of Equality of Variances p-value	Mean Difference IV – FV (Standard Deviation)	Test of Means of Differences p-value	n	Mean Imagery Values (Standard Deviation)	Mean Field Values (Standard Deviation)	Test of Equality of Variances p-value	Mean Difference IV – FV (Standard Deviation)	Test of Means of Differences p-value
Shrub	4	9.5 (3.8)	10.1 (3.0)	0.754	-0.6 (5.6)	0.832	7	17.2 (5.3)	12.7 (4.8)	0.828	4.4 (4.2)	0.032
Dead shrub	4	2.3 (1.1)	7.7 (4.4)	0.064	-5.4 (3.8)	0.067	7	6.1 (3.0)	10.1 (5.0)	0.031	-4.0 (2.5)	0.006
Grass	4	27.0 (9.7)	31.2 (10.5)	0.185	-4.2 (1.0)	0.004	7	30.8 (13.4)	27.0 (13.6)	0.976	3.7 (10.5)	0.377
Forb	4	9.7 (12.6)	26.9 (15.7)	0.507	-17.2 (6.5)	0.013	7	7.6 (16.3)	20.5 (14.5)	0.669	-12.9 (9.3)	0.010
Litter	4	7.2 (4.1)	9.5 (3.1)	0.695	-2.3 (4.3)	0.367	7	12.0 (3.6)	9.9 (3.5)	0.973	2.0 (4.4)	0.249
Bare ground	4	44.2 (6.5)	14.5 (5.4)	0.785	29.7 (5.3)	0.001	7	26.3 (9.7)	19.8 (13.9)	0.055	6.5 (5.6)	0.002

a. “n” indicates the number of observations.

5

Table 2-4. Data for June and July for field and imagery collection for all three observers. (Note: Values in red are significant at p = 0.05).

Cover Type	June						July					
	n[a]	Mean Imagery Values (Standard Deviation)	Mean Field Values (Standard Deviation)	Test of Equality of Variances p-value	Mean Difference IV − FV (Standard Deviation)	Test of Means of Differences p-value	n	Mean Imagery Values (Standard Deviation)	Mean Field Values (Standard Deviation)	Test of Equality of Variances p-value	Mean Difference IV − FV (Standard Deviation)	Test of Means of Differences p-value
Shrub	12	12.2 (4.4)	10.1 (3.0)	0.136	2.1 (4.4)	0.122	21	18.9 (8.1)	12.7 (4.8)	0.001	6.1 (5.7)	<0.001
Dead shrub	12	4.4 (3.2)	7.7 (4.4)	0.468	-3.3 (3.9)	0.014	21	8.2 (19.3)	10.1 (5.0)	0.613	-1.8 (3.2)	0.017
Grass	12	25.1 (12.3)	31.2 (10.5)	0.092	-6.1 (5.7)	0.003	21	29.2 (13.5)	27.0 (13.6)	0.710	2.2 (8.3)	0.248
Forb	12	13.5 (14.1)	26.9 (15.7)	0.940	-13.5 (7.9)	0.001	21	9.0 (16.5)	20.5 (14.5)	0.175	-11.5 (9.0)	<0.001
Litter	12	7.3 (4.2)	9.5 (3.1)	0.203	-2.2 (4.9)	0.148	21	9.8 (3.6)	9.9 (3.5)	0.773	-0.1 (4.0)	0.940
Bare ground	12	37.4 (11.3)	14.5 (5.4)	0.009	22.9 (10.7)	<0.001	21	24.9 (10.7)	19.8 (13.9)	0.110	5.1 (6.9)	0.003

a. “n” indicates the number of observations.

Evaluation of Accuracy between Methods

The July helicopter data for Observer 1 (H), show a significant difference in accuracy between methods only for shrub ($p = 0.017$) (Table 2-1, Figure 2-5). Scatter plots were generated with lines of perfect fit to evaluate the relationship between field and imagery values. Figure 2-4 shows a sample of one of these perfect-fit plots for Observer 1 (H), July, bare ground values. Appendix A has a complete set of these plots for Observer 1 and all observers combined. For Observer 2 (M) in July, the differences for dead shrub, grass, and litter were not statistically significant. For shrub ($p = 0.028$), forb ($p = 0.007$), and bare ground ($p = 0.006$), there was a statistically significant difference. For Observer 3 (L), the differences for grass and litter were not statistically significant. For shrub ($p = 0.032$), dead shrub ($p = 0.006$), forb ($p = 0.010$), and bare ground ($p = 0.002$) there was a statistically significant difference. For the combination of all three observers, the differences for grass and litter were not statistically significant. The values for shrub ($p = \leq 0.001$), dead shrub (0.017), forb ($p = \leq 0.001$), and bare ground ($p = 0.003$) were statistically significant.

For the June helicopter data for Observer 1 (H), there was a significant result for bare ground ($p = 0.037$) (Figure 2-6); forbs were marginally significant ($p = 0.073$). For the other four cover types, there were no significant differences; thus, there was no difference between the two methods for shrub, dead shrub, grass, and litter. A possible explanation for the difference for bare ground and forb is that the field values were collected in July, almost a month after the imagery collection. For the bare ground assessment, the grasses and shrubs had not yet reached their full growth for the year; thus, the imagery values collected in June show a higher value for bare ground by almost 10%. For Observer 2 (M), there was a significant difference for shrub ($p = 0.028$), dead shrub ($p = 0.032$), forb ($p = 0.014$), and bare ground ($p = 0.001$). For Observer 3 (L), there was a significant difference for grass ($p = 0.004$), forb ($p = 0.013$), and bare ground ($p = 0.001$). For the combination of the three observers for June, there was a significant difference for dead shrub ($p = 0.014$), grass ($p = 0.003$), forb ($p = 0.001$), and bare ground ($p = \leq 0.001$). There was no significant difference for shrub or litter.

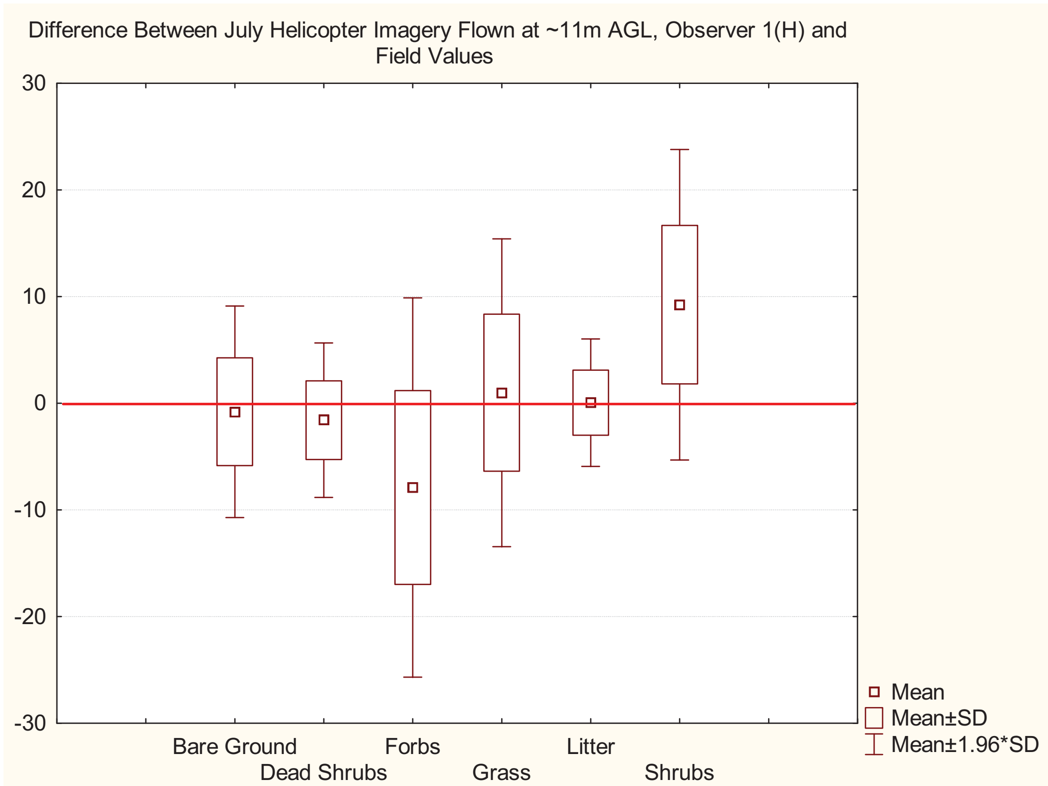


Figure 2-5. Difference between image and field values for Observer 1 (H) for July helicopter data at ≈11 m (35 ft) AGL.

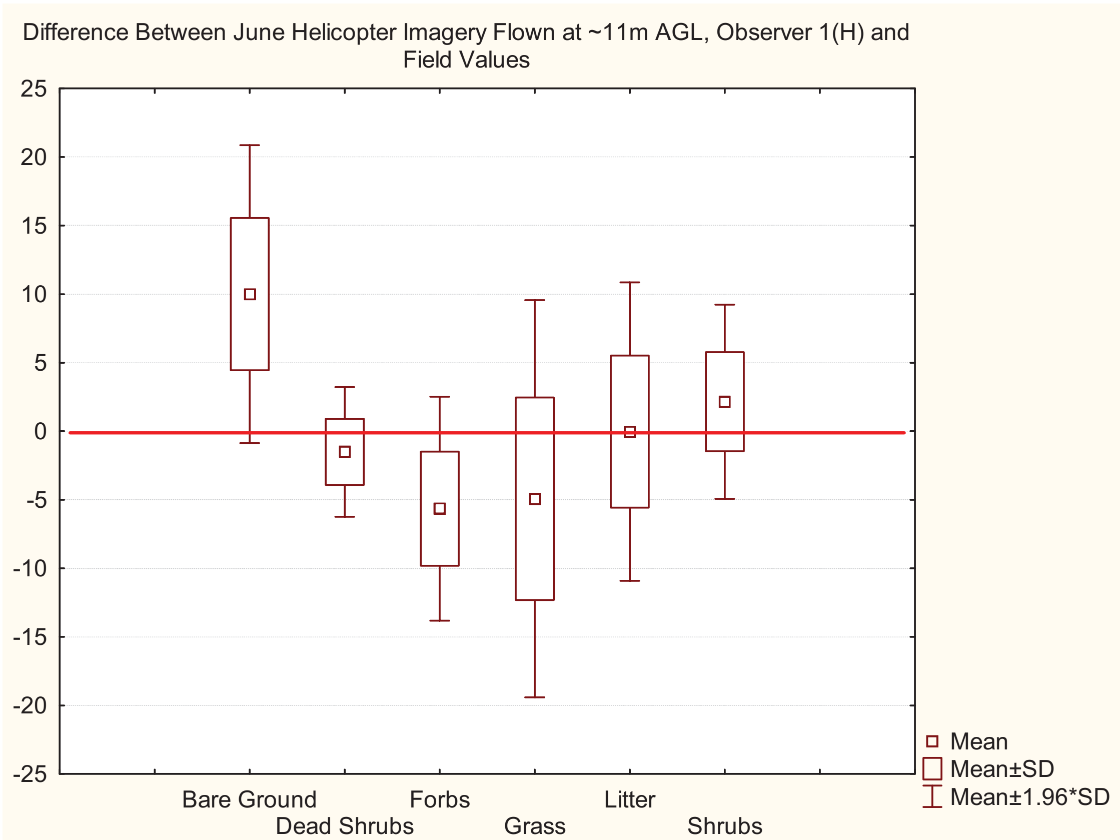


Figure 2-6. Difference between image and field values for Observer 1 (H) for June helicopter data at ≈11 m (35 ft) AGL.

Discussion

Impact of Phenological Time and Skill of Observers on Imagery Results

Ground cover has been identified as among 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; Pellant 2005).

The set of results from Observer 1 (H) is probably the best for comparing the relative accuracy of the imagery and field results because it presents results for only one highly trained observer. For the July data (where the imagery was collected within a week of the field data), it appears that Observer 1 (H) over classified imagery areas as shrub that were identified as forb in the field (Figure 2-7). It is understood that for these plots there is no connection among mean values for cover types, however a line is drawn among the points to make it easier to visually see differences between mean values. The shrub difference was statistically significant while forb was marginally significant ($p = 0.061$). There was very good comparison in mean values between imagery and field values for grass, litter and bare ground and to a lesser extent dead shrub. These results suggest that the relative accuracy of UAV technology when compared to more conventional field data is good for measuring litter, grass, and bare ground on rangelands.

The results for the combination of the three observers for July (Figure 2-8) follow similar patterns. In comparing the imagery to the field values, the imagery values have good agreement for grass and litter. Shrub and bare ground were statistically significant and overestimated while dead shrub and forb were statistically significant and underestimated. The significant difference for shrub may have been caused by the greater potential to count every shrub with the imagery method because the 100-point grid overlaid the entire subplot and the points were located 30 × 38 cm (12 × 15 in.) apart. For the field method, we read 50% of the subplots and the point frame was placed randomly. It is therefore possible that one or more entire shrubs were not counted in the subplots, especially in those plots that had very low shrub cover (i.e., Plots 1 and 2). For bare ground, the significance may have been due to the fact that the selected plots varied greatly; to reduce this variability, more plots would need to be evaluated in a larger field study. The mean differences for shrub, dead shrub, forb, and bare ground for all observers may have been caused by the difficulty in identifying forbs in the July imagery that were growing underneath and around the edges of shrubs, especially for observers with

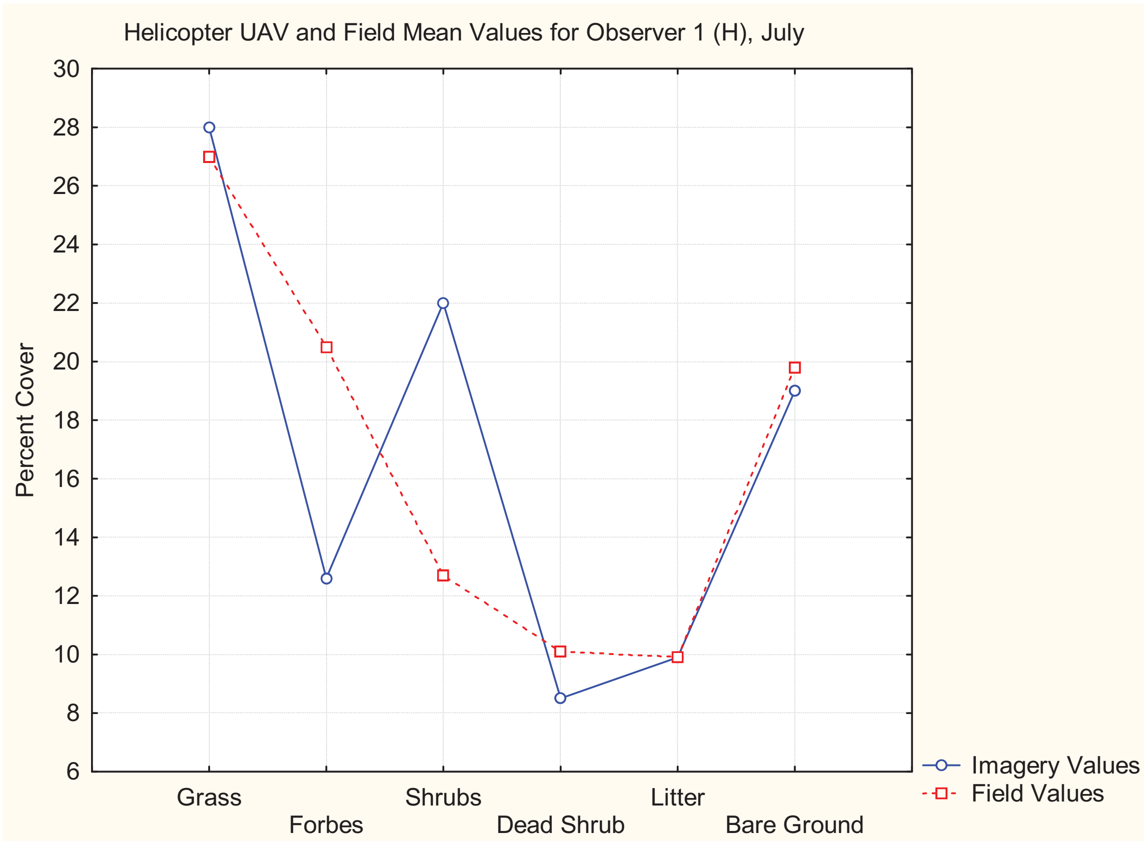


Figure 2-7. Comparison of imagery values against field values for Observer 1 (H) July helicopter data flown at ≈11 m (35 ft) AGL.

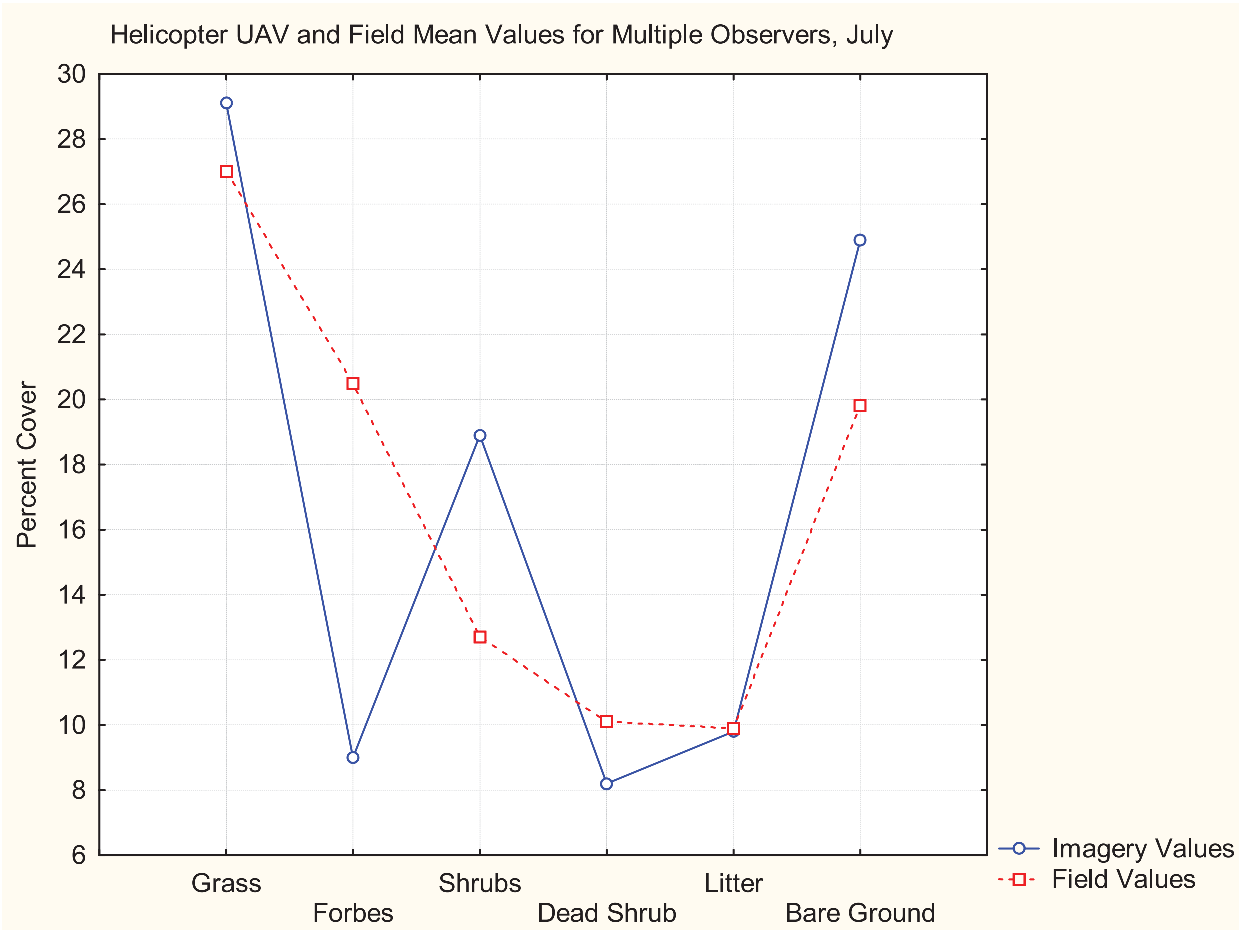


Figure 2-8. Comparison of imagery values against field values for multiple observers July helicopter data flown at ≈11 m (35 ft) AGL.

limited experience. Many of the smaller forbs had passed their peak growth period and some were senescing; therefore, the shape and color were difficult to differentiate with the current imagery quality and resolution (4 megapixel). Senescence also made it difficult to tell the difference between some of the forbs and grasses in the imagery. It may be possible to resolve this issue by using a camera with a higher resolution and collecting imagery values closer to the peak growing season. For the field method, all the subplots were read at the ground level and the observers could get right next to the vegetation for positive identification. Thus, timing of collecting imagery for rangelands is an important factor that needs to be evaluated more and considered when collecting and comparing aerial imagery with field data. For areas around the INL, the best window is probably between the end of June and first week of July. This could differ slightly depending on whether a study's objectives were focused at a species level or functional group assessment.

The helicopter imagery collected in June showed patterns similar to those for the July imagery and field data for the Observer 1 (H) (Figure 2-9) and the combination of all three observers (Figure 2-10). Much of the difference between the field and imagery values may be attributable to the fact that the field values were collected more than a month after the imagery values and the plants had not reached their peak growth period in early June. Results support this idea because the imagery values tend to classify more areas as bare ground when the field assessment shows it to be grass or forb. In Figure 2-9, only the difference for bare ground was statistically significant although the difference for forb was marginally significant ($p = 0.073$). The combined analysis of all three observers (Figure 2-10) follows the same general pattern as the results in Figure 2-9. In comparing the imagery values to the field values, the imagery values are greater for bare ground and are deficient for grass, forb, and, to a lesser extent, dead shrub. As might be expected, there was a greater difference in mean values for three observers because of the broad range of skill levels. The difference in training and experience among observers is an important issue that needs to be considered when using human judgment or creating teams to evaluate imagery. At the conclusion of the training, there was still some difference among observers but most of this was attributed to difficulty in distinguishing grasses from forbs and litter and the evaluation of growth under shrubs. As shown here, a well structured and verifiable quality-control training program is important for any project considering UAV technology for implementation at the field scale.

It is interesting that there was poor agreement between mean values for forb and shrub for both the experienced Observer 1 and the multiple observers (Figures 2-7 and 2-8) for July. Often in rangelands, forbs will grow under shrubs because there is greater moisture and nutrients and the shrub

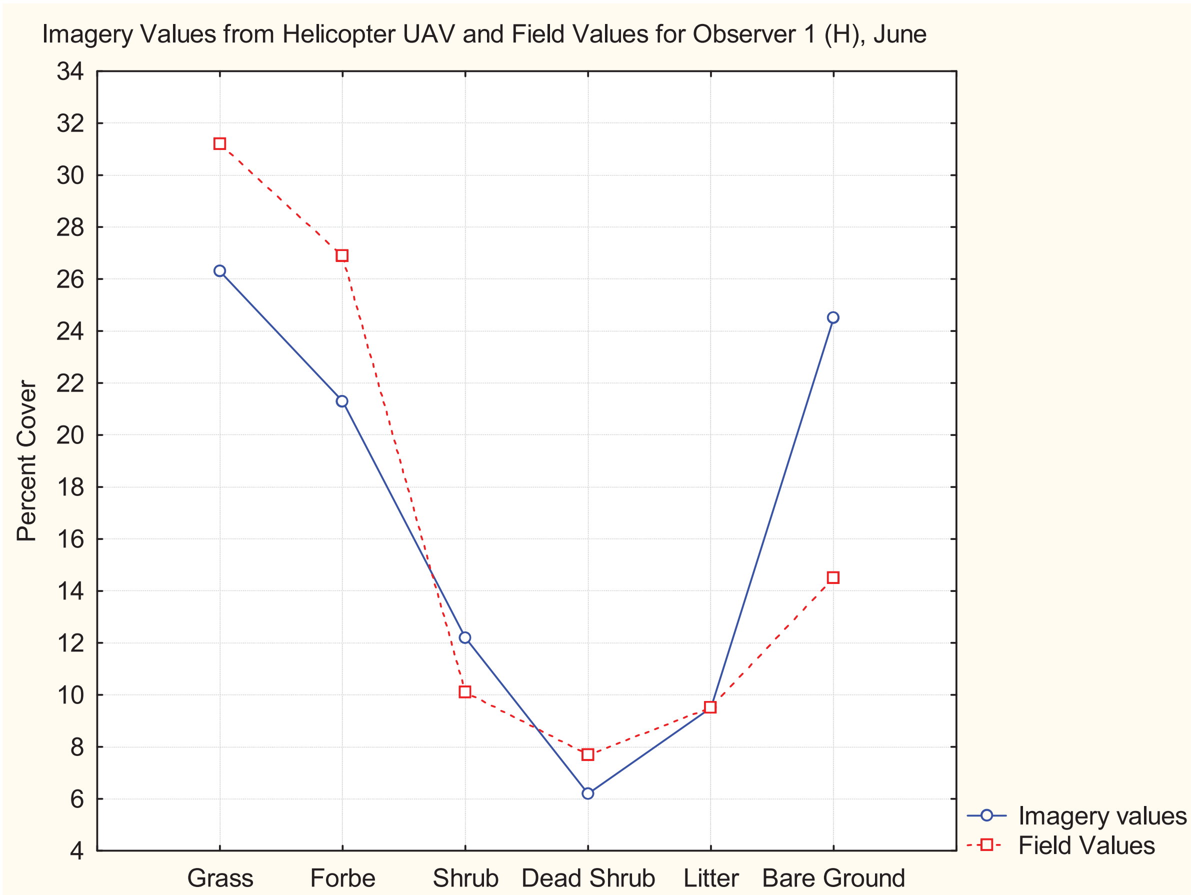


Figure 2-9. Comparison of imagery values against field values for Observer 1 (H) June helicopter data flown at ≈11 m (35 ft) AGL.

(Note: Field values were collected in July).

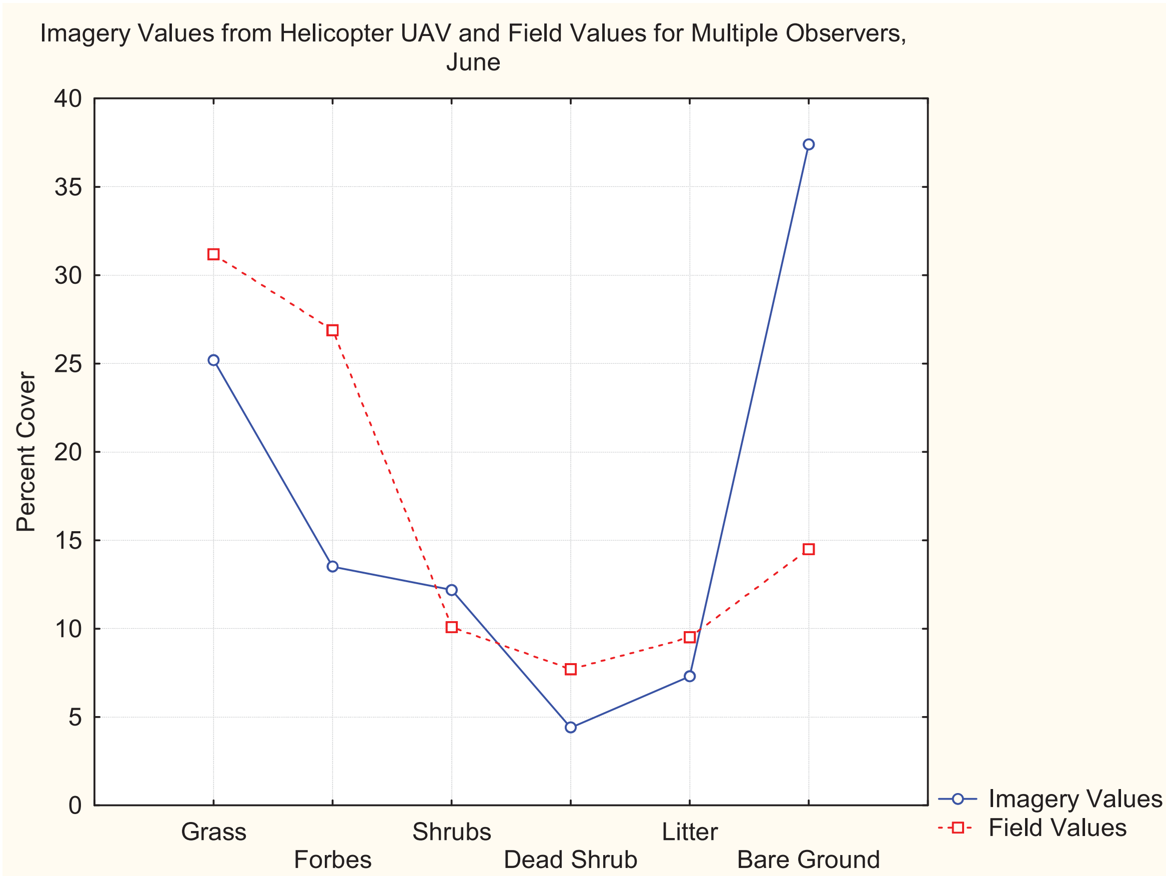


Figure 2-10. Comparison of imagery values against field values for multiple observers June helicopter data flown at ≈11 m (35 ft) AGL.

(Note: Field values were collected in July).

provides protection from grazers. Because many desert shrubs serve as islands of fertility (Carroll et al. 1999) and provide protection for forbs, it can be difficult to differentiate between the two without being able to make observations on the ground. A similar situation can occur with grasses, but often the grass will grow as high as small shrubs if they are not grazed and grasses are easier to identify with imagery. Grazing has been excluded, except for wildlife, in the study area for several decades.

Utility of UAV Technology for Sampling Diverse Vegetation Types

The plots selected for this study were chosen to represent the high degree of diversity found on the INL. Some of the plots were very high in forb cover and low in shrub cover (Plots 1 and 2), others had major components of rhizomatous or bunch grasses (Plots 4 and 5), and others had major areas with desert pavement (Plot 7), a form of bare ground. This high degree of diversity allowed UAV technology to be evaluated under a wide variety of conditions. This study has identified some of the limitations of using UAV technology for evaluation of shrubs and forbs and the possible advantage of the technology for evaluation of litter and grass. The remote sampling approach using a near-earth UAV platform may be best for collecting large random samples for rangeland assessments. However, to verify accuracy there will always need to be some level of comparison between field and remote sensing data results.

Comparison of Time Required for Data Collection and Analysis

A log was kept by each observer on the amount of time required to read each image along with observations about the imagery quality. The time required to read an image averaged five to six minutes. The UAV helicopter method did have an advantage over conventional field methods relative to the time required to collect and analyze data. Table 2-5 is a summary of the times required to collect data with both the helicopter 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 field-data collection could in general be reduced by experienced field crews, but it would be almost impossible to reduce the time to below that required to collect the imagery with the helicopters. The total flight time was 40 min and more than 210 images were collected. The remainder of the time was spent on setup, safety checks, and data transfer. One of the most difficult tasks with the UAV process was selecting the best image for analysis. Thus, objective three (comparing the level of effort to collect data) can be answered: under the constraints of this study, UAV technology, compared to field methods, requires a lower level of effort and produces a reliable digital data record.

The system tested here also addressed the first objective of this study (assess the feasibility of using UAV helicopters to collect data). As the study shows, UAVs are a feasible system for collecting data on rangelands and hold promise for measuring selected cover types under the conditions and constraints of this study. (Agencies considering UAV helicopters as a data collection alternative will need to evaluate the results from this study against their technical and legal requirements.) Two things almost certainly will influence the future use of unmanned helicopters: 1) improved technology will continue to decrease equipment weight and increase data storage capacity (including the helicopter platform, camera system, and image processing systems) and 2) high-quality, reliable data will be

Table 2-5. Comparison of times required for collection of UAV and field data sets.

Activity	Helicopter time requirement (hr)	Field method time requirement (hr)
Set up 7 plots (with 4 sub plots)	5	4
Collect UAV imagery, setup to takedown time	8	
Collect field data using point-frame method and sampling 50% of all 28 sub plots (7 plots x 4 sub plots)		36
Image processing (12.5 min/subplot × 28 subplots)	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
Total Time	**25.8**	**47**

required for making and defending management decisions. Considering these factors, along with the concerns of safety, increasing costs for field workers, and reduced availability of trained workers, UAV helicopters may provide cost-effective options for collecting future data for rangeland management.

Recommendations and Conclusions

The following recommendations have been developed as a result of this study:

1. UAV helicopters provide an excellent platform for collecting data over large areas; however, there are limitations about how long they can fly. Future research should focus on the design of the most robust and field-worthy system for collecting data and identify the best total system (camera and navigational instruments) that can be flown by operators with minimum UAV training.

2. Determining the optimum height above-ground level for conducting UAV flights is critical for making observations as quickly as possible. Flights conducted at higher levels can collect imagery for a larger area, but resolution is reduced. Future research should focus on establishing

the optimum height and resolution for the current technology for collecting rangeland data from UAV helicopters.

3. A study should be conducted to compare UAV helicopter-collected data against several conventional field methods currently being used by the BLM, USDA Forest Service, and other rangeland scientists. Greater involvement with land-management agency scientists will improve the understanding of the current challenges and will enhance data collection, which should make the data better accepted by the agencies.

4. To study specific species, future studies should focus on flying UAV helicopters at various times during the growing season and identify the best time for collecting vegetation data. It appears from this study that the best time frame for collecting imagery for high semi-arid ecosystems is late June to early July, a fairly short window.

5. Image processing using SamplePoint was reasonable for this study. However, for UAV helicopters or any other near-earth image collection system to become useful, image processing software needs to be developed into a process 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.

Management Implications

Results from collecting vegetation data using UAV helicopters 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, involve relatively low safety risk with proper training, and reduce the time spent in the field collecting data. Using results from this study, land managers in semi-arid ecosystems could consider using UAV platforms to collect data for selected vegetation types, specifically bare ground. Because there appears to be convergence in the scientific community (Maczko et al. 2004; Pellant et al. 2005) that bare ground is one of the most important vegetation cover measurements for assessing rangeland health, UAV platforms may play an important role in securing quality information for future resource inventory and monitoring activities.

Acknowledgements

The authors would like to extend sincere thanks to Mark McKay for piloting the helicopter; Ron Rope, Ryan Hruska, Sera White, and Angie Smith (INL), Marilynne Manguba (The Nature Conservancy), and Anthony Piscitella, Chase Eckersell, and Katherine Schoellenbach (students) for assistance in collecting field data, reading imagery, and assisting with edits; Terry Booth and Sam Cox (USDA-ARS) for developing and assisting in using SamplePoint; Dr. Larry Blackwood for providing guidance with statistical analysis; and Drs. Lee Vierling and Don Crawford (University of Idaho) and Sue Vilord, Jackie Hafla, and Roger Blew (Stoller Corporation) for technical guidance and assistance with providing equipment and quality control checks for field activities.

References

Anderson, J. E., K. T. Ruppel, J. M. Glennon, K. E. Holte, and R. C. Rope. 1996. Plant communities, ethnoecology, and flora of the Idaho National Engineering Laboratory. ESRF-005. Idaho Falls, ID: Environmental Science and Research Foundation. 110 p.

Blackwood, L. C., and E. L. Bradley. 1991. An omnibus test for comparing two measuring devices. *Journal of Quality Technology* 23:12–16.

Bonham, C. D. 1989. Measurements for Terrestrial Vegetation. John Wiley & Sons, New Your, New York. 319 p.

Booth, D. T., S. E. Cox, T. W. Meikle, and C. Fitzgerald. 2006a. The accuracy of ground-cover measurements. *Rangeland Ecology and Management* 59:179–188.

Booth, D. T., S. E. Cox, and R. D. Berryman. 2006b. Point sampling digital imagery with 'SamplePoint.' *Environmental Monitoring and Assessment* 123:97–108.

Booth, D. T., and P. T. Tueller. 2003. Rangeland monitoring using remote sensing. *Arid Land Research and Management* 17:455–467.

Brower, J. E., J. H. Zar, and C. N. Von Ende. 1990. Field and laboratory methods for general ecology (3rd edition). Dubuque, IA: Wm. C. Brown Publishers. 237 p.

Brown, D. E. (ED.). 1982. Biotic communities of the American Southwest—United States and Mexico. *Desert Plants*. Tucson, AZ: University of Arizona Press. 344 p.

Bunting, S. C. 2002. Natural and prescribed fires in Big Sagebrush steppe—response of individual species and implication to burning practices. Restoration and Management of Sagebrush/Grass Communities Workshop. 4–8 November 2002; Elko, NV: RangeNet. 54 p. *Available at* http://www.rangenet.org/trader/2002_Elko_Sagebrush_Conf.pdf. *Accessed 19 June 2006.*

Bunting, S. C., B. M. Kilgore, and C. L. Bushey. 1987. Guidelines for prescribed burning sagebrush-grass rangelands in the northern Great Basin. General Technical Report INT-231. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Research Station. 33 p.

Carroll, C. R., J. Belnap, R. Breckenridge, and G. Meffe. 1999. Ecosystem sustainability and condition. *In:* W. T. Sexton, A. J. Malk, R. C. Szaro, and N. C. Johnson (EDS.). A common reference for ecosystem management, Vol. II. New York, NY: Elsevier Science. p. 583–598.

Colket, E. C. 2003. Long-term vegetation dynamics and post-fire establishment patterns of sagebrush steppe: a thesis presented in partial fulfillment of the requirements for the degree of master of science with a major in rangeland ecology and management in the college of graduate studies [dissertation]. Moscow, ID: University of Idaho. 144 p.

Connelly, J. W., K. P. Reese, R. A. Fischer, and W. L. Wakkinen. 2000. Response of a sage grouse breeding population to fire in southeastern Idaho. *Wildlife Society Bulletin* 28:90–96.

Cook, C. W., and J. Stubbendieck. 1986. Range research: basic problems and techniques. Denver, CO: Society for Range Management. 317 p.

Crawford, J. A., R. A. Olson, N. E. West, J. C. Mosley, M. A. Schroeder, T. D. Whitson, R. F. Miller, M. A. Gregg, and C. S. Boyd. 2004. Ecology and management of sage-grouse and sage-grouse habitat. *Journal of Range Management* 57:2–19.

Daubenmire, R. F. 1970. Steppe vegetation of Washington. Technical Bulletin 62. Pullman, WA: Washington State University, Agricultural Experiment Station. 131 p.

Floyd, D. A., and J. E. Anderson. 1982. A new point frame for estimating cover of vegetation. *Vegetatio* 50:185–186.

Forman, A. D., and J. R. Hafla. 2005. Common plants of the INL. STOLLER-ESER-81. Idaho Falls, ID: Environmental Surveillance, Education and Research Program. 125 p. *Available at:* http://www.stoller-eser.com/CMP/Plant_handbook/index.asp. *Accessed 7 April 2007.*

French, N. R, and J. E. Mitchell. 1983. Long-term vegetation changes in permanent quadrants at the Idaho National Engineering Laboratory site. Bulletin Number 36. Moscow, ID: University of Idaho, College of Forestry, Wildlife and Range Sciences. 42 p.

Grubbs, F. E. 1973. Errors of measurement, precision, accuracy and the statistical comparison of measuring instruments. *Technometrics* 15:53–66.

Grubbs, F. E. 1948. On estimating precision of measuring instruments and product variability. *Journal of the American Statistical Association* 43:243–264.

Johnson, D. E., M. Vulfson, M. Louhaichi, and N. R. Harris. 2003. VegMeasure version 1.6 user's manual. Corvallis, OR: Oregon State University, Department of Rangeland Resources, VegMeasure Project. 51 p.

Knick, S. T., and J. T. Rotenberry. 1995. Landscape characteristics of fragmented shrubsteppe habitats and breeding passerine birds. *Conservation Biology* 9:1059–1071.

Maczko, K. A., L. D. Bryant, D. W. Thompson, and S. J. Borchard. 2004. Putting the pieces together: assessing social, ecological, and economic rangeland sustainability. *Rangelands* 26(3):3–14.

Mahalovich, M. F., and E. D. McArthur. 2004. Sagebrush seed (Artemisia ssp.) and plant transfer guidelines. *Native Plants* 5:141–148.

Maloney, C. J., and S. C. Rastogi. 1970. Significance test for Grubbs's estimators. *Biometrics* 26:671–676.

Mouat, D. A., and C. F. Hutchinson (EDS.). 1995. Desertification in developed countries. Dordrecht, The Netherlands: Kluwer Academic Publishers. 363 p.

National Research Council. 1994. Rangeland health: new methods to classify, inventory, and monitor rangelands. Washington, DC: Committee on Rangeland Classification, The National Academies Press. 180 p.

National Transportation Safety Board. 2007. *Aviation accident database & synopses*. *Available at:* http://www.ntsb.gov/ntsb/query.asp. Accessed *7 April 2007*.

Nevada Wildlife Federation. 2002. Enhancing sage grouse habitat … A Nevada landowner's guide. Reno, NV. 13 p. *Available at:* http://www.nvwf.org/. *Accessed 5 April 2007*.

Pedersen, E. K., J. W. Connelly, J. R. Hendrickson, and W. E. Grant. 2003. Effect of sheep grazing and fire on sage grouse populations in southeastern Idaho. *Ecological Modelling* 165:23–47.

Pellant, M., P. Shaver, D. A. Pyke, and J. E. Herrick. 2005. Interpreting indicators of rangeland health, Version 4. Technical Reference 1734-6, BLM/WO/ST-00/001+1734/REV05. Denver, CO: U.S. Department of the Interior, Bureau of Land Management, National Science and Technology Center. 122 p.

Pitman, E. J. G. 1939. A note on normal correlation. *Biometrics* 31:9–12.

Pyke, D. A., J. E. Herrick, P. Shaver, and M. Pellant. 2002. Rangeland health attributes and indicators for qualitative assessment. *Journal of Range Management* 55:584–597.

Rickard, W. H., L. E. Rogers, B. E. Vaughan, and S. F. Liebetrau, (EDS.). 1988. Shrub-steppe: balance and change in a semi-arid terrestrial ecosystem. New York, NY: Elsevier. 272 p.

Smith, R. L. 1990. Ecology and field biology (4th edition). New York, NY: Harper Collins. 922 p.

Society for Range Management, Task Group on Unity in Concepts and Terminology Committee Members. 1995. New concepts for assessment of rangeland condition. *Journal of Range Management* 48(3):271–282.

USDI-BLM (U.S. Department of the Interior, Bureau of Land Management). 1997. Standards for healthy rangelands and guidelines for livestock grazing management for the public lands administered by the Bureau of Land Management in the State of Wyoming. Booklet BLM/WY/AE-97-023+1020. Cheyenne, WY: U.S. Department of the Interior. 16 p.

Walker, B. H. 1993. Rangeland ecology: Understanding and managing change. *AMBIO* 22:80–87.

Whitford, W. G. (ED.). 1986. Pattern and process in desert ecosystems. Albuquerque, NM: University of New Mexico Press. 139 p.

Zager, P. 2006. UAVs and natural resources. Eleventh Biennial USDA Forest Service Remote Sensing Applications Conference. 24–28 April 2006; Salt Lake City, UT: U.S. Department of Agriculture Forest Service, Remote Sensing Applications Center. 33 p. *Available at:* http://www.fs.fed.us/eng/rsac/RS2006/presentations/zager.pdf. *Accessed 5 April 2007*.

Appendix A

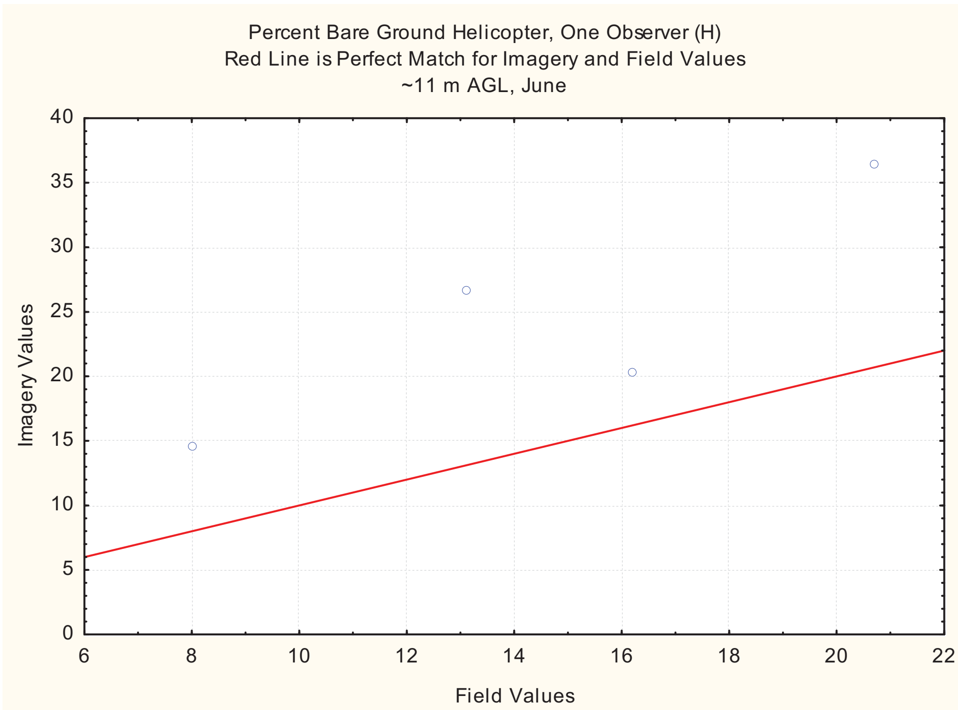
Graphs for June and July Data for Imagery against Field Values for One Observer with High Degree of Experience and Multiple Observers

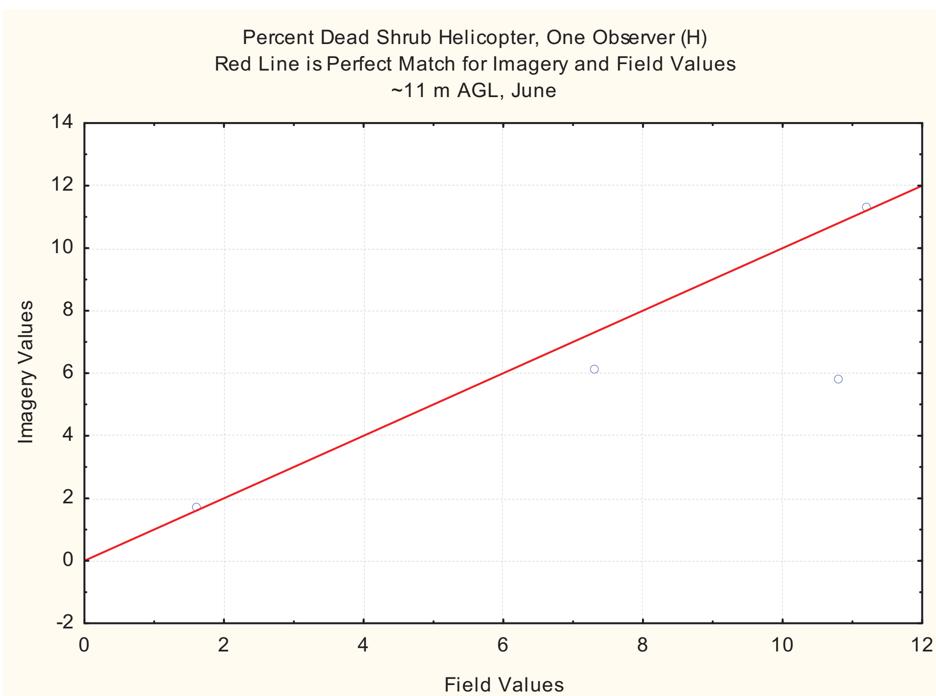
Below are the graphs for the June and July helicopter data with imagery values (on the Y axis) and field values (on the X axis) for the observer with a high degree (H) of experience and multiple observers. These graphs show the lines of perfect match between the imagery and field values. The imagery was collected in June (6/08/05) and July (7/20/05). The field values were collected in mid July from July 22–25, 2005. Entering the field plot areas before completing the flights would have compromised the integrity of the vegetation.

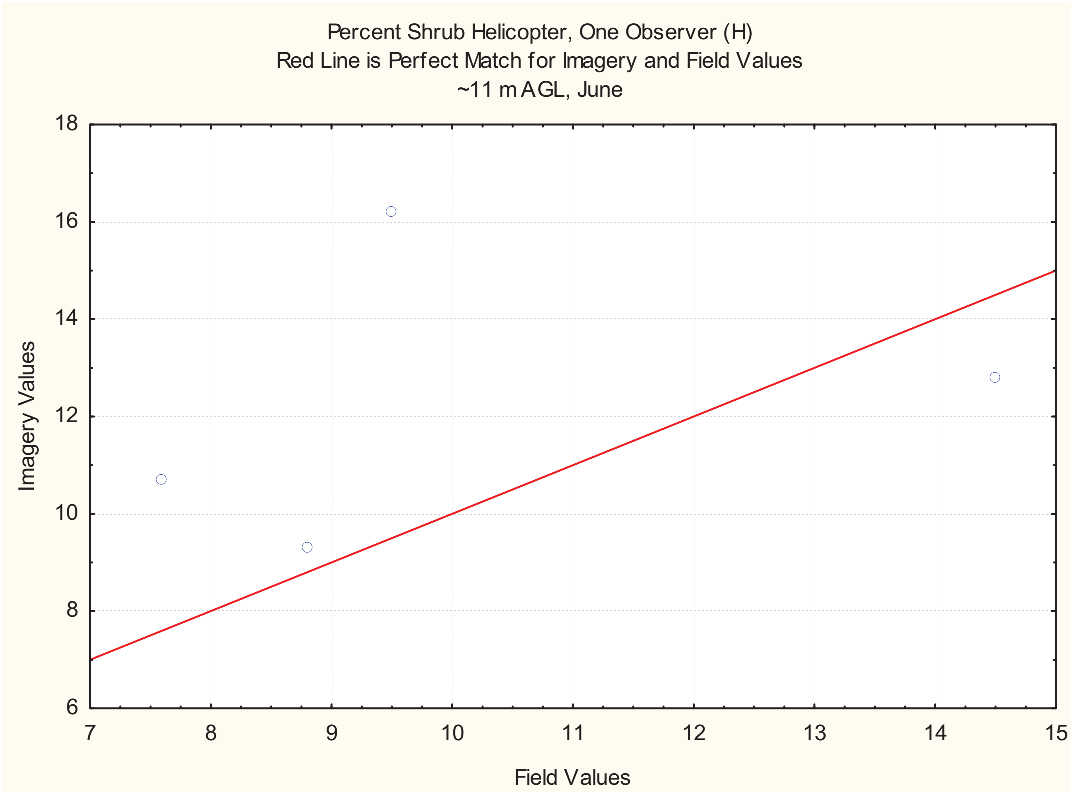
Results of most of the plots show reasonable comparison between values.

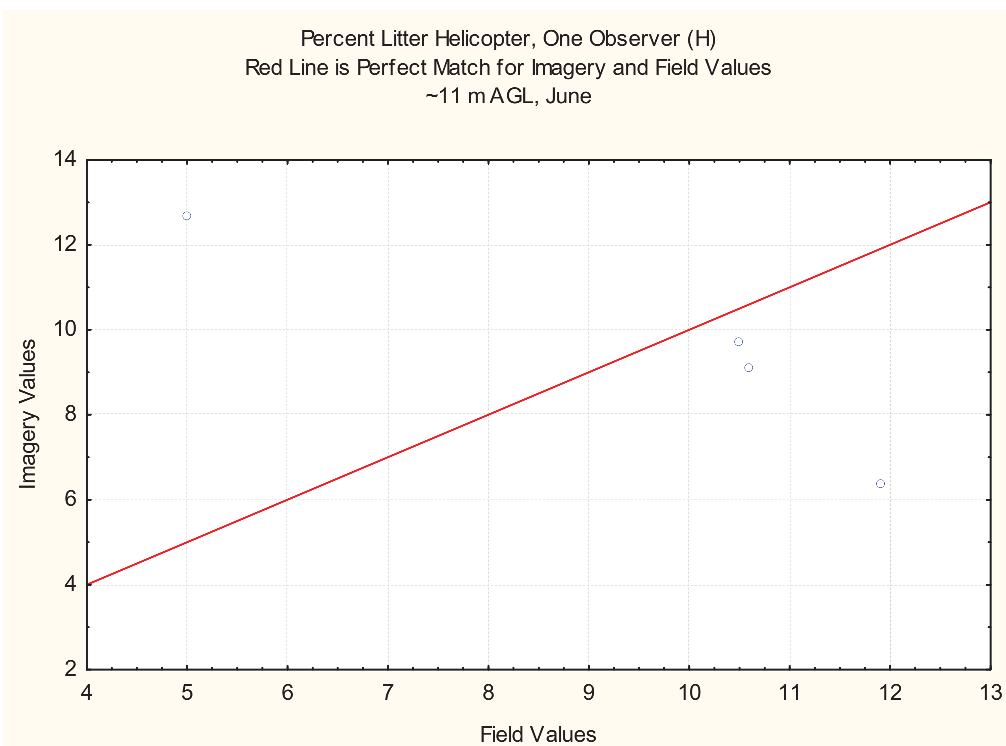
Scatter Plots for June, Observer 1 (H)

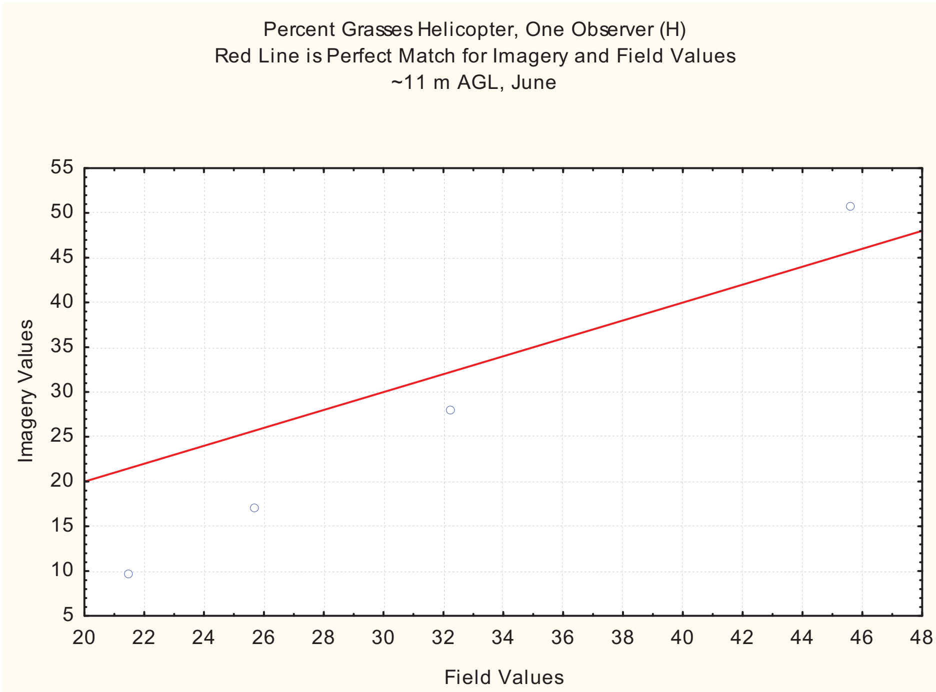
Note: Only four of seven plots were sampled because of equipment failure.

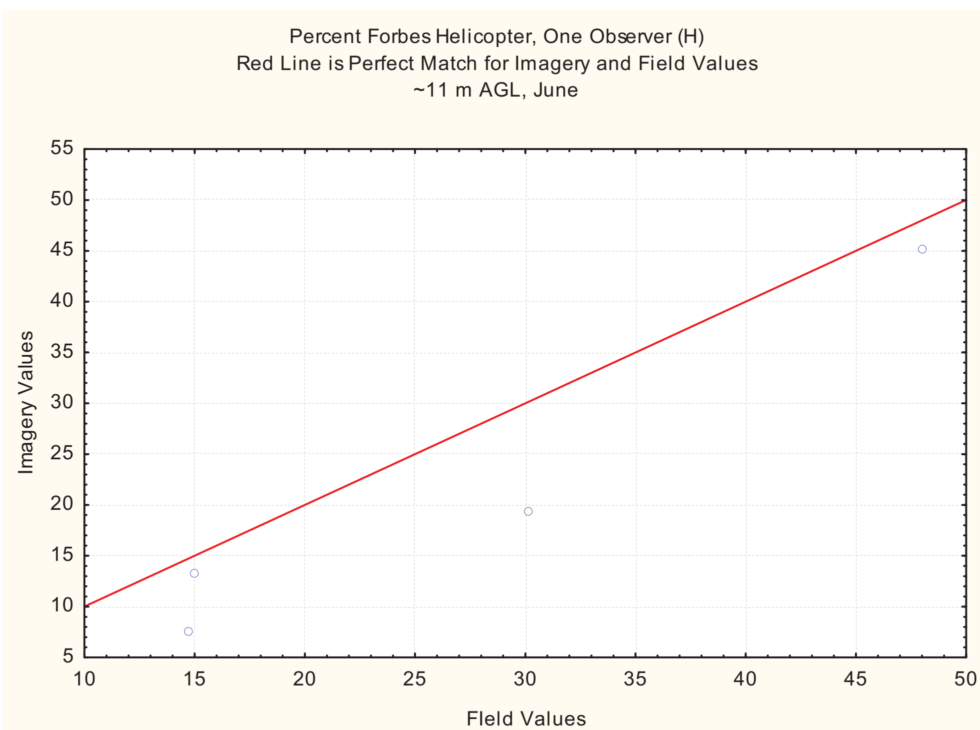





Percent Shrub Helicopter, One Observer (H)
Red Line is Perfect Match for Imagery and Field Values
~11 m AGL, June
Imagery Values
Field Values
18
16
14
12
10
8
6
7
8
9
10
11
12
13
14
15

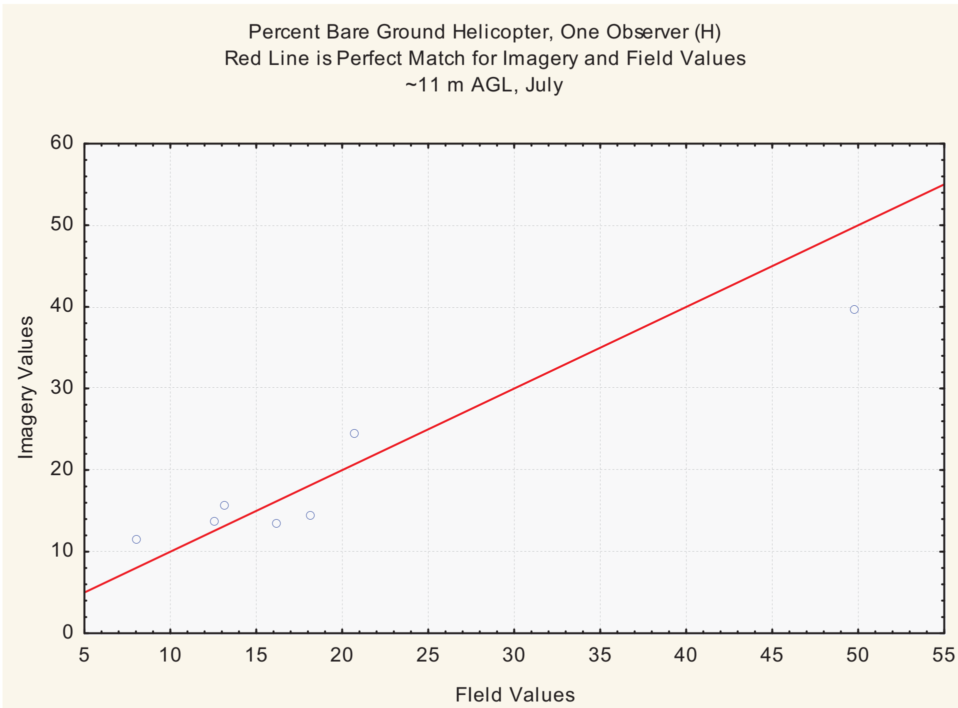

Percent Litter Helicopter, One Observer (H)
Red Line is Perfect Match for Imagery and Field Values
~11 m AGL, June
Imagery Values
Field Values
14
12
10
8
6
4
2
4
5
6
7
8
9
10
11
12
13

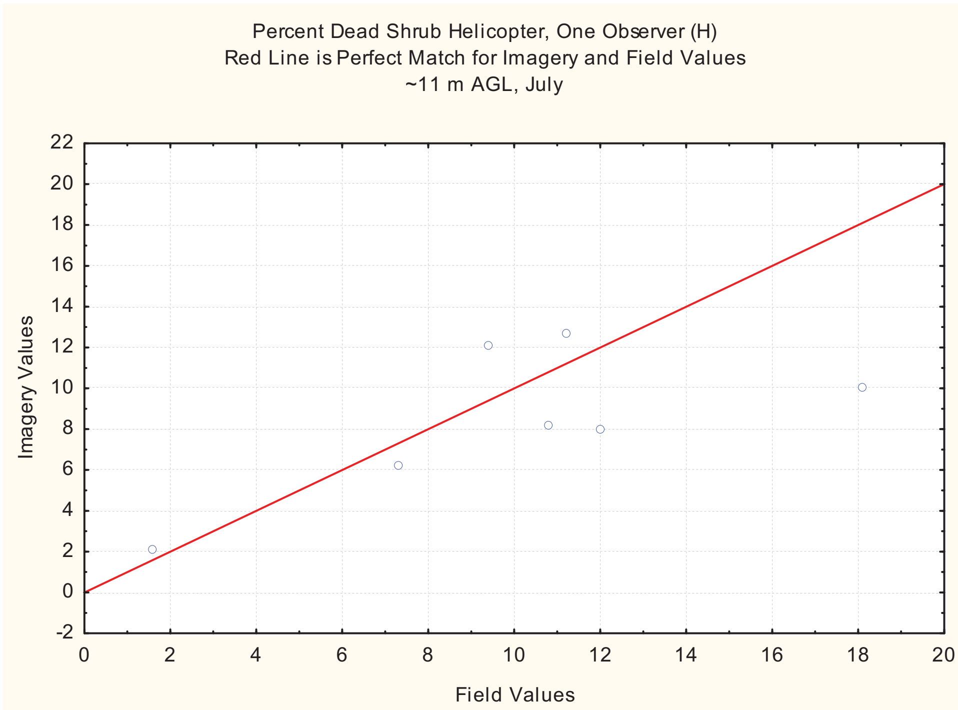

Percent Grasses Helicopter, One Observer (H)
Red Line is Perfect Match for Imagery and Field Values
~11 m AGL, June
Imagery Values
Field Values
55
50
45
40
35
30
25
20
15
10
5
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48

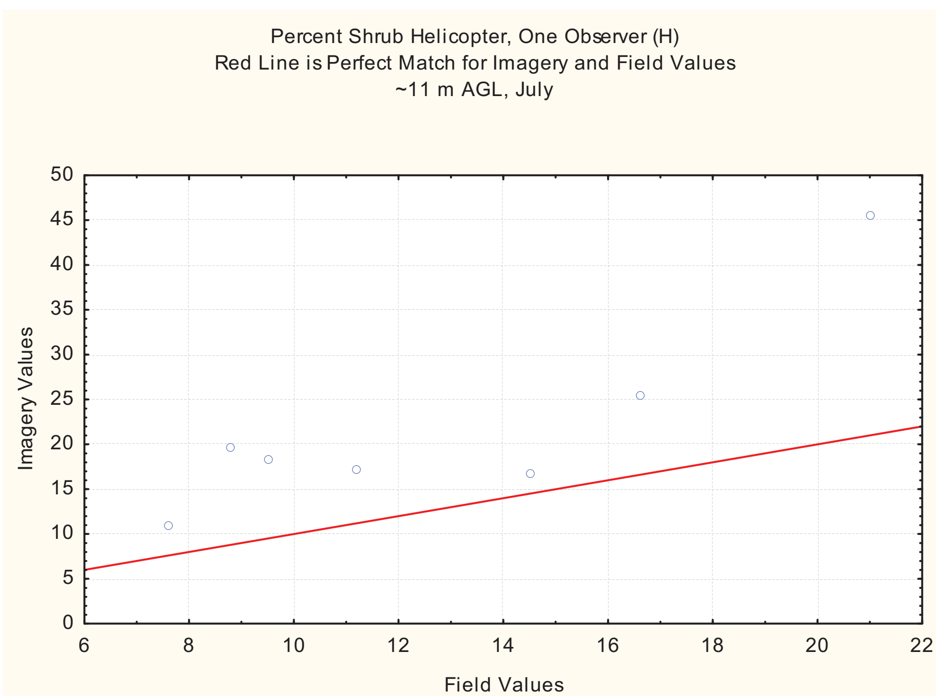

Percent Forbes Helicopter, One Observer (H)
Red Line is Perfect Match for Imagery and Field Values
~11 m AGL, June
Imagery Values
Fleld Values
55
50
45
40
35
30
25
20
15
10
5
10
15
20
25
30
35
40
45
50

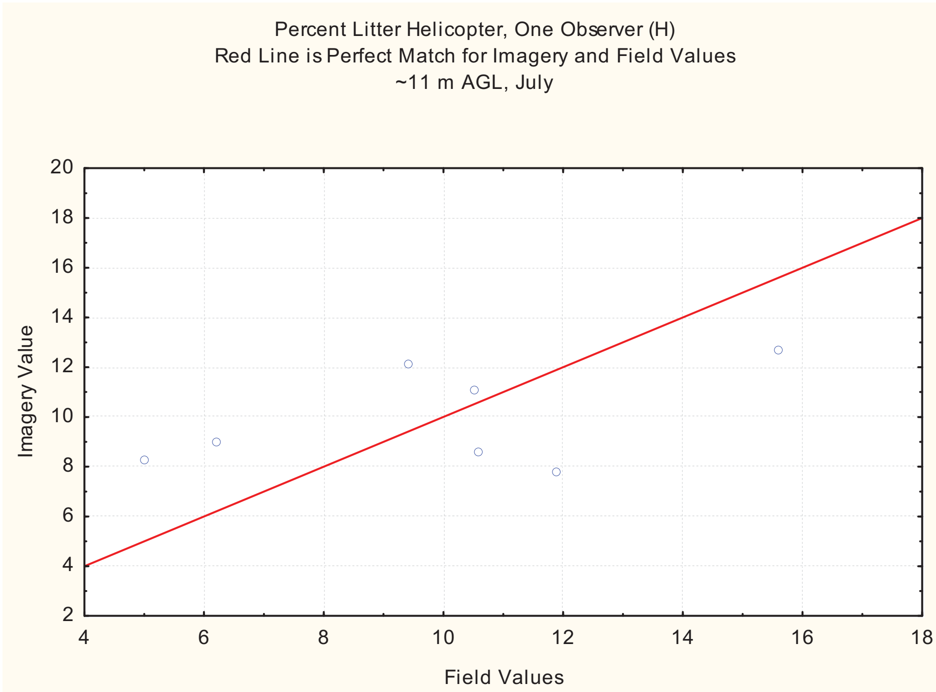
Scatter Plots for July, Observer 1 (H)

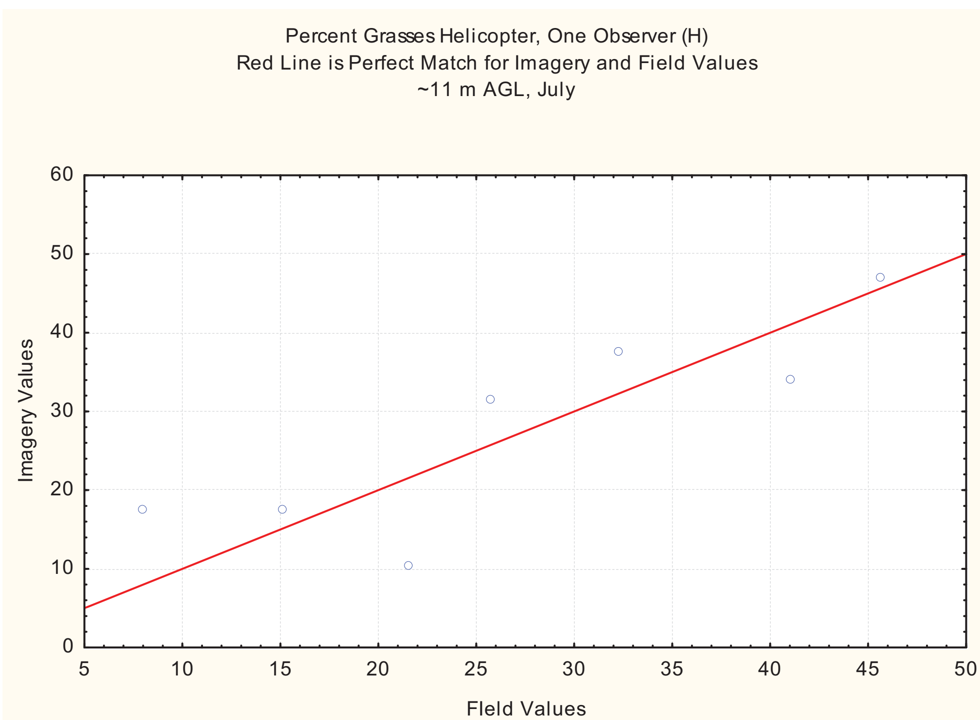
Note: Seven of seven plots were sampled.

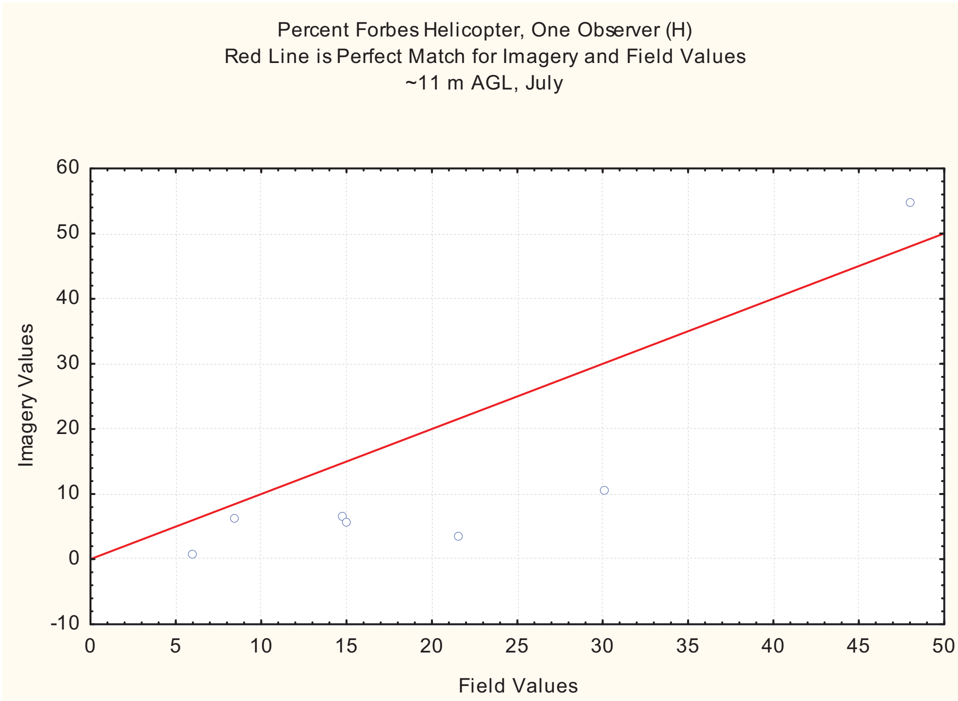



Percent Dead Shrub Helicopter, One Observer (H)
Red Line is Perfect Match for Imagery and Field Values
~11 m AGL, July
Imagery Values
Field Values
22
20
18
16
14
12
10
8
6
4
2
0
-2
0
2
4
6
8
10
12
14
16
18
20


Percent Shrub Helicopter, One Observer (H)
Red Line is Perfect Match for Imagery and Field Values
~11 m AGL, July
Imagery Values
Field Values
50
45
40
35
30
25
20
15
10
5
0
6
8
10
12
14
16
18
20
22

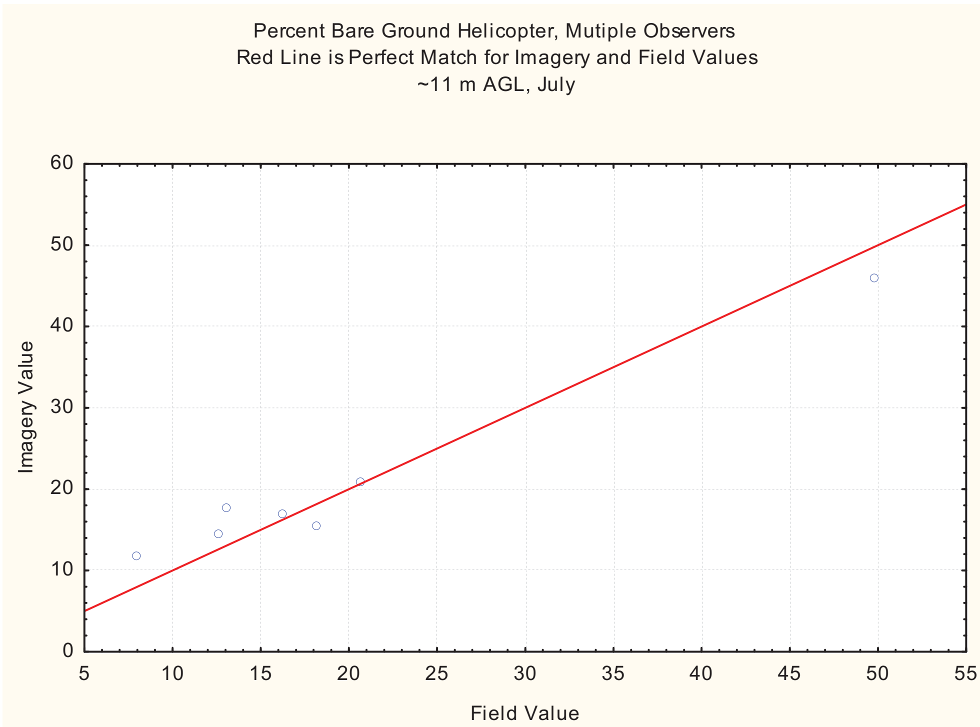

Percent Litter Helicopter, One Observer (H)
Red Line is Perfect Match for Imagery and Field Values
~11 m AGL, July
Imagery Value
Field Values
20
18
16
14
12
10
8
6
4
2
4
6
8
10
12
14
16
18

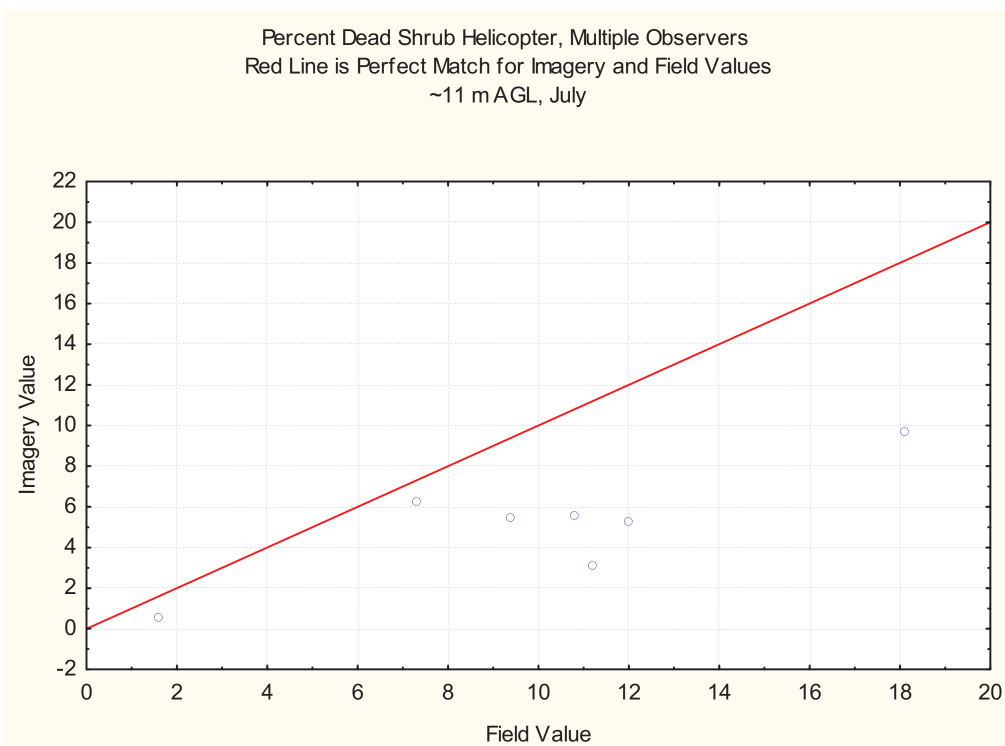

Percent Grasses Helicopter, One Observer (H)
Red Line is Perfect Match for Imagery and Field Values
~11 m AGL, July
Imagery Values
FIeld Values
60
50
40
30
20
10
0
5
10
15
20
25
30
35
40
45
50

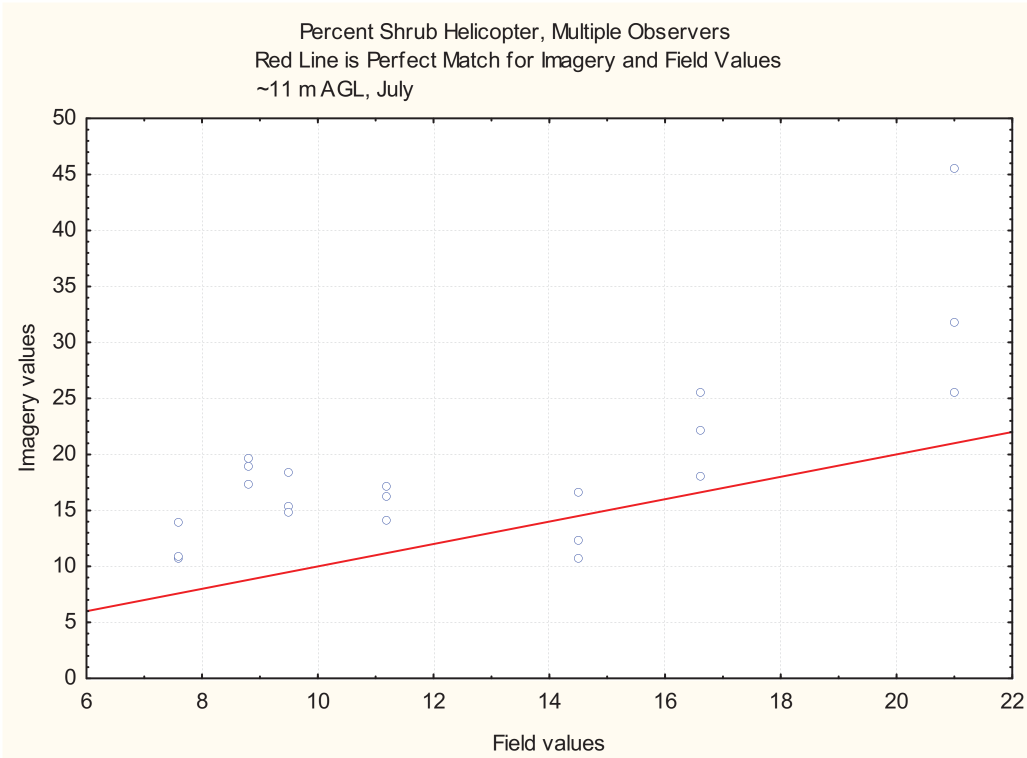

Percent Forbes Helicopter, One Observer (H)
Red Line is Perfect Match for Imagery and Field Values
~11 m AGL, July
Imagery Values
Field Values
60
50
40
30
20
10
0
-10
0
5
10
15
20
25
30
35
40
45
50

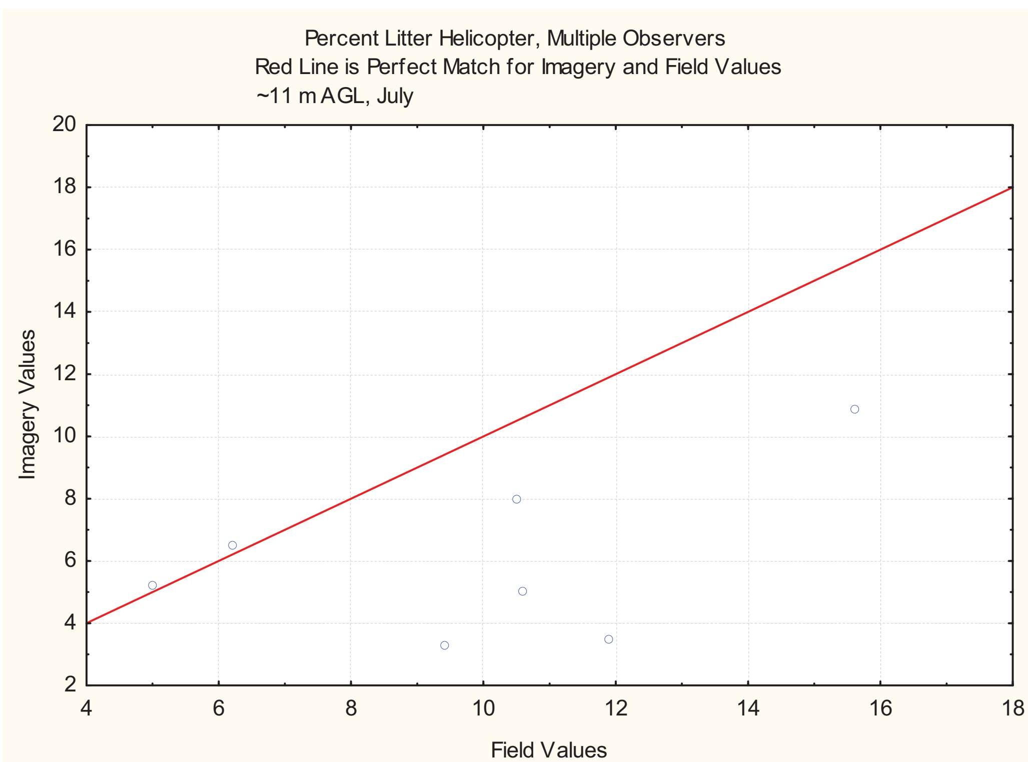
Scatter Plots for July, Combined Observers

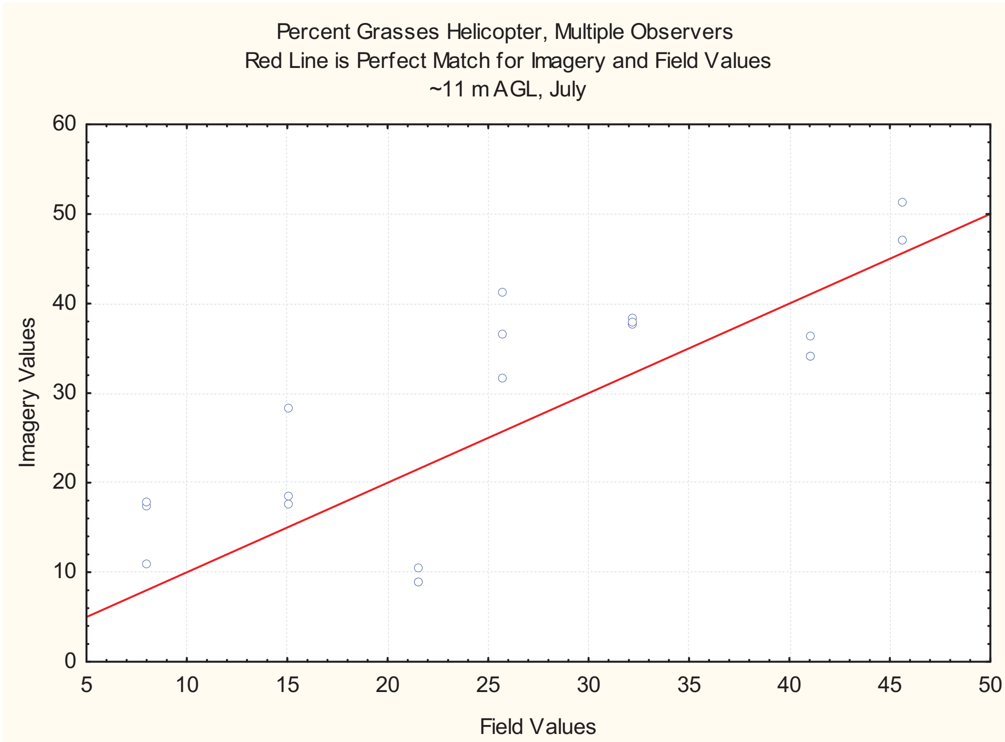
Note: Seven of seven plots were sampled; all plots flown at ≈11m AGL.

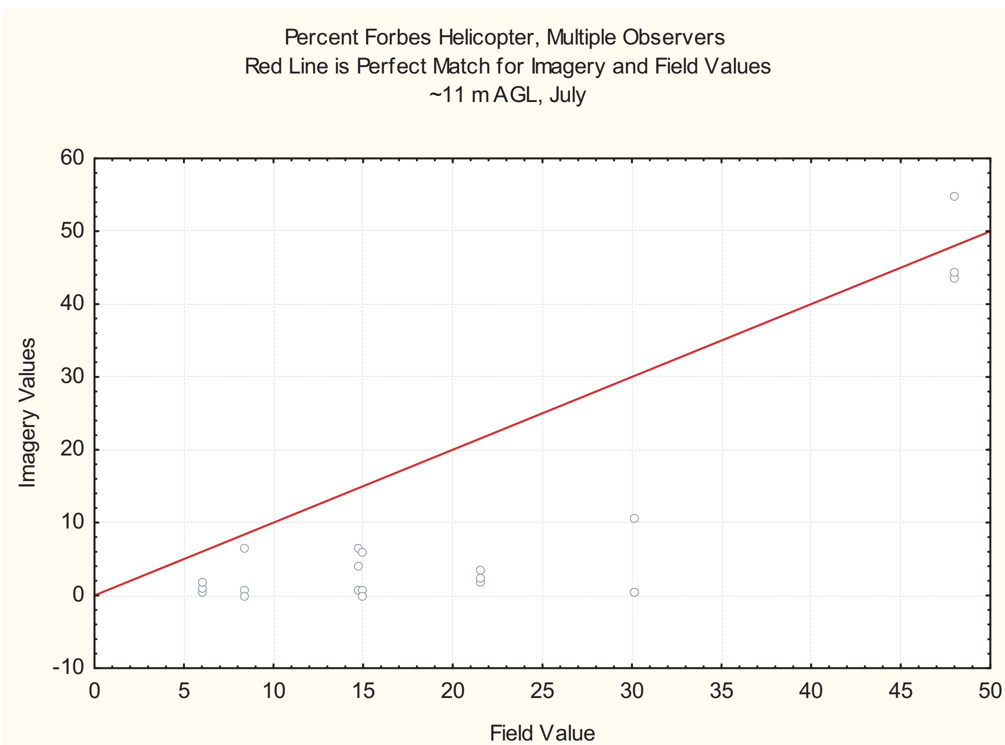





Percent Shrub Helicopter, Multiple Observers
Red Line is Perfect Match for Imagery and Field Values
~11 m AGL, July
Imagery values
Field values
0
5
10
15
20
25
30
35
40
45
50
6
8
10
12
14
16
18
20
22


Percent Litter Helicopter, Multiple Observers
Red Line is Perfect Match for Imagery and Field Values
~11 m AGL, July
Imagery Values
Field Values
2
4
6
8
10
12
14
16
18
20
4
6
8
10
12
14
16
18


Percent Grasses Helicopter, Multiple Observers
Red Line is Perfect Match for Imagery and Field Values
~11 m AGL, July
Imagery Values
Field Values
0
10
20
30
40
50
60
5
10
15
20
25
30
35
40
45
50


Percent Forbes Helicopter, Multiple Observers
Red Line is Perfect Match for Imagery and Field Values
~11 m AGL, July
Imagery Values
Field Value
-10
0
10
20
30
40
50
60
0
5
10
15
20
25
30
35
40
45
50

Chapter 3: Comparison of Unmanned Aerial Vehicle Platforms for Assessing Vegetation Cover in Sagebrush-Steppe Ecosystems

Abstract

The use of unmanned aerial vehicles (UAVs) as a quicker and safer method for monitoring biotic resources was evaluated. Evaluating vegetation cover and amount of bare ground are important factors in understanding the sustainability of many ecosystems. Methods that improve speed and cost efficiency could greatly improve how biotic resources are monitored on western lands. Sagebrush steppe ecosystems provide important habitat for a variety of species (e.g., sage grouse and pygmy rabbits). Improved methods are needed to support monitoring these habitats because there are not enough resource specialists or funds available for comprehensive ground evaluations. In this project, two 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 percent cover for six different vegetation types and (2) 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 vegetation cover. A software program called SamplePoint was used to evaluate percent cover for the six cover types (shrub, dead shrub, grass, forb, litter, and bare ground). Results were compared against standard field measurements to assess accuracy. The comparison of both fixed-wing and helicopter UAV technology against field values shows good agreement for measurement of bare ground, one of the single most important cover indicators for assessment of rangeland health. This study shows that if a high degree of detail and accuracy is desired to meet management objectives then a helicopter UAV may be a good platform to use. If management objectives are to assess broad-scale landscape level changes, then the collection of imagery with a fixed-wing system is probably more appropriate.

Introduction

Evaluating vegetation cover is an important factor in maintaining the sustainability of rangeland biotic resources. Cover data provide important information relative to ecological structure and processes such as nutrient and energy cycling, erosion, fuel management, and desertification (National Research Council 1994; Carroll et al. 1999; Pyke et al. 2002; Pellant et al. 2005; Crawford et al. 2004; Mouat and Hutchinson 1995). Inventory and monitoring requirements for meeting land management mandates and supporting legal challenges on federal lands in the western United States are monumental tasks. Arid lands in the conterminous U.S. account for about 37% of the lands west of 95°W longitude (Bender 1982). Resource managers are facing tremendous challenges because there are not enough natural resource specialists or funds for ground surveys on many of these lands. New approaches are needed to collect information to address challenges with fellow agencies, tribes, non-government organizations, and ranching communities.

Using manned aircrafts for monitoring and inventorying western lands, when the pilots are often required to fly slowly and low in remote areas, is very risky and has resulted in fatal accidents. Data compiled for 1990–2002 from the National Transportation Safety Board aviation accident database and synopses compiled by the Idaho Fish and Game Department show that flying aircraft for wildlife and fisheries applications is dangerous and has resulted in 2.6 fatalities per year for fixed-wing aircraft; for helicopters, there have been 1.3 survey-related incidents per year resulting in one fatality every 4 years (National Transportation Safety Board 2007; Zager 2006). Satellite-based remote sensing systems provide an option; however, these systems have potential issues with cost and accuracy at the sub-meter level and are impacted by cloud cover. A near-earth system that provides accurate data at a reasonable risk and cost is needed to improve monitoring on western lands.

Unmanned aerial vehicle (UAV) platforms are a potential option for collecting near-earth data in almost real time. UAV technology has matured from many years of using UAVs as hobby aircraft. The technology has also been used by the military to collect reconnaissance information without putting humans in harm's way. The major advancement in UAVs has come about with the miniaturization of electronics in specialized cameras, video, navigational, and global positioning systems (GPSs). It is now possible to equip a UAV to fly a specific flight path, collect data at a pre-defined GPS location, and automatically trigger the camera. In addition, real-time video feed can be sent to a receiver on the ground. Some UAVs can be flown using autonomous navigational systems and many of the fixed-wing platforms can fly for several hours, depending on engine configuration.

These platforms can carry a variety of sensors to capture imagery of the resources on the ground. (UAVs do have payload limitations, however, so sensors and cameras need to be relatively light [< 6.8 kg {15 lb}].) This wealth of information provides a unique opportunity and challenge for scientists and managers tasked with collecting inventory and monitoring data to ensure proper management of biotic resources on federal lands.

This study examined the use of fixed-wing and helicopter UAV technology to monitor cover types and selected biotic resources on rangelands. The objectives of the study were to

1. Assess the feasibility of using UAV technology to collect imagery useful in evaluating six cover types (shrub, dead shrub, grass, forb, litter, and bare ground) in sagebrush steppe ecosystems.

2. Compare the relative accuracy of cover values collected and processed from UAV technology with values from field measurements.

3. Determine the feasibility of using UAV imagery to identify the presence and sex of bird decoys (by identifying color differences) in sagebrush communities.

4. Compare the level of effort for collecting vegetation cover data from UAV and field methods.

As stated, one of the most observed features of a given community is its physical structure (Smith 1990). Total vegetation cover is an important part of a rangeland structure and is used to assess the condition of rangelands (Society for Range Management 1995; Pyke et al. 2002; Pellant et al. 2005). Total cover also plays an important role in understanding the desertification process (Mouat and Hutchinson 1995). Total vegetation 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 the proportion of ground covered by the different cover types, as viewed from above. For this reason, UAVs provide a good potential platform for coverage measurements.

Vegetation cover is usually evaluated by several-person field crews using one of a variety of field methods such as line-transect or quadrant sampling (Bonham 1989; 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 with emerging automated methods has been recently evaluated (Booth et al. 2006a; Booth and Tueller 2003). Results indicate that conventional techniques have significantly greater correlation (≥ 92% agreement of measured to known) than algorithm-driven measurements from VegMeasure software (70%) (Johnson et al. 2003). The critical factor influencing the accuracy of a point-sampling method was the area of the contact point for the given method (Booth et al. 2006a). This supports findings from other researchers that point sampling with minimal contact points results in the greatest measurement accuracy (Cook and Stubbendieck 1986). A number of different approaches exist for collecting both field and imagery values. Brower et al. (1990) and Bonham (1989) provide excellent discussions on the importance and methods for measuring vegetation to support research and management objectives. Breckenridge et al. (2006) also provides a discussion of UAV technology and how it can be applied the assessment of different cover types on rangelands. Cover type, as used in this study, is defined as the material located above the soil surface. This material can be either live or dead vegetation or, in cases where there is nothing present, bare ground.

Forbs are an important cover component because of their importance to wildlife (Connelly et al. 2000; Pedersen et al. 2003) and nutrient cycling (Smith 1990). The amount of litter and 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).

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 vegetation type in more arid big sagebrush communities has been greatly influenced by annual grasses, particularly cheatgrass (*Bromus tectorum*) (Bunting 2002). Dead shrub, litter, and bare ground are important to the ecological condition of a site (National Research Council 1994). Both dead shrub and litter play a role in influencing ecological process such as nutrient and water cycling (Pyke et at. 2002). Data on these cover types can serve as an indicator for how erosion processes are impacting a site (Pellant et al. 2005).

Vegetation and cover analysis techniques are needed to support state-and-transition models, evaluation thresholds, and rangeland health evaluations (Briske et al. 2005). Vegetation evaluation procedures must be able to assess continuous and reversible, as well as discontinuous and nonreversible, vegetation dynamics because both patterns occur and neither pattern alone provides a complete assessment of the vegetation dynamics on rangelands (Briske et al. 2005). Ecological thresholds describe a complex set of potential interacting components rather than discrete boundaries in time and space (Briske et al. 2005). A specific disturbance or event (i.e., fire or drought) may trigger the crossing of a threshold that affects both structural and functional modifications during ecosystem transition of various time scales (Briske et al. 2005). Development of techniques that improve vegetation composition information available to support models and threshold evaluations at the landscape scale are critical for large-scale management of rangeland health.

Methods

Study Area Selection and Design

The Idaho National Laboratory (INL) field site is located about 80 km (50 mi) west of Idaho Falls, Idaho. The INL is a U.S. Department of Energy (DOE) facility and was designated a National Environmental Research Park (NERP) in 1975 (DOE 1994). DOE encourages research and development activities on the NERP to support improved understanding of how human activities impact natural systems.

The INL's landscape is dominated by a sagebrush steppe ecosystem with the unique aspects of a high elevation, semi-arid ecosystem (Rickard et al. 1988; Whitford 1986). These ecosystems often go through transitions from grasslands to shrub lands with numerous vegetation states, including extensive grasses, mixtures of grasses, forbs and sparse shrubs, and dense shrub cover (Walker 1993; Colket 2003). Activities such as grazing, burning, exotic weed infestation, and planting of non-native species (such as crested wheatgrass [*Agropyron cristatum*]) can cause major changes to vegetation cover and have significant potential management implications (Knick and Rotenberry 1995).

Sagebrush steppe habitat is often 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 steppe communities that provide the best habitat to support sage grouse have shrub canopy cover between 15 and 25%. Beyond these values, as shrub cover increases, the preference displayed by grouse declines (Connelly and Braun 1997; Nevada Wildlife Federation 2002). The importance of the forb component varies across the big sagebrush steppe communities. Forb richness increases with increasing precipitation; consequently, mountain big sagebrush (*Artemisia tridentata ssp. vaseyana*) steppe has a greater diversity of associated forbs than does Wyoming big sagebrush (*A. tridentata ssp.wyomingensis*) steppe (Bunting 2002).

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 and Basin big sagebrush (*A. tridentata ssp. 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. The vegetation communities of the INL have been very well described by a number of researchers (Anderson et al. 1996; Mahalovich and McArthur 2004; Colket 2003). The INL has had a unique history relative to vegetation monitoring and has a number of long-term vegetation transits with established plots that have been monitored for over 50 years (French and Mitchell 1983; Anderson and Holte 1981; Anderson and Inouye 1999). The most common plants and communities have been described by a number of researchers (French and Mitchell 1983; Anderson and Holte 1981; Anderson and Inouye 1999). The Stoller Corp., through their Environmental Surveillance, Education, and Research (ESER) Program, has developed an index to the plants found on the INL (Forman and Hafla 2005). The most common native and exotic species found on the INL are described in this index. Specific communities and their composition around the INL study area are described in detail in Chapter 2 of this dissertation.

Data collection using the UAV platforms occurred during the spring and summer of 2005. The selection of the study site was heavily influenced by the location of a UAV runway built within the NERP (Figure 3-1). Because UAV technology is fairly new and equipment is limited, this study relied on acquiring images during missions flown by INL's UAV program for other projects; thus, timing for the flights was not a controllable factor. 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 (see Figure 3-1). The plots were selected near the runway to accommodate the helicopter's flight restrictions. The specific locations selected represent the diverse vegetation in both sagebrush- and grass-dominated communities that is typically seen in sagebrush steppe ecosystems.

Field plots were established in the early spring by locating the northwestern corner of each plot and laying out four 3 × 4-m (10 × 12-ft) subplots within each of seven plot locations. Each corner of a subplot was marked by a 30.4-cm (12-in.) plastic paint bucket lid (from a 20-L [5-gal] bucket) mounted on a 2.5-cm × 5.1-cm × 1.2-m (1-in. × 2-in. × 4-ft) wooden stake. Orange lids were always used on the north ends of the plots and subplots to make it easier to ensure orientation and identify

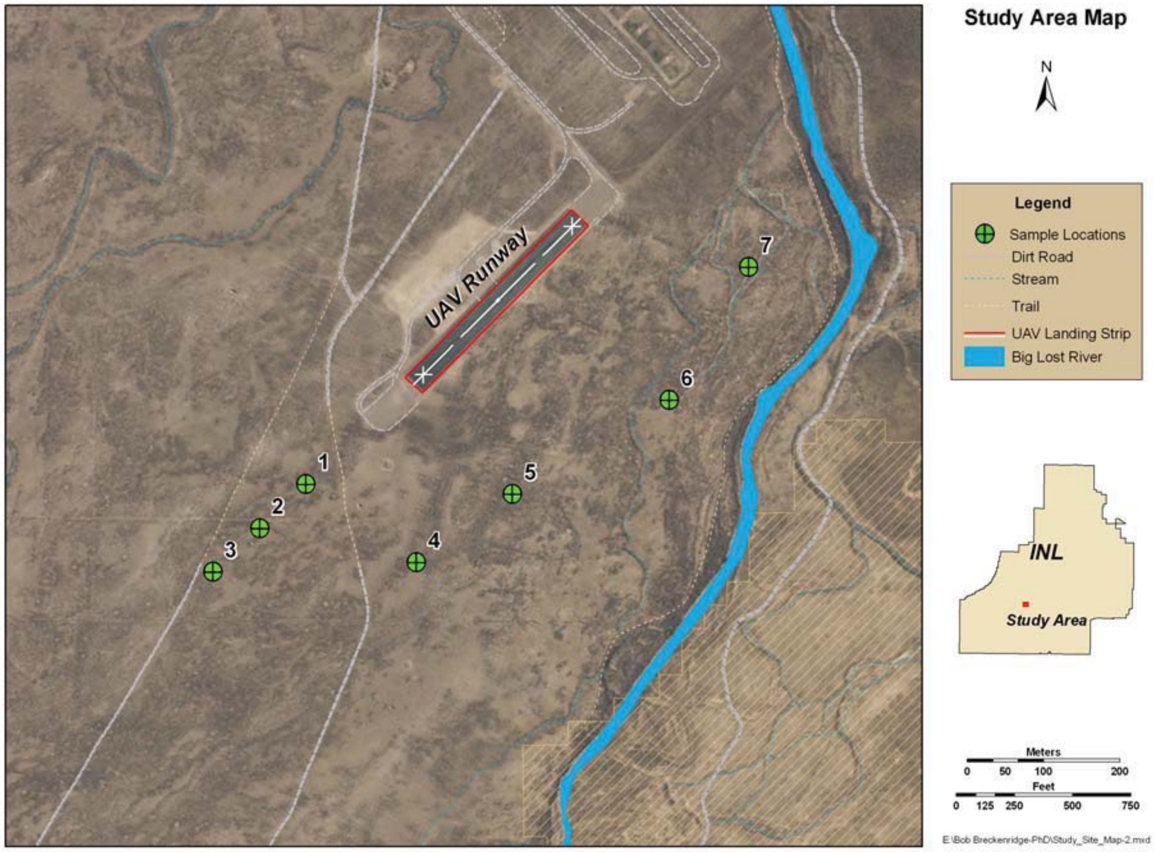


Figure 3-1. The locations of the INL UAV runway and seven field plots.

images during analysis. Multiple orange lids were placed in the northwestern corner of each plot to equal the plot number (i.e., Plot 7 had seven lids, including the lid on the subplot corner [Figure 3-2]). Plot numbers were sprayed on the lids using a special, highly-visible paint for plastics so that they could be viewed in the UAV imagery at different heights above ground level (AGL). The AGL designation is used with UAV flights because it provides a better representation of the height of the actual flight above the ground (elevation that can vary in uneven terrain). Soil color information for each plot was determined using a Munsell soil color chart and was used in the assessment of bare ground during the imagery assessment. The values for the plots were 10 YR 6/2. When the soils were wet from recent precipitation events, as occurred during the May fixed-wing UAV flight, they were darker. The white color on any object (such as on the decoys, see below) stood out well against the darker background.

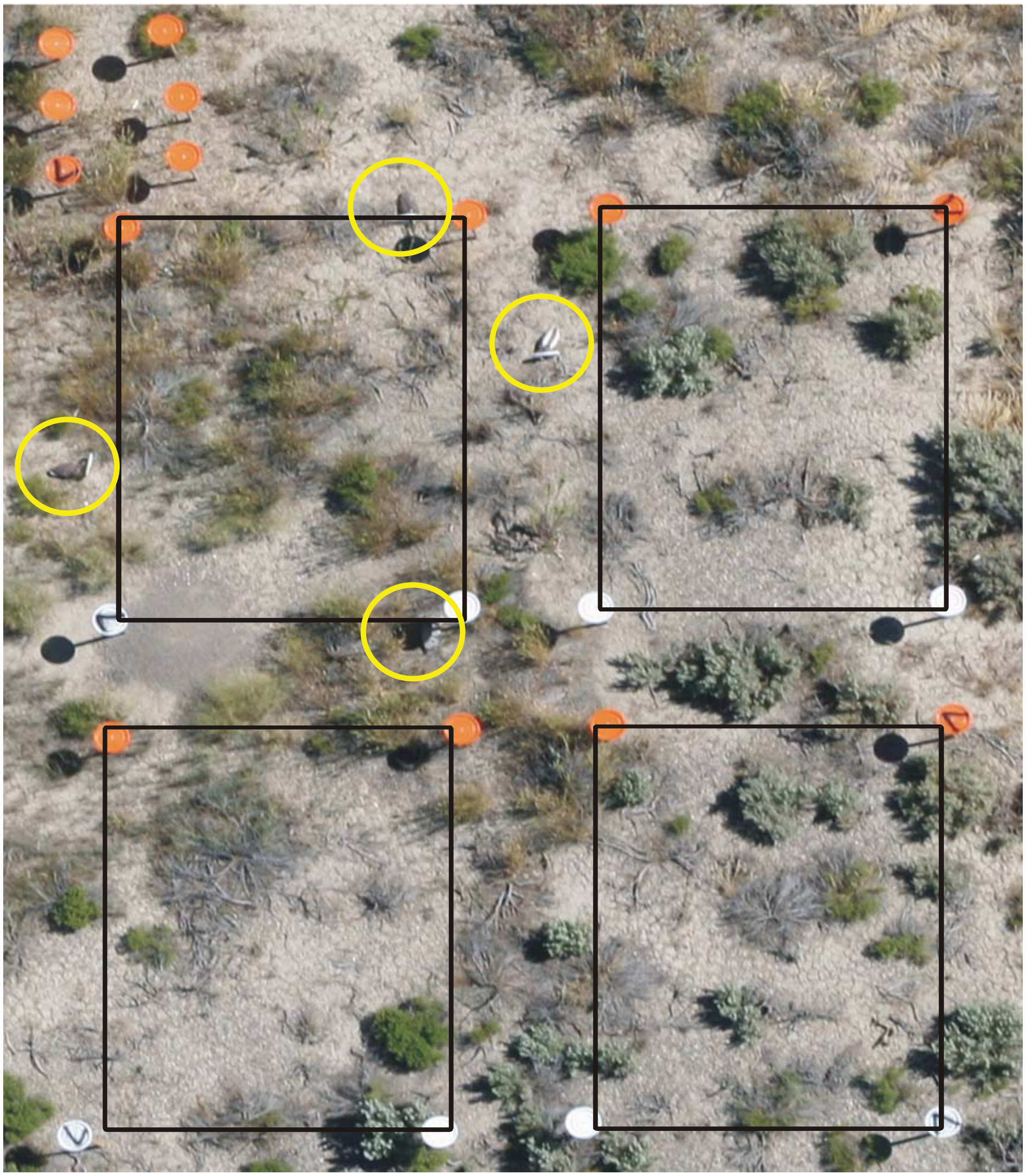


Figure 3-2. Sample plot design for UAV image collection and analysis study. This image was taken at 76 m AGL from a fixed-wing platform in July and shows the layout of Plot 7 with the four 3 × 4-m subplots identified and three male and one female decoy (in the shadow of the lid) (in yellow rings).

To simulate sage grouse on a lek site, duck decoys were “dressed” using 25.4-cm (10-in.) white plastic paint lids. The 25.4-cm (10-in.) size was based on a wildlife biologist’s knowledge of the size of a sage grouse’s white chest while strutting on a lek. The decoy’s posture was either standing or lying. The plots had between zero and seven decoys oriented in a manner that would 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 (60 mi/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 (10-ft) wing span made by RnR Products. This aircraft flew using an autonomous navigation system and carried a 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 (250 ft) AGL. The 153- and 305-m (500- and 1000-ft) imagery was collected May 5–12, 2005; the imagery from 76 m (250 ft) was collected July 14, 2005. Manual controls were used during take-off and landing. During image acquisition, the plane was controlled with an autopilot system tied into a 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 still images were collected along with videos.

The fixed-wing UAV images were collected by an 8-megapixel Canon Mark II camera with a 50-mm lens (f-stop 1:1.8) mounted under the body of the UAV. The original approach to collect images over each plot was to have the camera automatically triggered off the GPS system. The problem with this approach was that there was a slight lag between the time the GPS signal was sent to the camera and when the shuttle triggered. To overcome this situation, a measurement system was painted on the runway. Images were then collected from the runway to calculate the lag between the GPS signal and time the image was recorded by the camera. To ensure at least one image of each plot was obtained, the camera was programmed to take a series of seven pictures in rapid succession (using the sport mode function). (The camera could capture seven images before it needed to write to the memory card.) This approach proved very effective; often there were several images of a plot from which to select.

The fixed-wing platform was also outfitted with a through-the-lens video system (in the Canon camera) that collected digital video at 30 frames/second as the plane flew. The video was transmitted down to a base station through a remote frequency connection and researchers on the ground could view the flight progress in real time. Video was captured on an analog recorder as a proof of concept and was evaluated to determine if it could have potential to identify vegetation and identify the decoys. The May flight video was collected at 153 and 305 m (500 and 1000 ft) AGL. The July video was collected at about 76 m (250 ft) AGL.

The limiting factor for the fixed-wing platform was storage capacity for the imagery. The fixed-wing UAV was able to handle a larger payload, including the fuel and camera, than the helicopter. The fixed-wing UAV could also be flown for 4–8 hr depending on how the engine and camera power system were configured.

The second UAV 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 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 11–15 m (35–50 ft) AGL. Several different methods were tried for locating the helicopter over a plot and are described in detail in Breckenridge et al. (2006). The original plan was to use a helicopter that has a gyro-stabilizer system designed to allow for clear images to be taken even in moderate winds. However, the original helicopter was designed and built at a location near sea level. When it was flown at the INL site with an elevation of about 1500 m (5000 ft), the helicopter did not have sufficient lift to fly. Wind became a factor on the days we flew after about 10:00 AM. In the early morning winds were calm, but by mid afternoon we often had to fly the helicopter in winds up to 25 km/hr. This made for difficult landings that required a high degree of skill by the operator.

The helicopter had a flight-time limitation of about 15 min because of its fuel capacity and camera memory. After flying each plot, imagery was 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 for shrub, dead shrub, grass, forb, litter, and bare ground were evaluated in the field using a point frame method (Floyd and Anderson 1982). Field values were collected within one day of the second helicopter flight and within one week of the fixed-wing flight during the second week of July; specifics are described by Breckenridge et al. (2006). There were three observers that read the plots over a one-week period. Training and quality checks were conducted for all field observers to ensure consistency. Usually it took about one day to read the four sub-plots within a plot. Observers rotated after reading a sub-plot to minimize fatigue.

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 a process described in Breckenridge et al. (2006). The rotated, cropped, and matched images were then imported into image analysis software called SamplePoint.

SamplePoint is a software program developed at the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS) in Cheyenne, Wyoming, and was used to assess vegetation cover on the images (Booth et al. 2006b). Images were analyzed using a computer-based ocular process to identify the vegetation 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 eight types (shrub, dead shrub, grass, forb, litter, bare ground, shadow, or outside). For the fixed-wing imagery, an analysis was attempted 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 with 256 total points per plot.

It took about a week to become proficient in using SamplePoint to read the images. During the initial stages, it took 12–20 minutes to read a 100-point image. Within a few days, the time required to read an image was reduced to 5–7 minutes. Details on the use of SamplePoint are available in Booth et al. (2006b) and Breckenridge et al. (2006).

If the cover types at a point could not be determined (due to shadow) or the vegetation fell outside of the corners of the sub plots, it was recorded as shadow or outside and considered “unknown.” Data from each image were normalized to account for unknown values so that the remaining six vegetation types sum to 100% for each image. Because the total percents for the six cover types needed to sum to 100%, this might affect some of the results. The number of points that were recorded as "outside" was higher for the fixed-wing UAV imagery because we evaluated the entire plot using the 16 × 16 grid as discussed above and some of the points fell between the subplots. There was a 1-m space around the subplots that served as a walkway if repairs to the plot markers or decoys had to be made (Figure 3-2). The largest shadow and outside values were respectively 5 and 78 of 225. The average shadow and outside values respectively were 3.1% and 66.1%. The shadow values are probably not great enough to significantly alter total plot cover results. The outside values are large because when we read the entire plot the 1-m walkway values between sub plots all became outside values. With the outside values removed, there were still 159 values read on average for each plot. For the 10 × 10 helicopter images at the subplot level, the largest shadow and outside values were respectively 11% and 21%. The average shadow and outside values respectively were 1.8% and 6.4% and thus did not have a significant impact on the overall plot data.

Data Analysis

A series of analyses were conducted to assess how well the UAV imagery method compared to the field method for assessing percent cover for the six vegetation types. An assumption made for this study is that the field method of estimating percent cover is most representative of the true values and is considered the standard against which the imagery values are compared. Prior to conducting the statistical analyses, a quality check was performed to ensure all data fields had been properly entered and that the transfer process was successful. Some shorthand notations were used in the field entry program that did not directly transfer; thus, a small amount of programming was needed to correct this issue. Values were verified as correct by checking 10% of the values by hand before proceeding.

Statistical assessments were conducted to evaluate how well the imagery collection method compared to the field method. Relative accuracy in measurement is assessed by considering the two component parts of measurement error: precision and accuracy (also called bias) (Blackwood and Bradley 1991). Precision was measured first by comparing variances between the methods; accuracy was then assessed by using paired *t*-tests. Before running the statistical tests, we checked normality using histograms and normal probability plots. The distribution of the data appeared to satisfy the assumption of normality.

Once the normality assumption was verified, the variance caused by the measurement method (field or imagery) was separated from other sources of variability (e.g., among vegetation types).

Grubbs (1948, 1973) specifies an applicable model that identifies the different sources of variance (Blackwood and Bradley 1991). Under Grubbs' model, and assuming a bivariate normal distribution for the paired data, Maloney and Rastogi (1970) have shown that Pitman's test (Pitman 1939) applied to the observed variance in measurement (i.e., the sum of the field and imagery variances) is also a test of the relative precision of the two methods. More descriptive details of the statistical approach have been described by Blackman and Bradley (1991) and in Chapter 2 of this dissertation. Statistical analyses were conducted on the UAV imagery and field data using a statistical software package called Statistica (version 7.1).

Results

Scatter plots were used to visually compare the results from the two UAV platforms against field values for the six cover types. The perfect-fit plot for the fixed-wing data flown at 76 m (250 ft) AGL is shown in Figure 3-3. The perfect-fit plot for bare ground for imagery vs. field values for the helicopter, flown at 11 m (35 ft) AGL, is shown in Figure 3-4. A box and wisker plot of these data is presented in Figure 3-5. The perfect-fit plots for the other five cover types are provided in Appendix A. A line plot comparing the mean July helicopter and fixed-wing values to the field values is shown in Figure 3-6 .

Table 3-1 shows the mean values for the imagery and field data and the results of the statistical evaluations for both precision (as tested by evaluation of the variances) and accuracy (as tested by an evaluation of the mean of the differences). In presenting and discussing results, the helicopter data will be addressed first because they were collected within a week of when the field data were collected. The fixed-wing data will then be presented and discussed; these data were collected two weeks earlier than the field data. This small difference in time does make a difference because some of the early season forbs were already in senescence. Phenology of the plant communities in high desert ecosystems can change quickly, especially in the month of July.

Evaluation of Precision between Methods

The first analysis conducted was to determine if there was a difference in precision between methods using the Pitman test (Pitman 1939). For the July helicopter data there was a significant difference for shrub ($p = 0.008$) and bare ground ($p = 0.045$) (Table 3-1). For the fixed-wing UAV, there was no significant difference for the other cover types. The conclusion from the evaluation is

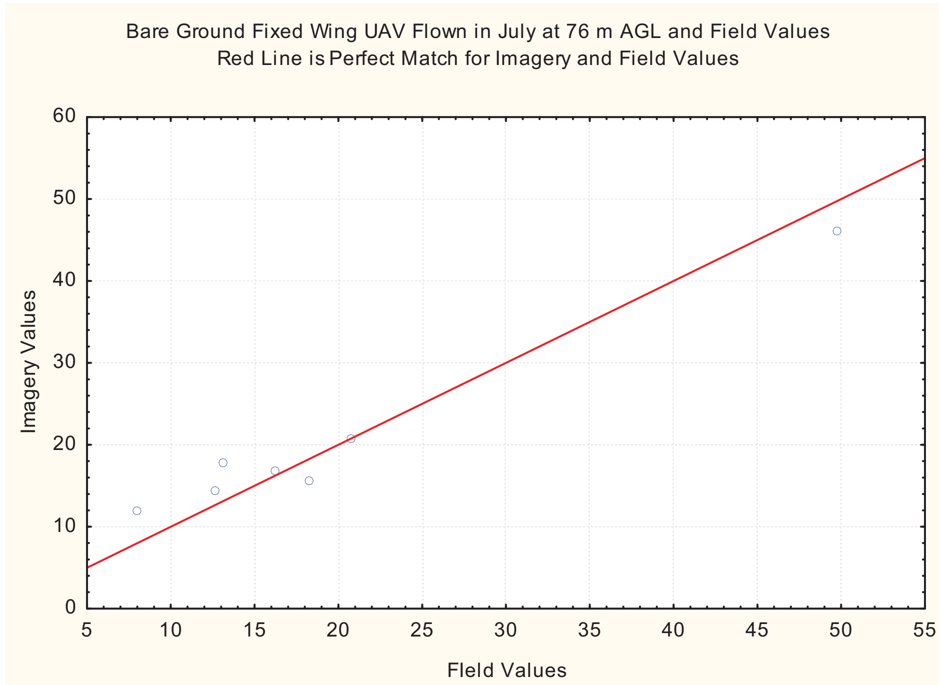


Figure 3-3. Perfect-fit plot for comparison for bare ground for July fixed-wing UAV vs. field values flown at ≈76 m (250 ft) AGL.

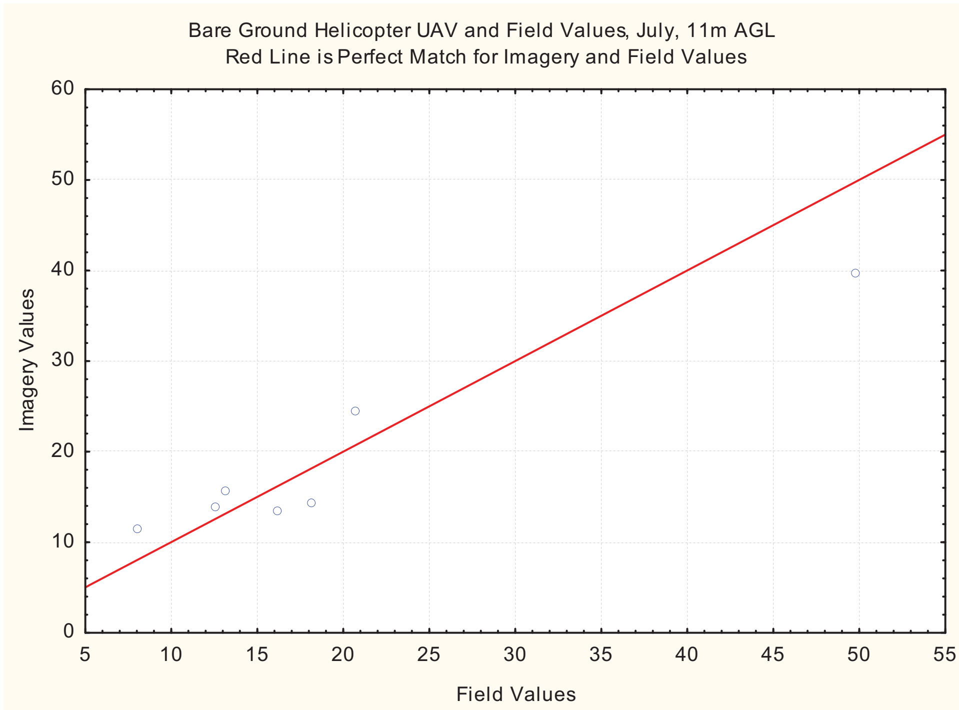


Figure 3-4. Perfect-fit plot to compare helicopter and field bare ground values for July data.

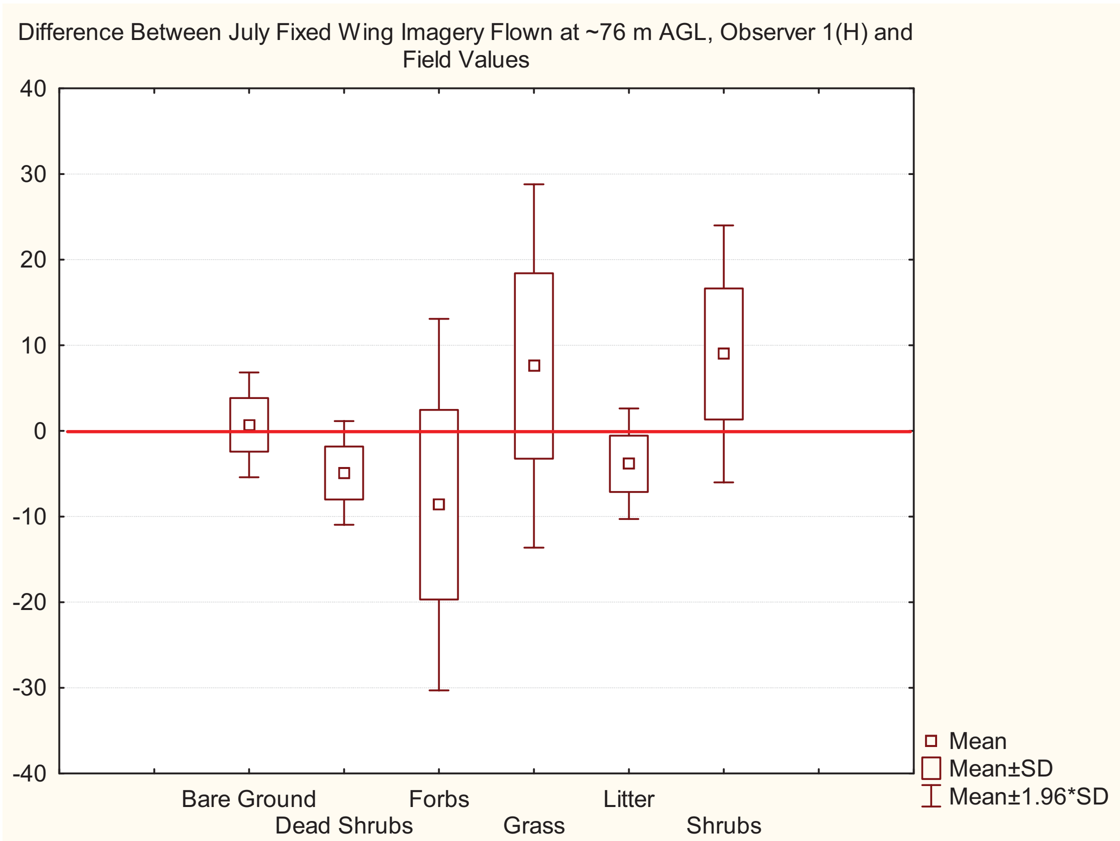


Figure 3-5. Difference between image and field values for July fixed-wing at ≈76m (250 ft) AGL.

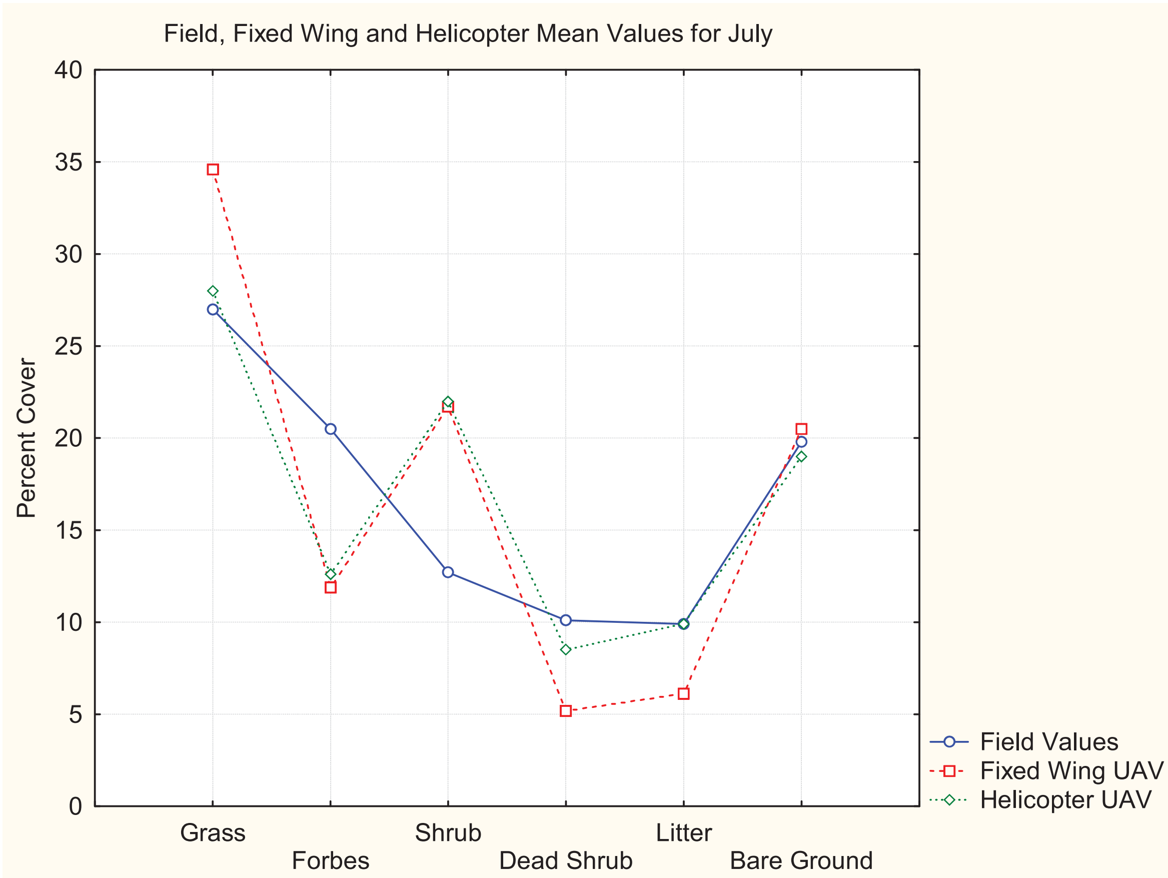


Figure 3-6. Line plot for July fixed-wing and helicopter UAV mean imagery vs. field values (Note: Field values are in blue).

Table 3-1 .UAV helicopter and fixed-wing imagery values and field values collected in July. (Note: Values in red are significant at p = 0.05).

Cover Type	July UAV Helicopter and Field Values						July Fixed-wing UAV and Field Values					
	n[a]	Mean Imagery Values (Standard Deviation)	Mean Field Values (Standard Deviation)	Test of Equality of Variances p-value	Mean Differenc e IV – FV (Standard Deviation)	Test of Means of Differences p-value	n	Mean Imagery Values (Standard Deviation)	Mean Field Values (Standard Deviation)	Test of Equality of Variances p-value	Mean Difference IV – FV (Standard Deviation)	Test of Means of Differences p-value
Shrub	7	22.0 (11.2)	12.7 (4.8)	0.008	9.2 (7.4)	0.017	7	21.7 (10.1)	12.7 (4.8)	0.055	9.0 (7.7)	0.021
Dead shrub	7	8.5 (3.6)	10.1 (5.0)	0.372	-1.6 (3.7)	0.299	7	5.2 (2.8)	10.1 (5.0)	0.058	-4.9 (3.1)	0.006
Grass	7	28.0 (13.1)	27.0 (13.6)	0.890	1.0 (7.4)	0.735	7	34.6 (17.7)	27.0 (13.6)	0.365	7.6 (10.8)	0.113
Forb	7	12.6 (18.7)	20.5 (14.5)	0.274	-7.9 (9.1)	0.061	7	11.9 (21.3)	20.5 (14.5)	0.135	-8.6 (11.1)	0.085
Litter	7	9.9 (1.9)	9.9 (3.5)	0.171	0.0 (3.0)	0.962	7	6.1 (2.7)	9.9 (3.5)	0.512	-3.8 (3.3)	0.022
Bare ground	7	19.0 (10.0)	19.8 (13.8)	0.045	-0.8 (5.1)	0.690	7	20.5 (11.6)	19.8 (13.8)	0.067	0.7 (3.1)	0.567

a. “n” indicates the number of observations.

that, while there are limited cases where there are statistically significant differences in variances, there was not enough significance in variances to indicate a difference in precision between the two UAV measurements and the field method.

Evaluation of Accuracy between Methods

Because the above test results only consider relative precision, a separate paired *t*-test was used to test that the mean of the differences between the field and imagery values was equal to zero (Table 3-1). For the July helicopter data there was a significant difference only for shrub ($p = 0.017$) (see Table 3-1 for data and Figure 3-5 for the box and whisker plot). For the fixed-wing UAV system, the results for shrub ($p = 0.021$), dead shrub ($p = 0.006$), and litter ($p = 0.022$) were statistically significant.

Decoy Evaluation

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 were not evaluated because it is not a viable system for evaluation of wildlife due to the high noise factor. We evaluated imagery from the fixed-wing UAV at three different heights: 76, 153, and 305 m (250, 500, and 1000 ft) AGL. The evaluation determined if decoys could be identified, recorded results, and compared the results with the field values for decoy location and sex for each subplot. For the 76-m (250-ft) 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 3-2. This image has three male decoys and one female. The three male decoys are fairly easy to see; the female is difficult to see because she is better camouflaged and 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 (500 and 1000 ft) AGL. Because vegetation was much greener in June and the imagery was collected one day after a rain event, the decoys showed well. For the 153-m (500-ft) 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 (Table 3-2).

Table 3-2. Comparison of sage grouse decoy identification from images collected with a fixed-wing UAV.

Collection AGL (m)	% Male identified	% Female identified
73	100%	80%
153	100%	60%
305	90%	10%

Video imagery was evaluated to determine its use in assessing presence of sage grouse-like decoys on rangelands. At 76 m (250 ft) AGL, it is possible for a trained observer to identify the white on the male decoys in only some of the plots because of the lack of image clarity (Figure 3-7). The imagery was too grainy to evaluate cover types. This is mostly because the technology at the time only allowed for streaming video to be collected. The video that was collected at 305 m (1000 ft) AGL was only of sufficient quality to identify the plot locations; it was not possible to see the decoys. For the 153-m (500-ft) AGL video, the plots and sub plots were visible and some of the larger male decoys could be identified. However, because of the video is a combination of pictures, there is quite a bit of blur to the image. The video may be a viable technology for assessment of sage grouse and cover type, but only if it is either flown at a lower elevation or a more sophisticated system is used that can be zoomed during flight.

Discussion

Fixed-wing Imagery Values

Cover Analysis

Table 3-1 and Figure 3-5 show a good comparison between the field and imagery values for cover type assessment from the fixed-wing platform. When compared with field values, the fixed-wing platform was just slightly over (+0.7 %) for bare ground, over for grass (+7.6%), and under for forb (−8.6%); none of these differences were statistically significant. The statistically significant differences between mean values for shrub (+9.0%), dead shrub (−4.9%), and litter (−3.8%) are very similar to the patterns noted from the helicopter values (Figure 3-6). During the July flights, many of the forbs had passed their peak and had senesced and/or were located under the shrubs, making them very difficult to spot unless the observer was on the ground directly above the vegetation.

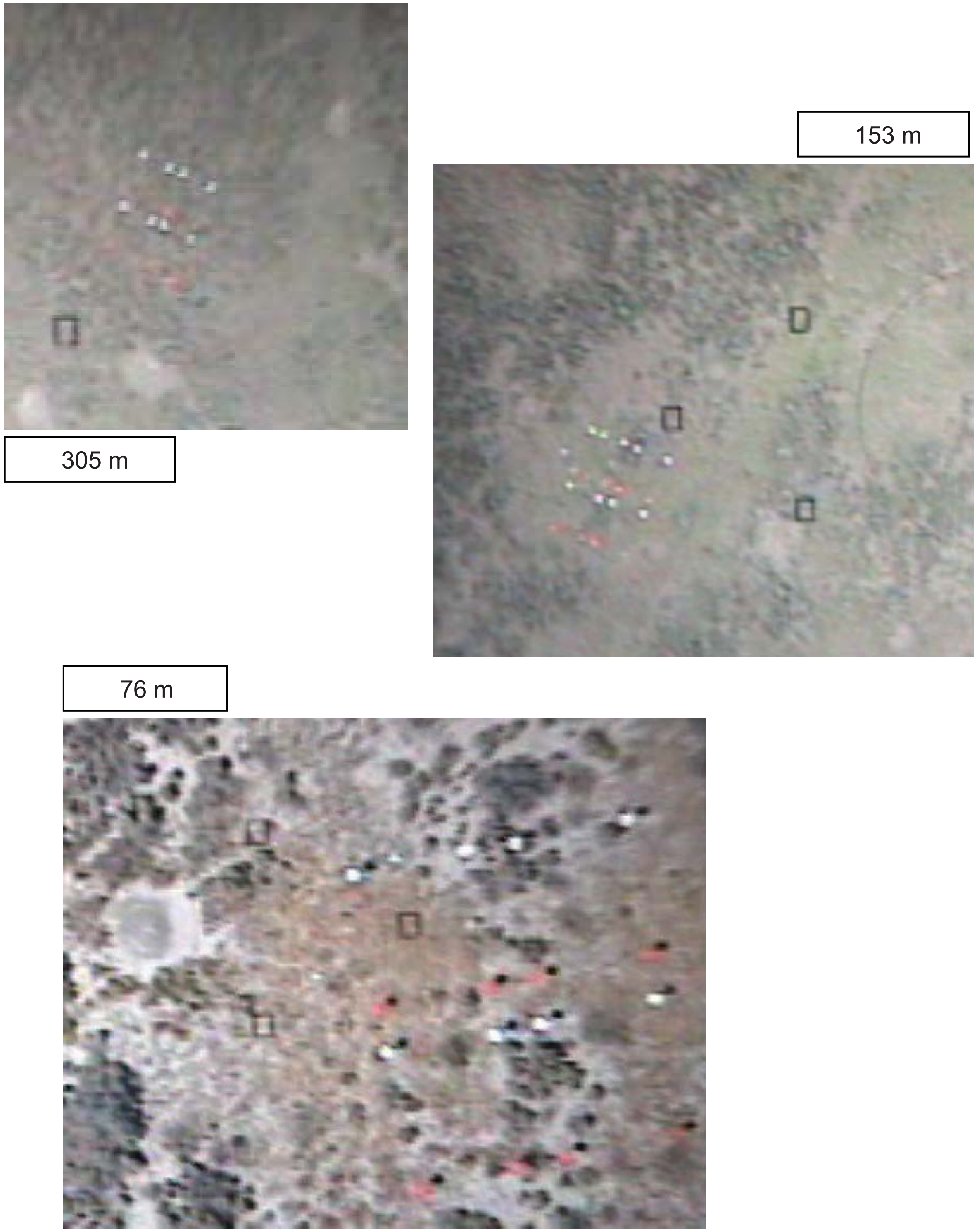


Figure 3-7. Video from three fixed-wing UAV flights: the top two flown at 305 and 153 m (500 and 1000 ft) AGL were flown on May 10th, the bottom was flown at 76 m (250 ft) AGL on July 14th.

The results of both the helicopter and fixed-wing values suggest that if individual values for shrubs or forbs are needed, a different approach should be selected. The Nevada Wildlife Federation (2002) and Connelly et al. (2000) found that the ideal sagebrush cover values in Wyoming big sagebrush and Basin big sagebrush communities similar to the communities where the study plots were located is 15–25 % shrub (Hagen et al. 2007). They also found that 10% or more forb cover was desirable for sage grouse. The cover values obtained from the UAV imagery show good agreement for collecting data that support the recommendations for sage grouse habitat noted above. These values compare favorably with recommendations presented in a recent manuscript (Hagen et al. 2007) Thus, UAV platforms may have value for collecting information for sage grouse habitat if exact cover values are not needed. Evaluation to determine if this level of data is sufficient for habitat evaluations may present opportunities for future research for both wildlife and range sciences. This is because there is often a symbiotic relationship established between shrubs and forbs in rangeland communities. As long as the percent shrub does not exceed desirable limits, UAV cover values for shrubs and forbs may be a reasonable approach for collecting habitat and forage information for some sagebrush obligate species.

The fixed-wing platform was not flown below 76 m (250 ft) AGL because of concerns that the platform might loose altitude during sharp banking maneuvers. The aircraft had a lot of expensive equipment on board and we did not want to risk loosing it in a crash. After the flight was completed and we realized that on average we never lost more that a few meters in the banked turns, we felt it would have been possible to fly at an AGL as low as 30 m (100 ft). We also could have considered flying lower over the plots and then going up to a higher AGL during turns to increase our margin of safety. The lower flights would have produced images of better quality.

Decoy Evaluation

Fixed-wing imagery was used to evaluate how well decoys could be identified at three different elevations: 76, 153, and 305 m (250, 500, and 1000 ft). We flew missions of over 1 hr (fuel was available to fly up to 4 hr) and collected imagery that was limited by memory space on the camera chip. Currently, technology has already advanced to address this concern. The results discussed above suggest that fixed-wing platforms could have application for identification of sage grouse on a lek. However, there are several issues that need to be evaluated in future research. One is the height and shape of the aircraft and its similarity to the silhouette of a bird of prey. For both the 76- and 153-m (250- and 500-ft) AGL the identification of both the male and female decoys was possible; however, there is a high probability that flights at these elevations would impact the birds on a lek. For the 305-m (1000-ft) AGL flight, 90% of the males was identified but only 10% of the females. It may be possible to use UAV flights with higher AGLs such as this for sage grouse evaluations because it was difficult to spot and hear the plane at this altitude. It also may be possible to use other UAV platforms that have different designs so the silhouette would not resemble that of a bird of prey and would not impact grouse activity on a lek. These concepts could be to a topic to be evaluated by future researchers.

Video Imagery

The video system used in both UAVs is a through-the-lens streaming video system. Both systems were designed to allow for remote transmission of data to a ground receiver allowing real-time viewing of imagery. Using the video to locate the helicopter over the plot was not useful because it was difficult to view the image on a small screen in the sunlight. In addition, orientation of the helicopter with the video was difficult because the exhaust of the helicopter often clouded the image. The helicopter UAV imagery was very difficult to evaluate because of the instability of the platform; therefore, this imagery was not recorded. Newer technology is being developed to allow for individual frames to be separated, thus producing a much clearer image. The screen shots presented in Figure 3-7 provide some indication of the potential to use video to view plots. There were situations where the video was zoomed for other missions that produced higher quality imagery; thus, it is possible to acquire better imagery. As a proof-of-concept, this project showed it is feasible to collect video imagery for evaluation of large tracks of land. Future work could consider requirements for video quality to meet land managers or research objectives and then evaluate if obtaining that level of quality is feasible.

The potential use of imagery collected from UAVs may have greater application with improved video collection systems and for imagery collected at either a lower AGL or with a system that has a quality zoom capability. Video imagery collected by UAVs may have application for management of natural resources, especially in situations with high contrast (e.g., identification of total shrub cover or wildlife presence with snow cover on the ground) and should be evaluated by future studies.

Comparison of Time among Methods

The UAV methods have an advantage over conventional field methods relative to the time required to set plots and collect and analyze data. Table 3-3 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

Table 3-3. A comparison of the time required to collect UAV and field data sets.

Activity	Helicopter UAV Time Requirement (hr)	Fixed-wing UAV Time Requirement (hr)	Field Method Time Requirement (hr)
Set up 7 plots (4 subplots/plot)	5	5	4
Collect imagery from UAV platform, set-up to takedown time	8	4	
Collect field data using point frame method and sampling 50% of all 28 subplots			36
Image processing Fixed-wing, (30 min/plot × 7 plots) Helicopter, (12.5 min/subplot × 28 subplots)	5.8	3.5	
Analyze data and report (60 min/plot × 7 plots)	7.0	7.0	7.0
Totals	**25.8**	**23.5**	**47**

difficult to reduce the time below that required to collect the imagery with the UAVs. For the fixed-wing system, the actual flight time was 75 min and over 700 images were collected. 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 setup, safety checks, and data transfer. One of the most difficult tasks with the UAV process was selecting the best image for analysis.

Helicopter Imagery Values

Figure 3-6 shows a comparison of the UAV helicopter and field values from July. The helicopter imagery from early July shows a high degree of agreement with the field values for dead shrub, grasses, litter, and bare ground. Shrub cover is often overestimated by the imagery approach and forbs were underestimated. It is likely that forbs were hard to identify because the imagery was acquired at a time that was past their peak growth period. Training on the use of the SamplePoint system did help improve the quality of the results.

Recommendations and Conclusions

Comparison of both fixed-wing and helicopter UAV technology against field values show good agreement for measurement of bare ground, one of the single most important cover indicators for assessment of rangeland health. One of the reasons that bare ground is considered important is that it integrates how the range has been managed or impacted by climatic factors over a long period of time. If an area has been overgrazed or there has been a prolonged drought, desirable vegetation cover (both living and dead) will be reduced and the amount of bare ground will increase. All of the plots selected for these studies were in areas that have not been grazed for many years or impacted by unusual climatic conditions and were in fairly good condition. If bare ground can be evaluated in conditions where the rangeland is fairly healthy, there is good potential that it will be effective in an unhealthy area where the amount of bare ground is more extensive. The values determined for the seven plots were within 1 % of the field values (field value 19.8%, helicopter 19.0%, and 20.5 % for the fixed-wing UAV); thus, there was good agreement for bare ground values among methods.

As this study shows, different types of UAVs may be more effective in certain situations. If a high degree of detail and accuracy is desired to meet management objectives, then a helicopter UAV may be a better platform than fixed wing because the helicopters can fly at lower AGLs and therefore can collect higher-quality images. If the objectives are to collect imagery for much larger areas (e.g., an allotment) to assess landscape level changes, then a fixed-wing system is probably more appropriate. This is because fixed-wing UAVs can carry larger payloads and can fly much longer missions (4–8 hr compared with 15–min.).

In the two years since this study was conducted, the UAV platforms, camera systems, and image processing systems have improved by reducing weight, increasing data storage, improving picture quality, and improving image processing systems. These changes will allow for continuous improvements in data quality. Because there will always be a demand for high-quality reliable data for making and defending management decisions, there is a shortage of field workers, and labor costs continue to rise, UAVs may provide cost-effective options for collecting information for management of vast western rangelands.

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 low they can fly with current image storage systems. Future 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).

2. The fixed-wing UAV was initially flown at 153 and 305 m (500 and 1000 ft) AGL. These elevations produced marginal images that were too blurry to enlarge for evaluation. The 76-m

(250-ft) AGL provided imagery that was of good quality, but better imager may be collected at 30–60 m (100–200 ft). Future UAV systems should be designed to fly at lower AGLs.

3. A future study should be developed as a joint effort with the appropriate agencies that would benefit from using UAV systems to enhance management of their lands (e.g., BLM, USDA Forest Service, DOE, U.S. Department of Defense, and the National Park Service). A study designed to focus on collection of data that directly supports their mandated management objectives would improve the possibility of having this technology accepted by both line management and research staff. Greater involvement with land management agency scientists will improve the understanding of the current challenges and opportunities made available by UAV systems.

4. UAV systems do require some setup time before flight. The more instrumentation that is located on the platform the greater the time requirement for preprogramming flight information and system setup. Future research should focus on the design requirement to meet different management objectives. Once a set of objectives are established, UAV platform requirements can be established and optimized. The helicopter UAV system was easy to set up and fly. These are ideal for collection of detailed information for small areas, but require more training to operate, especially in areas where landing areas are limited, terrain is highly variable, or winds are a factor. Future fixed-wing systems could be optimized to be operated in remote areas using hand or mechanical launch and parachute landing systems. These can be flown over much larger areas.

5. Future studies should consider the optimum phenological times for collecting the best data for analysis to meet land managers' objectives. 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. For example, if it is important to secure accurate shrub data, flights could be

timed during periods where there was a slight amount of snow cover to enhance contrast between shrubs and background.

6. Shadow and time of day should be evaluated against study objectives to determine if their overall importance is significant. These variables could be optimized by future studies. Shadows were present in all the images, but were not a major concern with the exception of separation of forbs from shrubs. For both UAV platforms, it was best to fly early in the day before the winds developed.

7. This study focused on using UAV systems for assessment of vegetation cover and to a less extent identification of wildlife decoys. The technology has much greater application for collection of many other types of data needed by land managers, including off-road vehicle use, riparian area condition, exotic species encroachment, fire mapping, landscape changes, and law enforcement. Future studies should be conducted in these and other applications.

8. Image processing for this study used mostly a manual, ocular approach. Future research to develop a more automated system to process both fixed frame and video imagery would enhance the application and reduce error. This would improve the usefulness of image analysis systems for rangeland management. Evaluation of newer video collection systems should be a high priority for future work.

9. 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. The AGL and shape of the UAV are both factors that should be evaluated.

Management Implications

Results from collecting vegetation data using fixed-wing and helicopter UAVs 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, involve relatively low safety risk with proper training, and reduce the time spent in the field collecting data. UAV technology has advanced to carry a sufficient payload to acquire high-quality imagery over fairly large areas. Different UAV platforms may meet different management objectives. As this shown here, helicopter UAVs capture higher-quality images while fixed-wing UAVs can cover larger areas. It is also important to match the objectives of an organization against capabilities that a UAV system can provide. For example, there may be scientific or management reasons to combine shrubs and/or forbs in assessment of habitat and forage for sage grouse, as suggested by some scientists (Hagen et al. 2007). If so, then the UAV system may be useful.

Using results from this study, land managers in semi-arid ecosystems could consider using UAV platforms to collect data for selected vegetation types, specifically bare ground. Both the fixed-wing and the helicopter system collected data comparable with field measurements for bare ground. Because there appears to be convergence in the scientific community (Maczko et al. 2004; Pellant et al. 2005) that bare ground is one of the most important vegetation cover measurements for assessing rangeland health, UAV platforms may play an important role in securing quality information for future resource inventory and monitoring activities.

Lessons Learned

A number of lessons were learned in conducting this research. A summary of the more important lessons are provided below to help those conducting future research in these areas.

- Field plots should be selected to optimize the ability of the UAV to collect data. Important considerations are location relative to launching areas, spacing between plots (cameras take time to transfer imagery to storage devices) and terrain.
- Selection of the size of the plots and subplots should strongly consider the type of camera and lens available to the researcher and the AGL that the UAV can fly. Marching these before laying out the plots is important.
- UAVs are not toys and can be dangerous if proper safety steps are not developed and followed.
- The optimum time for data collection on vegetation needs to be considered and evaluated against the objectives of the research.

- Conducting UAV flights early in the day is important in the west because as temperatures rise, winds and thermals increase, which makes collecting high-quality imagery more difficult; however, flying too early creates issues with have long shadows. The optimum window usually is between 8 and 11 AM.

Acknowledgements

The authors would like to extend sincere thanks to Mark McKay and Matthew Anderson for piloting the helicopter and fixed-wing systems and collecting imagery; Ron Rope, Ryan Hruska, Sera White, and Angie Smith (INL), Marilynne Manguba (The Nature Conservancy), and Anthony Piscitella, Chase Eckersell, and Katherine Schoellenbach (students) for assisting in collection of field data, reading imagery, and assisting with edits; Terry Booth and Sam Cox (USDA-ARS) for developing and assisting in using SamplePoint; Dr. Larry Blackwood for providing guidance with statistical analysis; and Dr. Don Crawford (University of Idaho) and Sue Vilord, Jackie Hafla, and Roger Blew (Stoller Corporation) for technical guidance and assistance with providing equipment and quality control checks for field activities.

References

Anderson, J. E., and K. E. Holte. 1981. Vegetation development over 25 years without grazing on sagebrush-dominated rangeland in Southeastern Idaho. *Journal of Environmental Management* 34:25–29.

Anderson, J. E., K. T. Ruppel, J. M. Glennon, K. E. Holte, and R. C. Rope. 1996. Plant communities, ethnoecology, and flora of the Idaho National Engineering Laboratory. ESRF-005. Idaho Falls, ID: Environmental Science and Research Foundation. 110 p.

Anderson, J. E., and R. S. Inouye. 1999. Long-term vegetation dynamics in sagebrush steppe at the Idaho National Engineering and Environmental Laboratory. Idaho Falls, ID: Environmental Science and Research Foundation. 58 p.

Bender, G. L., 1982. Reference handbook on the deserts of North America. Greenwood Press, Westport Connecticut.

Blackwood, L. C., and E. L. Bradley. 1991. An omnibus test for comparing two measuring devices. *Journal of Quality Technology* 23:12–16.

Bonham, C. D. 1989. Measurements for Terrestrial Vegetation. John Wiley & Sons, New Your, New York. 319 p.

Booth, D. T., S. E. Cox, T. W. Meikle, and C. Fitzgerald. 2006a. The accuracy of ground-cover measurements. *Rangeland Ecology & Management* 59:179–188.

Booth, D. T., S. E. Cox, and R. D. Berryman. 2006b. Point sampling digital imagery with 'SamplePoint.' *Environmental Monitoring and Assessment* 123:97–108.

Booth, D. T., and P. T. Tueller. 2003. Rangeland monitoring using remote sensing. *Arid Land Research and Management* 17:455–467.

Breckenridge, R. P., W. G. Kepner, and D. A. Mouat. 1995. A process for selecting indicators for monitoring conditions of rangeland health. *Environmental Monitoring and Assessment* 36:45–60.

Breckenridge, R. P., M. Dakins, S. Bunting, J. L. Harbour, and R. D. Lee. 2006. Employing unmanned aerial vehicles for monitoring habitat in sagebrush-steppe ecosystems. *In:* J. R. Greer (ED.). Proceedings of the 11th Biennial USDA Forest Service Remote Sensing and Applications Center Conference. 24–28 April 2006; Salt Lake City, UT: USDA Forest Service, Remote Sensing applications Center.

Briske, D. D., S. D. Fuhlendorf, and F. E. Smeins. 2005. State-and-Transition Models, Thresholds, and Rangeland Health: A Synthesis of Ecological Concepts and Perspectives. *Rangeland Ecology & Management* 58:1–10

Brower, J. E., J. H. Zar, and C. N. Von Ende. 1990. Field and laboratory methods for general ecology (3rd edition). Dubuque, IA: Wm. C. Brown Publishers. 237 p.

Bunting, S. C. 2002. Natural and prescribed fires in Big Sagebrush steppe—response of individual species and implication to burning practices. Restoration and Management of Sagebrush/Grass Communities Workshop. 4–8 November 2002; Elko, NV: RangeNet. 54 p. *Available at* http://www.rangenet.org/trader/2002_Elko_Sagebrush_Conf.pdf. *Accessed 19 June 2006*.

Bunting, S. C., B. M. Kilgore, and C. L. Bushey. 1987. Guidelines for prescribed burning sagebrush-grass rangelands in the northern Great Basin. General Technical Report INT-231. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Research Station. 33 p.

Carroll, C. R., J. Belnap, R. Breckenridge, and G. Meffe. 1999. Ecosystem sustainability and condition. *In:* W. T. Sexton, A. J. Malk, R. C. Szaro, and N. C. Johnson (EDS.). A common reference for ecosystem management, Vol. II. New York, NY: Elsevier Science. p. 583–598.

Colket, E. C. 2003. Long-term vegetation dynamics and post-fire establishment patterns of sagebrush steppe: Thesis. University of Idaho, Moscow. 144 p.

Connelly, J. W., K. P. Reese, R. A. Fischer, and W. L. Wakkinen. 2000. Response of a sage grouse breeding population to fire in southeastern Idaho. *Wildlife Society Bulletin* 28:90–96.

Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage-grouse *Centrocercus urophasianus* populations in western North America. *Wildlife Biology* 3:229–234.

Cook, C. W., and J. Stubbendieck. 1986. Range research: basic problems and techniques. Denver, CO: Society for Range Management. 317 p.

Crawford, J. A., R. A. Olson, N. E. West, J. C. Mosley, M. A. Schroeder, T. D. Whitson, R. F. Miller, M. A. Gregg, and C. S. Boyd. 2004. Ecology and management of sage-grouse and sage-grouse habitat. *Journal of Range Management* 57:2–19.

DOE. 1994. National environmental research parks. DOE/ER-0615P. Washington, DC: DOE, Office of Energy Research.

Floyd, D. A., and J. E. Anderson. 1982. A new point frame for estimating cover of vegetation. *Vegetatio* 50:185–186.

Forman, A. D., and J. R. Hafla. 2005. Common plants of the INL. STOLLER-ESER-81. Idaho Falls, ID: Environmental Surveillance, Education and Research Program. 125 p. *Available at:* http://www.stoller-eser.com/CMP/Plant_handbook/index.asp. *Accessed 7 April 2007.*

French, N. R, and J. E. Mitchell. 1983. Long-term vegetation changes in permanent quadrants at the Idaho National Engineering Laboratory site. Bulletin Number 36. Moscow, ID: University of Idaho, College of Forestry, Wildlife and Range Sciences. 42 p.

Grubbs, F. E. 1973. Errors of measurement, precision, accuracy and the statistical comparison of measuring instruments. *Technometrics* 15:53–66.

Grubbs, F. E. 1948. On estimating precision of measuring instruments and product variability. *Journal of the American Statistical Association* 43:243–264.

Hagen, C. A., J. W. Connelly, and M. A. Schroeder. 2007: A meta-analysis of greater sage-grouse Centrocercus urophasianus nesting and brood-rearing habitats. *Wildlife Biology* 13(Supplement 1): 27–35.

Johnson, D. E., M. Vulfson, M. Louhaichi, and N. R. Harris. 2003. VegMeasure version 1.6 user's manual. Corvallis, OR: Oregon State University, Department of Rangeland Resources, VegMeasure Project. 51 p.

Knick, S. T., and J. T. Rotenberry. 1995. Landscape characteristics of fragmented shrubsteppe habitats and breeding passerine birds. *Conservation Biology* 9:1059–1071.

Maczko, K. A., L. D. Bryant, D. W. Thompson, and S. J. Borchard. 2004. Putting the pieces together: assessing social, ecological, and economic rangeland sustainability. *Rangelands* 26(3):3–14.

Mahalovich, M. F., and E. D. McArthur. 2004. Sagebrush seed (Artemisia ssp.) and plant transfer guidelines. *Native Plants* 5(2):141–148.

Maloney, C. J., and S. C. Rastogi. 1970. Significance test for Grubbs's estimators. *Biometrics* 26:671–676.

Mouat, D. A., and C. F. Hutchinson (EDS.). 1995. Desertification in developed countries. Dordrecht, The Netherlands: Kluwer Academic Publishers. 363 p.

National Research Council. 1994. Rangeland health: new methods to classify, inventory, and monitor rangelands. Washington, DC: Committee on Rangeland Classification, The National Academies Press. 180 p.

National Transportation Safety Board. 2007. *Aviation accident database & synopses*. *Available at:* http://www.ntsb.gov/ntsb/query.asp. Accessed *7 April 2007*.

Nevada Wildlife Federation. 2002. Enhancing sage grouse habitat … A Nevada landowner's guide. Reno, NV. 13 p. *Available at:* http://www.nvwf.org/. *Accessed 5 April 2007*.

Pedersen, E. K., J. W. Connelly, J. R. Hendrickson, and W. E. Grant. 2003. Effect of sheep grazing and fire on sage grouse populations in southeastern Idaho. *Ecological Modelling* 165:23–47.

Pellant, M., P. Shaver, D. A. Pyke, and J. E. Herrick. 2005. Interpreting indicators of rangeland health, Version 4. Technical Reference 1734-6, BLM/WO/ST-00/001+1734/REV05. Denver, CO: U.S. Department of the Interior, Bureau of Land Management, National Science and Technology Center. 122 p.

Pitman, E. J. G. 1939. A note on normal correlation. *Biometrics* 31:9–12.

Pyke, D. A., J. E. Herrick, P. Shaver, and M. Pellant. 2002. Rangeland health attributes and indicators for qualitative assessment. *Journal of Range Management* 55:584–597.

Rickard, W. H., L. E. Rogers, B. E. Vaughan, and S. F. Liebetrau, (EDS.). 1988. Shrub-steppe: balance and change in a semi-arid terrestrial ecosystem. New York, NY: Elsevier. 272 p.

Smith, R. L. 1990. Ecology and field biology (4th edition). New York, NY: Harper Collins. 922 p.

Society for Range Management, Task Group on Unity in Concepts and Terminology Committee Members. 1995. New concepts for assessment of rangeland condition. *Journal of Range Management* 48:271–282.

USDI-BLM (U.S. Department of the Interior, Bureau of Land Management). 1997. Standards for healthy rangelands and guidelines for livestock grazing management for the public lands administered by the Bureau of Land Management in the State of Wyoming. Booklet BLM/WY/AE-97-023+1020. Cheyenne, WY: U.S. Department of the Interior. 16 p.

Walker, B. H. 1993. Rangeland ecology: Understanding and managing change. *AMBIO* 22:80–87.

Whitford, W. G. (ED.). 1986. Pattern and process in desert ecosystems. Albuquerque, NM: University of New Mexico Press. 139 p.

Zager, P. 2006. UAVs and natural resources. Eleventh Biennial USDA Forest Service Remote Sensing Applications Conference. 24–28 April 2006; Salt Lake City, UT: U.S. Department of Agriculture Forest Service, Remote Sensing Applications Center. 33 p. *Available at:* http://www.fs.fed.us/eng/rsac/RS2006/presentations/zager.pdf. *Accessed 5 April 2007*.

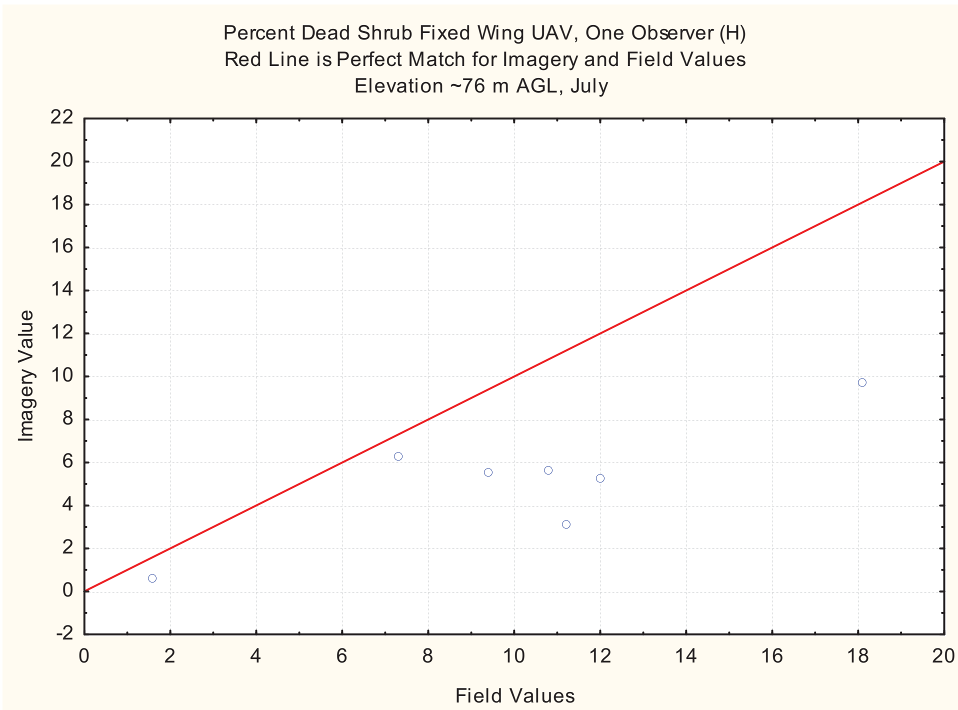
Appendix A

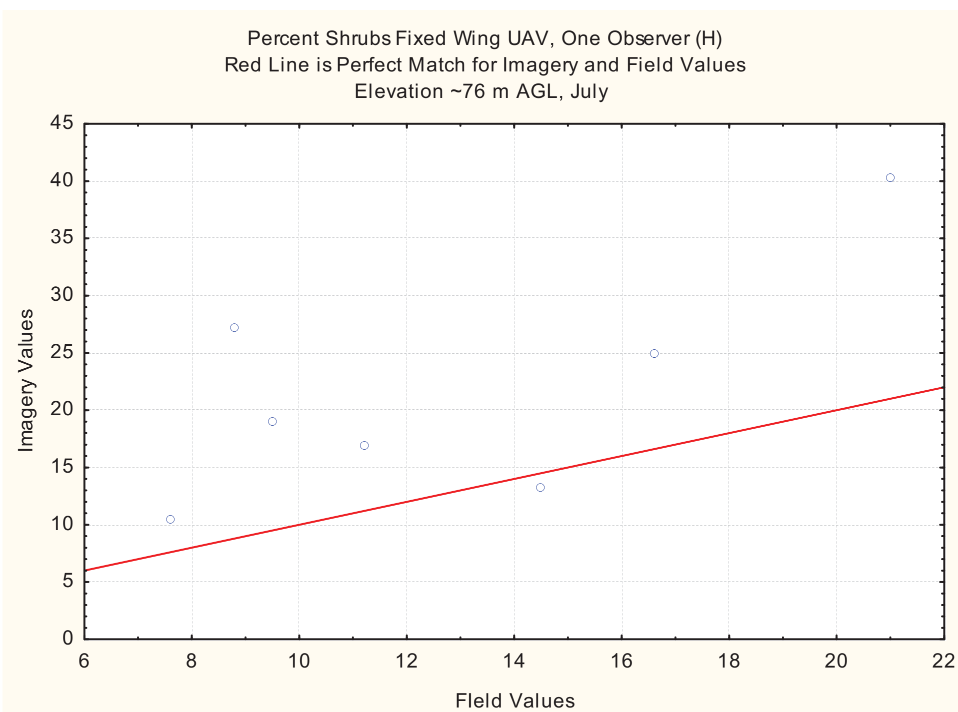
Graphs for July Fixed-wing UAV Data for Imagery against Field Values for One Observer with High Degree of Experience

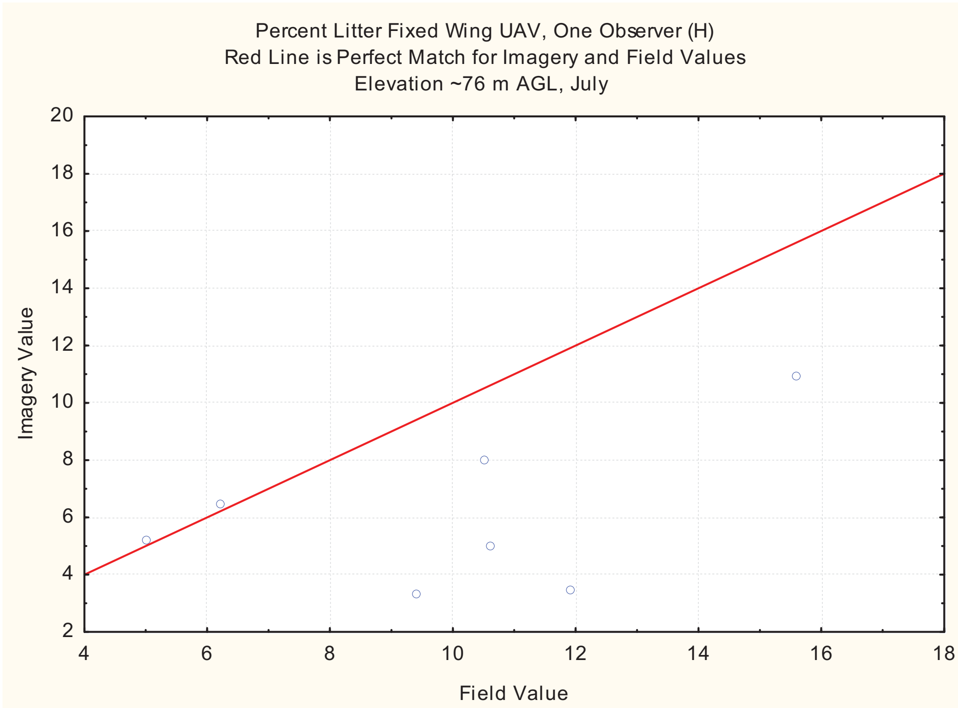
Below are the graphs for the July fixed-wing UAV data with imagery values and field values flown at ≈76 m (250 ft) AGL for the observer with a high degree (H) of experience. These graphs show relationships to the perfect-fit red line (Y=X) between the imagery and field values. The imagery was collected in July (7/20/05). The field values were not collected until mid July (7/22–25/05). Entering the field plot areas before completing the flights would have compromised the integrity of the vegetation.

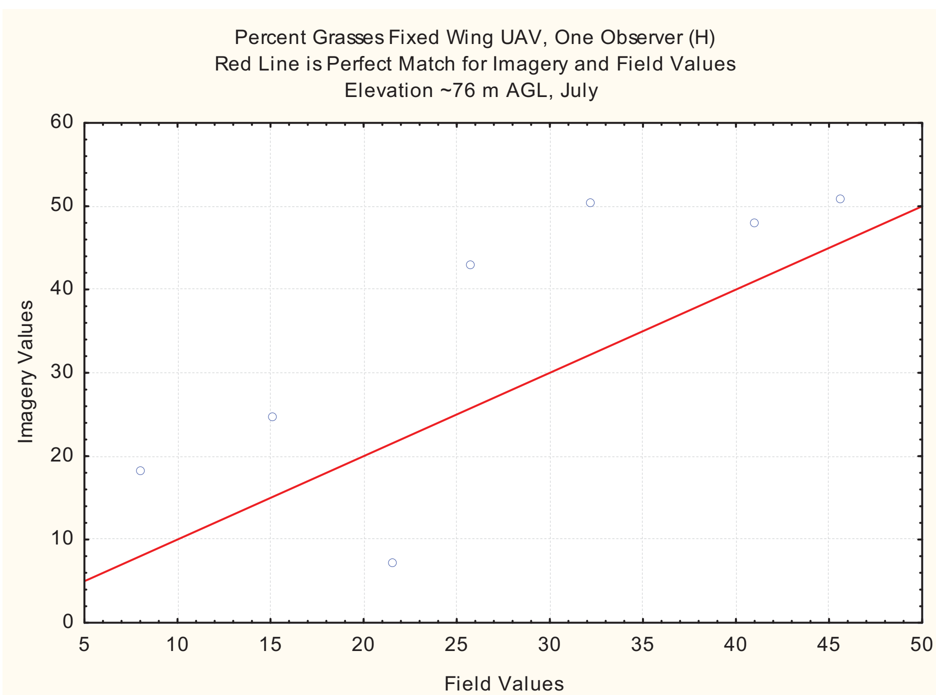
Scatter Plots for July, Observer 1 (H)

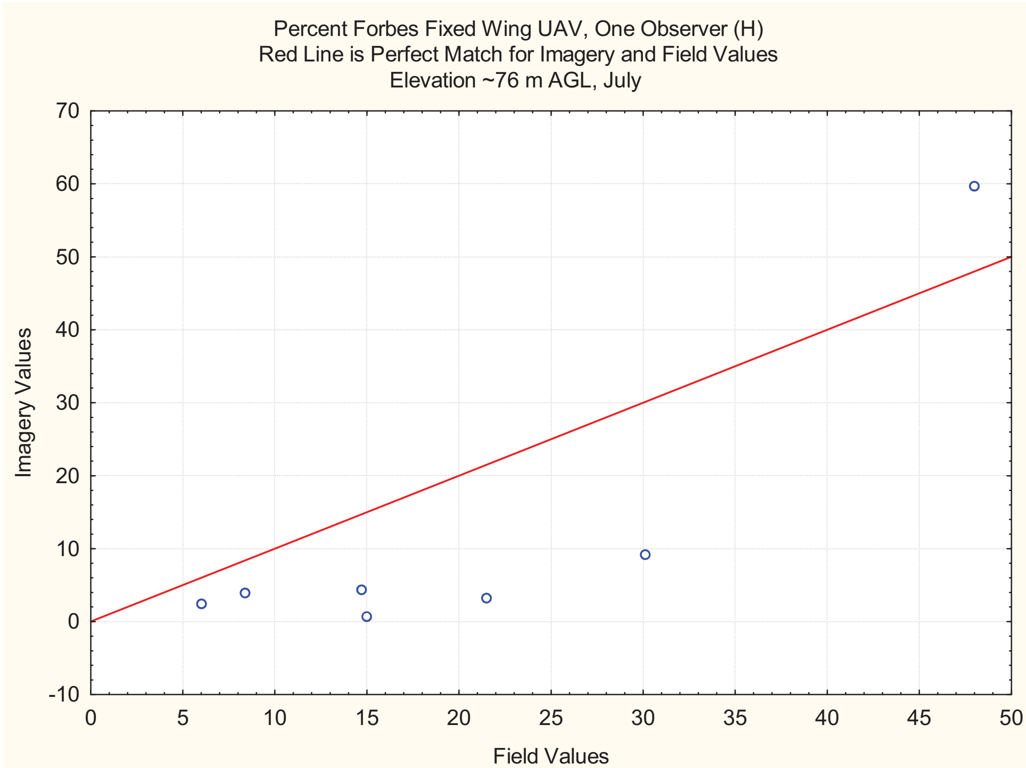
Note: Imagery from seven plots was evaluated and compared against field values.






Percent Litter Fixed Wing UAV, One Observer (H)
Red Line is Perfect Match for Imagery and Field Values
Elevation ~76 m AGL, July
Imagery Value
Field Value
2
4
6
8
10
12
14
16
18
20
4
6
8
10
12
14
16
18


Percent Grasses Fixed Wing UAV, One Observer (H)
Red Line is Perfect Match for Imagery and Field Values
Elevation ~76 m AGL, July
Imagery Values
Field Values
0
10
20
30
40
50
60
5
10
15
20
25
30
35
40
45
50


Percent Forbes Fixed Wing UAV, One Observer (H)
Red Line is Perfect Match for Imagery and Field Values
Elevation ~76 m AGL, July
Imagery Values
Field Values
70
60
50
40
30
20
10
0
-10
0
5
10
15
20
25
30
35
40
45
50