Development of a Remote Sensing Based Initial Assessment Burn Severity Model

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Abstract

Two hundred seventy sample points were taken during the summer of 2005 within the USDA-ARS Sheep Experiment Station, DuBois Idaho. Fine-scale vegetation data were collected (n=270) using randomly located ocular estimation methodology (3600m^2, n= 205), point frame methodology (800m^2, n= 45), and twenty stratified-random plots. Ocular estimates included a description of percent cover of shrubs, grasses, forbs, litter, bare ground, and rock as well as an indication of the dominant shrub and weed species, fuel load, sagebrush age, GAP vegetation class, presence/absence of microbial crust, litter type, homogeneity, and four photo points. These estimates and measurements attempted to describe the vegetation within a 60x60m sample area. Point frame estimates included a description of percent cover of shrubs, grasses, forbs, litter, bare ground, and rock using a dot grid (0.5m^2) overlooking underlying vegetation and bare ground. All sample points were stratified by fuel load. Within the study area 64% of the samples indicate a moderate fuel load (~3 tons/acre; n=173), while 21% was low fuel load (n=56) and 15% was high fuel load (n=41). An additional method of shrub cover measurement was incorporated to compare cover results. Ultralight images were taken the week of July 11, 2005 and a classification of shrub cover was made using VegMeasure software. Linear correlation analysis indicates that the best agreement between these estimation methodologies is between the 60x60m ocular methodology and point frame methodology (r 0.7997 for shrub). Correlations between either of these estimation methods and VegMeasure results were poor (60x60m: r 0.1625, point frame: r 0.0224). These correlations were based on a comparison of samples taken within 30 meters of one another. To further examine the relationship between these estimation methods an Inverse Distance Weighted spatial interpolation was performed using shrub cover estimates derived from VegMeasure (point frame: n= 42, 60x60m: n= 195). This was done to predict shrub cover at the exact location where ocular and point-frame estimates were taken, thereby allowing for a more direct comparison of estimation methods. These estimates were compared with both 60x60m ocular and point frame estimates using linear correlation analysis; both relationships resulted in very low R-squared values (R^2 = 0.0049 and 0.0207 respectively).

Keywords

USDA-ARS Sheep Station, ocular estimation, point frame method, percent cover, shrubs, VegMeasure

Introduction

This study focused on detecting burn severity in a sagebrush-steppe ecosystem using field data and remote sensing techniques. The Normalized Burn Ratio (NBR) is an index based on remote sensing data and is used to calculate the extent and severity of a fire. NBR has been proven to function well in forested ecosystems (Key and Benson, 2004) due to a high contrast of vegetation change before and after the fire. There are two strategies of NBR, initial assessment and extended assessment; with the latter typically considered more representative of fire severity. The difference in assessment strategy is related to the time when post-fire imagery is acquired. This study applied an initial assessment burn severity assessment using multi-spectral imagery following a fall, 2005 prescribed fire at the USDA-ARS U.S. Sheep Experiment Station near Dubois, Idaho. This project uses field and remote sensing data to develop the burn severity assessment specific to semiarid environments. The final model and technique will provide land managers with a tool to assist in accurately describing the characteristics (size, distribution, and severity) of burned areas.

This research also assessed whether pre-fire conditions can reliably predict burn severity in rangeland environments. Regression was used across fuel load categories with their corresponding burn severity ratings to determine possible correlation. The relationship between pre-fire vegetation cover and burn severity, as well as the correlation between burn severity and vegetation re-growth is poorly understood. Once developed and tested, the burn severity model may be applied to current remote sensing data to determine its corresponding burn severity if the area were to burn. To determine if there is a relationship between burn severity and vegetation re-growth, the model may be applied to historical remote sensing data and thus, the results can be compared with the current stages of vegetation re-growth. This opportunity provides the scientific community abundant new data to further explore the relationship between pre-fire vegetation cover and burn severity, and the associated rangeland community dynamics after a fire. This remote sensing application will enhance fire management and recovery efforts across semiarid rangelands worldwide. For example, this information is useful in making assessments on how quickly the landscape will recover, and thus determine what type of treatments land managers can apply to speed recovery in a more efficient and cost effective manner.

For this research, burn severity is defined as the completeness of the burn, or the proportion of biomass removed by the fire. This includes how thoroughly the vegetation was burned, regardless of the pre-existing fuel load. Burn severity was assessed using field data and remote sensing techniques to evaluate the difference in vegetation cover before and after the fire. Both vegetation percent cover field data (n= 10 days) and remote sensing images were acquired shortly before and after the fire. The difference between field vegetation estimates was compared with differenced remote sensing data with the goal of delineating areas of high and low amount of biomass lost as a result of the fire.

An ocular field assessment of burn severity was established based on three field practices for determining burn severity: the composite burn index, (developed by Key and Benson (2004)), the US Park Service field methods (USDI NPS, 2003), and the US Forest Service field methods (USDA FS, 2001, 2002). They were incorporated collectively and modified for application in rangelands. The composite burn index, developed by Key and Benson (2004), as well as the Forest Service and Park Service methods are all post-fire field procedures used to detect and categorize burn severity. Also included in the burn severity analysis will be percent live vegetation cover and litter, as well as exposed rock and bare soil measurements made immediately after the fire. Using field data, multi-temporal imagery, and remote sensing techniques this study aims to develop a reliable burn severity model which can be applied in rangeland ecosystems.

Field Methods

Prior to sampling, large-scale (~3.24km^2) vegetation variability and fuel load estimates were assessed across the study area (Figure 1). The variability in fuel load is important to know to adequately sample across all fuel loads. These large-scale fuel load estimates were performed using the BLM's Determining Fuel Models method (Anderson, 1982), which estimates the amount of fuel in tons/acre. The categories used were very low (0.74 ton/acre=grass only), low-medium (1-2 tons/acre=grass with small, sparse shrubs), medium (3 tons/acre=medium shrubs), and high (4 tons/acre=large, dense shrubs) fuel load categories were observed. These categories were condensed to three total fuel loads: low= 0.74-2 tons/acre, medium= 3 tons/acre, high=4 tons/acre. Seventy-eight polygons with sizes ~8267m^2 were recorded with a Trimble GeoXT GPS receiver (+/- 0.7m @ 95% CI) and labeled with their respective fuel loads category.

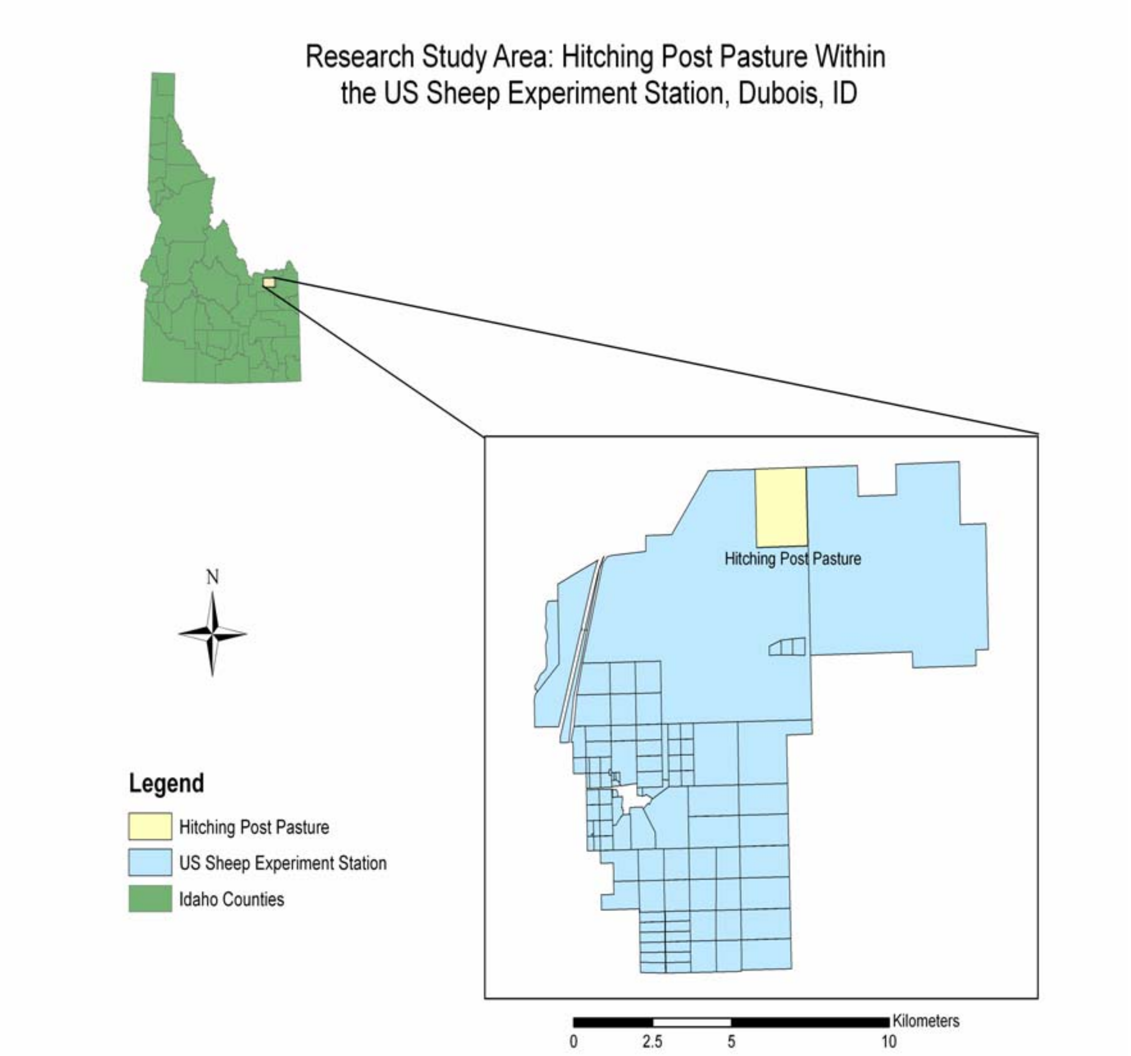


Figure 1: The project study area is within the Hitching Post Pasture of the US Sheep Experiment Station (USSES) in Dubois, Idaho.

After large-scale fuel load estimates were completed, fine-scale sampling of the vegetation was evaluated using 60x60m plot areas. Two hundred sample points were randomly generated across the study area using Raster Drilldown (GIS TReC, http://giscenter.isu.edu/software/index.htm) which were navigated to and sampled for percent cover (Table 1), as well as identifying the dominant weed and estimating its abundance (percent cover; Table 1), estimating fuel load (tons per acre) following BLM protocols (Anderson, 1982), and four photo points were taken, one in each cardinal direction. Percent cover (Table 1) of 6 cover categories (shrub, grass, forb, litter, rock, and bare ground) were estimated by walking around the plot and visually estimating/generalizing a cover category for each class (McMahan, et al., 2003). Each plot center location was recorded using a Trimble GeoXT GPS receiver (+/- 0.7m @ 95% CI). At the center of each sample plot, sagebrush was described by its average height and diameter using calipers (+/-1cm) to approximate the age of each plant (Perryman and Olson, 2000). Homogeneity of vegetation cover was assessed across the plot. If vegetation cover was consistent across the entire 60x60m plot it was marked as being homogenous. Each point met the following criteria: 1) >20m from all dozer-created black-lines (for enclosure of the prescribed burn), and 2) >20m from all roads. The 60x60m ocular estimate measurements were taken within all fuel load types.

Table 1: The six cover categories were ocularly measured within these eight cover classes.

Cover Classes

None	0
1-5%	1
6-15%	2
15-25%	3
26-35%	4
36-50%	5
51-75%	6
>75%	7

The second method of fine-scale vegetation sampling was the use of 20x40m point frame measurements (0.5m^2 each). The point frame technique, designed by Floyd and Anderson (1982) is a well-accepted, accurate sampling method used to determine percent cover of various vegetation types. Designed in sagebrush steppe ecosystems, the point frame establishes a dot grid overlooking underlying vegetation and bare ground. Fifteen point frame observations were collected within each 20x40m plot. The number of point frames was determined by plotting the arithmetic mean and standard deviation for each cover category (Table 1) in relation to the cumulative number of frames used (Figure 2). The corresponding number of frames where the arithmetic mean and standard deviation start to level off was interpreted as the number of point frame observations needed to capture the population's variability for that particular cover type. Because each 20x40m plot results in different frame numbers, an over-estimation of fifteen was chosen as a safety measure. The example in Figure 2 indicates 9 frames would be needed to account for the variability in grass. Note that the number of frames needed cannot actually be acquired until the field data itself has been acquired.

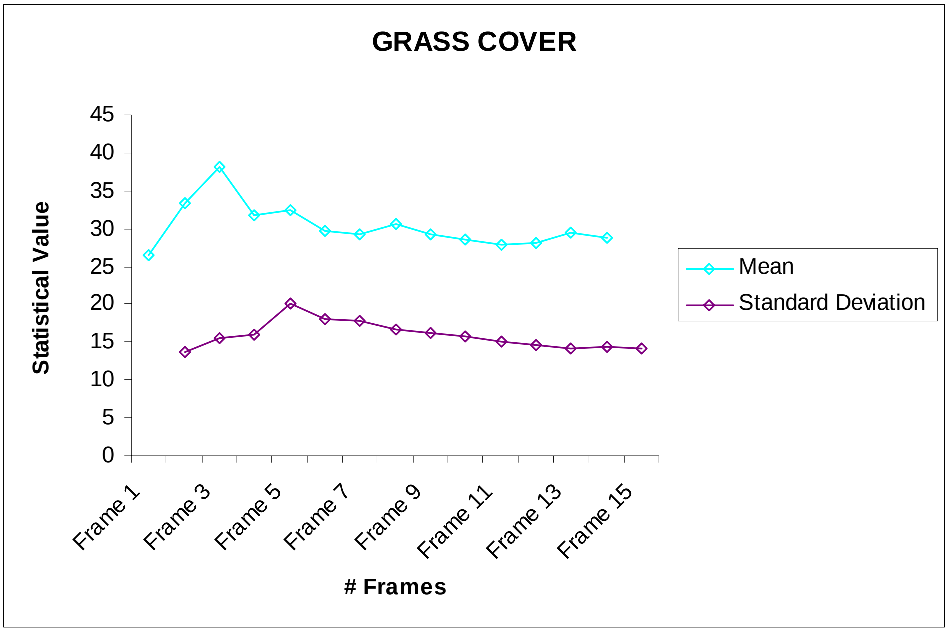


Figure 2: To determine the number of frames needed to accurately depict grass percent cover in each 20x40m plot, one finds where the arithmetic mean (average grass cover for the plot) and standard deviation (standard deviation of grass cover for the plot) level out together. In this figure, the statistical values level out at 9 frames.

Point frame measurements were taken across all fuel load types (n=3) within the established fuel load polygons (n=78; see large scale field methods above). In total there were 20 stratified random point frame plots established within these fuel load polygons. Each fuel load area (as well as areas designated as unburned relative to the prescribed fire) was characterized using four, 20x40m point frame plots. Forty-five additional point frame plots were established randomly across the pasture. A Trimble GeoXT GPS receiver recorded the 20x40m plot boundaries. At each of these locations four photo points were taken, one in each cardinal direction, homogeneity was described, and fuel load (tons per acre) was estimated following BLM protocols within each plot (Anderson, 1982).

Results

Generally, this pasture was in good rangeland health because there was little bare ground and weeds observed and high percent live vegetation cover (sagebrush, forbs, and grass) throughout. Most of the study area was within the medium fuel load classification (3 tons/acre).

Percent Cover of Litter, Forb, Grass, Shrub, Rock, and Bare Ground: Point Frame

Forty-six percent of all litter, forb, and bare ground cover categories were within the 6-15% cover class for the point frame results (n=65). Forty-three percent of all grass samples were within the 16-25% cover class; thirty-one percent of all shrub samples were within the 26-35% cover class; and sixty-nine percent of all rock samples were within the 1-5% cover class.

Percent Cover of Litter, Forb, Grass, Shrub, Rock, and Bare Ground: 60x60m Ocular Estimate

The majority of litter and rock cover categories were within the cover class of 1-5% for the 60x60m ocular estimate results (n=205): 52% and 75% respectively. Forb and bare ground were mostly within the 6-15% cover class and were 82% and 39% respectively. The majority of grass, within the 16-25% cover class, was 49%. 40% of shrub cover was within the 36-50% cover class.

Big Sagebrush Age Estimation

The mean age of sagebrush plants was 10.62 years (n=205). The minimum age was 6.91 years and the maximum age was 23.52 years. This was determined using stem diameter/age relationships of big sagebrush (Perryman, and Olson, 2000).

Weeds

The dominant weed in the study area was cheatgrass (*Bromus tectorum)* which was found within 18% of all plots (n=205), with 97% of these samples having ≤ 5% cover. Other weeds present in the study area include spotted knapweed (*Centaurea maculosa)*, mullein (*Verbascum thapsus L.*), and leafy spurge (*Euphorbia esula*), within 2%, 9%, and 1% of all plots respectively; all with ≤ 5% cover.

Shrubs

The study area is a sagebrush-steppe ecosystem having two primary subspecies of sagebrush (*Artemisia* ssp.): mountain big sagebrush (*A. tridentata* ssp. *vaseyana*), and threetip sagebrush (*A. tripartita ssp. tripartita*). Other shrub species within the study area were antelope bitterbrush (*Purshia tridentata*), green rabbitbrush (*Chrysothamnus viscidiflorus)*, and horsebrush (*Tetradymia canescens)*.

Shrub cover was estimated using three distinct methodologies. We compared the results of shrub cover estimates to determine if a correlation existed between the methodologies and to help validate/corroborate our estimates. To determine the relationship between 60x60m ocular estimates and point frame estimates, we used 49 sample points located within 10 meters of one another. Using linear correlation analysis, an r of 0.7997 indicates high correlation between these estimation methodologies (Figure 3) for percent shrub cover and this is significant (*P* <0.0001). Table 2 shows that correlations are good for bare ground as well, 63% of the time (+/-5 %; *P* <0.0001), and that ocular estimates and point frame methods are not correlated for all other cover categories. These r values and significance ratings are given in Table 3.

An additional method of shrub cover estimation was incorporated for comparison. Aerial ultralight images were taken the week of July 11, 2005 and a classification of shrub cover was made using VegMeasure software. Correlations with the VegMeasure results were poor (Figures 4 and 5). However, compared points (n = 42 and 39) were located within 30 meters.

In an attempt to allow for spatial heterogeneity effects, another shrub cover estimation was derived using the VegMeasure shrub cover estimates to perform a spatial interpolation using inverse distance weighted (IDW) techniques. IDW estimates shrub cover across the entire study area, giving greatest weight to those sample points nearest the focal pixel being classified (Longley et al., 2005). These results were compared (minimum cells = 12, maximum search distance = 600m, power = 1) to the 60x60m ocular estimates (Figure 6, n = 195) and point frame estimates (Figure 7, n = 42); both show poor agreement (r 0.07 and r 0.1439 respectively).

Other Cover Types

In order to show heterogeneity for each cover type across the study area (Table 4), we compared the arithmetic means for percent cover of each cover category across a 20x40m point frame plot (n=15 samples per plot) with standard error of mean (SEM) bars. The plots are different among the plots, indicating heterogeneity of all cover types across the study area.

Standard deviation around the mean (Table 5) indicates variability within each 20x40m plot. A SPOT pixel (10x10m) has smaller spatial resolution than the point frame, therefore cover is variable among pixels as well (Figure 9). This is important to know when using the imagery for modeling.

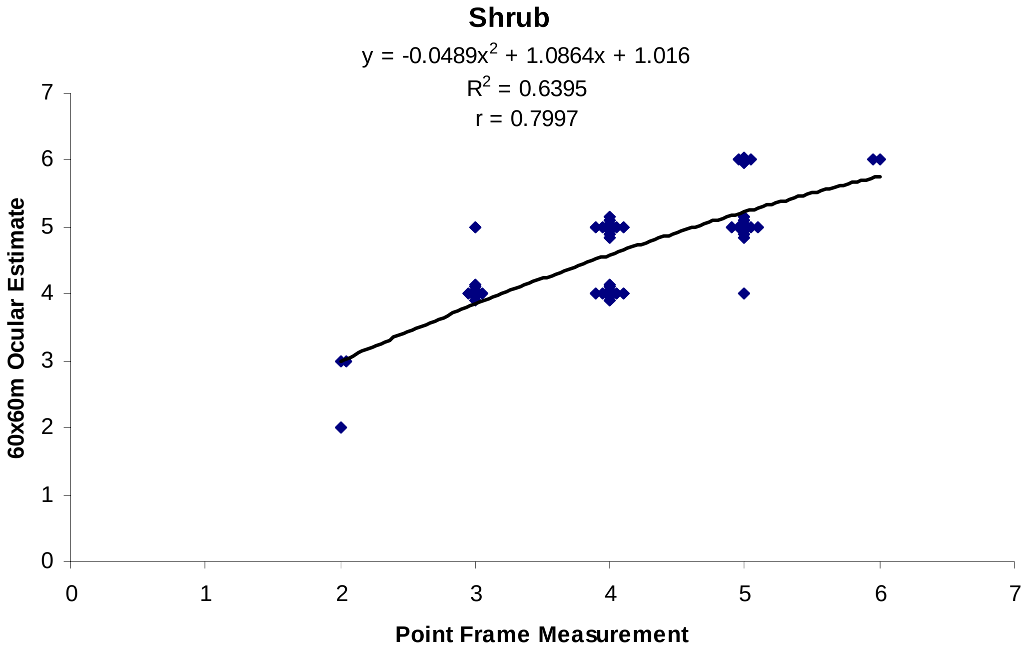


Figure 3: Shrub percent cover estimates were compared using two sampling methods: 60x60m ocular estimates and point frame estimates (n = 48). This correlation uses sample points within 10m. A second order polynomial trendline has been added.

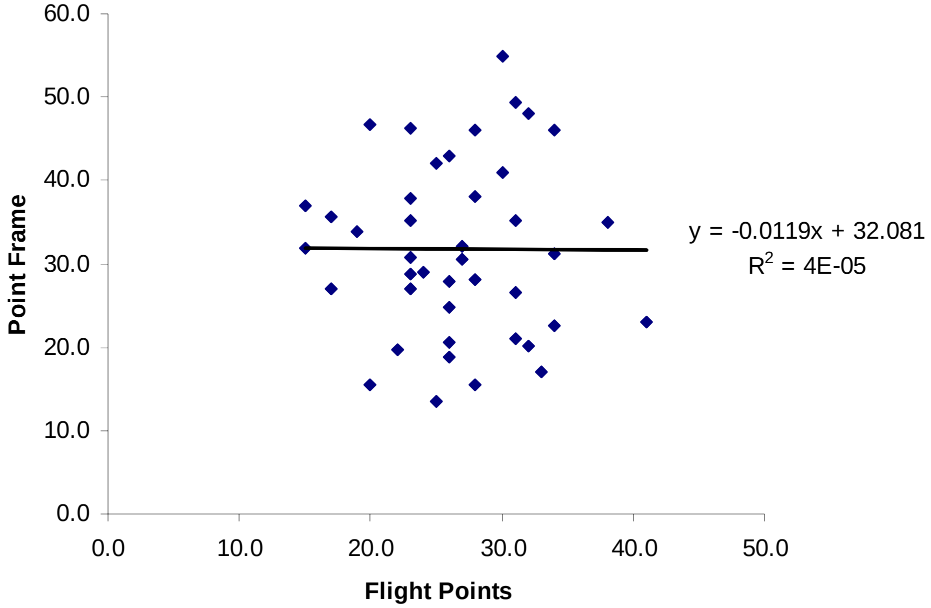


Figure 4: Shrub percent cover estimates were compared using two sampling methods: aerial photography interpretation (n = 42) and point frame estimates (n = 42). This correlation uses sample points within 30m.

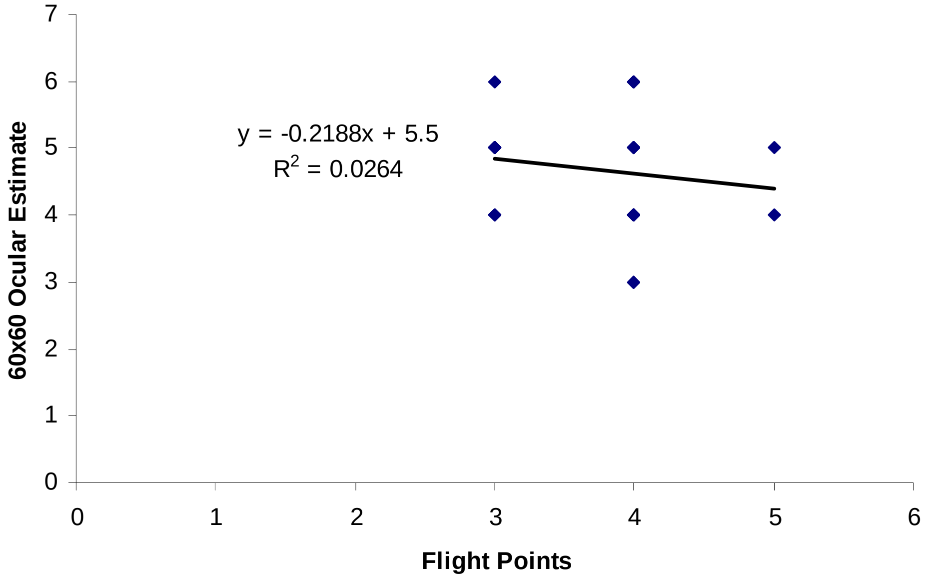


Figure 5: Shrub percent cover estimates were compared using two sampling methods: aerial photography interpretation (n = 39) and 60x60 ocular estimates (n = 39). This correlation uses sample points within 30m.

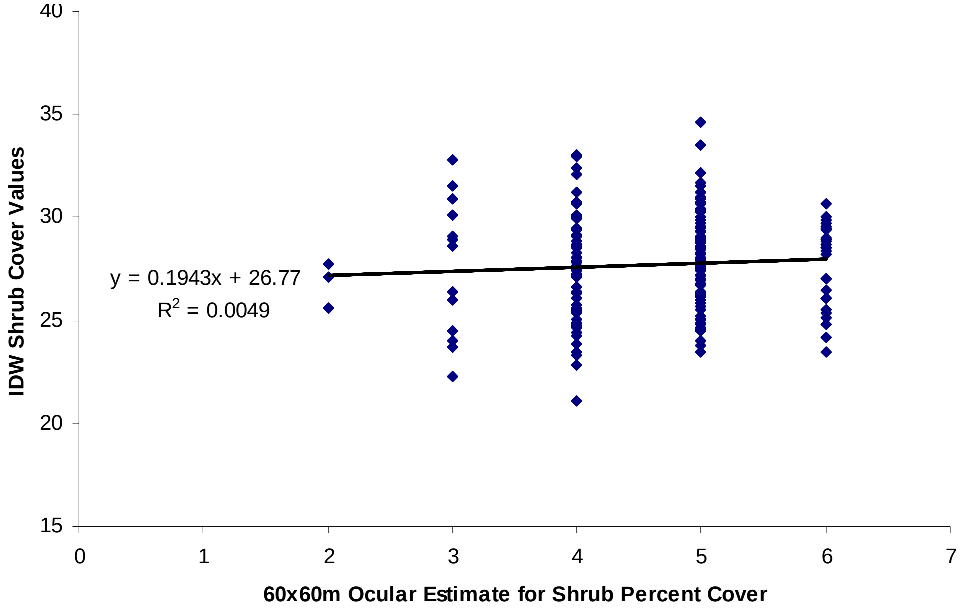


Figure 6: The relationship between 60x60m ocular estimates for percent shrub cover (n = 195) and the inverse distance weighting (IDW) values (n = 195). The linear relationship (y=0.1943x + 26.77) does not explain much of the variation in percent cover of shrub values.

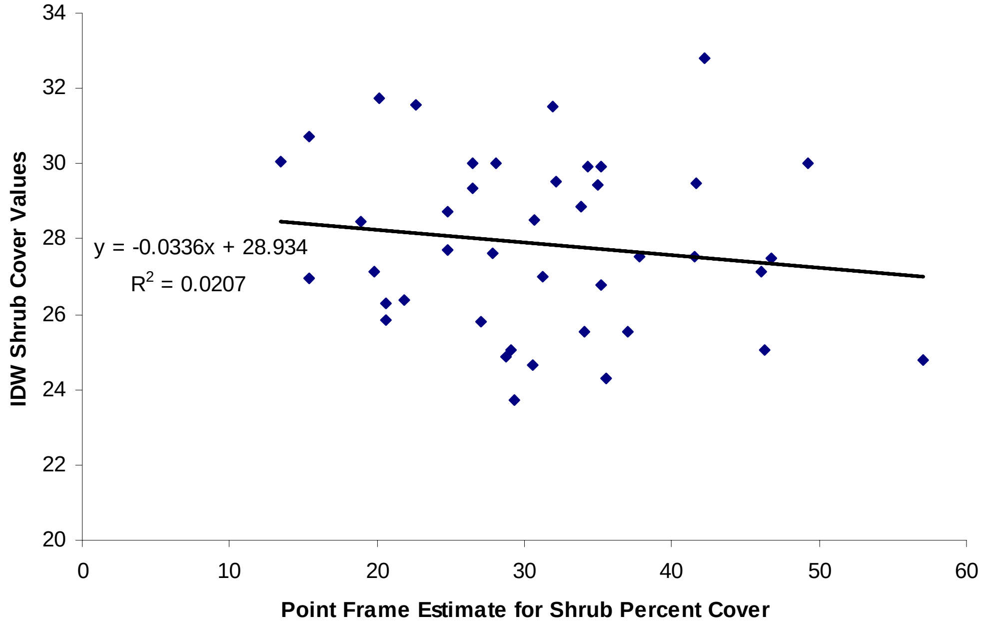


Figure 7: There is a negative correlation between the point frame percent shrub cover estimates (n = 42) and the inverse distance weighting (IDW) values (n = 42). The linear relationship (y=-0.0336x + 28.934) does not explain much of the variation in percent cover of shrub values.

Table 2: Point frame estimates are correlated with ocular estimates (n=49) in the same area for shrub and bare ground, consistently estimating the shrub cover or bare ground ≈ 80% or ≈ 63% respectively. Other classes are not correlated between methods. These correlations use sample points within 10m, and second order polynomial trendlines have been added.

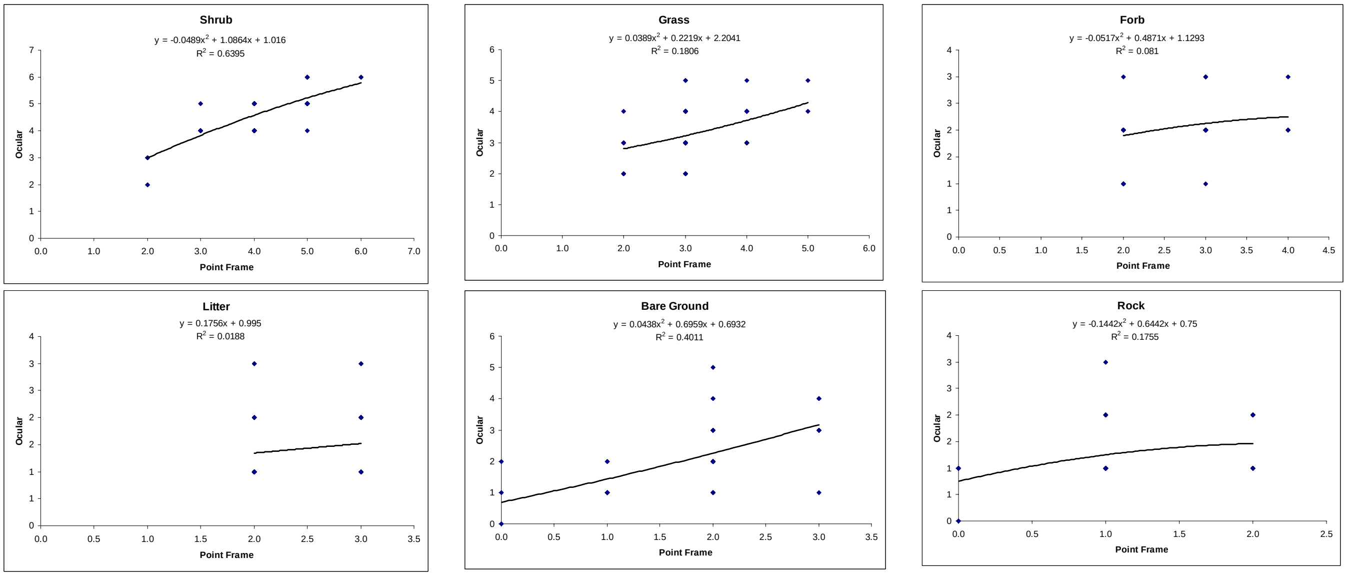
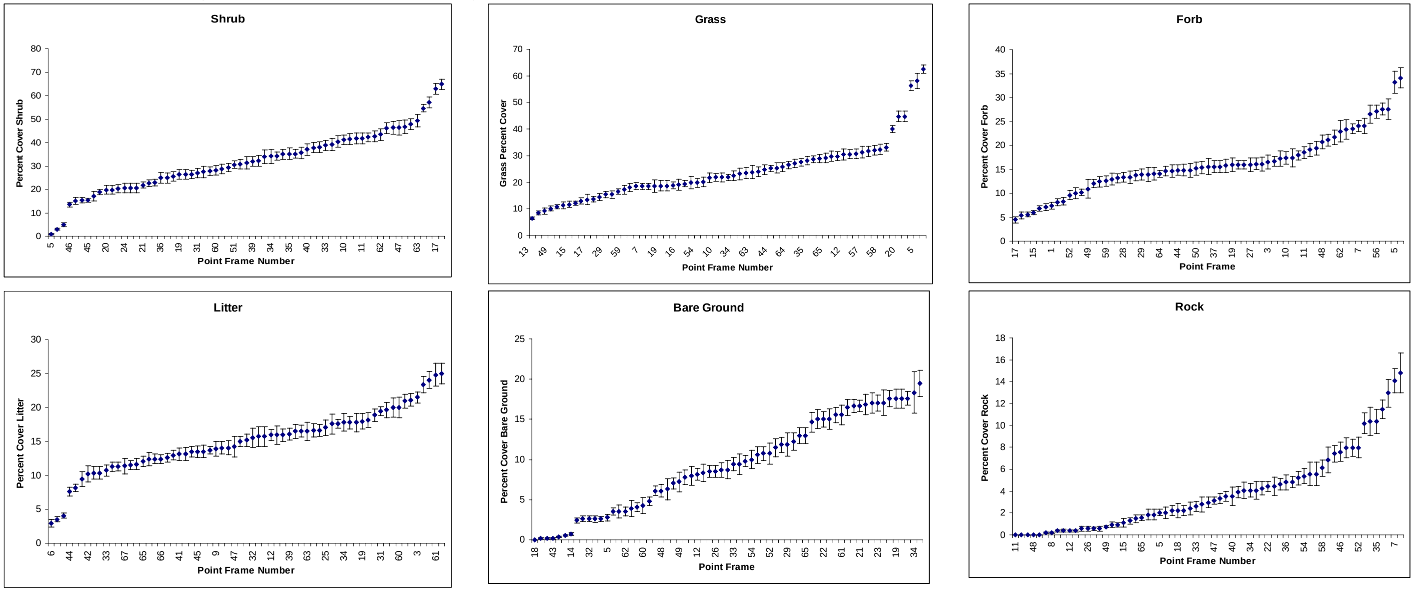


Table 3: Significance ratings for all cover categories. All are highly significant (*) except forb which is marginally significant; litter is not significant most likely due to its fine-scale presence.

Cover Category	r Value	*P* Value
Shrub	0.7997	<0.0001 *
Grass	0.4249	0.0024 *
Forb	0.2846	0.0504
Litter	0.1371	0.3473
Bare Ground	0.6333	<0.0001 *
Rock	0.4189	0.0046 *

Table 4: Spread of the mean percentage of all cover types (+/- 1 standard error of mean (SEM)) using the Point Frame method **(**n=65). Comparing two means at a time for shrub cover, multiple comparisons as part of an ANOVA indicates that some point frames are significantly different 95% of the time. There is heterogeneity of all cover categories across the study area.



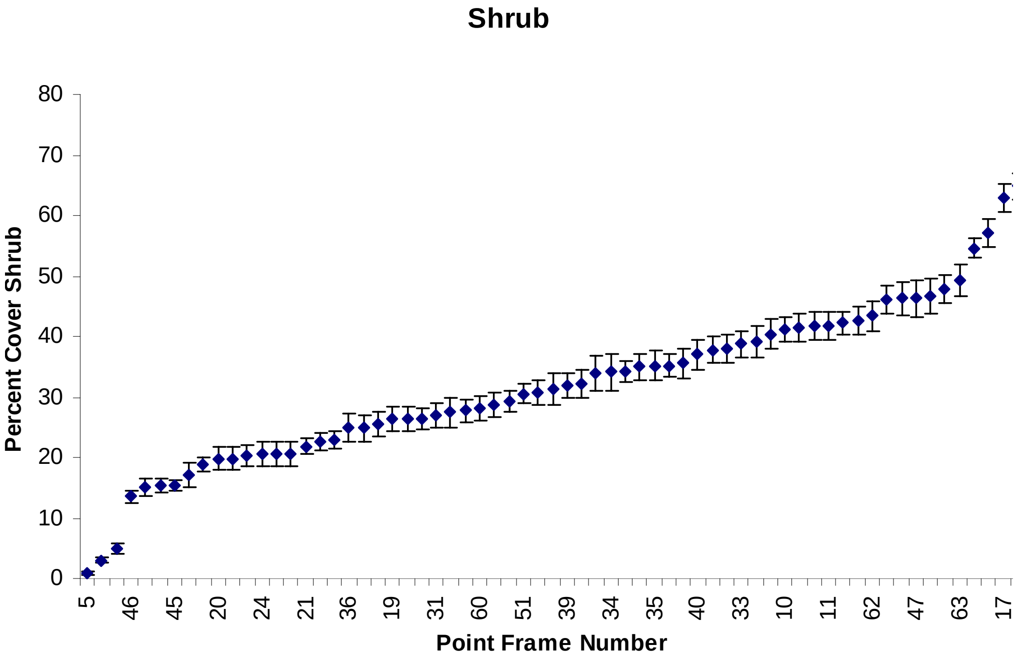
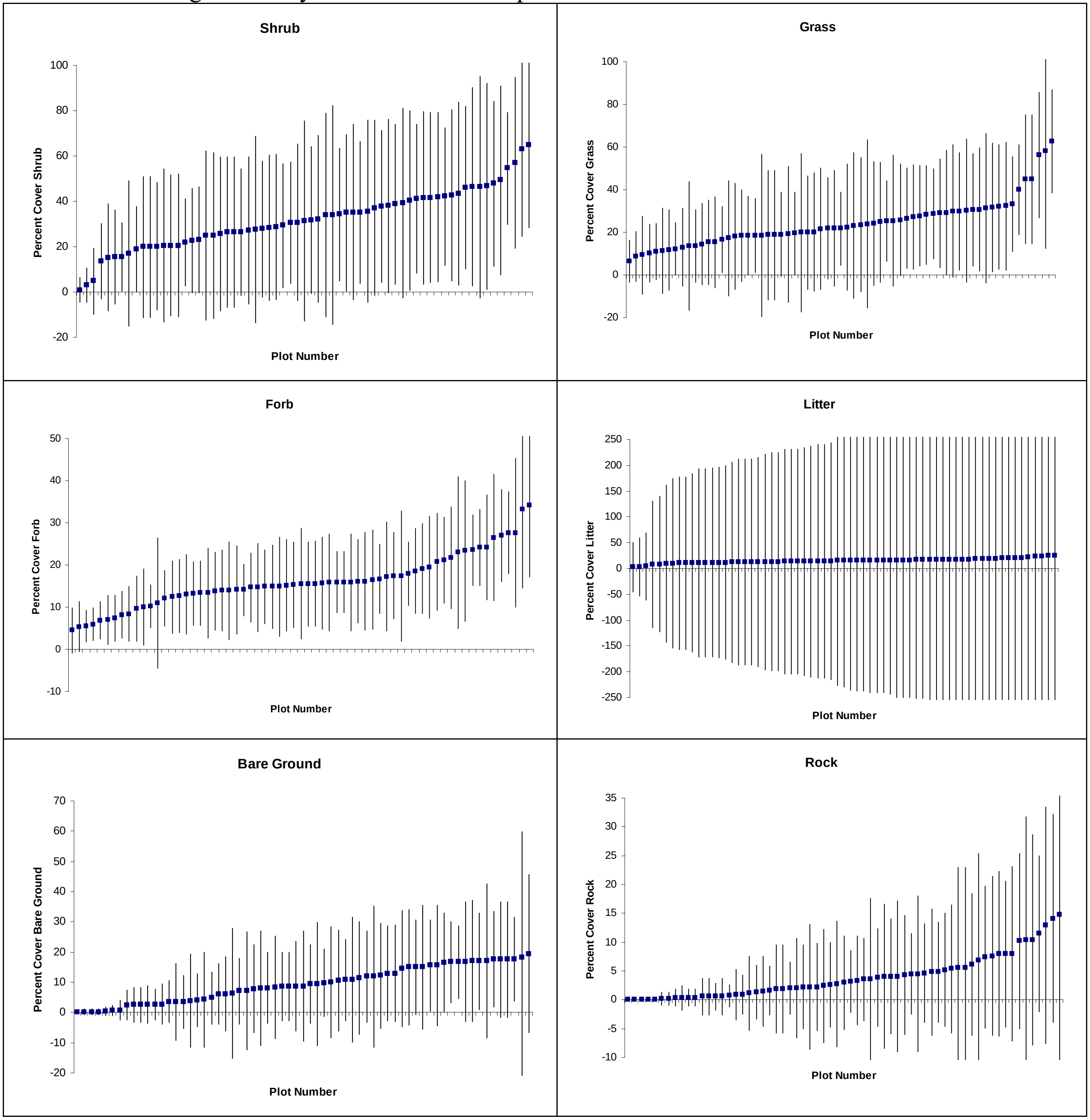


Figure 8: Spread of the means (+/- 1 SEM) of percent shrub cover in 65 plots based on the point frame method. Pairwise mean comparisons (Tukey HSD) found that 8% of the pairs differed at an experiment-wide error rate (α) = 0.05. The study area shrub cover is homogenous.

Table 5: Average percent cover for all cover categories with 2 standard deviations (95%) indicating variability amid each 20x40m plot.



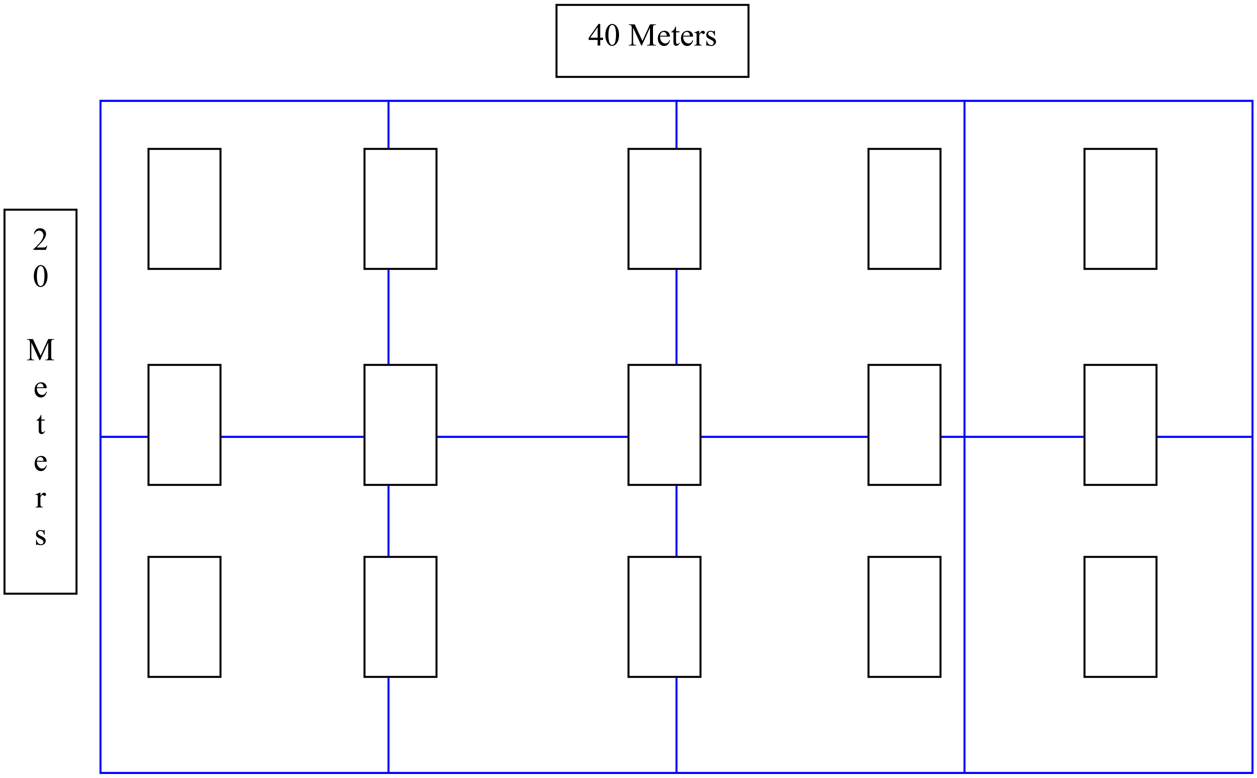


Figure 9: Approximate location of 15 point frames within each 20x40m plot. Blue lines indicate potential SPOT pixel 10x10m placement.

Conclusions

Due to low R^2 values for the correlations between the ultralight Veg Measure points/ IDW values and other cover estimate methods, we conclude that point frame and 60x60m ocular estimates were better measures of cover. However, this result may be premature. To gather a large enough sample to compare with other analyses (ocular estimation and point frame) we were required to select points within +/- 30m of one another, and used a maximum distance of 600m to produce the IDW spatial interpolation grid. This is in contrast to using points within 10m of one another when comparing point frame and ocular estimates. The 60x60m ocular estimates and point frame estimates explained very little (0.49% and 2.07%) of the variation in IDW values. Ideally, point frame and ocular estimates should have been collected at the same location as the VegMeasured points. This was not done because 1) a poor correlation was not expected and 2) the purpose of this study was not to compare estimation methods but to compile data describing the vegetation and fuels present within the study area. In comparing the mean percent shrub cover for the point frames with SEM, only some (158/2080 ≈ 8%) of the point frames were different at a 95% confidence interval using pairwise mean comparison (Tukey HSD). This indicates that the study area's shrub cover is heterogenous. Note that this is an extremely conservative test of significance because the sample size is so large. The best correlations between the point frame and ocular estimates are of shrub cover; there is 80% correlation. Ocular estimates compared well with point frame measurements for all cover categories except litter (forb was marginal), however; ocular estimates were somewhat coarse (≈ 14% increments), were inherently subjective, and their precision varied among cover types. We found that within each 20x40m plot there is high variability for each cover type, therefore there will be variability within each pixel of SPOT imagery as well.

References Cited

Anderson, Hal E. 1982. Aids to Determining Fuel Models for Estimating Fire Behavior. Ogden, (UT): USDA Forest Service, Intermountain Forest and Range Experiment Station. General Technical Report INT-122. 22 p.

Floyd, D.A., and Anderson, J.E. 1982. A New Point Interception Frame for Estimating Cover of Vegetation. *Vegetation* 50:185-186.

Floyd, D.A., and Anderson, J.E. 1987. A Comparison of Three Methods for Estimating Plant Cover, *Journal of Ecology* 75:221-228.

GIS TReC, http://giscenter.isu.edu/software/index.htm

Longley, P.A., Goodchild, M.F., Maguire, D.J., and Rhind, D.W. 2005. Geographic Information Systems and Science. John Wiley & Sons Ltd, England.

Johnson, D.E., Vulfson, M., Louhaichi, M., and Harris, N.R. 2003. VegMeasure Version 1.6 User’s Manual. Department of Rangeland Resources, Oregon State University, Corvallis, OR.

Key, Carl and Benson, Nathan. 2004. FIREMON Landscape Assessment V4.

Key, Carl H. and Benson, Nathan. 1999a(?). The Composite Burn Index (CBI): Field Rating of Burn Severity, http://www.nrmsc.usgs.gov/research/cbi.htm.

Key, Carl H. and Benson, Nate C. 1999b(?). The Normalized Burn Ratio (NBR): A Landsat TM Radiometric Measure of Burn Severity, http://www.nrmsc.usgs.gov/research/ndbr.htm.

McMahan, Ben, Narsavage, D., and Weber K.T. 2003. “The Pole Cam”: Corroborating field estimations with High Spatial Resolution Imagery. http://giscenter.isu.edu/research/techpg/nasa_wildfire/Final_Report/Documents/Chapter3.pdf.

Perryman, B.L., and Olson, R.A. 2000. Age-stem diameter relationships of big sagebrush and their management implications. *Journal of Range Management*. 53:342-346.

Wagtendonk, J.W. van, Root, R., and Key, C. 2004. Comparison of AVIRIS and Landsat ETM+ Detection Capabilities for Burn Severity. *Remote Sensing of Environment* 92:397-408.