Effect of Spatial Resolution on Cover Estimates of Rangeland Vegetation in Southeastern Idaho

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ABSTRACT

High-resolution aerial imagery has been frequently used to study rangelands. Still, due to resolution limitations, it is not always possible to identify plant species or ground cover accurately. The objective of this study was to use high resolution aerial imagery (1.0 m, 0.3m and 0.15m spatial resolution) to: 1) determine the percent cover of shrubs and grasses as well as percent bare ground and; 2) compare the results of these cover estimates to determine the degree of agreement between the cover class estimations. For this purpose a digital technique, similar to a field-based point frame technique, was employed using a 10x10 (one pixel thick) grid overlaid upon an image to identify features beneath the grid intersection points (n=100) through visual interpretation. Features were identified as either shrub, grass, or bare ground (“S”, “G”, or “B”). Using these data, percent cover of shrub, grass, and bare ground was calculated. These data were also utilized to compute single factor Analysis of Variance (ANOVA). A pair-wise comparison was also performed using General Linear Model (GLM) groups, i.e., (1.00 meter per pixel [mpp] and 0.30 mpp, 1.00 mpp and 0.15 mpp, and 0.30 mpp and 0.15 mpp pixel imagery). All the percent cover estimations showed statistically significant differences ($P<0.001$) except for the bare ground comparison at 0.30 mpp and 0.15 mpp ($P=0.417$) and grasses comparison at 0.30 mpp and 0.15 mpp ($P=0.163$).

KEYWORDS: Aerial imagery, comparison study, ANOVA, General Linear Model (GLM), point frame, O’Neal ecological reserve

INTRODUCTION

In the United States of America, approximately 324 million ha are composed of rangelands (Sivanpillai and Booth, 2008). In Southeastern Idaho gentle high-desert plains exist alongside mountain ranges. The economy of this semiarid region is varied but geographically dominated by agriculture and ranching industries. For these reasons, southeastern Idaho is especially appealing for researchers concerned with the effects of drought, global climate change, and desertification on rangeland ecosystems (Sivanpillai and Booth, 2008).

Quick and accurate assessments of these diverse rangelands are imperative for sustainable management. In the past, evaluation and monitoring of expansive landscapes have relied more on judgment and experience than science (NRC 1994; Stoddart and Smith, 1995). Since conventional field survey and sampling techniques are almost impossible or impractical to implement on such a vast area, people on all sides of management issues are now calling for more quantitative monitoring approaches (NRC 1994; Donahue 1999) such as those available through remote sensing. New measures are needed, with acceptable error rates, that are cost-effective and provide timely information about those regions undergoing change (Sivanpillai and Booth, 2008; Floyd and Anderson 1987; Brady et al., 1995; Brakenhielm and Quinghong 1995).

The term remote sensing has been defined as readings and measurements that are collected from a distance without physically disturbing the object (Colwell, 1983). Remote sensing studies using satellite and aerial imagery have been used in the past to conduct studies over large areas (Blumenthal et al., 2007). Advancements in digital camera development and lens technologies have improved image sharpness up-to 1mm/pixel (Booth et al., 2006). In the past, researchers have used remote sensing techniques to study rangelands and indentify features such as invasive species, shrubs, grass, and bare ground. A study by Blumenthal (2007) used high resolution imagery to study and measure infestations of invasive terrestrial weeds. Anderson et al., (1996), Bradley and Mustard (2006), Everitt et al., (1995, and 1996) and Lass et al., (2005) suggested that satellite and aerial imagery can be used to obtain accurate results for invasive weed studies. Another study by Sivanpillai and Booth (2008) used various remote sensing techniques to determine percent cover of vegetation over the 9,000 ha Hay Press Creek Pasture near Jeffrey City, Wyoming.

The objectives of this study were to use high resolution aerial imagery (1.00 meter per pixel [mpp], 0.30 mpp and 0.15 mpp spatial resolution) to: 1) determine the percent cover of shrubs and grasses as well as percent bare ground and; 2) compare the results of these cover estimates to determine the degree of agreement between the cover class estimations. This paper is presented as a case study that may aid in the selection of future aerial imagery acquisitions, specifically those focused on the identification of land cover in semiarid rangeland.

MATERIALS AND METHODS

Study Area

Aerial imagery was collected for the O’Neal Ecological Reserve, a 50 ha area of sagebrush-steppe rangelands in southeastern Idaho approximately 30 km southeast of Pocatello, Idaho (42° 42' 25''N 112° 13' 0'' W), an area where many local-scale rangeland studies are currently being conducted (Figure 1). The O'Neal Ecological Reserve (http://www.isu.edu/departments/CERE/o'neil.htm) was donated to the Department of Biological Sciences, Idaho State University by Robin O'Neal 1987. This 50 ha site, located along the Portneuf River, contains riparian areas in contrast with typical sagebrush steppe upland areas located on higher elevation lava benches. The O'Neal Ecological Reserve receives <0.38 m of precipitation annually (primarily in the winter) and is relatively flat with an elevation of approximately 1400m. The dominant plant species include big sagebrush (*Artemisia tridentata*) with various native and non-native grasses and forbs, such as Indian ricegrass (*Oryzopsis hymenoides*) and needle-and-thread (*Stipa comata*).

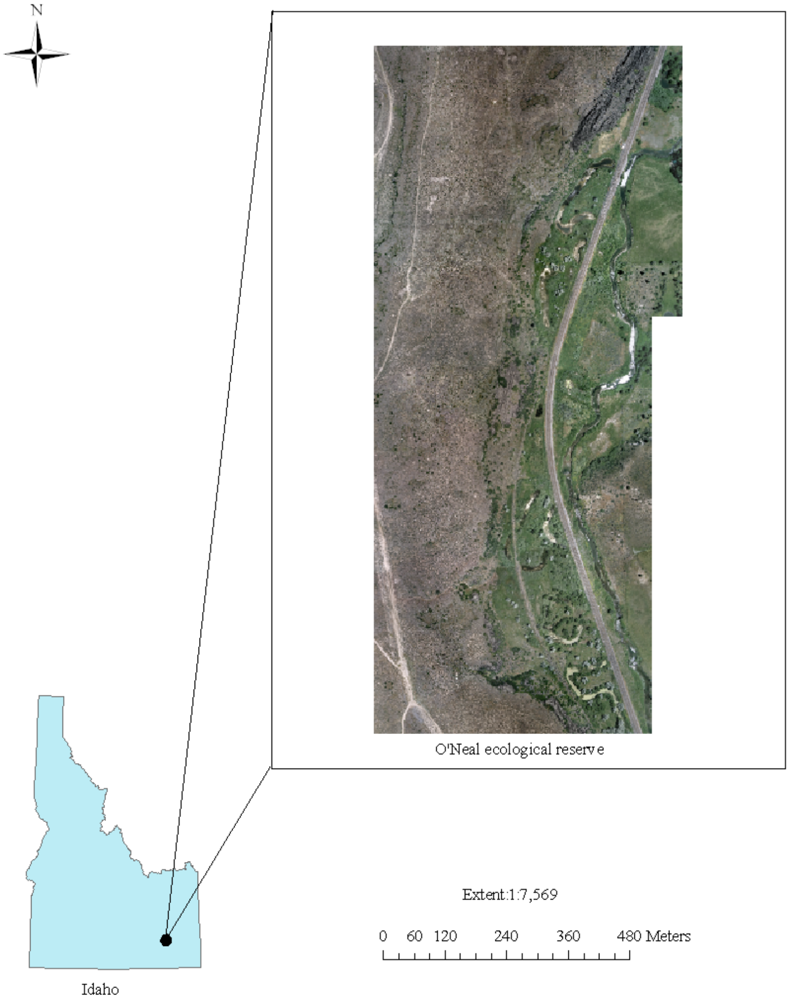

Figure 1. Area of study: O'Neal Ecological Reserve, Idaho.

Aerial imagery

National Agriculture Imagery Program (NAIP) imagery from 2004 was selected for use in this study (1 mpp). In addition 3Di West/GeoTerra Mapping Group's 2005 0.15 mpp imagery was also used. The 0.30 mpp spatial resolution image used was derived by re-sampling the 0.15 mpp using nearest neighbor algorithm. Figure 2a shows the NAIP imagery for 1.00 mpp spatial resolution, Figure 2b and Figure 2c show 0.30 mpp and 0.15 mpp spatial resolution imagery respectively.

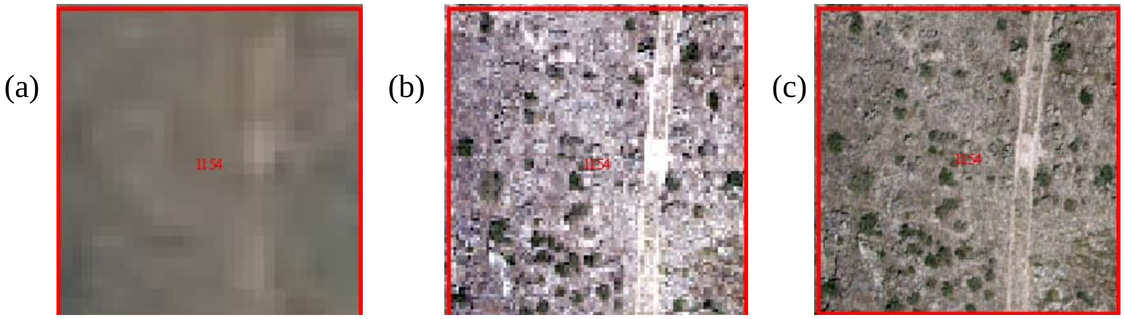

Figure 2. An example of 1.00 mpp imagery (a), 0.30 mpp imagery (b), and 0.15 mpp imagery (c) displayed at 1:500 scale.

Data Analysis

Johnson et al., (2003) created “VegMeasure” computer software that determines percent plant cover by first imposing a grid of “n” rows and “n” columns on an image. Next the information from each pixel beneath each grid is read. From there, percent cover is estimated. We developed a technique similar to “VegMeasure”, for use in this study to estimate percent cover of shrubs and grasses along with percent bare ground. This point-sampling technique utilized a high resolution image that was displayed on a computer monitor near 100% magnification. Next, a grid 1-pixel thick was superimposed on the aerial image, and the cover type seen beneath each intersection (point) of the grid was manually recorded for later use (Blumenthal et al., 2007). To randomly sample the study area a shapefile containing 470 30m x 30m square polygons was created. Twenty of these polygons were randomly selected using Hawth’s tools in ESRI ArcMap GIS software. The selected polygons were then extracted and saved as a new polygon shapefile. The sampling polygon shapefile was placed over the aerial imagery and all pixels inside the polygon were captured as independent TIFF files using Corel Paint Shop Pro (PSP) graphics software. This process was repeated using 1.00 mpp, 0.30 mpp, and 0.15 mpp imagery. Twenty files were collected at each spatial resolution, for an overall total of 60 files. Each image was then opened in PSP and an equi-distance grid with 10 rows and 10 columns was superimposed over the captured image (Figure3). The land cover type (shrub, grass, or bare ground [“S”, “G”, or “B”]) at the intersection of each horizontal and vertical line of the grid was estimated through visual interpretation.

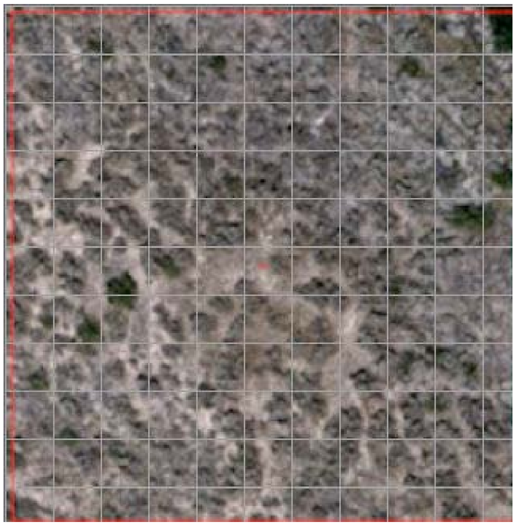

Figure 3. An example of a 10X10 grid superimposed on an image for visual interpretation (shrub, grass, bare ground) beneath each grid intersection.

This process, very similar to the field based point-frame technique ((Johnson et al., 2003; Blumenthal et al., 2007; Booth et al., 2006), was repeated for all 100 grid points in each image. The 1.00 mpp imagery was processed first, followed by the 0.30 mpp imagery and lastly, the 0.15 mpp imagery. This sequence of processing was used to reduce or eliminate biased point sampling. Following visual interpretation, a frequency distribution was created that shows the occurrences of “S”, “G”, and “B” within each individual image. From these data, percent cover was determined.

Statistical analysis

The percent cover of shrub, grass, and bare ground was computed using the frequency distribution for 1.0m, 0.3m and 0.15m aerial imagery. To test the precision of percent cover estimation, single factor Analysis of Variance (ANOVA) was computed between pair-wise groups (1.00 mpp and 0.30 mpp, 1.00 mpp and 0.15 mpp, and 0.30 mpp and 0.15 mpp) utilizing the percent cover for shrub, grass, and bare ground.

ANOVA can be defined as a “procedure by which the total variation in the data of the sample is split up into meaningful components that measure different sources of variation. Each of the components yield an estimate of the population variance” (Beg and Mirza, 1997). To perform a Single factor ANOVA, “independent samples each consisting of *n* observations are selected from each of K populations” (Beg and Mirza, 1997). The F-distribution values were derived from ANOVA and used to further interpret the results. The process of comparing the variability of one population with that of another population is known as F-distribution (Beg and Mirza, 1997). The P-value is the probability that ranges from 0 to 1; a lower P-value indicates that the results are less likely to occur due to random chance. The critical value established for p is the lowest level of significance at which the null hypothesis could have been accepted. In this study the null hypothesis states, “Is there a significant degree of agreement among the three different cover class estimations at the O’Neal Ecological Reserve in southeastern Idaho?”

Pair-wise comparison within General Linear Model (GLM) is a more robust statistical approach used to test whether the percent cover estimation for shrub, grass, and bare ground was different and to determine the degree of agreement between the cover class estimations at the O’Neal Ecological Reserve in southeastern Idaho. This comparison is used when one has more than two groups to compare. When H0 is rejected in an ANOVA, it is concluded that not all the means are statistically equal. This is NOT saying that all of the means are different. However, GLM Pair-wise comparisons were used to compare any two particular means using a modified 2-sample t-test to determine which means were different (Jager, 2009). The standard deviation was calculated using the Root Mean Square Error (RMSE). Using the Pair-wise comparison to compare each pair of means at $\alpha = 0.05$, some P-values will be less than 0.05 because many comparisons are made (Jager, 2009). To take care of the P-values that fall under $\alpha = 0.05$, a Bonferroni corrections was applied to the P-values to provide an adjustment factor. The Bonferroni adjusted P-values were obtained by multiplying the individual P-value by “C”, where “C” is the total number of pairs of mean that has “K” population groups in an ANOVA test. C is usually computed by $C = K(K-1)/2$ (Jager, 2009). Following these methods, one can reject H0 if their P-value is $< \alpha$ (Jager, 2009).

RESULTS AND DISCUSSION

Table 1 shows the results that were obtained from single factor ANOVA. The F-values and P-values are shown in separate columns and computed for each cover class resolution pair (i.e., shrub, grass, and bare ground at 1.00 mpp, 0.30 mpp, and 0.15 mpp resolution). The analysis results using the coarsest imagery (1.00 mpp) will be discussed first, followed by comparisons made with the finer resolution imagery (0.30 mpp). The F-value for shrubs at 1.00 mpp and 0.30 mpp and 1.00 mpp and 0.15 mpp were 34.45 and 304.38, respectively. The P-values for the same comparisons were both <0.001. If we carefully observe the F-values for these two groups within the same category, i.e., shrub, we see a direct relationship between the difference in spatial resolution (e.g, 1.00 mpp and 0.30 mpp vs 1.00 mpp and 0.15 mpp) and F-values. As the difference between the spatial resolutions (1.00 mpp and 0.15 mpp) was increased, the F-value showed an increasing trend. For the grass cover class, between the groups of 1.00 mpp and 0.30 mpp and 1.00 mpp and 0.15 mpp, the F-values were 128.50 and 242.68, respectively and P-values were again <0.001. The F-values for the grass cover class showed the same direct relationship between the spatial resolution and the F-values. Similarly, for bare ground, the F-values between the 1.00 mpp and 0.3 mpp and 1.00 mpp and 0.15 mpp image resolution groups were 18.29 and 2.13, respectively, with P-values of 0.00 and 0.15, respectively. The F-values for bare ground did not follow the same direct relationship pattern as shown by shrub and grass cover classes. However, instead the F-value for this category showed an inverse pattern, i.e., the F-value decreased when the difference between the spatial resolution increased.

Table 1. ANOVA results involving 1.00 mpp imagery

ANOVA Categories	Groups	F Value *	P Value
Shrub	1.00 mpp and 0.30 mpp	34.45	<0.001
Shrub	1.00 mpp and 0.15 mpp	304.48	<0.001
Grass	1.00 mpp and 0.30 mpp	128.50	<0.001
Grass	1.00 mpp and 0.15 mpp	242.68	<0.001
Bare ground	1.00 mpp and 0.30 mpp	18.29	<0.001
Bare ground	1.00 mpp and 0.15 mpp	2.13	0.151

*NOTE: ** $F_{critical = 4.09}$

The test results for the shrub and grass cover classes show statistical significance for all comparisons computed with the 1.00 mpp and 0.30 mpp and 1.00 mpp and 0.15 mpp images (F=34.45, F=128.50). This suggests that there are many inconsistencies present in the data collected at these resolutions. These inconsistencies are present because of the visual “guessing”, i.e., errors associated with ocular estimation required to differentiate shrub, grass, and bare ground, which was based on the hue of the feature in the image (for the 1.00 mpp imagery).

The statistical data presented for bare ground (Table 1) using 1.00 mpp imagery shows F-values as 18.29, and 2.13 and P-values of 0.00 and 0.15 respectively. These values suggest that data collection was more consistent for this cover class. Alternatively, these values may represent a statistical anomaly or may be because bare ground was more easily detected at all three spatial resolutions. To test this, a second iteration of analysis based on the hue of the feature could be repeated using new polygon sample sites. This was not done due to the time constraints in this study.

Table 2 shows the statistical data for the shrub cover class at 0.30 and 0.15 mpp resolutions. The F-value for this comparison was 70.55 with a P-value of <0.001. This suggests that the shrub cover class percent cover estimation at resolutions of 0.30 mpp and 0.15 mpp was not consistent. The F-value for the shrub cover class showed a direct relationship between the difference in spatial resolution and F-values. As the difference between the spatial resolutions (e.g, 0.30 mpp and 0.15 mpp) increased the F-value increased as well (F=70.55). The statistical comparison for the grass cover class at 0.30 mpp and 0.15 mpp results in an F-value of 2.28 and a P-value of 0.13. This indicates that the grass cover class estimates at 0.30 mpp and 0.15 mpp resolution were consistent as no statistical difference was found. Further, the F-value for the grass cover class did not follow the same trend as the shrub cover class, i.e., as the difference between the spatial resolutions (0.30 mpp and 0.15 mpp) was increased the F-value decreased (2.28).

Table 2. ANOVA results involving 0.15 mpp imagery

ANOVA Categories	Groups	F Value *	P Value
Shrub	0.30m and 0.15m	70.55	<0.001
Grass	0.30m and 0.15m	2.28	0.138
Bare ground	0.30m and 0.15m	38.74	<0.001

*NOTE: ** $F_{critical = 4.09}$

However, when comparing bare ground at relative fine resolutions (0.30 mpp and 0.15 mpp), the consistency was lost as the F-value was 38.74 (P-value = <0.001). Bare ground showed the same trend of F-value found in shrub cover class, i.e., as the difference between the spatial resolutions (0.30 mpp and 0.15 mpp) increased the F-value also increased. The P- and F-values for grass differ from the P- and F-values for shrubs and bare ground indicating that a statistical anomaly for grass cover class was present or, perhaps bare ground was more easily detected at all three spatial resolutions. These results were also consistent with the reality, for example, if individual grains of sands were observed, at that scale, it is still bare earth. If shrubs and grass were looked at the same scale then nothing would detectable.

Table 3 shows the pair-wise statistical comparison for shrub cover class using (1.00 mpp, 0.30 mpp, and 0.15 mpp resolutions. The first column of table 3 shows the resolutions as input data. The second column shows the difference of means in percent cover calculated for the two resolutions. The third column shows the standard error, representing the standard deviation describing the dispersion of data points above and below the regression line (Weiers, 1998). The fourth column shows whether the test results for shrub percent cover estimates were statistically significant or not. The fifth and sixth columns describe (lower bound and upper bound) percent cover values that lies on a normal curve. The lower bound value lies on the left side of the mean whereas the upper bound value lies on the right side of the mean, assuming the data follow normal distribution. However, the percent cover estimation values did not follow a normal distribution as the Kurtosis values for shrub, grass and bare ground were not equal to three and Skewness values were greater than zero.

The GLM Pair-wise comparison was done on the same resolutions group. For example, GLM pair-wise comparison between 1.00 mpp and 0.30 mpp yields a “Mean Difference (I-J)” of “-20.30”, a standard error of “4.07”, Significance value of “0.00” with a lower and upper bound of “-30.99” and “-9.60” respectively. The significance value of “0.00” suggests that there is no agreement between the two cover class estimates for shrub. Similarly, all of the different resolution data for shrub was compared against each other. These results also suggest that the percent cover estimation was not consistent. Table 3 results are also consistent with the results computed in table 2, utilizing simple ANOVA for shrub.

Table 3. GLM Pair-wise comparison of percent cover of shrubs using 1.00 mpp, 0.30 mpp, and 0.15 mpp imagery

(I) resolution	(J) resolution	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.00 mpp	0.30 mpp	-20.300*	4.073	.000	-30.992	-9.608
	0.15 mpp	-53.300*	2.829	.000	-60.725	-45.875
0.30 mpp	1.00 mpp	20.300*	4.073	.000	9.608	30.992
	0.15 mpp	-33.000*	4.499	.000	-44.811	-21.189
0.15 mpp	1.00 mpp	53.300*	2.829	.000	45.875	60.725
	0.30 mpp	33.000*	4.499	.000	21.189	44.811

**. The mean difference is significant at the 0.05 level.*
a. Adjustment for multiple comparisons: Bonferroni.

Table 4 shows the GLM Pair-wise comparison for grass cover using 1.00 mpp, 0.30 mpp, and 0.15 mpp resolutions. The GLM Pair-wise comparison was done on these different resolution groups for percent cover estimates. For example, the pair-wise comparison between the group of 1.00 mpp and 0.30 mpp yields a “Mean Difference (I-J)” of “43.40”, a standard error of “2.94”, Significance value of “0.00” with a lower and upper bound of “35.67” and “51.12” respectively. A significance value of “0.00” describes that there is no agreement between the two cover class estimates for grass. Similarly all the different percent cover class estimates from different resolutions for grass cover class were compared against each other. These results suggests that the percent cover estimates were not consistent, except for the comparison of 0.30 mpp and 0.15 mpp and 1.00 mpp and 0.15 mpp percent cover estimates that suggests a consistent pattern. The consistency between these two groups might be the result of a statistical anomaly for grass cover class that had occurred. Table 4 results were also consistent with the results computed in table 2 utilizing simple ANOVA for grass.

Table 5 shows the GLM Pair-wise comparison for bare ground cover class using 1.00 mpp, 0.30 mpp, and 0.15 mpp resolutions. The GLM Pair-wise comparison was performed using these different resolution groups for percent cover estimates. For example, the Pair-wise comparison between the group of 1.00 mpp and 0.30 mpp yields a “Mean Difference (I-J)” of “-21.95”, a standard error of 4.52, a significance value of “0.00” with a lower and upper bound of “-33.82” and “-10.07” respectively. The significance value of “0.00” suggests that there is no agreement between the two cover estimations collected at different spatial resolutions for bare ground. Similarly all different percent cover class estimates from different resolutions for bare ground cover class were compared against each other. These results also suggests that the percent cover estimates were not consistent except for the results produced from the comparison of 1.00 mpp and 0.15 mpp and 0.15 mpp and 1.00 mpp percent cover estimates, suggesting a consistent pattern. The consistency between these two groups might be the result of a statistical anomaly for bare ground cover class that had occurred. Table 5 results were also consistent with the results computed in table 2 utilizing simple ANOVA for bare ground.

Table 4. GLM Pair-wise comparison of percent cover of grass using 1.00 mpp, 0.30 mpp, and 0.15 mpp imagery

(I) resolution	(J) resolution	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.00 mpp	0.30 mpp	43.400*	2.943	.000	35.675	51.125
	0.15 mpp	47.350*	2.605	.000	40.512	54.188
0.30 mpp	1.00 mpp	-43.400*	2.943	.000	-51.125	-35.675
	0.15 mpp	3.950*	1.927	.163	-1.108	9.008
0.15 mpp	1.00 mpp	-47.350*	2.605	.000	-54.188	-40.512
	0.30 mpp	-3.950*	1.927	.163	-9.008	1.108

**. The mean difference is significant at the 0.05 level.*

a. Adjustment for multiple comparisons: Bonferroni.

Table 5. GLM Pair-wise comparison of percent cover of bare ground using 1.00 mpp, 0.30 mpp, and 0.15 mpp imagery

(I) resolution	(J) resolution	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.00 mpp	0.30 mpp	-21.950*	4.523	.000	-33.823	-10.077
	0.15 mpp	5.950	3.854	.417	-4.166	16.066
0.30 mpp	1.00 mpp	21.950*	4.523	.000	10.077	33.823
	0.15 mpp	27.900*	5.081	.000	14.561	41.239
0.15 mpp	1.00 mpp	-5.950*	3.854	.417	-16.066	4.166
	0.30 mpp	-27.900*	5.081	.000	-41.239	-14.561

**. The mean difference is significant at the 0.05 level.*

a. Adjustment for multiple comparisons: Bonferroni.

The F-statistic for each comparison (1.00 mpp and 0.30 mpp, 1.00 mpp and 0.15 mpp, and 0.30 mpp and 0.15 mpp) of Table 1 and Table 2 was graphed (Figure 4) to better illustrate and visualize the results of the statistical analyses. On the x-axis are the resolution groups compared with F-distribution values given on the y-axis. The F-critical (i.e., F = 4.09) is shown to visualize which cover class fell below the critical region. The critical region is the region wherein the hypothesis statement made for the analysis is rejected, and one needs to consider the alternative of the statement (Beg and Mirza, 1997). All F-values in Table 1 for shrub and grass fall outside of the critical region suggesting that the percent cover estimates were different. However, the ANOVA for 1.00 mpp and 0.15 mpp for bare ground has F-value = 2.13, suggesting that the percent cover estimate was consistent. Similarly in Table 2, shrub and bare ground cover classes for 0.30 mpp and 0.15 mpp suggest that the percent cover estimate was not consistent as the F-value lies outside the critical region (i.e. $F_{critical} =$ 4.09). The F-value in table 2 suggests that the percent cover estimate was consistent as the F-value (i.e., F = 2.28) lies inside the critical region value.

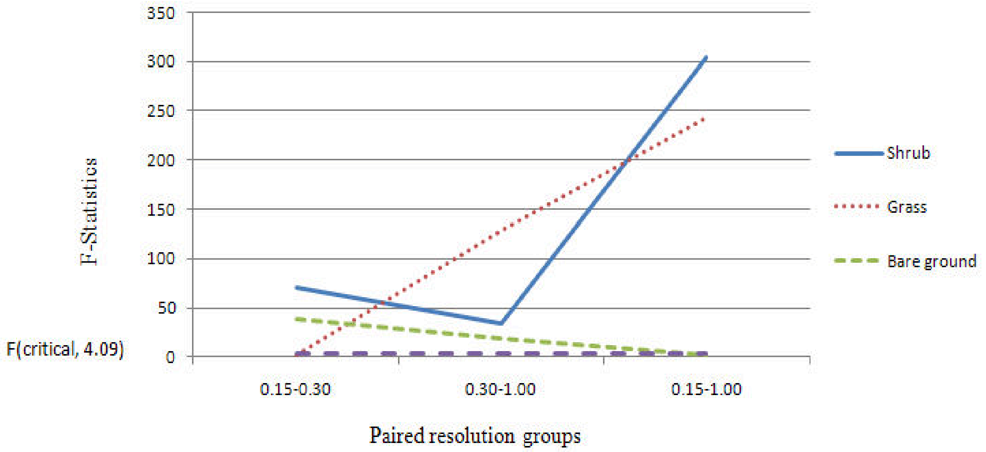

Figure 4. F-distribution plot for shrub, grass, and bare ground with F-critical values.

Assessment of Error and bias

Although much care was taken in the collection of samples from the aerial imagery there were a number of errors and biases worth noting. The 1.0m imagery used for sampling did not have sufficient resolution to see discernible plant features, but instead all decisions to indentify shrub, grass, and bare ground were made on the basis of the color or hue present in the image. NAIP imagery was shot in 2004 and 3Di West imagery was shot in 2005, therefore, what details that were seen in 2004 might have changed by the time imagery was shot in 2005. The time of year when images were acquired might have also provided error or bias in the results. The images may have been collected in early spring for one year and/or early fall for another year. This would introduce seasonal vegetation variety, a factor we did not account for in our study. In addition, the aerial images were not collected in the same year, so what was identified as shrub in one set of imagery might have changed. Lastly, the field condition itself We do not know which resolution actually gave the correct answer as no field data are available for either time period. Field information would clarify such distinctions as what was identified as shrub might actually be a hole in the ground, or what was identified as bare ground could actually be a reflective piece of metal lying on the ground. Still, our information is based on the best data we could obtain for this study.

CONCLUSIONS

Range scientists usually express cover as the percentage of the ground surface that is occupied by the plant crown or shoot area when it is projected downward (Johnson et al. 2003). The percent cover of shrub, grass, and bare ground can be estimated using point frames**,** quadrant charting, line intercept transect or other techniques. This study employed a digital technique, similar to the point frame technique, and used a 10x10 (one pixel thick) grid superimposed upon an image to identify features beneath the grid intersection points. The results were compared statistically for shrub, grass, and bare ground cover classes using ANOVA and GLM Pair-wise comparison. The ANOVA results for 1.00 mpp imagery shows that the percent cover estimates for the shrub and grass were not consistent, however, the bare ground percent cover estimates show a consistent pattern. The ANOVA result for 0.15 mpp imagery for shrub and bare ground shows inconsistency in the percent cover estimates, but the F-value for grass indicates that the percent cover estimation was consistent. The GLM Pair-wise comparison results for shrub, grass, and bare ground using 1.00 mpp, 0.30 mpp, and 0.15 mpp pixel imagery showed results similar to those produced by ANOVA. Overall percent cover estimations were not consistent across spatial resolutions or cover classes. This means that the percent cover estimation using three spatial resolutions (1.00 mpp, 0.30 mpp, and 0.15 mpp) differs from each other. Some statistical anomalies did occur in the study that suggests that the percent cover estimation for bare ground and grass were the same. To test this, a second iteration of analysis based on the hue of the feature could be repeated using new polygon sample sites. This was not done due to the time constraints in this study. Further research should be conducted by first surveying the field and then by using the HRSI of the same year.

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