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Book Cliffs Roadless Area Aspen Study 2013 : Grand & Uintah Counties, Utah

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BOOK CLIFFS ROADLESS AREA

ASPEN STUDY 2013

GRAND & UINTAH COUNTIES, UTAH

SUMMER 2013

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INTRODUCTION

The Utah Division of Wildlife Resources (UDWR) and the Bureau of Land Management Vernal Office (BLM) have contracted CNL Environmental Consultants to assess the condition of aspen stands within a portion of the Book Cliffs referred to as the “roadless area”. This project is an extension of a previous aspen study performed in the summer of 2012 (Rogers and Mittanck, 2013). The impetus for this 2013 project began with a collaboration between UDWR and BLM in an effort to further quantify aspen conditions and herbivore interactions for lands under their management. Specifically, the 2012 aspen study indicated elk were having a detrimental impact on aspen regeneration and therefore overall aspen sustainability on BLM lands within the study area (Map 1). UDWR managers recognized the need for an additional study on adjacent state lands which is encompassed by the 2013 study (Map 1). This area is managed by UDWR as “non-motorized access”. There are no current grazing leases for cattle, and elk are considered to be equally abundant in the 2013 study area as they are in the 2012 area. The paucity of cattle in the 2013 area suggested a potential for differences in aspen-herbivore interactions compared to the 2012 area. Therefore, the current study is designed as a comparative analysis between the two study areas with the aim of evaluating the respective impacts of “elk” and “elk+cattle” herbivore groups on aspen conditions. However, the study is not intended to be an experimental design and a therefore does not attempt to directly measure these impacts. Thus, the overall goal is to provide sufficient data on aspen conditions and herbivore interactions to allow land managers to make informed management decisions.

OBJECTIVES AND HYPOTHESES:

Objective 1. Characterize aspen communities within the study area through analysis of field data.

Objective 2. Compare the 2013 study area to the 2012 study area in order to attempt to understand the respective impacts of “elk” and “elk+cattle” groups on aspen stand conditions.

Hypothesis: If elk numbers and environmental conditions are similar in the 2013 area compared to the 2012 area and there are no cattle within the 2013 area , differences in elk “use” and browse levels between the two study areas may be attributable to the presence or absence of cattle.

APPROACH

These objectives were accomplished using the following approach. In order to compare the two study areas, it was important to follow the same procedures for data collection as was done during the 2012 season and therefore the same sample design was adopted for the 2013 season.

1. Aspen communities were first identified through photointerpretation methods of National Agricultural Imagery Program color infrared imagery (NAIP CIR). Polygons were delineated around aspen communities constituting the sample population. Plots were located using a stratified random design and metrics designed to assess forest structure, composition, health, and herbivore use were recorded at 39 selected plots.

2. The first phase of analysis was to compare environmental variables, such as elevation, slope, and solar radiation, derived from digital elevation models (DEMs) between the two study areas in order to determine if there were significant differences in environmental factors that may influence aspen condition.

3. Next, elk scat was assessed as a proxy for elk use in order to determine if elk were using aspen communities in both study areas equally.

4. After which, an analysis of covariance approach was used to determine if browse levels, and therefore detrimental impact on aspen health, was higher or lower in “elk” and “elk+cattle” areas.

5. After the comparative analysis had been exhausted, the second phase of analysis assessed the conditions and expected future conditions of aspen communities within the 2013 study area by looking at structure, composition, and trends within the dataset.

SUMMARY OF FINDINGS

The results show aspen occurring on steeper slopes and at a higher elevations in the 2013 area compared to the 2012 area. This has likely influenced the high proportion of seral aspen stand types observed in the 2013 area. Whether due to differences in environmental and stand type conditions or not, elk are using aspen significantly less within the 2013 area than the 2012 area. And while there is not a statisical difference overall in browse levels, there appear to be higher levels of browsing in the 2012 area when regeneration is abundant. However, the environmental and stand type differences make it difficult to attribute differences in stand condition solely to absence of cattle. Regardless, overall aspen conditions within the 2013 area that have been impacted by fire have extremely high levels of recruitment that have circumvented browsing and can be expected to replace the stand. Whereas, aspen stands in areas outside of the Rattle Creek fire are primarily seral stands with low levels of aspen recruitment. These stands can be expected to trend towards late-stage seral and conifer dominance within the next 50-100 years without disturbance.

STUDY AREA

The study area is on the eastern edge of the Book Cliffs within the Tavaputs Plateau near the edge of the Utah-Colorado border. This plateau slopes northward to the Uintah Basin and drops off abruptly to the south into the Canyonlands region of the Colorado Plateau. The topography is generally very steep, consisting of plateau tops and steep valleys often walled by cliffs. Soils are predominately rocky-to-sandy loams derived from sandstone and shale substrates. The elevation zone that aspen occurs within is very narrow compared to other areas aspen occurs within the state, suggesting there may be limiting environmental factors to aspen distribution within the study area (Kurzel et al., 2007; Rogers and Ryel, 2008; Mittanck, 2012). An average annual precipitation of 542 mm was recorded between 1987-2012 at a SNOTEL site (# 461) near the study area. General vegetation community patterns include sagebrush (*Artemesia spp.*) on dry sites adjacent to aspen and conifer communities and as elevation decreases communities are dominated by pinyon (*Pinus edulis*) and juniper (*Juniperus scopulorum*) woodlands. The 2013 study area boundary was delineated in order to capture the majority of state lands to the east of the Uintah and Ouray Indian reservation (Map 1).

<u>Overall size comparison</u>:

2013 Study Area = 120,532 ac

2012 Study Area = 50,050 ac

METHODS

ASPEN POLYGON DELINEATION AND PLOT SELECTION

Aspen polygons were delineated using photo-interpretation methods on 2009 NAIP color infrared imagery (National Agriculture Imagery Program). Photo-interpretation of NAIP imagery relies on knowledge of how surface materials (i.e. vegetation types) reflect and absorb light. It also considers the growth habits of the vegetation, such as shape and size differences within the crowns. High resolution NAIP aerial photography is often visually interpreted to delineate forest stands and to identify tree species (Paine, 1981). For a better interpretation of vegetation, enhancement of the image was performed using a linear stretch across 3 standard deviations of the data (Jensen, 2004). In order to calibrate photo-interpretation of aspen, data from 62 ground reference plots collected during thesis research conducted by the author (Table 1)(Mittanck, 2012) in addition to polygon data supplied by the BLM were used as reference.

The primary criteria used to delineate aspen polygons across the study area was done according to the following:

- The area is contiguously forested and interpreted to be aspen. In order to increase the probability of capturing all of the aspen across the study site, forested areas were considered "aspen" if they appeared to have any aspen in the canopy.

A total of 210 aspen polygons were delineated in the 2013 study area. From those polygons, 39 were randomly selected to sample. The sample plot was placed at the centroid of each of these polygons using the ArcGIS "Mean Center" tool in the spatial statistics toolbox (ESRI, 2010).

FIELD DATA COLLECTION

Data and data collection protocols for the 2013 study area were designed to be identical to the 2012 study area. However, some data was excluded from collection that was not considered to be useful for a comparison analysis. The following data was collected at each plot:

- Plot ID
- Date
- Plot center GPS location
- Stand Type (Stable or Seral)
- Number of Distinct Aspen Layers (i.e. age cohorts)
- Disturbance (Fire, Defoliation, Severe Grazing, Disease/Pathogens)
- Subjective Stand Condition (see Table 2)
- Plot level Comments

- Tree Count by DBH Class (Includes Dead and Alive)

-Browse Count (Number of Individual Aspen Browsed)

- Fecal Count (Number of Fecal Units of Elk, Cattle, Deer, Sheep)

- Photo Documentation

The sample unit consists of a ha^{-1} area, sampled by two perpendicular 30 x 2 m transects. In order to collect meaningful plot data, plots were sampled only if they were at least 50% aspen and entirely within a forested area. These requirements, along with the random polygon selection and systematic plot location, are assumed to provide mean conditions for each polygon. At each plot a walk-through of the ha^{-1} sample area was made to: gain an overall rating of stand conditions (criteria for the subjective estimate of stand condition are defined in Table 2), and to estimate discrete vertical "layers" of aspen. Afterwards, each plot was assigned an aspen stand type, either seral or stable (Harniss and Harper, 1982). We define seral aspen as containing more that 10% conifer cover or, if major disturbance within past three decades, the potential to exceed this cover. Stable aspen implies < 10% conifer cover and long-term "stability" in a single species state (i.e., $\geq$ 100 years). In most instances the distinction between seral and stable plots is immediately evident as there are either no conifers or many conifers within an aspen forest. Geographic position coordinates were obtained at plot center and one plot photo was taken to document general conditions.

At plot center, two perpendicular 30 x 2 m transects were established and the following field measures were taken: regeneration (< 2 m height), recruitment ($\geq$ 2 m height, < 8 cm diameter breast height [dbh]), and mature tree ($\geq$ 8 cm dbh) counts by species; mature tree counts by three diameter classes (8-15 cm; 16-25 cm; >25 cm dbh); and fecal pellet counts by groups for deer and elk and individual feces/pies for cattle. Pellet groups were defined as any assemblage of feces consisting of three or more pellets from the same defecation (Bunnefeld et al., 2006). Finally, we recorded recent disturbances, if applicable, across the sample ha^{-1}. All transect data were expanded to represent conditions on a ha^{-1} basis for analytical purposes.

ANALYSIS

All variables and analysis used in this study were calculated using R (R Development Core Team, 2004) and Python (Van Rossum, 2001), integrated within the ArcGIS (ESRI, 2010). Analytical efforts for the 2013 study have been grouped into two phases in order to meet our objectives in an organized fashion. The first phase of analysis was to compare environmental variables, such as elevation, slope, and solar radiation, derived from digital elevation models (DEMs) between the two study areas. We did this to determine if there were significant differences in environmental factors that may influence aspen condition. DEMs where used to calculate these environmental variables in place of field collection methods due to their ability to average measurements within the entire polygon as well as being non-biased and objective in nature. Elevation was directly derived from DEMs, whereas solar radiation and slope were calculated using ArcGIS Spatial Analyst tools. The equations used to calculate solar radiation are based on a Hemispherical Viewshed Algorithm making it a function of both slope and aspect. Units are estimates of direct plus diffuse radiation calculated at intervals throughout the year to get total radiation values for each pixel in a surface raster in Wh m^{-2}. While actual values are not useful, the continuous-level variable is considered to be an ecologically meaningful variable, much like a symmetric radiation wetness index (Roberts and Cooper, 1989). The non-parametric two-sided Wilcoxon-Mann-Whitney U test was used to compare mean differences in these variables between the 2012 and 2013 areas. In this first phase of analysis, elk scat was assessed as a proxy for elk use in order to determine if elk were using aspen communities in both study areas equally. In order to accomplish this the non-parametric two-sided Wilcoxon-Mann-Whitney U test was also used.

An analysis of covariance (ANCOVA) approach was used to determine if browse levels, which are assumed to have a detrimental impact on overall aspen replacement and sustainability, was higher or lower in “elk” and “elk+cattle” areas. To accomplish this the amount of aspen regeneration browsed ha^{-1} was compared between the 2012 and 2013 areas while treating the amount of aspen regeneration ha^{-1} as a covariate. It was assumed that regeneration browsed would logically covary with the amount of regeneration, as the former cannot exist without the latter. First an initial outlier analysis was performed to check for any data anomalies that could be explained by mistakes in data collection or entry (Peck, 2010). In order to meet statistical test assumptions, a square root transformation was then used to transform the distribution of the data from a Poisson distribution to a more normal distribution (Bartlett, 1936), which is often common of count data representing ecological phenomenon (McCune et al., 2002). A regression analysis was then performed to visually compare the relationship of aspen browse between the two study areas. The Kruskal-Wallace test, a non-parametric equivalent to ANOVA, using type III SS results for unbalanced sample sizes, was used to assess whether the slopes between the two regression lines were significantly different. Due to these results no further analysis was used to test significant differences in the y-intercept between the two regression lines. However, the non-parametric two-sided Wilcoxon-Mann-Whitney U test was used as an additional approach to test browse differences between the 2012 and 2013 areas. In this test the amount of regeneration was controlled for by comparing the mean percent regeneration browsed.

The second phase of analysis focused on frequencies and proportions in order to describe stand condition, current age structures, species compostions, and future trends. It does not use any statistical tests.

RESULTS

Comparison of environmental variables in aspen communities between the 2012 and 2013 study areas show a statistically significant difference. Elevation within the 2013 area is significantly higher than the 2012 area (*W=390, p-value=<0.001*) with a mean elevation of 2607 meters compared to a lower 2471 meters in the 2012 area (Figure 1). Aspen communities where also found on significantly steeper slopes in the 2013 area (*W=504, p-value=<0.001*)(Figure 2). However, solar radiation was not significantly different between the two study areas (W*=1197, p-value=0.07*)(Figure 3).

Fecal counts in the 2013 area showed presence of: elk in 87% of the aspen stands, deer in 64% of stands, and cattle in only 1 stand out of the 39 stands sampled. This is compared to the 2012 area with: elk in 96% of stands, deer in 54%, and cattle in 68% of stands. According to presence or absence of fecal matter, there is a higher proportion of elk presence in aspen stands in the 2012 area. Statistical comparisons of the mean of elk scat between the 2012 and 2013 areas also reveals a significant difference (*W=1629.5, p-value=0.04*)(Figure 4). These numbers also validate our assumptions that the 2013 area is nearly devoid of cattle.

Analysis of covariance began by regressing aspen regeneration browsed with total aspen regeneration for both 2012 and 2013 study areas. Both areas showed significant positive relationships (2012 area, *F=253.1, 75 DF, p-value=<0.0001*; 2013 area, *F=22.56, 37 DF, p-value=<0.001*). Model fit was higher for 2012 area with an adjusted R^2=0.76, and lower for 2013 area with an adjusted R^2=0.36 (Figure 5). Slopes of the lines were significantly different as shown by the results of the ANOVA Kruskal-Wallace test (Table 3). Without similar slopes, y-intercepts could not be compared in order to statistically test differences in aspen regeneration browsed between the 2012 and 2013 areas. However, regression lines indicate similar levels of browse between the two study areas for the majority of plots sampled with higher levels of browse in the 2012 area compared to the 2013 area when aspen regeneration is abundant. This relationship stays the same even after fire disturbed plots have been removed from the 2013 dataset. Approaching the same question using another analytical method indicates that when we control for the level of regeneration by calculating percent aspen regeneration browsed and compare the means between the 2012 and 2013 areas there is no significant difference overall in browse (*W= 1646.5, p-value=0.102*)(Figure 6).

Phase two results for stand composition show that the 2013 area has markedly higher proportions of the seral aspen stand type than the 2012 area, with 82% seral and 18% stable in the 2013 area compared to only 34% seral and 66% stable in the 2012 area (Figure 7). Stand conditions within each of these types are generally similar between study areas. While stand composition between the two study areas is very different, there appears to be similarities in stand structure in regards to levels of aspen recruitment. Only three of 77 sampled plots contained greater than 500 recruitment stems ha^{-1} in the 2012 area, a suggested minimum threshold for stand replacement (O'Brien et al., 2010). However, many of the sample plots had fewer than 500 mature trees ha^{-1}. So in order to use a more site-driven approach, we calculated live recruitment as a percentage of total mature trees ha^{-1} with the logic that 100% would support complete immediate stand replacement and 50% would be ample recruitment for gradual (i.e., gap-phase) replacement (Rogers and Mittanck, 2013). Using this approach, the 2012 area had very poor recruitment/replacement with 71% of stands yielding zero recruitment. Within the 2013 area, 69% of stands yielded zero recruitment (Figures 8a and 8b).

In the 2013 area, 10 out of 39 plots showed evidence of fire within the last 10 years. It was assumed that plots impacted by the Rattle Creek fire would show very different structure and composition and would therefore require data stratification along this variable in order to get a better picture of aspen characteristics across the entire 2013 study area. The average non-browsed regeneration and recruitment ha^{-1} within plots impacted by fire is much higher than plots not impacted by fire (Figure 9). While interestingly, percent regeneration browsed is higher in plots not impacted by fire (Figure 10), though the difference is not significant (*W=129.5, p-value=0.62*).

Future conditions in the 2013 area for aspen stands impacted by fire are very good with high levels of aspen regeneration and recruitment, however conditions within aspen stands not impacted by fire currently have high proportions of mature conifer and are trending towards pure conifer communities. This trend is evident in figure 11 where we can see the current average compostion of aspen stands have nearly a proportion of 2:1 aspen to conifer . However, if we consider the recruitment cohort to represent future composition we can expect to see these stands becoming dominated by conifer with a proportion of 4:1 conifer to aspen. Current aspen regeneration levels in the majority of these seral stands is 1,179 stems ha^{-1}. A number considered to be close to “marginal” in regards to stand-replacement by O’Brien (2010). Vigorous, self-replacing stands, will typically have regeneration levels >2,500 stems ha^{-1}. In addition conifer regeneration levels in these stands are very high with 615 stems ha^{-1}. We can expect nearly all these individuals to make it into the canopy as conifer are not targeted as browse and are not considered to be self-thinning.

DISCUSSION AND RECOMMENDATIONS

The first phase of the analysis was designed to determine whether aspen occupied significantly different environmental space between the two study areas. Results showed that aspen within the 2013 area occurs at higher elevations and on steeper slopes. We interpret these statistically significant diffferences to be ecologically significant as well. Aspen is very "plastic" in its response to environmental pressures. It has wide distribution within which it inhabits disparate environmental conditions and shares a wide variety community assemblages (Mueggler, 1988). Due to this its functional roles across the landscape change with the largest difference being between the general community types of seral and stable. Seral aspen communities are often defined as having a conifer component >10% (Mueggler, 1998) and can be in various early to late successional stages moving towards an end-point or climax pure conifer community. Stable aspen communities on the other hand, have been described as one that persists free of conifers and is self-regenerating (Langenheim, 1962; Betters and Woods, 1981; Mueggler, 1988; Romme et al., 2000). There is evidence that slope and elevation influence whether an aspen community is seral or stable (Crawford et al., 1998; Strand et al., 2009a; Mittanck, 2012, Rogers and Mittanck, 2013). Considering these previous studies, our analysis of stand compostion within the 2013 area suggests that steeper slopes and higher elevation may have influenced higher proportions of seral aspen (82% of stands) to stable aspen (18% of stands). These stand type proportions have likely had an effect on grazing ungulates due to higher understory productivity and therefore available biomass in stable compared to seral aspen communities (Warner and Harper, 1972; Debyle et al., 1985; Mueggler, 1998), suggesting an overall effect of elk utilizing aspen stands less for grazing. This is also supported by our fecal count analysis, which suggests that elk presence in aspen stands is significantly lower in the 2013 area compared to the 2012 area, in addition, 87% of stands showed presence of elk scat in the 2013 area compared to 96% of stands in the 2012 area. It should be mentioned, that use of scat counts as surrogates for habitat use have been criticized by some (Smart et al., 2004), but favored by others when compared to animal radio-telemetry data (Borkowski, 2004, Bunnefeld et al., 2006). For our study scat counts offered the advantage of direct correspondence to site and scale of sampling, which cannot be made through radio-telemetry methods.

While elk appear to be using aspen less within the 2013 area, analysis of covariance results suggest levels of browse between the two study areas are similar in the majority of aspen stands after controlling for the quantity of regeneration available to be browsed. However, the results do suggest that browse levels are higher in the 2012 area as aspen regeneration becomes more abundant. This relationship remains the same even after removing fire impacted stands from the 2013 dataset.

The difference in environmental conditions and resulting stand type proportions makes it difficult to attribute lower elk use and browse levels within 2013 aspen stands solely to the absence of cattle. However, observationally, the absence of cattle within the 2013 area had a noticeable effect on vegetation communities. There was a much higher graminoid biomass in meadows, valley bottoms and near riparian areas. Whereas within the 2012 area, severe grazing, and a resulting increase in sagebrush cover, was evident in these communities and topographic positions. Aspen was often found only within steep eroded washes and growing within dense sagebrush where cattle could not access. This observation suggests our results of lower elk use and browse levels in 2013 aspen may also be due to elk “shifting” use into other vegetation communities that have not been severely grazed by cattle.

High proportions of seral aspen communities in the 2013 area along with lower use and browse suggest succession to conifer dominance may be a more important issue than herbivore interactions. When we stratify the 2013 dataset by fire and non-fire impacted stands, we see that in stands that have not been “reset” by fire, we have a recruitment cohort with an average proportion of 4:1 conifer to aspen (Figure 11). This suggests that we can expect to see the majority of aspen stands across this landscape moving into a late successional stage of conifer dominance within a generation (50-100 years). Non-metric multidimensional (NMS) ordination results from the 2012 dataset strongly linked elk use and browse level to aspen recruitment success (Rogers and Mittanck, 2013). Other studies have shown moderate to high levels of browsing of aspen suckers leads to a decline in stand density (Olmstead, 1979; Jones et al.,

2005) and limited predation of elk and accessible aspen terrain can be severely limiting to aspen recruitment (Beschta and Ripple, 2010; Rogers et al., 2010). These studies suggest that severe browsing of aspen regeneration can lead to a paucity of recruitment age aspen and eventually a decline or loss of the aspen stand. However, this pathway as a mechanism for stand decline is primarily a concern in stable aspen communities (O'Brien, 2010). Within these stands, despite light-limiting requirements of young aspen shoots, juvenile aspen have been shown to grow under the canopy and in gaps, enabling self-regeneration without stand-level disturbance required for replacement (Kurzel et al., 2007). Browsing in such stands may suppress any "background" aspen regeneration from entering recruitment stage and therefore preventing stand replacement. While background levels of aspen recruitment are important for mixed aspen-conifer stands to retain an aspen component and regenerate aspen after disturbance, the disturbance itself is the primary means of sustaining aspen in these communities. Browsing in seral stands may therefore be a primary concern if high levels of browsing severely impacts the flush of aspen suckering occurring after disturbance to such a level that regeneration is prevented from making it into the recruitment stage (Campbell and Bartos, 2001). This does not appear to be happening in the 2013 area, where browsing is not having a detrimental effect on aspen stands impacted by the Rattle Creek fire. To the contrary, in stands disturbed by fire an average of 3,627 stems ha^{-1} of aspen regeneration have made it into the recruitment stage. In the "Guidelines for Aspen Restoration on the National Forests in Utah", O'Brien suggests recruitment levels <1,250 stems ha^{-1} is not self-replacing and recommends investigation. Interestingly, the percent of aspen regeneration browsed is slightly higher in non-fire stands compared to fire impacted stands (Figure 10). This suggests that large flushes of aspen regeneration in recently burned areas may not be targeted by herbivores any more than non-burned areas. Romme et al. documented similar effects after large fires in Yellowstone Park that burned 22% of ungulate winter range (1995).

Considering the above discussion, we recommend land managers focus on maintaining disturbance in the 2013 area in order to sustain aspen communities across the landscape. This recommendation is based on the high proportion of seral aspen communities trending towards late-stage succession and conifer dominance in non-fire areas and the successful recruitment of aspen in recent fire impacted stands. We estimated 25% of the aspen stands across the 2013 study have been impacted by the recent Rattle Creek fire. However, the estimate is likely much larger due to a bias in photointerpretation methodology; without mature aspen canopy individuals nearby, aspen regeneration and recruitment is often mistaken for other vegetation types (Table 1). Recent studies show that aspen establishment by seed is more common than previously thought and such situations often happen after large scale fires (Long and Mock, 2012). Such events increase genetic diversity and adaptations to environmental pressures.

Pro-active management through prescribed burns, conifer-thinning, or allowance of natural burns have shown to be useful tools for treating seral aspen communities (DeByle et al., 1985; Shinneman et al., 2013). The question arises as to when this disturbance should occur in order to sustain aspen. Background aspen regeneration and gap-dynamics will often maintain a mixed aspen-conifer forest for long periods allowing aspen to respond vigorously in patches after the stand has burned. Studies have found that aspen will often successfully recruit new stems despite conifer cover at 60-70% (DeRose and Long, 2010). Smith et al. found that overstory aspen and conifer were the most important variables in determining when a stand should be burned and recommend promoting fire when conifer is >80% and aspen is <200 stems ha^{-1} for maintaining aspen on the landscape (2011). Considering current densities of mature and recruitment age aspen and conifer (Figure 11), we can expect to meet these numbers within the next 50-100 years. In the meantime, studies in mixed aspen-conifer forests indicate the importance of canopy gaps in creating high light conditions within late successional stands that allow aspen to persist until a large stand-replacing fire occurs (O’Brien, 2010). Our results indicate that non-fire stands on average have extremely low aspen recruitment with only 63 stems ha^{-1} and non-browsed regeneration levels of 1,179 stems ha^{-1}. It is unclear whether such low recruitment levels are due to competition with conifer or repeated browsing. In such stands we recommend conifer-thinning to open canopy gaps and monitoring pre- and post-treatment to evaluate browsing impacts and treatment success in recruiting aspen.

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APPENDIX A

FIGURES AND TABLES

Table 1 Error matrix derived from interpreting Book Cliffs Color Infrared NAIP imagery.

		Ground Truth Reference Data				
		Other	Aspen	Conifer	Mixed	Row Total
NAIP Interpretation	Other	18	0	5	3	26
	Aspen	1	9	1	0	11
	Conifer	0	0	21	1	22
	Mixed	0	0	0	7	7
	Column Total	19	9	27	7	62

Overall Accuracy = 55/62 = 88.70%

Producers Accuracy	Users Accuracy
Other = 18/19 = 94.73%	Other = 18/26 = 69.23%
Aspen = 9/9 = 100%	Aspen = 9/11 = 81.81%
Conifer = 21/27 = 77.78%	Conifer = 21/22 = 95.45%
Mixed = 7/7 = 100%	Mixed = 7/7 = 100%

Kappa Coefficient of Agreement = 83.35%

*Table adapted from data collected during thesis work (Mittanck, 2012)

Table 2. Ranking of stand condition based on overstory, regeneration/recruitment, and browse of young aspen suckers. A stand must meet all the criteria for either "Good" or "Poor" condition, otherwise it is rated as moderate. "Mortality" is defined as standing dead. Browse includes branch tips, buds, and leaves missing, as well as presence of multi-stemmed ("bushy") aspen regeneration.

Code	**Descriptor**	**Overstory Mortality**	**Vertical Stand Layers**	**Browse Impacts**
1	Good	Minimal overstory mortality (< 5%)	Several aspen layers (≥ 3)	Browsing impacts on regeneration uncommon (< 25%)
2	Moderate	Does not fit 1 or 3	Does not fit 1 or 3	Does not fit 1 or 3
3	Poor	Overstory mortality (> 25%)	layering absent or minimal (≤ 2)	Browsing impacts clearly evident (> 50%) on regeneration.

Table 3. R output from ANOVA model run. Single term deletions function [drop1(Model, ~.,test=”F”)] was used to get type III SS, which is considered better for unbalanced designs. Variable “Regen:Area” is significant, indicating that the relationship between regeneration and browse are significantly different between study areas.

```
Model:
Browse ~ Regen * Area
           Df Sum of Sq   RSS    AIC  F value    Pr(>F)
<none>                  13984 563.88
Regen       1   27635.7 41620 688.40 221.3358 < 2.2e-16 ***
Area        1     355.4 14340 564.79   2.8462  0.094376
Regen:Area  1    1220.6 15205 571.59   9.7760  0.002253 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

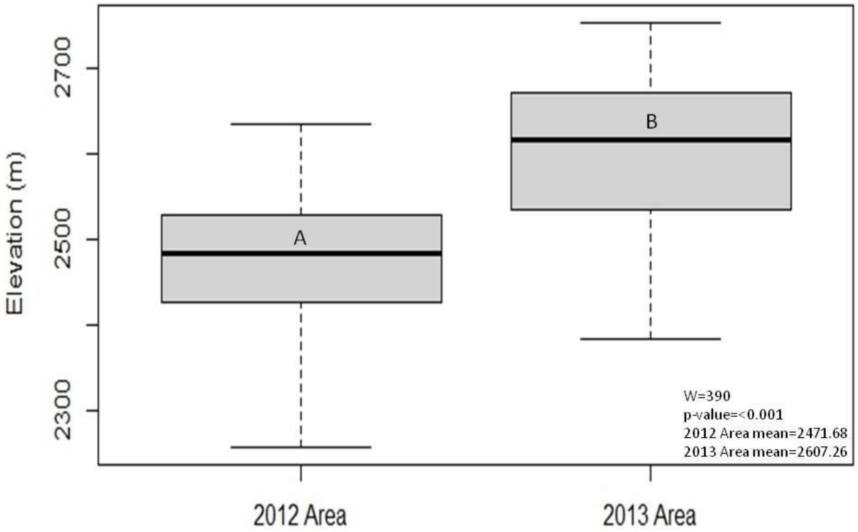


Figure 1. Boxplot of aspen elevation differences between the 2012 and 2013 study areas. Elevation (m) values are shown on the Y-axis. Whiskers represent minimum and maximum values, boxes represent 25-75% data ranges, while horizontal lines within boxes are medians. Non-parametric two-sided Wilcoxon-Mann-Whitney U test results are shown in lower right, different letters indicate significant differences at $\alpha=0.05$.

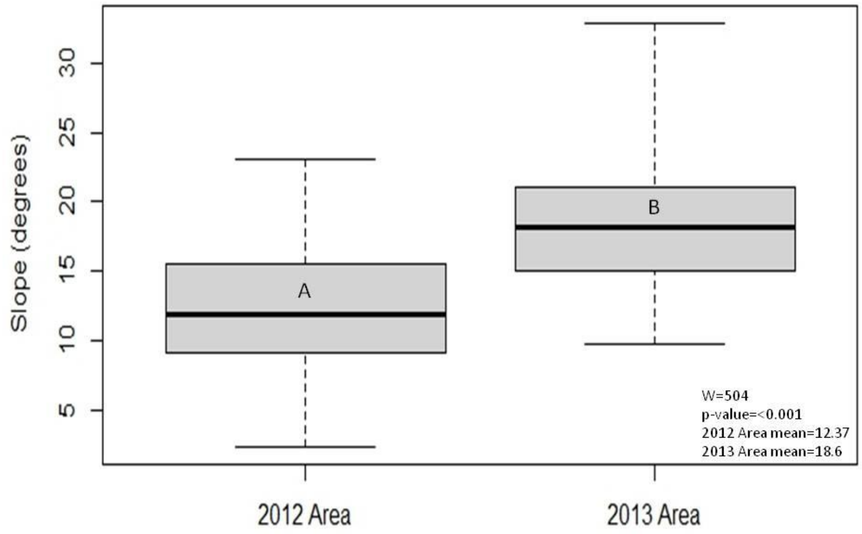


Figure 2. Boxplot of aspen slope differences between the 2012 and 2013 study areas. Slope (degrees) values are shown on the Y-axis. Whiskers represent minimum and maximum values, boxes represent 25-75% data ranges, while horizontal lines within boxes are medians. Non-parametric two-sided Wilcoxon-Mann-Whitney U test results are shown in lower right, different letters indicate significant differences at α=0.05.

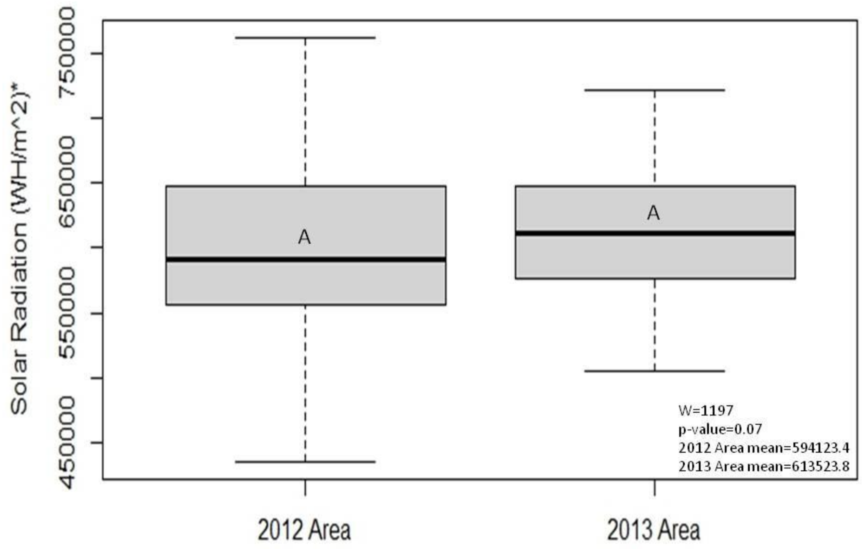


Figure 3. Boxplot of aspen solar radiation differences between the 2012 and 2013 study areas. Solar radiation (WH m^{-2}, *Units are estimates of direct plus diffuse radiation calculated at intervals throughout the year to get total radiation values for each pixel in a surface raster) values are shown on the Y-axis. Whiskers represent minimum and maximum values, boxes represent 25-75% data ranges, while horizontal lines within boxes are medians. Non-parametric two-sided Wilcoxon-Mann-Whitney U test results are shown in lower right, different letters indicate significant differences at $\alpha=0.05$.

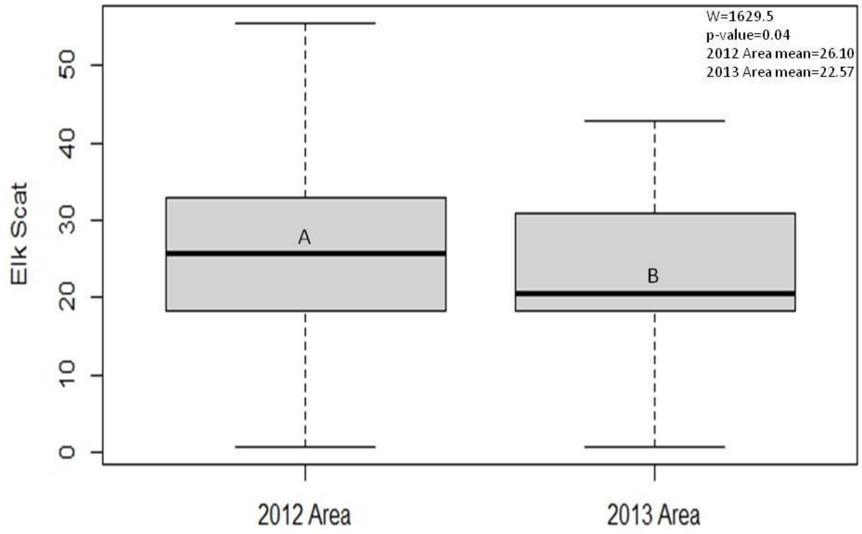


Figure 4. Boxplot of elk scat differences between the 2012 and 2013 study areas. Elk scat values have undergone a square root transformation and are shown on the Y-axis. Whiskers represent minimum and maximum values, boxes represent 25-75% data ranges, while horizontal lines within boxes are medians. Non-parametric two-sided Wilcoxon-Mann-Whitney U test results are shown in the upper right, different letters indicate significant differences at α=0.05.

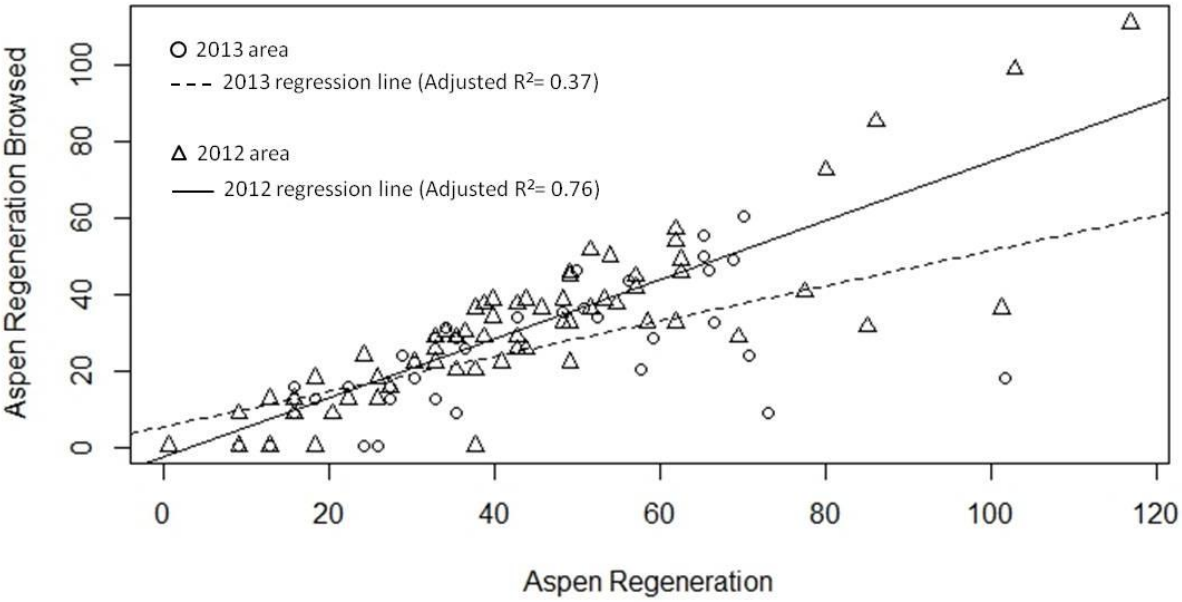


Figure 5. Analysis of covariance results. X and Y values have undergone square root transformations. Both areas show significant positive relationships (2012 area, *F=253.1, 75 DF, p-value=<0.0001*; 2013 area, *F=22.56, 37 DF, p-value=<0.001*). Model fit was higher for 2012 area with an adjusted R^2=0.76, and lower for 2013 area with an adjusted R^2=0.36. Model indicates higher browse levels in the 2012 area when aspen regeneration is abundant. However, as expected ANOVA results (Table 3) indicate the slopes of these lines are significantly different, therefore browse levels (i.e. y-intercepts) could not be statistically tested for differences.

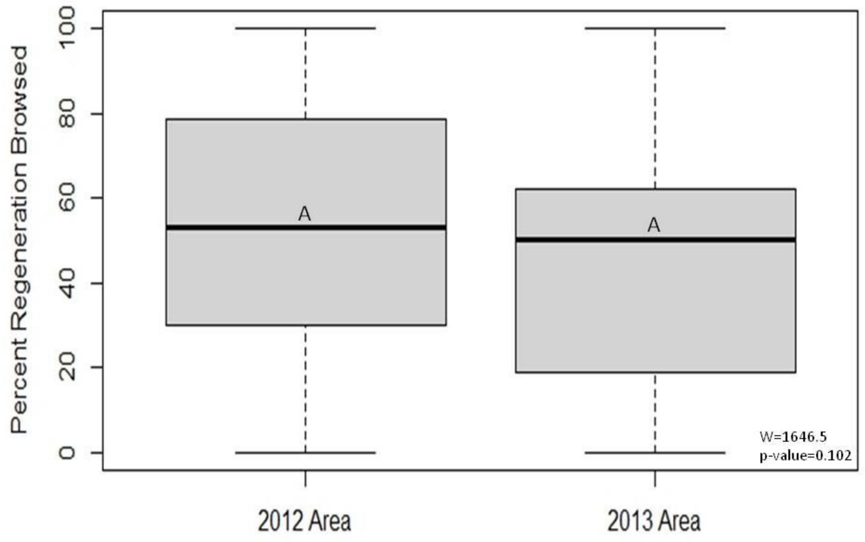


Figure 6. Boxplot of percent aspen regeneration browsed differences between the 2012 and 2013 study areas. Whiskers represent minimum and maximum values, boxes represent 25-75% data ranges, while horizontal lines within boxes are medians. Non-parametric two-sided Wilcoxon-Mann-Whitney U test results are shown in the lower right, different letters indicate significant differences at $\alpha=0.05$.

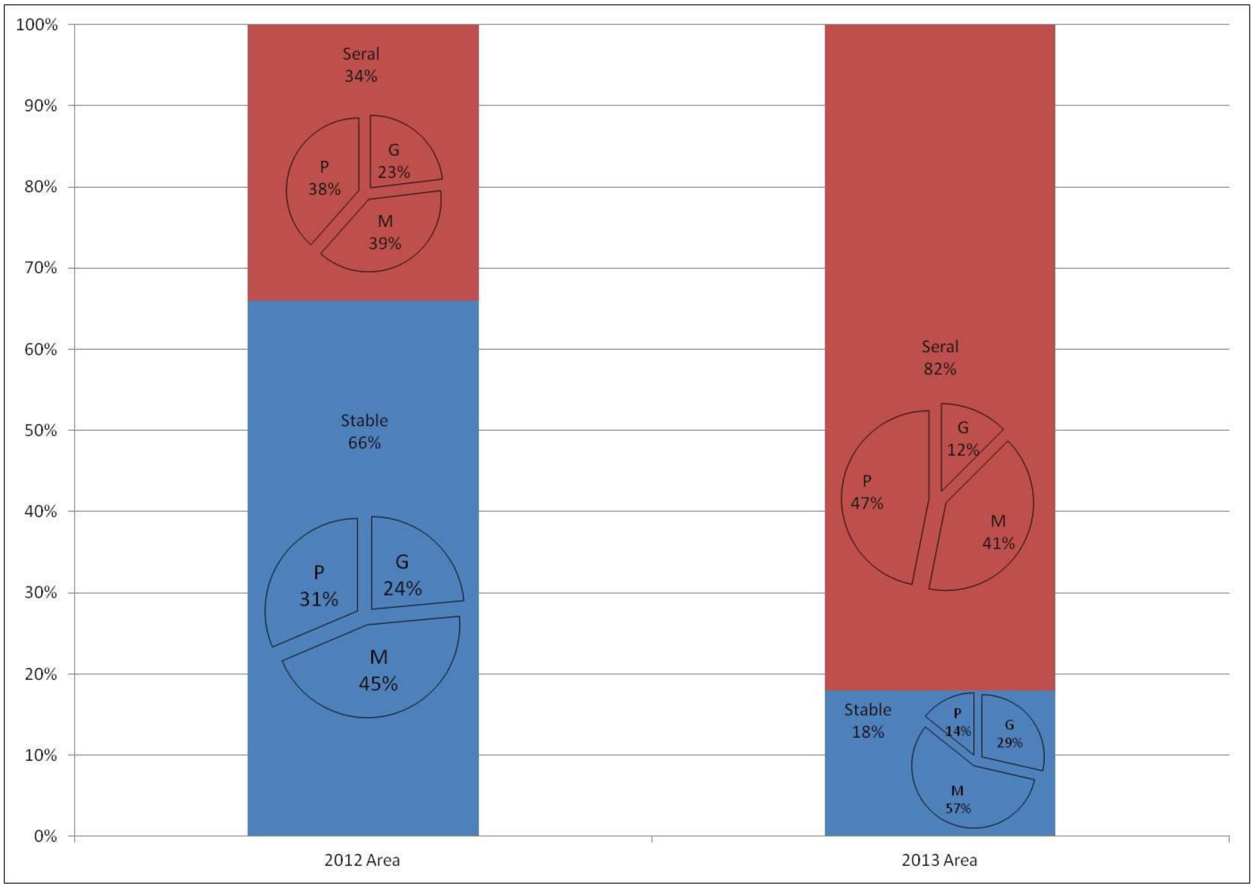


Figure 7. Aspen stand type proportional differences between the 2012 and 2013 study areas. Proportions of stand condition (criteria defined in Table 2) are shown in pie charts within columns of respective stand types. The 2013 area has markedly higher proportions of the seral aspen stand type than the 2012 area, while stand condition proportions are generally similar.

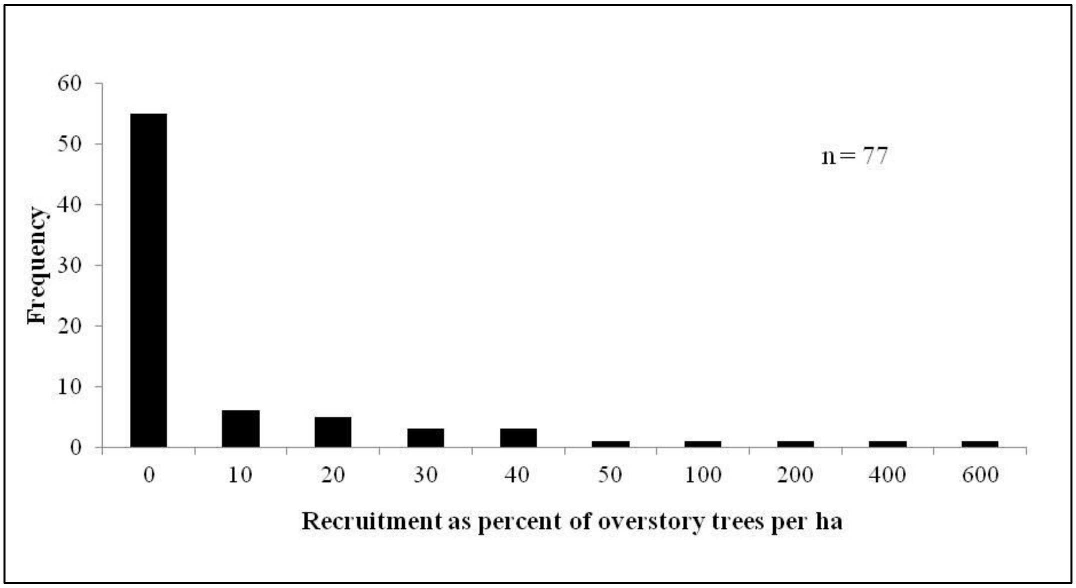


Figure 8a. 2012 Study Area.

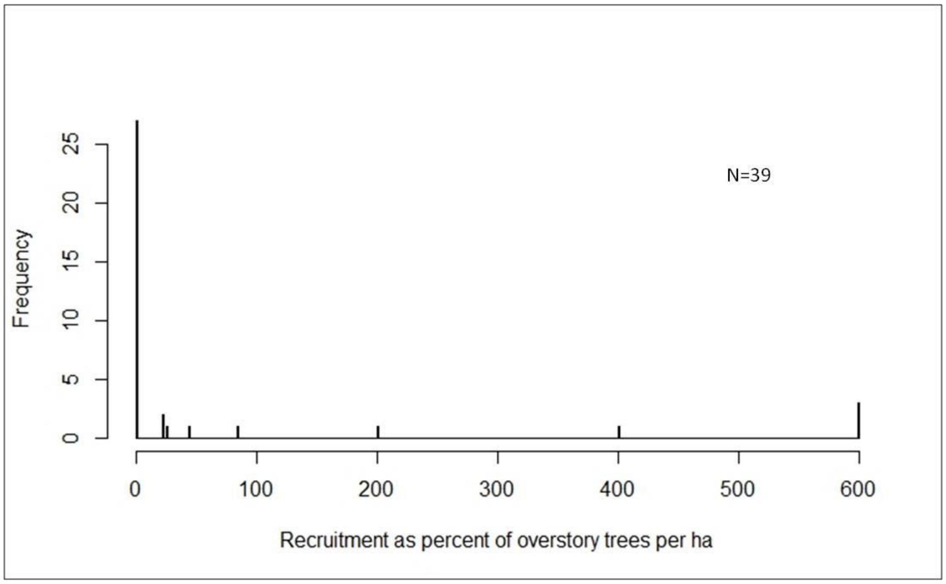


Figure 8b. 2013 Study Area.

Figures 8a and 8b. Frequency of aspen recruitment as percent of overstory aspen $^{ha-}$. Calculation assumes 100% would support complete immediate stand replacement and 50% would be ample recruitment for gradual (i.e., gap-phase) replacement. The 2012 area has very poor recruitment/replacement with 71% of stands yielding zero recruitment, while within the 2013 area, 69% of stands yielded zero recruitment.

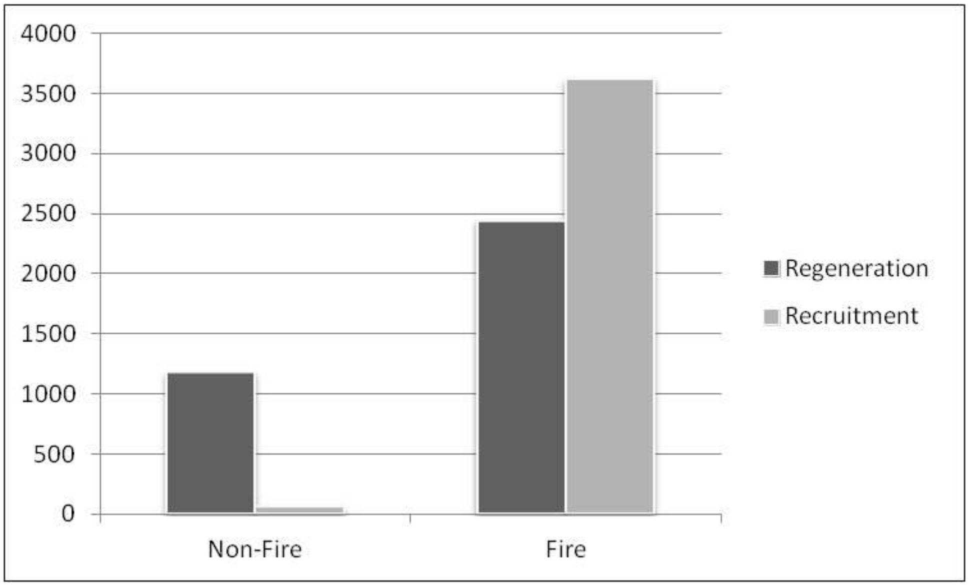


Figure 9. Mean levels of live non-browsed aspen regeneration and recruitment within stands impacted by fire and non-fire stands. Y-axis represents stems per hectare. Aspen recruitment levels in non-fire stands is extremely low with a mean of 63 stems ha^{-1}, while recruitment in fire impacted stands is well above the number needed for stand replacement.

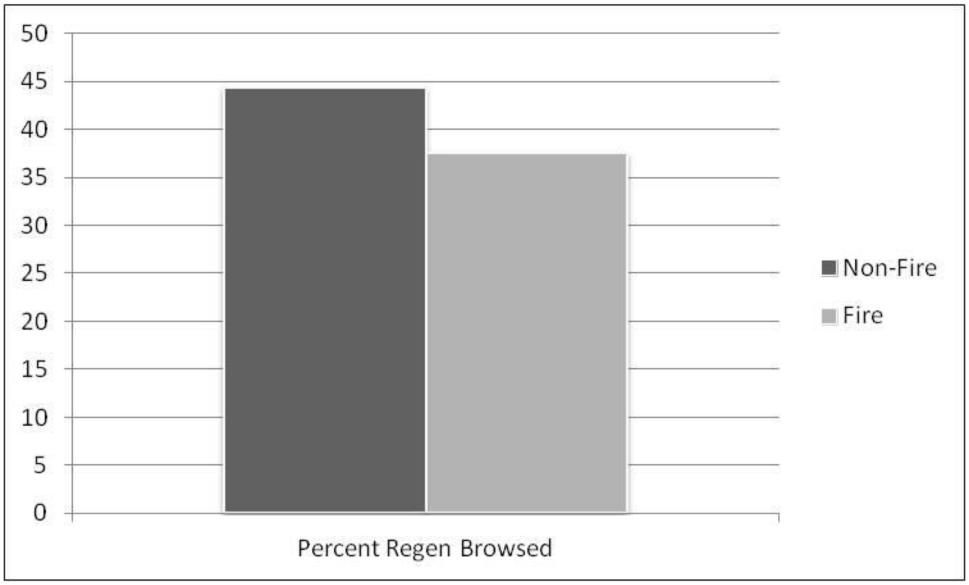


Figure 10. Percent aspen regeneration browsed within stands impacted by fire and non-fire stands. Interestingly, percent regeneration browsed is higher in plots not impacted by fire though the difference is not significant (*W=129.5, p-value=0.62*).

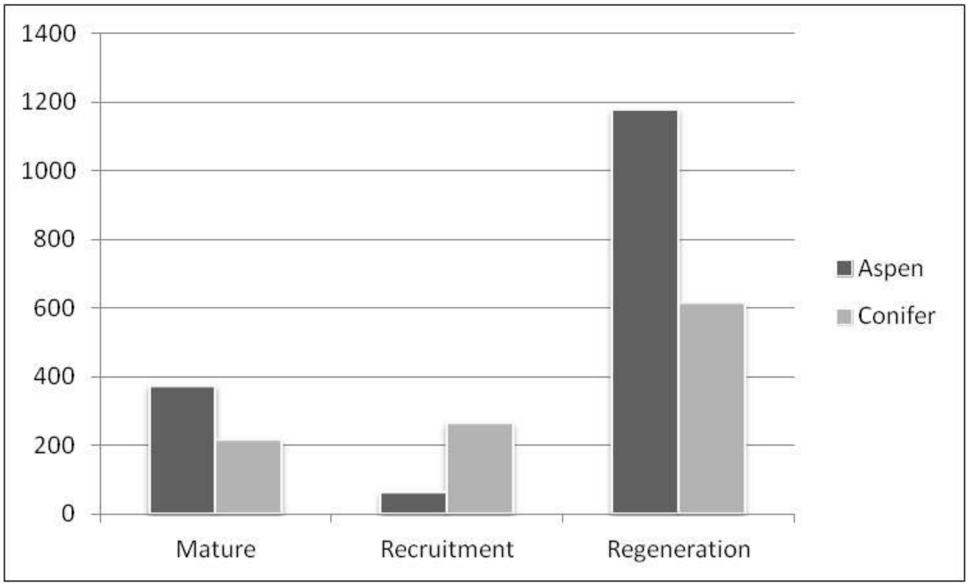
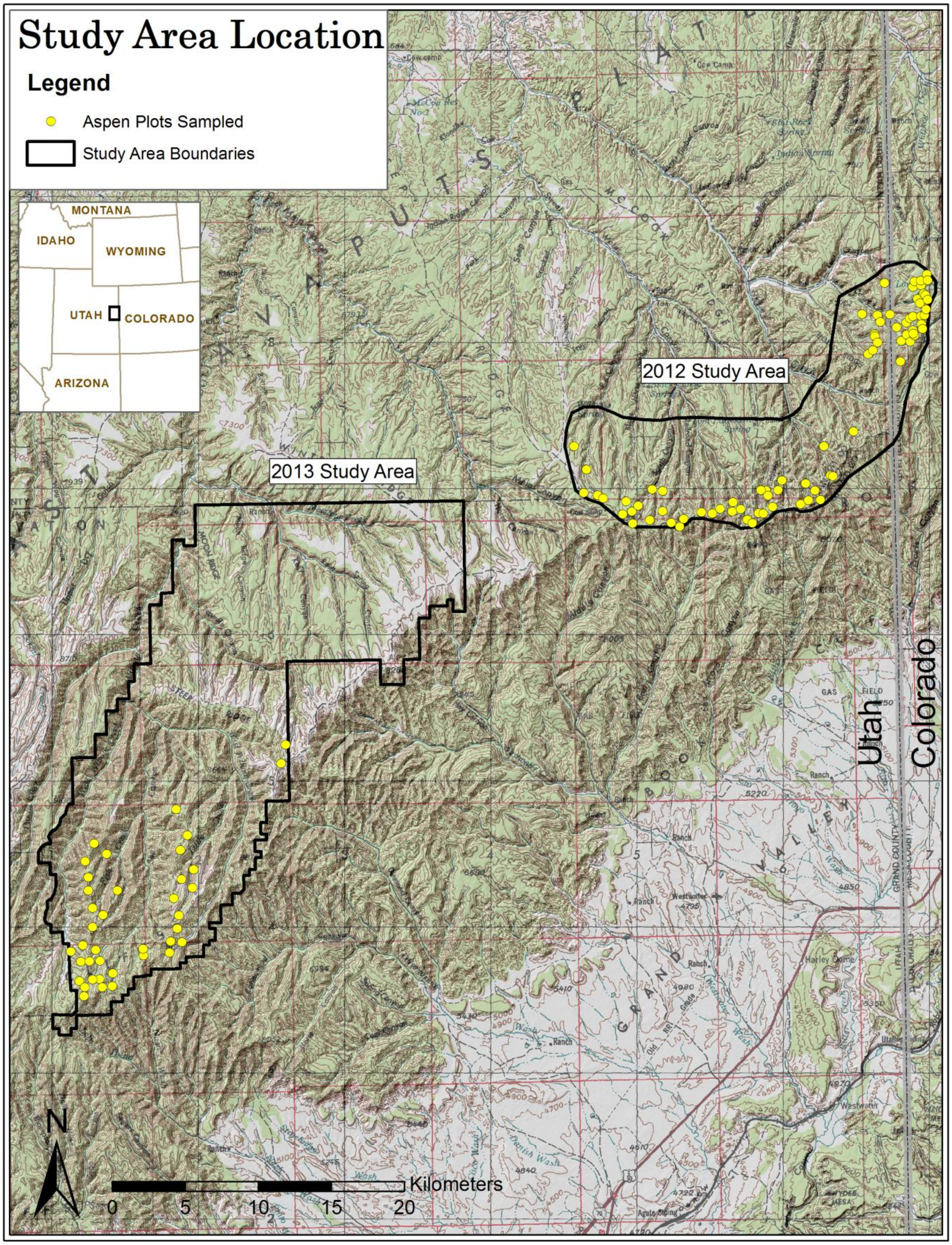


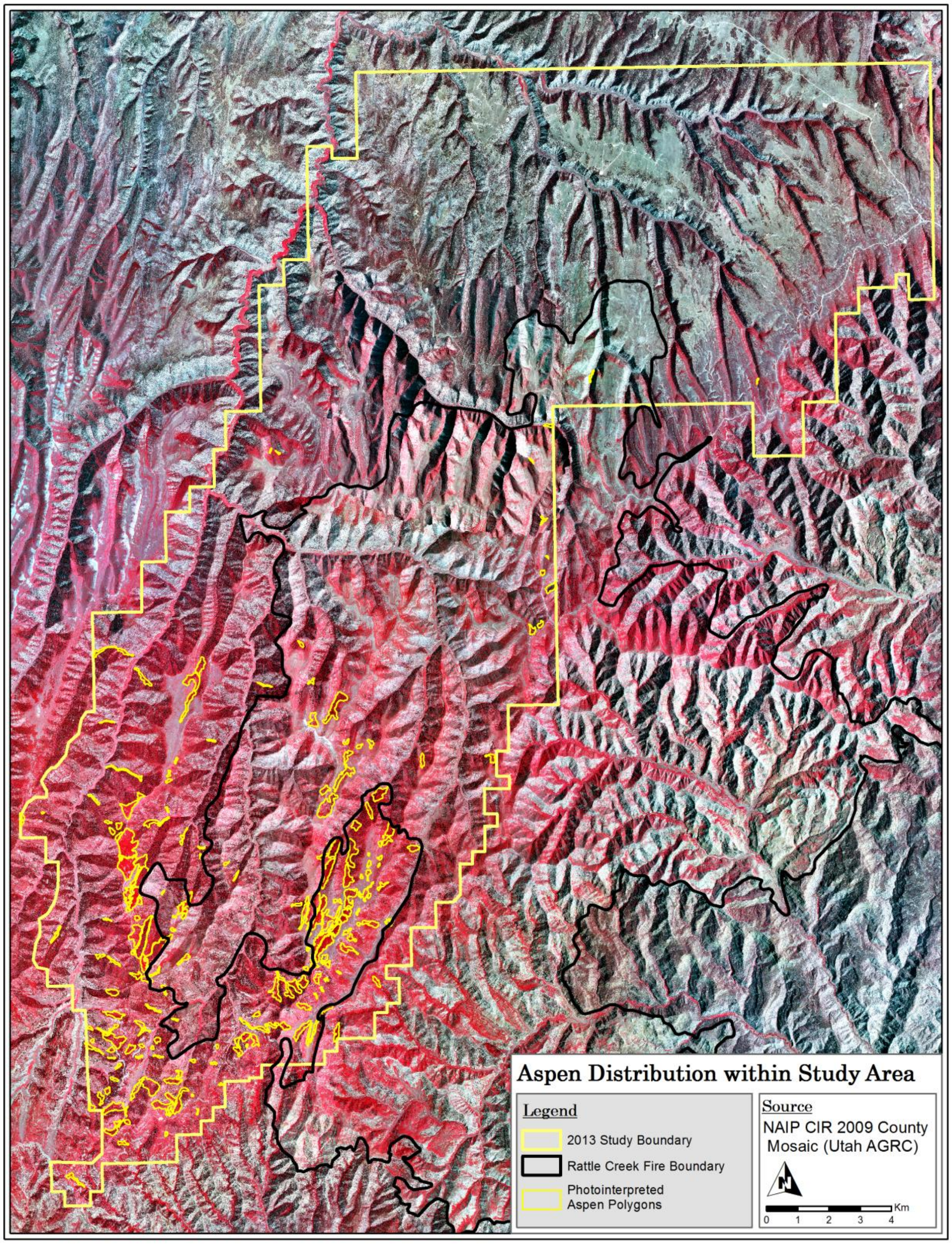
Figure 11. Mean stems per hectare of live aspen and conifer separated by age cohort within stands not impacted by fire. Y-axis represents stems ha^{-1}. Proportions of conifer to aspen in both recruitment and regeneration age classes indicate future conifer dominance of the stand.

APPENDIX B

MAPS



Map 1. 2012 and 2013 study area locations and plots sampled.



Map 2. Aspen distribution within 2013 study area. Yellow polygons indicate aspen stands identified through photointerpretation of National Agricultural Imagery Program (NAIP) color infrared imagery. Estimates of aspen within the Rattle Creek fire boundary are low due to difficulty in identifying aspen regeneration and recruitment age classes without mature aspen canopy nearby.

APPENDIX C

PHOTOS

Photo 1. Example of a "Good" condition stable aspen community. Stand exhibits: low canopy mortality, more than 3 vertical layers or aspen age cohorts, and low browse impact.

Photo 2. Example of a late-stage seral aspen community. Gaps within these stands, as shown in the photo, allow aspen to persist until a large stand-replacing fire occurs.

Photo 3. Example of an early-stage seral aspen community. The dense layer of conifer regeneration in the understory will eventually grow to overtop the aspen and out-compete it for light and nutrients.

Photo 4. Example of a seral aspen community post-fire. There are many conifer snags still standing indicating a high density of conifer pre-fire. Aspen has responded vigorously with a high density of successful recruitment that is now above the "browse-line".