The effects of various Sudden Aspen Decline intensities on understory microclimate and plant biomass in southwest Colorado

Ellen Keaveny
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Introduction

Rapid mortality of aspen (*Populus tremuloides*) featuring high crown loss, concurrent branch dieback, and poor suckering was first observed extensively in southwestern-Colorado in 2004 (Worrall et al. 2008). This unusual abrupt fatal phenomenon, often referred to as Sudden Aspen Decline (SAD), is the result of predisposing factors, inciting factors, and contributing factors (Manion 1991; Manion and LaChance 1992). Long-term predisposing factors of SAD account for slow changing or static elements and include low elevation, southerly or southwesterly aspects, low stand density and physiological maturity (Worrall et al. 2010). Inciting factors, biological or physiological components leading to severe stress, consist of drought and increased temperatures during the growing season, while contributing factors, or immediate affects, include insects and pathogens which eradicate debilitated trees already stressed by predisposing factors (Worrall et al. 2010). Because aspens are considered clonal species, numerous stems found in one area can originate from a single organism, meaning that all stems are composed of identical genetic make-up (Romme et al. 2009). Aspen clonal stands are commonly found on soils that are rich in organic minerals with a high pH. In contrast, aspen growth is hindered in soils with low nutrients and pH (Cryer & Murray 1992). In order to promote aspen regeneration, Sharpe and others (1976) illustrated that clear-cutting assisted in maintaining high nutrient, high pH soil by new ramets, creating heavy leaf fall and litter enriching and soil with high organic matter, raising the pH, and maintaining temperature favoring aspen conditions (DeByle & Winokur 1985). Bartos and others (1994) illustrated that natural or prescribed fire also promotes regeneration in declining stands with poor suckering due to the increase in pH, organic carbon, and nutrients that burning brings to the soil (Martin & Dell 1978). In stands prevalent with the effects of SAD, suckering is often commenced and new ramets are absent (Worrall et al. 2008). Although clear-cutting an aspen forest usually sparks an abundant growth of new stems as well as an increase in understory vegetation, harvesting stands undergoing SAD do not exhibit the fertile benefits of the standard clear-cutting, making SAD a perplexing phenomenon potentially due to excessive browsing by both native and domesticated ungulates (Romme et al. 2009).

Microclimate, one potential inciting factor for the lack of aspen regeneration in SAD, encompasses a significant importance in maintaining a stable aspen forest and understory vegetation. Forest openings, present in SAD stands due to high crown loss and synchronous branch dieback at amplified levels, may be strongly influential in the regeneration of forests (Carlson and Groot 1995). Powell and Bork (2007) illustrated in a study that quantified forest openings and understory microenvironment, that forest gaps within closed canopy forests have a direct effect on temperature extremes and photosynthetically active radiation (PAR). Specifically they found that aspen canopies become less dense, temperature maximums increase and minimums decrease, maximum relative humidity increases in the evenings, and a higher amount of PAR reaches the understory vegetation (Powell and Bork 2007).

With an increase of PAR being accessed by understory vegetation from the lack of high canopy interception, an increase of vegetation at the soil surface develops (Carlson and Groot 1995). The availability of the understory vegetative species to photosynthesize creates an opportunity for an increase of understory species richness. Cardinal and others (2007) called attention to the influence of species richness on primary production illustrating that a reduction in herbaceous species richness resulted in lower biomass production because soil nutrient uptake by plants became less efficient. Because aspen root growth primarily occurs within 20 cm of the soil surface, as aspen root density increases, herb cover decreases due competition of spatial resources (Strong & La Roi 1983). Powell and Bork (2007) point out that overstory vegetation—aspens—can increase soil moisture due to a decrease in wind and direct solar radiation, although this increase of water may be absorbed by the trees

Given the importance of abiotic factors—such as soil surface and subsurface temperatures, soil moisture, PAR, precipitation, and relative humidity, on understory plant regeneration and growth, information is needed to determine the degree in which aspen stands afflicted by SAD vary in microclimate. Examining the microclimate of treated moderate stands is also imperative in order to investigate how microclimate changes affect understory plant biomass and aspen. The Mancos-Dolores Ranger District of the San Juan National Forest, southwest Colorado possessed the highest percentage of SAD, ~10 percent, in Colorado as of 2008 making it the ideal location to study SAD effects on both biotic and abiotic variables. In 2009, SAD stands of different intensities were established by Dr. Julie Korb and District Forester Mark Krabath along with FLC Environmental Biology students. Our research answers a new question not yet answered regarding SAD related to microclimate and understory plant biomass response to SAD. With our study, we intended to close this knowledge gap in SAD research by answering the following two specific questions: 1) quantifying the effects of different intensities of SAD and clear-cutting on soil surface and subsurface soil temperatures and soil moisture; and 2) quantifying the effects of different intensities of SAD and clear-cutting on understory vegetative standing biomass from different plant functional groups.

Methods

2.1. Study site

We conducted our study within the Mancos-Dolores Ranger District of the San Juan National Forest (SJNF) (N 37.69; W 107.81), due to the large percentage of aspen cover lost caused by SAD (~10%) (Worrall et al. 2008). This portion of the SJNF is located in the southwestern-most extent of the San Juan mountain range of southwest Colorado (Figure 1). The La Plata Mountains border the study site to the east and is topographically composed of mountains backing into foothills. In this semiarid southwest part of the state, the majority of the precipitation throughout the year occurs during the winter months from snow, an average total equaling 54.7 inches (138.9 cm) while June brings the least precipitation. Humidity in the area is low due to high evapotranspiration further contributing to semiarid conditions. Temperatures during the summer months have an average maximum temperature of 83.8ºF (28.8ºC) while being capable of plummeting to an average minimum temperature of 12.8ºF (-10.7ºC) during the winter months (Western Regional Climate Center, Mancos, 1898-2010, www.wrcc.dri.edu). The combination of high mesas, causing relatively consistent weather patterns, and middle-elevation foothills (2600 m to 3000 m) produce a habitat suitable for aspen. Aspen trees (*Populus tremuloides*) account for ~53,000 hectares, the expanse of the study area, while supporting an abundance of snowberry (*Symphoricarpos rotundifolia*), the most frequent shrub in the aspen understory (Bombaci & Korb in press). A range of different soil types are found in the study plots with the majority composed of Behanco-Powderhorn family complex, 0 to 15 percent slopes, the Fly-Foidel complex, 0 to 15 percent slopes, and the Teedown-Nordicol complex on 15 to 30 percent slopes (Bombaci & Korb in press). Grazing is also significant in the area which may have considerable effects on the natural landscape of the area as well as timber harvesting. The magnitude of timber harvest has caused a diverse aspen habitat ranging from open meadows, regenerating immature stands, and mature stands. (Bombaci & Korb in press)

2.2. Experimental design

In 2009, Bombaci and Korb utilized a stratified random sampling design in stands composed of >95% aspen overstory in order to maintain homogeneity among sample points (in press). They controlled for slope, aspect, and elevation during stand selection. Stands were defined as any area of contiguous aspen forest with relative similarities in tree species composition, height, and density (Bombaci & Korb in press). A total of 60 sample points were positioned randomly within areas that met study criteria using ArcGIS software (ArcGIS: Release 9.3. Redlands, California: Environmental Systems Research Institute, 1999-2009) and Hawth's Analysis Tools (Beyer 2004). Transects that were within 50 m of a stand perimeter were thrown out. The sample point locations were classified based on the percentage of SAD in each plot (stems with SAD/total stems in plot) into one of three categories: 1) low SAD (0-29.9%), 2) moderate SAD (30-69.9%), and 3) high SAD (70-100%), with 20 sample points for each SAD category (Bombaci & Korb 2009). In the summer and fall of 2010, the USFS did a coppice cut on some of the moderate SAD stands. The USFS only harvested moderate SAD stands because high SAD stands are considered beyond salvageable to induce resprouting aspen ramets. We randomly selected seven of the harvested stands as our harvest treatment. Our experimental design consists of seven randomly selected low SAD no harvest plots, seven moderate no harvest plots, seven moderate harvest plots, and seven high no harvest plots for a total of 28 plots. Throughout the rest of the text, these plots will simply be referred to as low SAD, moderate SAD, high SAD, and treated harvest SAD. Crown fade allowed us to assess the different levels of SAD and establish the experimental design. Differences became apparent when analyzing crown fade (%) between low and moderate stands ($F(3, 22) = 40.119$, $p = 0.02$), low and high and treated stands ($F(3, 22) = 40.119$, $p \leq 0.001$), treated and moderate and high stands ($F(3, 22) = 40.119$, $p < 0.001$), and moderate and high stands ($F(3, 22) = 40.119$, $p = 0.014$). Crown fade (%) in low crown stands had a mean of 3.475, 5.340 in moderate stands, 7.289 in high stands, and 0.750 in treated stands.

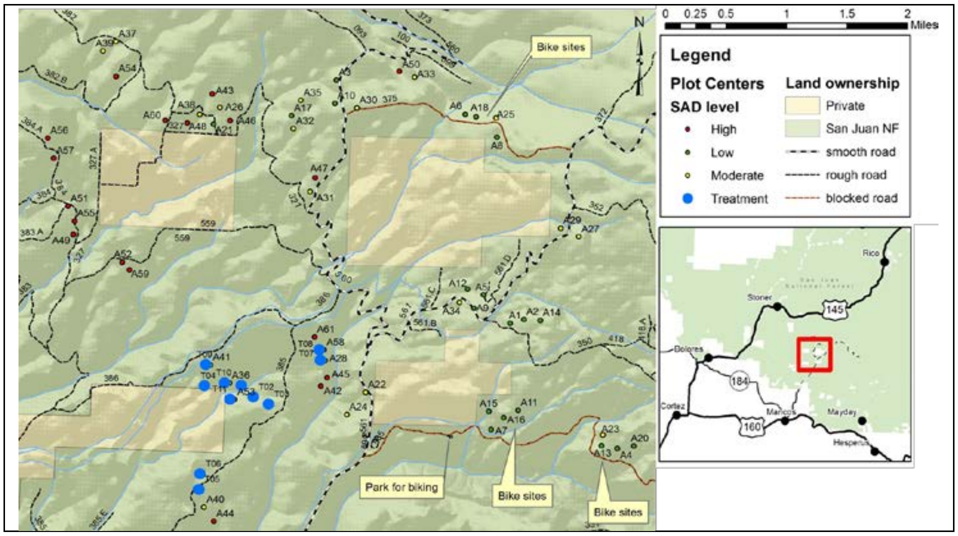

Figure 1. Figure 1. SAD study plots in Dolores-Mancos Ranger District of the San Juan National Forest. We randomly chose 28 of the 60 established plots to conduct surveys in four different levels of SAD: low SAD stands (0-29%), moderate SAD stands (30-69%), high SAD stands (70.1-100%), and clear-cut treatment (N=7/SAD level).

2.3. Forest survey protocol

In 2009 and 2010 vegetation data was recorded using two variable size circular plots at the center of each sample point (for details of sampling protocol in the 2009 and 2010 surveying, see Bombaci and Korb in press). In 2011 we followed-up on data previously collected by recording: 1) species, 2) tree condition (derived from the USFS tree standing scale {1 = live, 2 = declining, 3 = recent snag, 4 = loose bark snag, 5 = clean snag, 6 = broken above breast height, 7 = broken below breast height}), and 3) crown fade (assessed by ocular estimation of the percentage of crown loss in an individual tree, which was categorized into a 1-9 scale (0 = 0-9% fade,…9 =90-99% fade) in 16 m diameter circular plots for all trees greater or equal to breast height (1.37 m) and with a diameter at breast height (dbh) greater or equal to 5 cm (Bombaci & Korb in press). In addition, we measured tree canopy cover on a 50-m transect which intersected the two circular plots using a densitometer every 3 meters along the transect—summing to 16 total points. We examined the changes in these SAD related variables between 2009, 2010, and the data recorded in 2011 and calculated the percentage of SAD (average crown fade values/plot).

2.4. Microclimate survey protocol

We conducted microclimate surveys during the summer growing season from June 17, 2011 until September 2011 in the twenty-eight plots. At the center of each plot we established a modified, modified-Whittaker plot (Korb et al. 2003) consisting of a 50x20m^2 plot with four 1 m^2 subplots (0.5x2.0m^2) that were placed along the 50 m transect at 0-2 m, 17-19 m, 30-32 m, and 48-50 meters (Figure 2). We randomly positioned two Thermochron I-button temperature data loggers (Embedded Data Systems, Lawerenceberg, KY) in the 17-19 m subplot; one at the soil surface and the second at a depth of 3 to 5 cm beneath the soil surface, directly below the surface temperate logger (28 plots x 2 loggers = 56 total loggers). We then positioned small plastic shields over the surface sensors to prevent direct solar radiation on the loggers skewing temperature data. Once positioned, the loggers collected data at 30 minute intervals for the duration of the full three month study from June until September 2011. We also positioned a

Hobo Micro Station Data Logger (Onset Computer Corporation, Pocasset, MA) with two sensors to collect soil moisture data within the 17-19 m subplot in two randomly chosen plots for each SAD category (low, moderate, high, treated harvest) for a total of 8 data loggers, 16 soil moisture sensors, and 8 PAR sensors. However, due to a high amount of mammalian activity and interference with the equipment, only 5 PAR sensors and 4 soil moisture loggers collected data for the intended duration of the project.

We collected understory vegetation standing biomass within the modified, modified-Whittaker plots. Adjacent to the 17-19 m 0.5x2.0 m^2 subplot where microclimate data was collected, we clipped all vegetation. We followed the same protocol adjacent to the 30-32 m subplot where species abundance and composition were recorded (Figure 2). Plant biomass was clipped during peak biomass in mid-late July. The biomass was clipped using sharp pruning shears at the soil surface and was divided by species functional groups—forbs, grasses, and shrubs—with standing dead material being classified with associated living functional group counterparts. The total standing biomass was determined as the sum of forbs, grass, and shrub biomass for each plot. We quantified the understory vegetation standing biomass using a traditional destructive oven dried biomass clipping methodology by drying the vegetation in a forced air oven within 24 hours of clipping at 65ºC for 48 hours then weighing the oven-dried biomass (Cornelissen et al. 2003). Biomass was recorded as kg / ha $\pm$ SE.

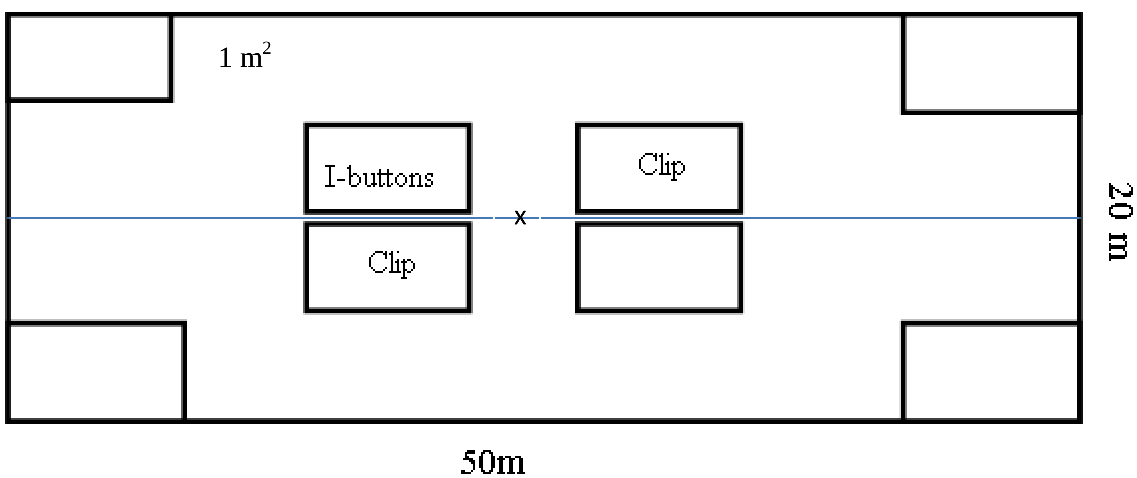

Figure 2. Modified, modified-Whittaker plot along a 50m transect through a 1,000m^2 plot with 0.5x2.0m^2 subplots used for estimation of species composition and abundance, biomass clipping and I-button temperature data logger and soil moisture data loggers.

2.4. Statistical Analysis

Vegetation data from individual plots were averaged for analysis among the four SAD categories (low, moderate, high, and treated harvest) (N = 7). Forest stand variable, microclimate data, and plant biomass among the different categories of SAD were analyzed using multiple Kruskal-Wallis one-way analysis of variance (ANOVA) tests. If the test was significant, a Tukey post-hoc pairwise comparison of the different SAD categories was used to assess where the differences were significant. Pearson's correlation analyses were performed in order to determine correlations and significance among the SAD conditions and microclimate data. Correlations were also performed comparing the SAD conditions to the understory biomass data collected. Each of the stated analyses was performed using SPSS version 18 software.

Results

3.1 Forest Structure

A difference was found between the SAD conditions when analyzing elevation between low and high stands ($F(3, 24) = 14.937$, $p = 0.029$), low and treated stands ($F(3, 24) = 14.937$, $p < 0.001$), moderate and high stands ($F(3, 24) = 14.937$, $p = 0.002$), and moderate and treated stands ($F(3, 24) = 14.937$, $p < 0.001$) (Table 1). Elevation means ranged from 8887 ft. found in the treated stands to 9273 ft. in the low stands, while moderate stands had a mean of 9393 ft., and high stands had a mean of 8978 ft.

3.2 Biotic Forest Variables

Differences were found between treated and low, moderate, and high SAD conditions when analyzing DBH (cm) ($F(3, 24) = 27.350$, $p = 0.000$). Basal area/ha in treated SAD stands was different when compared with low ($F(3, 24) = 11.605$, $p < 0.001$), moderate ($F(3, 24) = 11.605$, $p = 0.001$), and high ($F(3, 24) = 11.605$, $p = 0.005$). The mean basal area/ha in low stands was 174.508, 152.451 in moderate stands, 125.740 in high stands, and 33.437 in treated stands. Tree status was different within all groups with p-values < 0.001, ($F(3, 24) = 111.601$) except when comparing low to moderate stands ($F(3, 24) = 111.601$, $p = 0.004$). The mean tree status in low stands was 1.587, 2.283 in moderate stands, 3.437 in high stands, and 0.333 in treated stands. Tree density (tree/ha) also illustrated strong significance between all SAD conditions with a p-value < 0.001 ($F(3, 24) = 36.539$) except between moderate and high stands which showed no significant difference Differences were found in regards to tree canopy cover (%) between low and high stands ($F(3, 21) = 6.330$, $p = 0.006$) and low and treated stands ($F(3, 21) = 6.330$, $p = 0.020$). Tree canopy cover (%) exhibited a mean of 77.679 in low stands, 64.286 in moderate stands, 34.821 in high stands, and 0.000 in treated stands. The only differences found dealing with percent shrub cover (%) was between treated and low stands ($F(3, 23) = 6.888$, $p = 0.002$), and treated and moderate stands ($F(3, 23) = 6.888$, $p = 0.005$). Shrub cover (%) in low stands had a mean of 36.157, 32.903 in moderate stands, 25.119 in high stands, and 3.833 in treated stands. There was no significance found among the regeneration within the SAD conditions (Table 2).

After analyzing SAD agents present within the SAD stands, such as poplar borer, bronze poplar borer, bark beetle, and Cytospera, differences were found within the SAD conditions (Table 3). As for poplar borer, there were strong significant differences found between high and all other conditions with a p-value < 0.001 ($F(3, 22) = 43.498$). Differences were also found between low and moderate stands ($F(3, 22) = 43.498$, $p = 0.021$) and moderate and treated stands ($F(3, 22) = 43.498$, $p = 0.002$). The bronze poplar borer also showed strong differences between high and the remaining conditions with p-values < 0.001 ($F(3, 22) = 33.227$), while exhibiting less significance between low and moderate stands ($F(3, 22) = 33.227$, $p = 0.019$) and moderate and treated stands ($F(3, 22) = 33.227$, $p = 0.003$). Again there were strong differences found between high and all other conditions with a p-value < 0.001 ($F(3, 22) = 45.826$) in regards to presence of the bark beetle while less significance was found between low and moderate stands ($F(3, 22) = 45.826$, $p = 0.005$). Presence of Cytospera was significant when comparing treated stands to low, moderate, and high stands with a strong difference ($F (3, 22) = 15.541$, $p < 0.001$).

3.3 Understory Plant Biomass

Between the various SAD conditions—low, moderate, high, and coppice clear-cut treatment—species functional groups were analyzed with mean biomass (kg/ha) (Figure 3). There were differences found within the SAD conditions in regards to the grass functional group, while no differences were found within the shrub functional group ($F (3, 24) = 1.644$, $p = 0.206$). Mean biomass (kg/ha) of grass found in low stands was 215.45, 351.53 in moderate stands, 445.49 in high stands, and 128.56 in treated stands. Differences were found between low and high SAD stands ($F (3, 24) = 7.118$, $p = 0.025$), moderate and coppice clear-cut treatment stands ($F (3, 24) = 7.118$, $p = 0.030$), and high and coppice clear-cut treated stands ($F (3, 24) = 7.118$, $p = 0.002$) within the grass functional group. Differences were also illustrated from the forb biomass data collected with a difference found between moderate and coppice clear-cut treated SAD stands ($F (3, 24) = 3.755$, $p = 0.019$). Mean biomass (kg/ha) of forbs with standard error found in low stands was 660.95, 824.57 in moderate stands, 482.75 in high stands, and 226.80 in treated stands. Total standing biomass (kg/ha) was also analyzed between SAD conditions and a difference was illustrated between moderate SAD stands and treated stands as $p = 0.042$ ($F (3, 11) = 3.866$) (Figure 4). Total mean standing understory biomass (kg/ha) in low stands had a mean and standard error of 655.54, 941.20 in moderate stands, 666.35 in high stands, and 117.57 in treated stands. Total standing understory biomass (kg/ha) also demonstrated a positive correlation with tree density with significance (tree/ha) ($r^2 = 0.414$; $p = 0.029$) (Figure 9). Total standing understory biomass (kg/ha) was correlated with tree canopy cover (%) as well which also demonstrated a positive correlation with significance ($r^2 = 0.442$; $p = 0.019$) (Figure 10).

3.4 Microclimate

Mean temperatures for daytime surface (7am – 6:59pm), night surface (7pm – 6:59am), daytime subsurface soil, and night subsurface soil were analyzed among the low, moderate, high, and coppice clear-cut SAD conditions. All location/time sites for the established I-buttons illustrated differences among the SAD conditions excluding mean night surface temperature (°C) ($F (3, 16) = 0.137$, $p > 0.05$). Mean temperature (°C) for day surface and subsurface soil and for nocturnal subsurface surface soil location/times of day all indicated differences within the SAD conditions. For the daytime surface soil time/location differences were found between low and treated stands ($F (3, 16) = 0.007$, $p = 0.014$) and moderate and treated stands ($F (3, 16) = 0.007$, $p = 0.014$). Daytimes subsurface soil mean temperatures (°C) also illustrated a difference between low and treated stands ($F (3, 22) = 3.883$, $p = 0.014$). As for night subsurface soil mean temperatures (°C), the only significant difference was found between moderate and treated stands ($F (3, 22) = 3.587$, $p = 0.034$) (Figure 5).

Soil moisture and PAR data collected at 30 minute intervals at two randomly chosen plots for each SAD category summing to 16 moisture sensors and 8 PAR sensors illustrated a negative correlation when analyzed with mean tree canopy cover (%). This signified that as tree canopy cover (%) increased, both soil moisture and PAR decreased ($r^2 = -0.531$; $r^2 = -0.237$) (Figure 11). However, these analyses did not have p-values indicating significance ($p \geq 0.05$) due to high mammalian activity and interference with data collecting apparatuses resulting in a decrease of replicates (Table 4).

When comparing mean tree canopy cover (%) to mean day temperature at the surface soil level, a negative correlation was found accompanied by a strong difference (r^2 = -0.617; p = 0.004) (Figure 6). Night subsurface soil temperature (°C) correlated with mean tree canopy cover (%) demonstrated a significant difference with a negative correlation as well (r^2 = -0.472; p = 0.015) (Figure 7). Daytime subsurface soil temperature (°C) correlated with mean tree canopy cover (%) also demonstrated a strong difference with a negative correlation (r^2 = -0.405; p = 0.040) (Figure 8).

Table 1. Mean and standard errors of abiotic and biotic variables measured in the aspen forest survey for general forest stand characteristics within low (0-29/9%), moderate (30-69.9%), high (70-100%), and coppice clear-cut treatment SAD plots in Mancos, Colorado in May-August of 2011 using a Kruskal-Wallis one-way analysis of variance (ANOVA) followed by a Tukey post-hoc pairwise comparison. Different letters indicate a significant difference when $p \leq 0.05$ (N=7).

SAD Condition	Elevation (ft)	Aspect	DBH (cm)	Tree Status	Basal area/ha	Tree/ha (density)	Height (m)	Crown Fade (%)	Percent Cover	Percent Shrub Cover	Slope
Low	9273.43 ± 31.27 a	232 ± 14.04 a	15.81 ± 1.62 a	1.59 ± 0.15 a	174.51 ± 18.38 a	1648.79 ± 178.18 a	40.23 ± 5.01 a	3.47 ± 0.58 a	77.68 ± 5.26 a	36.16 ± 6.79 a	5.94 ± .086 a
Moderate	9393.14 ± 114.14 ab	287.42 ± 11.38 a	20.79 ± 1.07 a	2.28 ± 0.07 b	152.45 ± 26.87 a	884.55 ± 112.56 b	37.44 ± 2.83 a	5.34 ± 0.26 b	64.29 ± 9.81 ab	32.90 ± 5.44 a	4.97 ± 1.24 a
High	8978.86 ± 52.86 c	195.43 ± 34.20 a	20.73 ± 1.05 a	3.44 ± 0.06 c	125.74 ± 14.46 a	785.48 ± 67.87 b	44.04 ± 3.64 a	7.29 ± 0.22 c	34.82 ± 9.53 b	25.12 ± 4.96 ab	4.87 ± 0.36 a
Treatment	8887.75 ± 41.21 c	202.75 ± 42.11 a	17.24 ± 17.24 b	0.33 ± 0.33 d	19.11 ± 19.11 b	10.71 ± 10.71 c	50.19 ± 4.92 a	0.75 ± 0.75 d	34.38 ± 7.44 b	4.09 ± 2.31 b	4.80 ± 0.34 a

Table 2. Mean and standard errors of regeneration measured within low (0-29/9%), moderate (30-69.9%), high (70-100%), and coppice clear-cut treatment SAD plots in Mancos, Colorado in May-August of 2011 using a Kruskal-Wallis one-way analysis of variance (ANOVA) followed by a Tukey post-hoc pairwise comparison. Different letters indicate a significant difference when $p \leq 0.05$ (N=7).

SAD Condition	Total Live Regen/ha	Total Dead Regen/ha	Total Live No Browse/ha	Total Live Browse/ha	Total Dead Browse/ha	Total Dead No Browse
Low	1270.83 ± 656.95 a	282.41 ± 221.80 a	282.41 ± 136.72 a	988.42 ± 557.78 a	176.50 ± 117.08 a	105.90 ± 105.90 a
Moderate	776.62 ± 429.45 a	35.30 ± 34.30 a	176.50 ± 176.50 a	600.12 ± 294.64 a	35.30 ± 35.30 a	0
High	1447.33 ± 697.73 a	70.60 ± 45.57 a	670.72 ± 443.72 a	776.62 ± 363.44 a	70.60 ± 45.57 a	0
Treatment	988.43 ± 761.63 a	370.66 ± 294.11 a	803.09 ± 648.90 a	185.33 ± 118.29 a	61.78 ± 61.78 a	308.88 ± 233.88 a

Table 3. Mean and standard errors of agents present within low (0-29/9%), moderate (30-69.9%), high (70-100%), and coppice clear-cut treatment SAD plots in Mancos, Colorado in May-August of 2011 using a Kruskal-Wallis one-way analysis of variance (ANOVA) followed by a Tukey post-hoc pairwise comparison. Different letters indicate a significant difference when $p \leq 0.05$ (N=7).

SAD Condition	Poplar borer	Bronze Poplar Borer	Bark Beetle	Cytospera
Low	0.10 ± 0.03 a	0.09 ± 0.02 a	0.13 ± 0.05 a	0.67 ± 0.11 a
Moderate	0.32 ± 0.07 b	0.32 ± 0.07 b	0.37 ± 0.05 b	0.83 ± 0.08 a
High	0.74 ± 0.05 c	0.69 ± 0.07 c	0.73 ± 0.05 c	0.79 ± 0.06 a
Treatment	0	0	0	0.07 ± 0.07 b

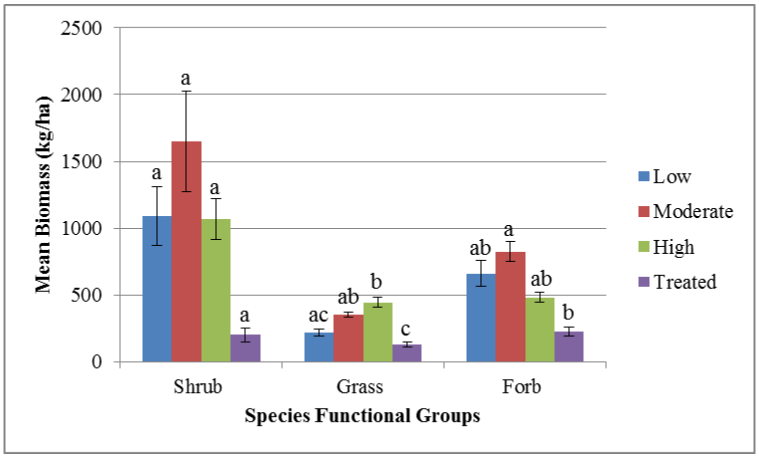

Figure 3. Mean biomass (kg/ha) of standing understory vegetation separated into species functional groups in low (0-29.9%), moderate (30-69.9%), high (70-100%), and coppice clear-cut treated SAD plots in Mancos, Colorado in 2011 (N=7). Different letters indicate a significant difference ($p \leq 0.05$) using a Kruskal-Wallis test.

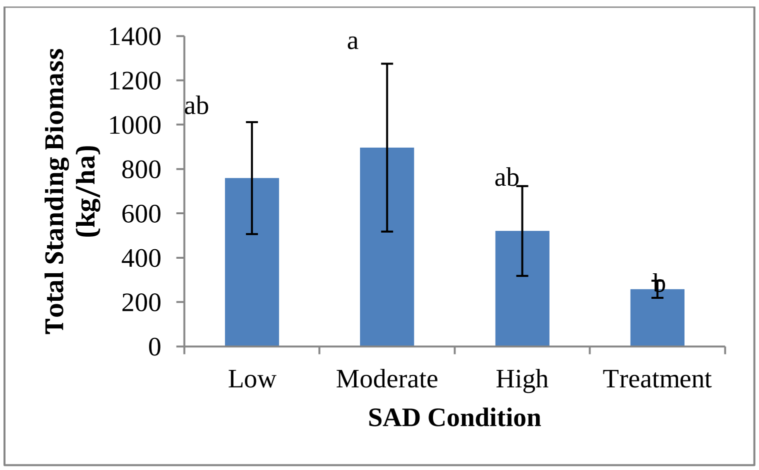

Figure 4. Mean total standing understory biomass (kg/ha) in low (0-29.9%), moderate (30-69.9%), high (70-100%), and coppice clear-cut treated SAD plots in Mancos, Colorado in 2011 (N=7). Different letters indicate a significant difference ($p \leq 0.05$) using a Kruskal-Wallis test among treatments.

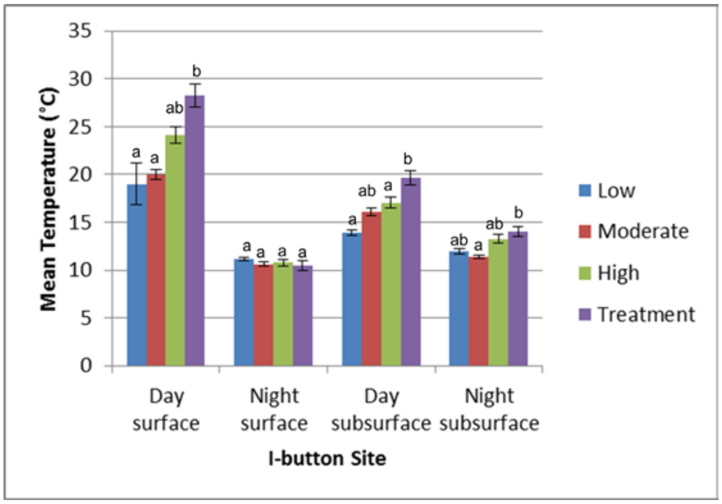

Figure 5. Mean temperature (°C) of soil surface and subsurface (3 cm below soil surface) from diurnal (7am – 6:59pm) and nocturnal settings (7pm – 6:59am) within low (0-29.9%), moderate (30-69.9%), high (70-100%), and coppice clear-cut treated SAD plots in the Mancos-Dolores Ranger District, Colorado in 2011 (N=7). Different letters indicate a significant difference at $p \leq 0.05$ within established time/location I-button sites.

Table 4. Mean percent canopy cover (%) correlated with mean biotic and abiotic variables between low (29.9%), moderate (30-69.9%), high (70-100%), and coppice clear-cut treated SAD plots in Mancos, Colorado in 2011 using a Pearson's coefficient correlation analysis.

Canopy Cover (%)	**r-squared**	**p-value**
Soil moisture	-0.531	p = 0.175
PAR	-0.237	p = 0.573
Shrub biomass (kg/ha)	0.329	p = 0.094
Grass biomass (kg/ha)	0.198	p = 0.323
Forb biomass (kg/ha)	0.324	p = 0.099
Day surface soil temperature (°C)	-0.617	p = 0.004
Night surface soil temperature (°C)	0.219	p = 0.354
Day subsurface soil temperature (°C)	-0.405	p = 0.040
Night subsurface soil temperature (°C)	-0.472	p = 0.015

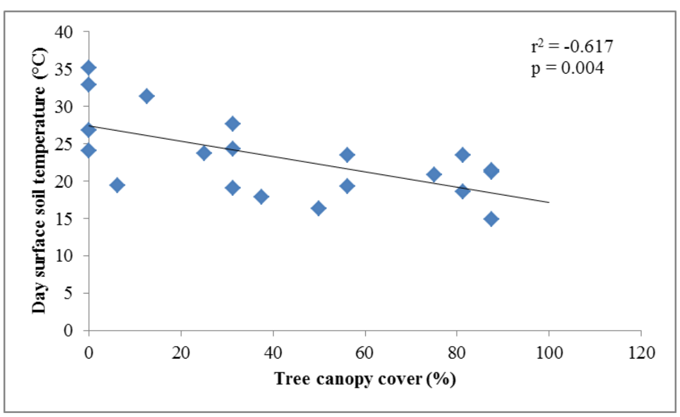

Figure 6. Mean day surface soil temperature (°C) (7am – 6:59pm) correlated with plot density (tree/ha) within low (0-29.9%), moderate (30-69.9%), high (70-100%), and coppice clear-cut

treated SAD plots in Mancos, Colorado in 2011 using a Pearson's coefficient correlation analysis.

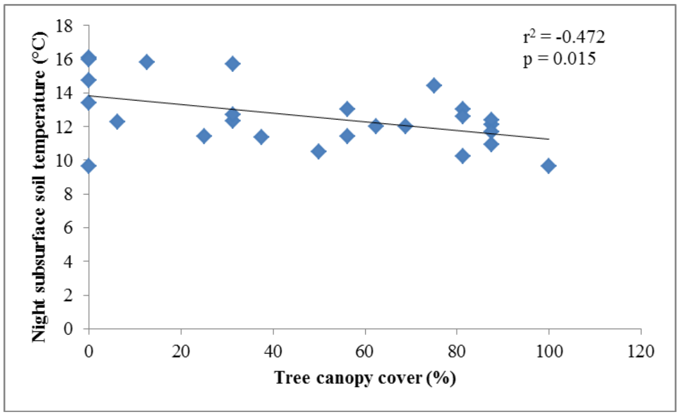

Figure 7. Mean night subsurface soil temperature (°C) (7pm– 6:59am) correlated with tree canopy cover (%) within low (0-29.9%), moderate (30-69.9%), high (70-100%), and coppice clear-cut treated SAD plots in Mancos, Colorado in 2011 using a Pearson's coefficient correlation analysis.

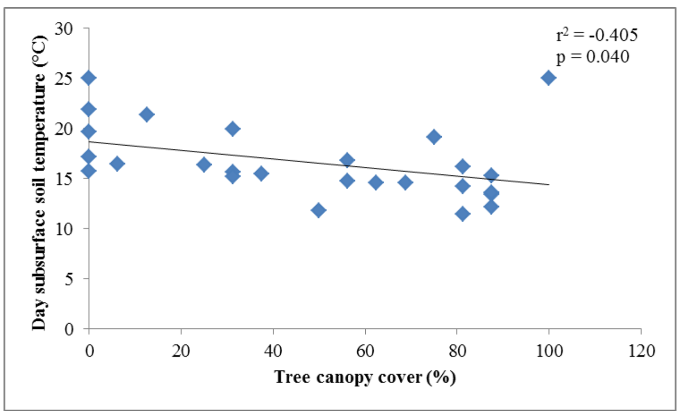

Figure 8. Mean day subsurface soil temperature (°C) (7am –6:59pm) correlated with tree canopy cover (%) within low (0-29.9%), moderate (30-69.9%), high (70-100%), and coppice clear-cut treated SAD plots in Mancos, Colorado in 2011 using a Pearson's coefficient correlation analysis.

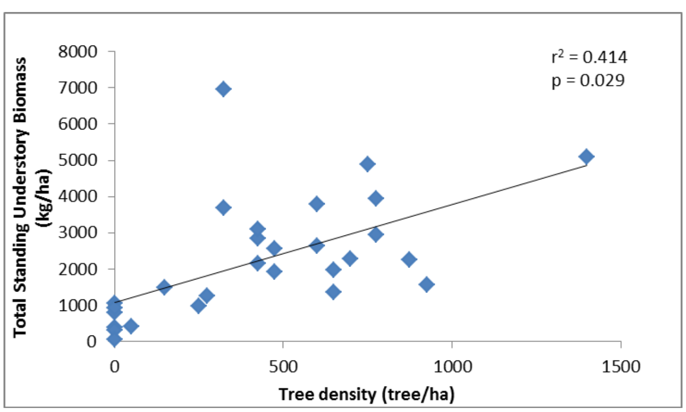

Figure 9. Mean total standing understory biomass (kg/ha) correlated with plot density (tree/ha) within low (0-29.9%), moderate (30-69.9%), high (70-100%), and coppice clear-cut treated SAD plots in Mancos, Colorado in 2011 using a Pearson's coefficient correlation analysis (N=7).

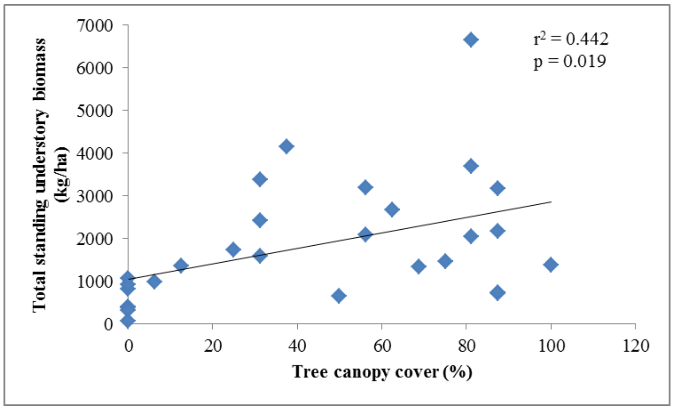

Figure 10. Mean total standing understory biomass (kg/ha) correlated with tree canopy cover (%) within low (0-29.9%), moderate (30-69.9%), high (70-100%), and coppice clear-cut treated SAD plots in Mancos, Colorado in 2011 using a Pearson's coefficient correlation analysis (N=7).

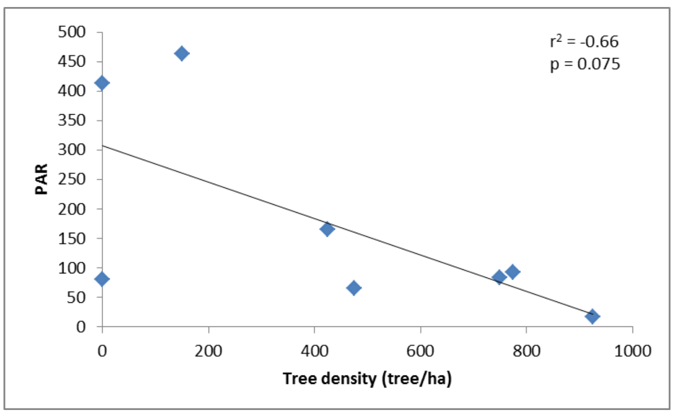

Figure 11. Mean plot PAR correlated with plot density (tree/ha) within low (0-29.9%), moderate (30-69.9%), high (70-100%), and coppice clear-cut treated SAD plots in Mancos, Colorado in 2011 using a Pearson's coefficient correlation analysis (N=2).

Discussion

After analyzing forest stand structure with understory plant biomass and understory microclimate, strong relationships between tree canopy cover with understory plant productivity, soil surface and subsurface temperatures, soil moisture, and PAR were brought to light using data from 2011. Specifically in regards to microclimate, the mean temperature (°C) followed the general trend of the research conducted by Powell and Bork with increases in maximum temperatures and decreases in minimum temperatures as canopy cover decreases in aspen forests (2007). For maximum temperatures, mean diurnal temperature (°C) both at the soil surface and at the subsurface soil level at the treated site had an absence of canopy cover and had the highest mean temperatures in comparison to the other SAD conditions. The trend continues down the line of SAD conditions for diurnal temperature means. This data corresponds with a study by Breshears and others in which soil temperatures were consistently warmer in intercanopy locations, at times up to 10 degrees warmer, in comparison to soil temperatures underneath a full canopy (1998). As SAD intensity decreases, the maximum means also decrease. Nighttime mean temperatures (°C) did not follow the trend as strictly. Subsurface soil temperatures in the treated SAD plots had the lowest recorded minimum temperatures although as SAD conditions decreased, the mean minimum temperatures did not respectively increase. While low stands had the highest minimum temperatures, indicating that canopy cover helped in regulating the understory microclimate, moderate stands had lower minimum temperatures than high stands. These results correspond to the conclusions of Pierson and Wight who performed a study that also illustrated lower maximum and higher minimum temperatures at the subsurface soil level below a canopy of sagebrush plants (1991). The nighttime mean temperatures (°C) at the subsurface soil level did not reflect the previous research as the treated plots had the highest minimum temperatures in comparison to the other SAD conditions. This inconsistency could be due to the cut off times of the established diurnal/nocturnal criteria where daytime is considered 7am-6:59pm and nighttime is considered 7pm - 6:59am.

According to a previous study led by Powell and Bork, an increase of PAR reached the subcanopy as aspen mortality increased accompanied by excessive leaf loss of surviving aspens resulting in a belief that as canopy cover decreases, PAR reaching the understory increases (2007). The data gathered in this study follows the general trend, although due to the lacking p-value, further research should be conducted in order to verify the negative relationship between canopy cover and PAR. This weaker relationship exhibited by our study may be due a decrease of PAR sensors and lack of data because of destruction of sensors caused by mammals, as well as higher shrub cover at some sites lowering the solar angle that would hit the PAR sensor (Powell and Bork 2007).

The relationship exhibited between aspen canopy cover with soil moisture illustrated a negative correlation signifying that as canopy cover increases soil moisture decreases. These results may have been skewed due to the high amount of sensors destroyed by small mammals and ungulates lowering the amount of replicates for the study. Gálhidy and others point out that gap size does not have a large influence on soil moisture maxima perhaps due to lack of tree roots, temperature, soil depth and stoniness (2007). Further research should be conducted measuring soil moisture in order to continue to investigate the trend between the abiotic relationship of microclimate and SAD. Because an increase in canopy cover relates with a general increase in tree density, perhaps the decrease of soil moisture is caused by water uptake from the aspen root which usually occur within 20 cm of the soil surface (Powell and Bork 2007).

Overall mean understory biomass (kg/ha) was highest in the moderate plots, lowest in the treated plots, and low plots had more biomass present than high plots. Perhaps more understory biomass was present in the moderate plot versus the low plot due to spatial resources for root growth. As the aspen root density increases, herb cover decreases due to the competition of resources (Strong & La Roi 1983). Biomass data was collected during seasonal peak biomass (kg/ha), however a large population of browsing ungulates were present either during or before data collection began. When analyzing biomass (kg/ha) by plant species functional group, shrubs and forbs had the highest amount of productivity in the moderate SAD stands while grass had the highest productivity in the high SAD stands. Although one would think that with an increase of PAR being accessed by understory vegetation from the lack of high canopy interception, an increase of vegetation at the soil surface would develop (Carlson and Groot 1995), this was not observed in our data. This result reflected the conclusions of Woods and others which demonstrate that as canopy density increases, understory biomass increases (1982). Bartos and others also concluded that forb and grass productivity decreased after the first year of treatment, then increased and remained greater in biomass than before the disturbance (1994). Therefore, continuing to monitor the productivity of the species functional groups could be insightful in determining the effects of coppice clear-cut treatments to the understory biomass in SAD plots.

In terms of microclimate, perhaps humidity should be further researched in determining factors that contribute to plant productivity and understanding the relationships between plant species functional groups with SAD condition. In regards to understory plant biomass (kg/ha), the data was collected during seasonal peak biomass (kg/ha) although a large population of browsing ungulates were present either during or before data collection began. Regulating this variable will increase control of the factors leading to error.

Management Implications

Evaluating various SAD intensities and their effects on understory plant biomass may help land managers determine decisions dealing with placement of browsing and grazing ungulates. Treating the declining stands also appears to have an effect on the understory microclimate and plant productivity although more data would increase the trends demonstrated by a coppice clear-cut aspen forest. According to FitzGerald and Bailey, short duration, late season (August) grazing nearly exterminated regenerating aspen ramets (1984). After coppice clear-cut treatment implementation, this previous research would suggest that if grazing were permitted in the treated plots, the cattle should be prohibited from browsing during the latter months of the grazing season in order to encourage successful aspen regeneration. While heavy, late season grazing decreases aspen density, the browsing condition also increases unpalatable snowberry (Bailey et al. 1990). In order to encourage diversity in species functional groups perhaps cattle should be restricted to graze only during the early season in moderate stands, where shrubs, with snowberry (*Symphoricarpos rotundifolia*) being the majority present, were highest in comparison to the other plots.

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