Monitoring Aspen Restoration Treatments in the LTBMU

Methodology and Pre-treatment Data Summary

Hemispherical image of conifer-encroached aspen stand, South Lake Tahoe, CA. July 2009.

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ABSTRACT

Quaking aspen (*Populus tremuloides*) forest communities in the Lake Tahoe Basin are being encroached and out-competed by conifers that impact aspen vigor and stifle natural regeneration. Removal of conifers has been advocated, and is being tested around the Tahoe Basin. However, little is known about stocking and treatment persistence: specifically, how much growing space must we provide aspen trees and their root sucker regeneration for vigorous growth to be sustained until the next restorative thinning? This report provides a detailed account of the design and implementation of a rigorous monitoring strategy for aspen restoration treatments in the Lake Tahoe Basin Management Unit (LTBMU). Tree locations within 1-ha permanent sample plots were mapped, and tree size data collected before restoration treatments were implemented. These pre-treatment data are summarized for each tree species at four study sites. Conifer trees outnumbered aspen trees at all sites, and represented between 50% and 90% of total stand basal area or live stemwood volume. Dry mass of live conifer trees was estimated to range from 64-158 metric tons per hectare between the four sites. Regeneration was assessed in a grid of subplots, capturing the amount and spatial variability of natural aspen and conifer regeneration. Regeneration of both aspen and conifer was plentiful at the four sites. However, much aspen regeneration was shaded or completely overtopped by larger trees and appeared unlikely to persist or grow vigorously. Hemispherical canopy photos taken from the center of each subplot provide a digital record of pre-treatment canopy conditions and will be processed to obtain estimates of leaf area index and predicted understory light. All measurements and hemispherical photos will be repeated after restoration treatments are implemented and over time to monitor change and treatment effectiveness.

INTRODUCTION

Quaking aspen (*Populus tremuloides*) is considered a keystone species and one of the few broad-leaved hardwood trees in many western forests (Shepperd et. al. 2006). Issues such as providing wildlife habitat, aesthetics, water quality, natural firebreaks, and sustaining ecological processes are driving the interest in protecting and restoring aspen stands. Aspen stands in the Tahoe Basin currently cover ~2,500 acres; sixty-four percent of these aspen stands are currently at moderate, high, or highest risk of loss (EIP Project #10029: Aspen Community Spatial Distribution and Condition Assessment; Aspen Community Mapping and Condition Assessment Project, March 2007). Aspen communities in the Lake Tahoe Basin are being encroached by conifers. Aspen is classified as a 'shade intolerant' pioneer species that depends on high light levels to regenerate and maintain vigor (Perala 1990). Conversely, the majority of conifers encroaching aspen stands throughout the Tahoe Basin are moderately (lodgepole pine) to highly (red fir, white fir) tolerant of shade. Their tolerance of shade allows the conifers to grow under the shade of aspen tree crowns, and eventually overtop the relatively short-lived aspen stems (Shepperd et al. 2006).

Associated with shade tolerance is the ability of a tree species to withstand crowding and maintain vigor. Shade tolerant species can withstand greater crowding than intolerant species such as aspen (Smith and Smith 2005). Shade tolerant species retain live branches and foliage under partial shade, whereas the live crown base of intolerant trees quickly retreats upward as lower branches become shaded under crowded conditions. Loss of live crown leads to loss of vigor, with an associated decline in pest and disease resistance. In a clonal species such as aspen that regenerates mainly by vegetative root suckers, loss of crown volume and vigor among existing stems will lessen carbohydrate storage within root systems (DeByle and Winokur 1985). Entire aspen clones with depleted energy reserves could succumb to major disturbances or changes in climate (Rehfeldt et al. 2009).

Removal of conifers encroaching aspen stands has been advocated and is being practiced in the Tahoe Basin (EIP Project #10080: Aspen Community Restoration Projects). There is an opportunity to monitor in detail the effects of restoration treatments, to document changes over time and support adaptive management. For example, thinning in heavily encroached stands may liberate enough growing space for large aspen stems in the overstory to regain vigor, but may not reduce tree stocking to a level where aspen root suckers have sufficient growing space to maintain vigor until the next scheduled thinning treatment. Alternatively, vigorous aspen regeneration may not be the main objective of restoration in stands where larger aspen stems are still thrifty. Clearly one prescription will not suit all aspen stands in the Tahoe Basin or the goals of the land owner/manager, highlighting urgent need for rigorous ongoing monitoring to support decision making for multiple objectives across the diverse array of aspen stand structures in the Tahoe Basin.

Stand density index (SDI) is a widely-used metric of relative "crowding" in forest stands. It is easily calculated using the number of trees per acre and their quadratic mean diameter at breast height (dbh). Stands with many small trees could be experiencing the same level of "crowding" (i.e., same SDI) as stands with fewer larger trees. Values for SDI of each tree species in a mixed stand (e.g., aspen-conifer) or different age classes in a multiaged stand (e.g., aspen suckers and overstory trees) can be summed to give whole stand SDI (Long and Daniel 1990; Woodall et al. 2005; Shepperd 2007). Stand SDI cannot exceed a given upper level – once all available growing space is occupied – and this upper limit can differ widely between tree species of different shade tolerance. For example, the shade-tolerant red fir has an upper limit of SDI = 2470 (metric units, Reineke 1933) whereas lodgepole pine has an upper limit of SDI = 1705 (Long 1985). Theoretically, trees in a mixed lodgepole pine-red fir stand would grow until SDI > 1705 when lodgepole pine would be outcompeted by red fir that tolerates a higher level of crowding.

Long (1985) proposed guidelines for stand density management based on SDI expressed as a percentage of the upper limit of SDI, where: 25% = onset of competition; 35% = lower limit of full site occupancy; and 60% = lower limit of self thinning. Once SDI exceeds 60% of the maximum, stands enter the "zone of imminent mortality" (Long 1985). The upper limit of SDI and the zone of imminent mortality are yet to be established for aspen stands in the Tahoe Basin, but are certainly lower than SDI limits for encroaching red and white fir, and would help guide managers interested in relieving crowding in conifer-encroached aspen stands.

Visitors in conifer-encroached aspen stands within the Tahoe Basin will notice standing dead aspens and numerous fallen dead aspen trees in areas crowded with conifer. Patches of un-encroached area where aspens dominate are also present within many stands, including stand edges bordering meadows or other openings providing aspen with access to light. These spatial variations in the level of encroachment and crowding suggest that large monitoring plots are needed to capture the range of variability in conditions before and after restoration treatment. However, summary data (e.g., stand averages) from large plots can be misleading without an understanding of the spatial arrangement of trees of each species and areas devoid of trees; averaging data over a large plot area could obscure small localized areas of extraordinarily high stocking. This problem can be mitigated by mapping stem locations within large plots. Stem maps reveal spatial patterns of tree locations, areas of crowding, and unstocked areas, and can be queried to access and summarize tree data for any portion of the main plot area.

This report presents a monitoring strategy for conifer-encroached aspens stands designed to: (i) characterize pre-treatment "baseline" conditions before removal of encroaching conifers; (ii) facilitate repeat assessments by mapping tree locations and installing permanent tree tags and plot boundary markers; (iii) yield data that will support adaptive management and that are amenable to statistical multivariate and spatial analyses. We describe methods of data collection and summary, followed by results including stem location maps and summary tables of tree size data, tree stocking and volume, count data for saplings and regeneration, and an example of simulated thinning to an upper diameter limit and its effects on stand density.

METHODS

Data collection

In summer 2009, four aspen stands on the southern (3 plots) and northwestern (1 plot) sides of the Tahoe Basin were chosen for sampling. Within each stand, a one hectare (1-ha; 2.47ac) permanent sample plot was installed. Plot corners were permanently demarcated with rebar and PVC and their locations recorded with GPS. All aspen trees ≥ 10 cm diameter at 1.37 m breast height (dbh) were mapped and measured for dbh, total height, and live crown base height. All conifer trees ≥ 20 cm dbh were mapped and measured for dbh, and a large subset measured for total height and live crown base height. Instances of damage or poor health for all trees were coded (e.g., forked, crown damage, leaning). Existing regeneration was assessed in a systematic grid of 0.004-ha circular subplots (>10% subsample of main plot area) so that it could later be separated from new regeneration arising after/in response to restoration treatments. Within subplots, a count of each species was recorded for all trees ≤ 10 cm dbh, and for conifers with dbh ≥ 10 cm but ≤ 20 cm (i.e., all aspen ≥ 10 cm dbh were measured in the one hectare main plot). Hemispheric canopy photos were taken at the midpoint of each subplot to obtain estimates of canopy leaf area and understory light for each regeneration subplot. Pre-treatment data collected from one of the sites received a 'virtual thinning' (i.e., thinned by removing tree records from datasets) and SDI was calculated for the virtual post-treatment stand thinned to remove all conifers below 35 cm dbh.

Analysis

Missing height data

Height-diameter regressions were developed for each species to complete tree records without height data. Data for trees with broken or dead tops, forks, and leaning trees were excluded. Additional editing removed 'outliers' with unusually low height:diameter ratios indicative of either severe height growth repression or unrecorded damage that had impacted height growth. The total number of tree records used to develop the height-diameter regressions were: 453 aspen, 8 Jeffrey pine, 157 lodgepole pine, 159 red fir, and 330 white fir (Figure 1). Models were fitted to data for tree diameter at breast height 1.37m (dbh) in millimeters (mm) [25.4mm=1 inch], and total tree height minus 1.37m [1m=3.2808 ft] so that regressions passing through the origin would predict a total height of 1.37m for a tree with zero dbh. Therefore to obtain total tree height (H) predictions from each regression for any given dbh (D), 1.37m must be added to the model prediction, as shown:

$$H_{aspen} = 11.896 * ln(D) - 47.75 + 1.37$$

$$H_{jeffrey\ pine} = -0.00001 * D^2 + 0.0575 * D + 1.37$$

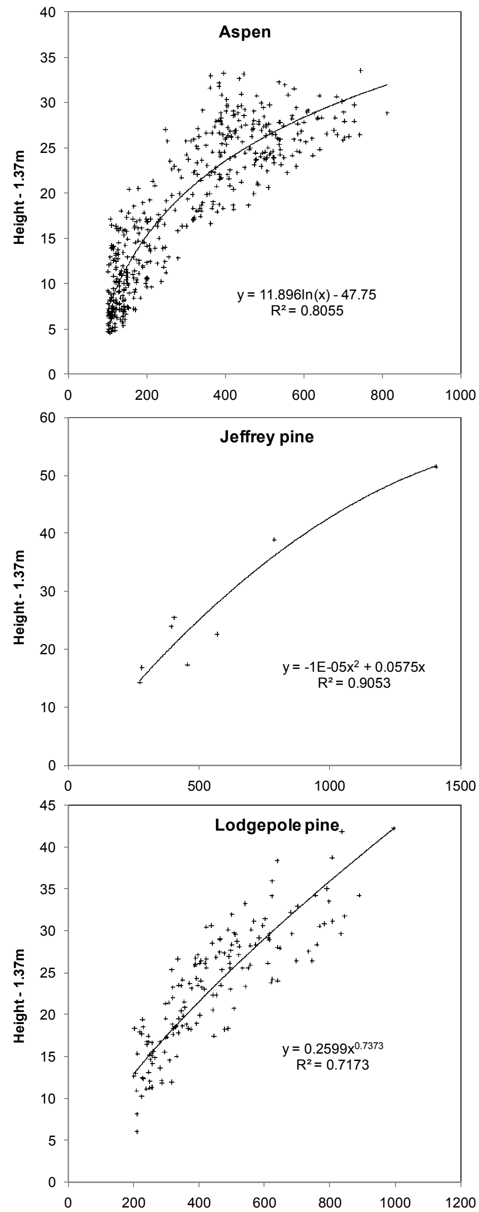
$$H_{lodgepole\ pine} = 0.2599 * D^{0.7373} + 1.37$$

$$H_{red\ fir} = -0.00001 * D^2 + 0.0511 * D + 1.37$$

$$H_{white\ fir} = -0.00001 * D^2 + 0.0536 * D + 1.37$$

This analysis should be repeated once more data are obtained, including testing for differences between species and sites.

Height predictions were obtained for two aspen trees, 54 red fir, and 220 white fir trees without height records.



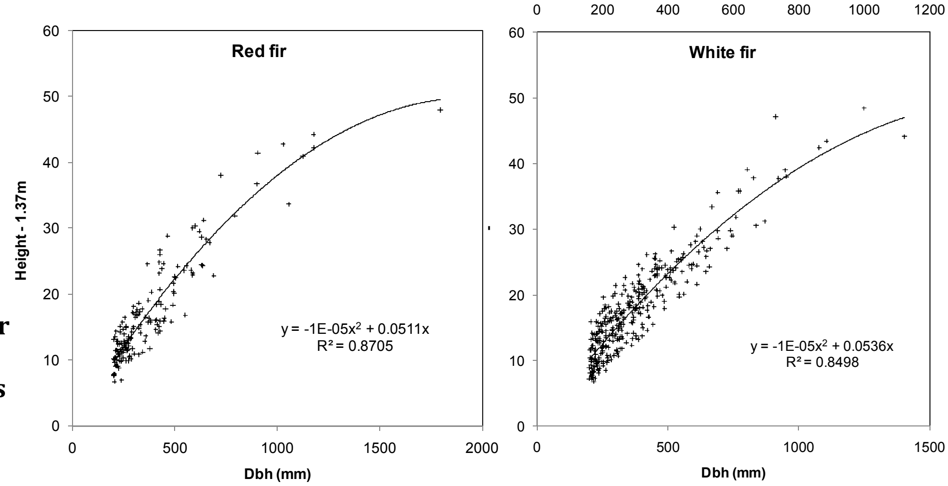


Figure 1: Height-diameter data and regressions by species at four study sites in LTBMU.

Tree volume estimates

Tree diameter and height data (or predicted height) entered tree volume equations to obtain estimates of stemwood volume for each tree of every species at the four study sites. The equations were used to predict cubic (ft^3) stemwood volume from height and diameter data converted to feet and inches, respectively. Conifer volumes (V) were predicted using form factor-based equations from McLean and Berger (1976) based on cylinder volumes adjusted by form factor equations for each species giving cubic volume to a 4-inch top, such that:

$$V = 0.005454154\, D^2 * H * F$$

Where F = form factor equation for each species:

$$F_{jeffrey\ pine} = 0.40206 - 0.899914 * (1 / D)$$

$$F_{lodgepole\ pine} = 0.422709 - 0.0000612236 * (H^2 / D)$$

$$F_{red\ fir} = 0.231237 + 0.028176 * (H / D)$$

$$F_{white\ fir} = 0.299039 + 1.91272 * (1 / H) + 0.0000367217 * (H^2 / D)$$

The aspen volume equation presented by Fowler and Hussain (1987): $V = b0 + b1 * D^{b2} * HS^{b3}$ where aspen cubic 'pulpwood' volume V is predicted as a function of merchantable height H to a 3.6-inch top in units of "no. of 100-in sticks" (i.e., height in sticks HS = H(ft) / (100 / 12); D = dbh in inches; b0 = 0.2075: b1 = 0.04384: b2 = 1.8713: b3 = 0.8546 was tested but performed poorly, and was replaced by a basic conic volume equation:

$$V = (((D / 12) * 0.5)^2 * 3.1415927) * H / 3$$

Stand density index

Stand density index (SDI) was calculated as a summation of individual tree values because the dbh data were for a combination of species and were not normally distributed:

$$SDI = \sum (\frac{1}{25} dbh_i)^a$$

where dbh_i = dbh in cm of the i^{th} tree in the plot, and a = 1.605 (Long and Daniel, 1990; Shaw, 2000).

Stand summary data

Trees per hectare or per acre summary data were calculated for all aspen and conifer trees > 20 cm dbh (8 inches), and for aspen, pine, and fir saplings (trees 10-20 cm dbh; 4-8 inches) and regeneration (< 10 cm dbh; 4 inches). Tree data were summarized separately for each species, for all conifers combined, and for all species combined, giving average, minimum, and maximum dbh, height, and tree volume for live trees >20cm dbh (8 inches dbh). Basal area, volume, and stand density index were calculated separately for each species, for all conifers combined, and for all species combined, in metric (per hectare) and in English units (per acre) [1 hectare (ha) = 2.47 ac]. Conifer totals (Jeffrey pine + lodgepole pine + red fir + white fir data) were also expressed as a percentage of the total for all species (aspen + conifer), indicating the relative 'share' of the basal area, volume, and SDI at each site comprising conifer.

Transforming wood volumes into dry mass involved an English unit conversion assuming 128 ft^3/cord, where a cord contains 1.2 U.S. tons of dry wood (Carbon ~0.6 tons or 50% of this tonnage). A cord of wood has a volume of 3.62 m^3 and weighs approximately 2400 pounds or 1089 kg bone dry; or 1.2/1.1 = 1.09 metric tons (http://bioenergy.ornl.gov/papers/misc/energy_conv.html). English unit summary data are listed in the Appendix.

RESULTS

Stem location maps were produced using ArcGIS ArcMap (ESRI) (Figures 2-5). They reveal patterns of encroachment and spatial distribution of tree species in stands. Note the high conifer density in Figure 4.

Stem location maps

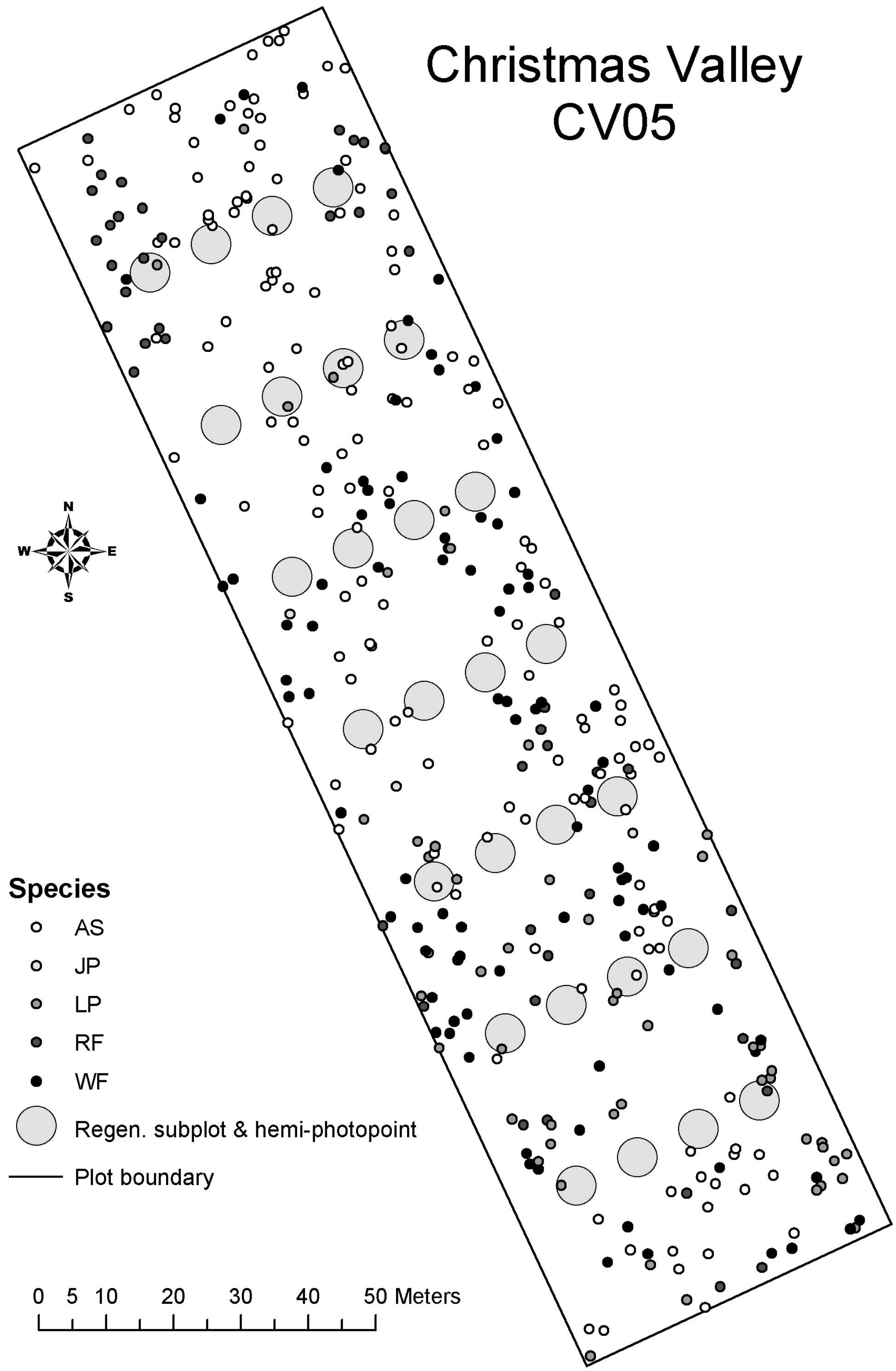


Figure 2: Tree locations inside 1-ha (200 x 50m) monitoring plot, and locations of 0.004ha regeneration subplots (10 x 25-m spacing) at Christmas Valley (CV05), South Lake Tahoe, CA.

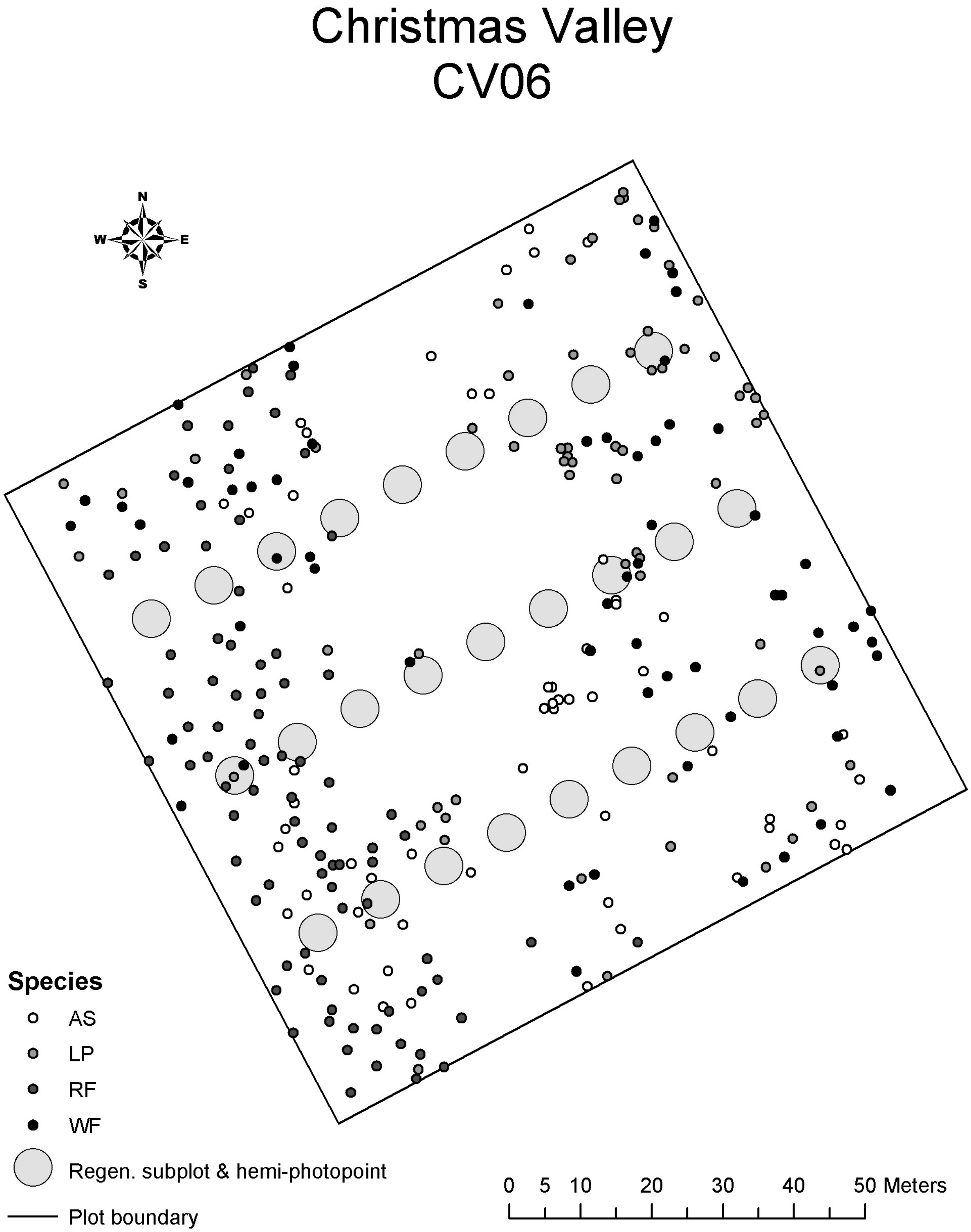


Figure 3: Tree locations inside 1-ha (100 x 100m) monitoring plot, and locations of 0.004ha regeneration subplots (10 x 25-m spacing) at Christmas Valley (CV06), South Lake Tahoe, CA.

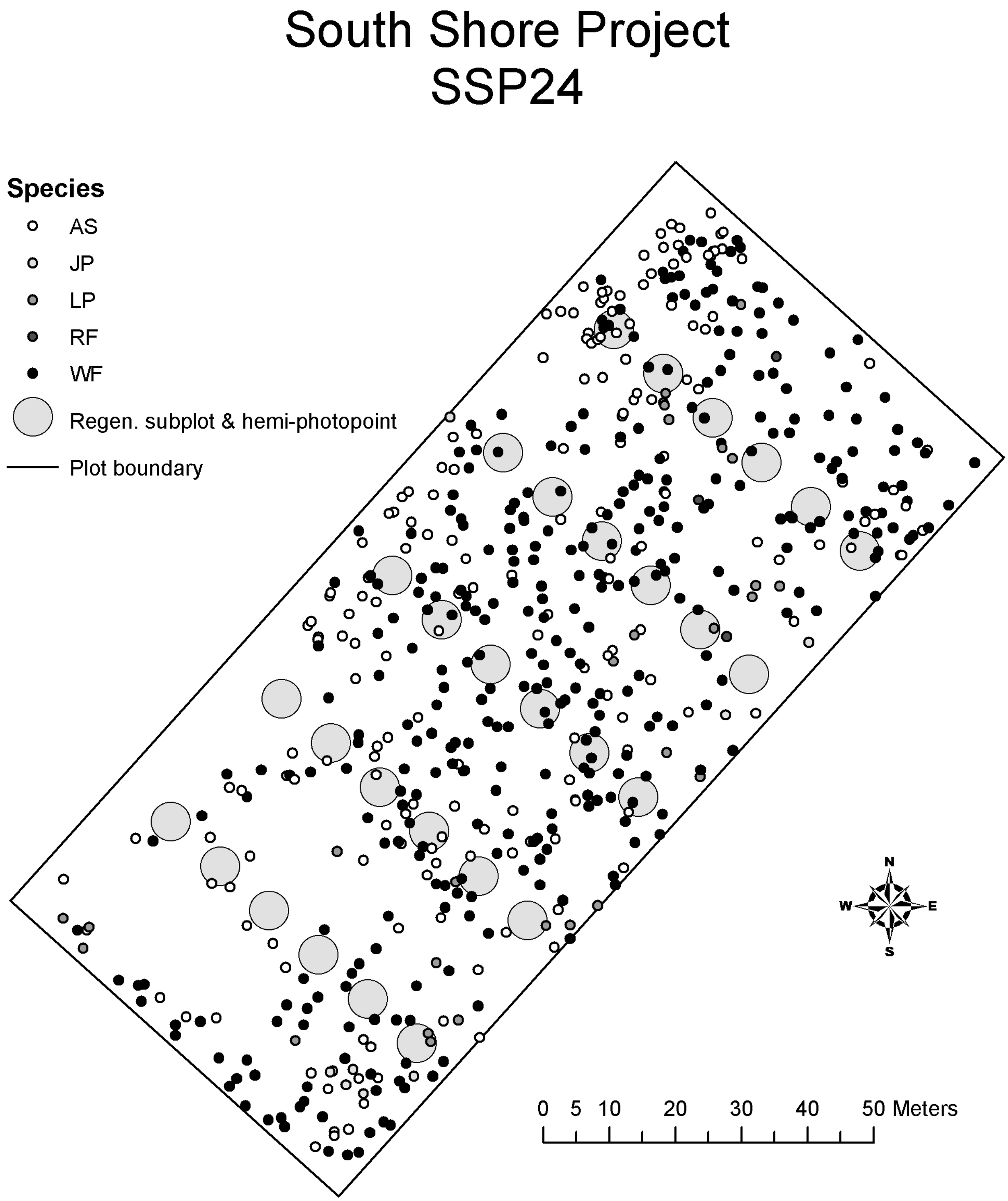


Figure 4: Tree locations inside 1-ha (150 x 67m) monitoring plot, and locations of 0.004ha regeneration subplots (10 x 25-m spacing) adjacent to meadow, South Shore Project (SSP24), South Lake Tahoe, CA.

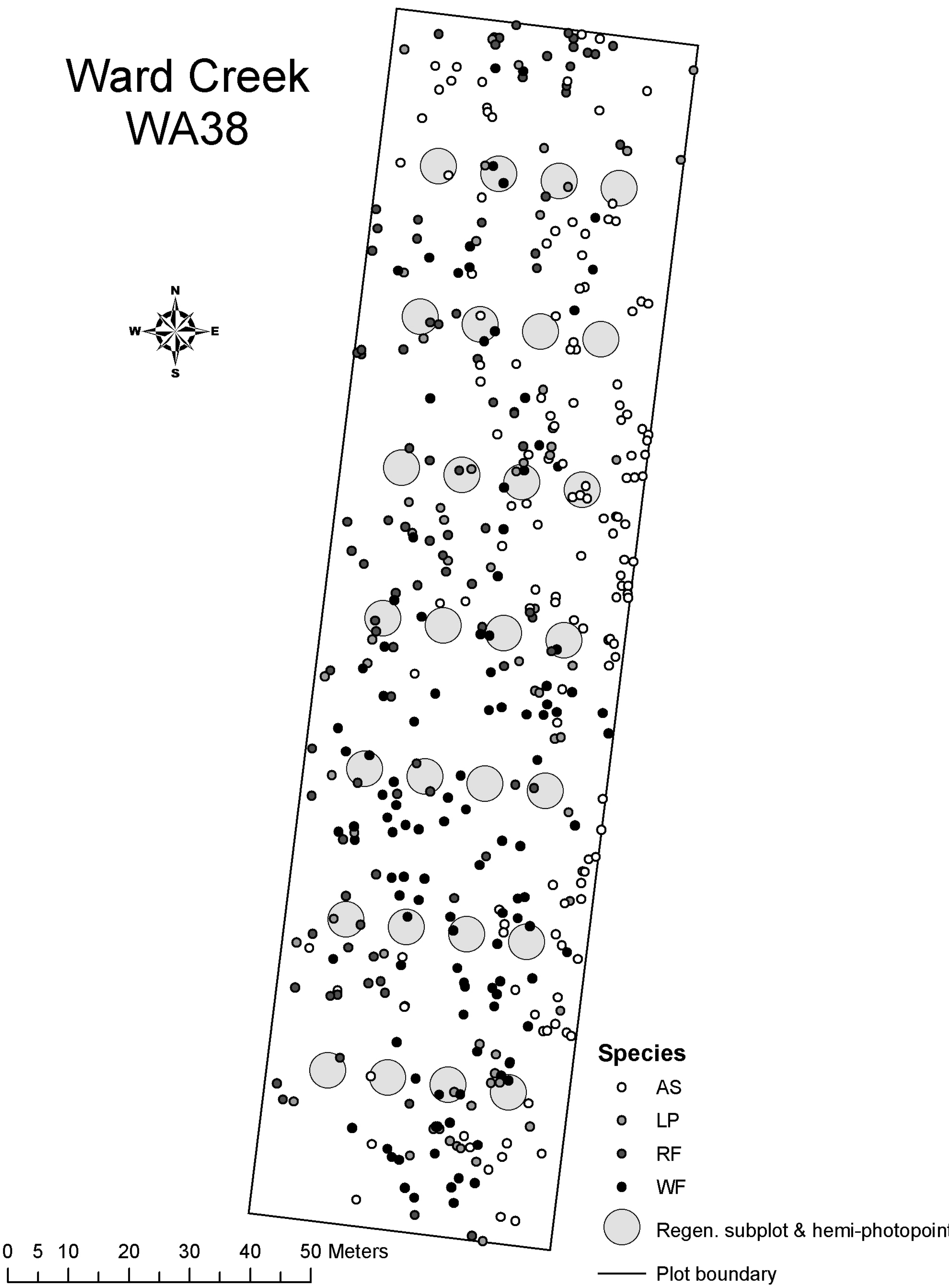


Figure 5: Tree locations inside 1-ha (200 x 50m) monitoring plot, and locations of 0.004ha regeneration subplots (10 x 25-m spacing) at Ward Creek (WA38), Tahoe City, CA.

Hemispherical photos

Two 180^0 hemispherical images were taken facing upward, oriented North, above each regeneration subplot center. Photos were taken in the absence of direct sun light either pre-dawn or after sunset. Figure 6 shows the negative impacts of conifer encroachment: aspen tree crowns retreating upwards faster than tree height growth, leading to loss of vigor from reduced production of photosynthates, and ultimately mortality of individual stems weakened by loss of live crown.

Figure 6: Pre-treatment hemispherical image at Ward Creek (WA38), LTBMU.

Summary data

The number of trees per hectare (ha), and the average (Av.), minimum (Min.), and maximum (Max.) values for each species at each study site are listed for dbh (Table 1), total tree height (Table 2), and individual tree volume (Table 3). Stand-level summary data for basal area, SDI, stemwood volume, and dry wood mass in metric tons is provided separately for each species, for all conifers combined, and the stand total for aspen and conifer (Table 4). Summary data in Tables 2-5 are for live trees >20 cm dbh (>200 mm dbh).

Table 1: Tree diameter (Dbh) summary data by species at each study site, LTBMU.

Site	Species	Trees/ha	Av. Dbh (mm)	Min. Dbh (mm)	Max. Dbh (mm)
CV05	Aspen	113	497	200	815
	Jeffrey pine	3	456	357	570
	Lodgepole pine	51	443	203	808
	Red fir	48	352	203	865
	White fir	91	373	200	837
CV06	Aspen	44	427	201	865
	Lodgepole pine	65	437	209	995
	Red fir	84	441	204	1794
	White fir	62	491	209	1303
SSP24	Aspen	120	394	208	745
	Jeffrey pine	8	530	235	1406
	Lodgepole pine	28	444	206	837
	Red fir	3	1110	1029	1177
	White fir	351	354	200	1403
WA38	Aspen	52	392	201	609
	Lodgepole pine	63	497	201	1117
	Red fir	93	362	201	1596
	White fir	117	406	200	922

Table 2: Tree height (HT) summary data by species at each study site, LTBMU.

Site	Species	Trees/ha	Av. HT (m)	Min. HT (m)	Max. HT (m)
CV05	Aspen	113	24.5	9.6	32.9
	Jeffrey pine	3	16.4	10	24
	Lodgepole pine	51	24.3	7	32.5
	Red fir	48	15.6	7.1	32.4
	White fir	91	16.2	6.1	32.2
CV06	Aspen	44	22.2	11.6	29.8
	Lodgepole pine	65	22.9	5.2	43.6
	Red fir	84	20.5	9.3	49.3
	White fir	62	18.9	6.7	48.5
SSP24	Aspen	120	27.4	11	34.9
	Jeffrey pine	8	26.7	15.7	52.9
	Lodgepole pine	28	26.0	12.5	43.2
	Red fir	3	43.3	42.3	44.1
	White fir	351	18.7	6.7	49.8
WA38	Aspen	52	19.6	10.1	27.7
	Lodgepole pine	63	24.2	10.1	37.3
	Red fir	93	17.3	5.7	42.7
	White fir	117	20.4	11.4	39.1

Table 3: Tree volume (Vol) summary data by species at each study site, LTBMU.

Site	Species	Trees/ha	Av. Vol (m^3)	Min. Vol (m^3)	Max. Vol (m^3)
CV05	Aspen	113	1.94	0.12	5.23
	Jeffrey pine	3	1.09	0.51	2.22
	Lodgepole pine	51	1.90	0.21	6.68
	Red fir	48	0.72	0.09	6.08
	White fir	91	0.87	0.08	5.78
CV06	Aspen	44	1.29	0.17	4.90
	Lodgepole pine	65	1.99	0.11	13.25
	Red fir	84	2.27	0.13	36.86
	White fir	62	2.09	0.09	16.27
SSP24	Aspen	120	1.23	0.13	5.07
	Jeffrey pine	8	5.40	0.21	31.69
	Lodgepole pine	28	2.14	0.19	9.16
	Red fir	3	13.57	12.17	15.10
	White fir	351	1.09	0.08	22.98
WA38	Aspen	52	0.86	0.13	2.13
	Lodgepole pine	63	2.74	0.16	11.77
	Red fir	93	1.15	0.06	20.54
	White fir	117	1.22	0.13	8.63

Table 4: Stand-level summary data for basal area (BA), stand density index (SDI), volume (Vol), and bone dry mass in metric tons by species at each study site, LTBMU.

Site	Species	Trees/ha	BA (m^2/ha)	SDI (metric)	Vol (m^3/ha)	Tons (t/ha)
CV05	Aspen	113	24.5	360.0	219.4	66.1
	Jeffrey pine	3	0.5	8.0	3.3	1.0
	Lodgepole pine	51	8.9	135.7	96.8	29.2
	Red fir	48	5.3	88.3	34.6	10.4
	White fir	91	11.5	185.5	79.3	23.9
	Conifer	193	26.2	417.5	214.0	64.4
	Total	**306**	**50.7**	**777.5**	**433.4**	**130.5**
CV06	Aspen	44	7.1	110.0	56.7	17.1
	Lodgepole pine	65	11.5	172.8	129.2	38.9
	Red fir	84	18.6	249.1	190.8	57.5
	White fir	62	15.0	206.8	129.5	39.0
	Conifer	211	45.1	628.7	449.5	135.3
	Total	**255**	**52.1**	**738.7**	**506.2**	**152.4**
SSP24	Aspen	120	15.5	255.7	147.9	44.5
	Jeffrey pine	8	2.6	32.4	43.2	13.0
	Lodgepole pine	28	4.9	75.1	59.9	18.1
	Red fir	3	2.9	32.9	40.7	12.3
	White fir	351	43.0	678.9	382.1	115.1
	Conifer	390	53.5	819.4	526.0	158.4
	Total	**510**	**69.0**	**1075.1**	**673.9**	**202.9**
WA38	Aspen	52	6.6	109.5	44.6	13.4
	Lodgepole pine	63	14.8	209.0	172.3	51.9
	Red fir	93	12.8	192.2	107.3	32.3
	White fir	117	17.3	271.9	142.9	43.0
	Conifer	273	45.0	673.1	422.6	127.2
	Total	**325**	**51.6**	**782.6**	**467.2**	**140.7**

Encroachment summary

Conifer totals expressed as a percentage of the total for all species show that 63-84% of trees >20 cm dbh are conifers at each study site, and conifers make up 52-87% of basal area (BA), 54-86% of stand density index (SDI), and 49-90% of live tree stemwood volume (Vol) among trees >20 cm dbh at each study site (Table 5).

Table 5: Conifer as a percentage of the number of trees per unit area, stand basal area (BA), volume (Vol), and stands density index (SDI) at each study site, LTBMU.

Site	No. trees (%)	BA (%)	SDI (%)	Vol (%)
CV05	63	52	54	49
CV06	83	86	85	89
SSP24	76	78	76	78
WA38	84	87	86	90

Regeneration

The numbers of aspen root suckers or conifer seedlings per hectare are listed for each study site (Table 6).

Table 6: Number of suckers or seedlings (trees <10 cm dbh) per hectare at each study site, LTBMU.

Site	Aspen/ha	Pine/ha	Red fir/ha	White fir/ha
CV05	3643	134	1455	2205
CV06	3815	167	769	880
SSP24	3967	0	17	850
WA38	2964	54	1250	946

Saplings

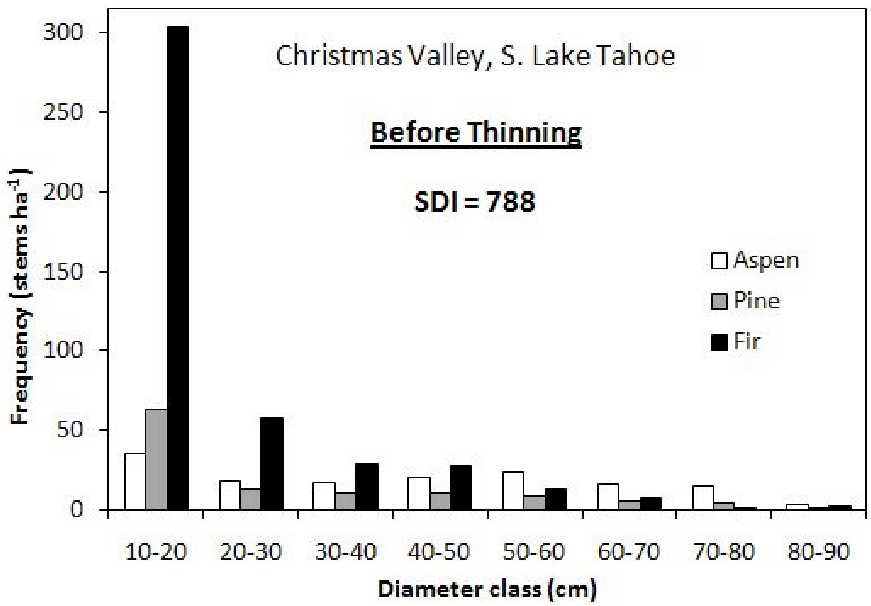
The numbers of aspen or conifer saplings per hectare are listed for each study site (Table 7).

Table 7: Number of saplings (trees 10-20 cm dbh) per hectare at each study site, LTBMU.

Site	Aspen/ha	Pine/ha	Red fir/ha	White fir/ha
CV05	35	63	9	295
CV06	14	28	111	28
SSP24	66	8	0	333
WA38	85	18	116	45

Simulated thinning

A thinning simulation using a 35-cm (14-inch) dbh limit (i.e., cut all trees below 35 cm dbh) indicated that removal of numerous smaller conifers (cut >350 stems/ha) only reduced stand density index (SDI) by 14% (Figure 7). This result suggests that such a treatment would have a short lifespan (needs to be repeated frequently); or that heavier thinning is required to relieve aspen trees and sucker regeneration from crowding.



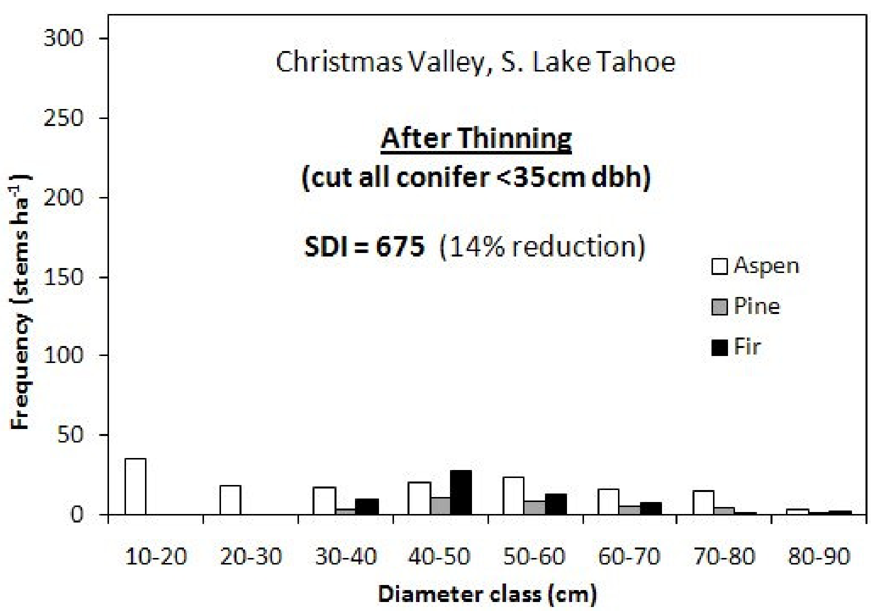


Figure 7: Diameter distribution data for aspen-conifer stand at Christmas Valley, South Lake Tahoe. Shown above are pre-treatment data from 1-ha permanent plot. Shown below is same stand after simulated "virtual thinning" removing all conifers below 35 cm dbh (14 inches dbh) from the dataset. Removal of hundreds of smaller conifers gave only minor reduction in stand density index (SDI), suggesting that very little relief from crowding would be achieved under this restorative thinning prescription. Note: the 1-ha plot included areas of stream channel and open rocky areas; SDI was much higher in heavily encroached parts of the plot. Data for regeneration <10 cm dbh not shown.

DISCUSSION

The pre-treatment data presented herein symbolize a unique opportunity to capture detailed forest data in conifer-encroached aspen stands prior to implementation of restoration treatments throughout the Tahoe Basin. In addition to documenting a part of our history - - the history of conifer encroachment during the post-Comstock/fire-suppression era - - the monitoring project recorded pre-treatment baseline conditions that likely influence post-treatment response, treatment impacts, and treatment effectiveness. For example, localized areas of severe encroachment may have a more pronounced response to restoration. Pine species may regenerate prolifically in heavily thinned areas. These and other foreseen/unforeseen consequences of restoration can be related back to pre-treatment conditions such as severe encroachment or lack of encroachment using the stem location maps and detailed tree records collected in the large permanent monitoring plots. The data-intensive project was also designed to allow for rigorous analysis of such sporadic phenomena as windthrow or sunscalding by collecting a large sample of pre- and post-treatment data.

We will re-measure and assess the permanent 1-ha plots after thinning to characterize relationships between understory light obtained from hemispherical photo analysis, overstory tree stocking, and aspen and conifer regeneration abundance and vigor. This will quickly provide some insight into the mechanics of natural regeneration and development in the early years after treatment. A definitive analysis of growth can be undertaken in future after repeated re-measurement of the permanent plots (e.g., after 10-20 years). Pre-treatment regeneration counts were assessed in a systematic grid of subplots and will allow us to separate pre- and post-treatment regeneration, and analyze patterns of regeneration as they relate to various ecological and environmental variables. Regenerating aspen and conifer will be tagged and measured repeatedly, giving initial survival/height growth in response to treatment. Hemispherical canopy photos taken at the center of each regeneration subplot before and after thinning will be processed to obtain estimates of canopy leaf area and understory light for each regeneration subplot.

The four 1-ha permanent plots collectively contain a total of 107 regeneration subplots giving approximately 12% sampling of ground area. Pre-treatment regeneration count data collected in these plots varied widely in composition and numbers, but overall suggested that aspen regeneration was not lacking in these heavily conifer-encroached stands (Table 6). We counted 2964-3967 aspen suckers per hectare (1200-1606 aspen suckers per acre) on average across the four 1-ha monitoring plots. The number of saplings (10-20 cm dbh) of each species at each site was highly variable (Table 7), and much lower than the number of trees in the smallest size class (<10 cm dbh). For aspen, this difference suggests that very few suckers survive and grow to become saplings. For the shade-tolerant conifers, prolific seedling regeneration may suggest that a new 'wave' of encroachment is imminent, and warns that thinning may release these seedlings that might otherwise grow slowly under the shade of aspen and conifer trees.

The summary of conifer encroachment was alarming (Table 5). Also humbling were the large estimates for mass of conifer stemwood in each plot (Table 4). These estimates indicate that much Carbon is stored in these stands and if burned will release much energy. Alternatively, it may represent a good source of renewable energy or a deep mat of masticated chips, but regardless, the sheer volume and mass of conifer wood must be considered, and certainly presents challenges.

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APPENDIX: Summary data - English units

The number of trees per acre (ac), and the average (Av.), minimum (Min.), and maximum (Max.) values for each species at each study site are listed for dbh (Table 8), total tree height (Table 9), and individual tree volume (Table 10). Stand-level summary data for basal area, SDI, stemwood volume, and dry wood mass in U.S. tons (short tons) is provided separately for each species, for all conifers combined, and the stand total for aspen and conifer (Table 11). Summary data in Tables 8-11 are for live trees >8 inches dbh.

Table 8: Tree diameter (Dbh) summary data by species at each study site, LTBMU.

Site	Species	Trees/ac	Av. Dbh (in)	Min. Dbh (in)	Max. Dbh (in)
CV05	Aspen	46	19.6	8.0	32.1
	Jeffrey pine	1	18.0	14.1	22.4
	Lodgepole pine	21	17.4	8.0	31.8
	Red fir	19	13.8	8.0	34.1
	White fir	37	14.7	8.0	33.0
CV06	Aspen	18	16.8	8.0	34.1
	Lodgepole pine	26	17.2	8.2	39.2
	Red fir	34	17.4	8.0	70.6
	White fir	25	19.3	8.2	51.3
SSP24	Aspen	49	15.5	8.2	29.3
	Jeffrey pine	3	20.9	9.3	55.4
	Lodgepole pine	11	17.5	8.1	33.0
	Red fir	1	43.7	40.5	46.3
	White fir	142	13.9	8.0	55.2
WA38	Aspen	21	15.4	8.0	24.0
	Lodgepole pine	25	19.6	8.0	44.0
	Red fir	38	14.2	8.0	62.8
	White fir	47	16.0	8.0	36.3

Table 9: Tree height (HT) summary data by species at each study site, LTBMU.

Site	Species	Trees/ac	Av. HT (ft)	Min. HT (ft)	Max. HT (ft)
CV05	Aspen	46	80.5	31.5	107.9
	Jeffrey pine	1	53.8	32.8	78.7
	Lodgepole pine	21	79.7	23.0	106.6
	Red fir	19	51.0	23.3	106.3
	White fir	37	53.0	20.0	105.6
CV06	Aspen	18	72.9	38.1	97.8
	Lodgepole pine	26	75.1	17.1	143.0
	Red fir	34	67.3	30.5	161.7
	White fir	25	62.0	22.0	159.1
SSP24	Aspen	49	90.0	36.1	114.5
	Jeffrey pine	3	87.6	51.5	173.6
	Lodgepole pine	11	85.4	41.0	141.7
	Red fir	1	142.2	138.8	144.7
	White fir	142	61.4	22.0	163.4
WA38	Aspen	21	64.3	33.1	90.9
	Lodgepole pine	25	79.5	33.1	122.4
	Red fir	38	56.9	18.7	140.1
	White fir	47	67.0	37.4	128.3

Table 10: Tree volume (Vol) summary data by species at each study site, LTBMU.

Site	Species	Trees/ac	Av. Vol (ft³)	Min. Vol (ft³)	Max. Vol (ft³)
CV05	Aspen	46	68.6	4.1	184.5
	Jeffrey pine	1	38.5	18.2	78.3
	Lodgepole pine	21	67.0	7.2	235.9
	Red fir	19	25.5	3.1	214.6
	White fir	37	30.8	3.0	204.3
CV06	Aspen	18	45.5	6.0	172.9
	Lodgepole pine	26	70.2	3.8	467.8
	Red fir	34	80.2	4.7	1301.6
	White fir	25	73.8	3.3	574.7
SSP24	Aspen	49	43.5	4.6	179.1
	Jeffrey pine	3	190.7	7.4	1119.0
	Lodgepole pine	11	75.6	6.9	323.5
	Red fir	1	479.1	429.8	533.1
	White fir	142	38.4	2.9	811.5
WA38	Aspen	21	30.3	4.5	75.1
	Lodgepole pine	25	96.6	5.8	415.6
	Red fir	38	40.7	2.2	725.2
	White fir	47	43.1	4.6	304.8

Table 11: Stand-level summary data for basal area (BA), stand density index (SDI), volume (Vol), and bone dry mass in U.S. tons (short tons) by species at each study site, LTBMU.

Site	Species	Trees/ac	BA (ft²/ac)	SDI (English)	Vol (ft³/ac)	U.S. tons (t/ac)
CV05	Aspen	46	106.6	145.7	3136	29.4
	Jeffrey pine	1	2.2	3.2	47	0.4
	Lodgepole pine	21	38.7	54.9	1384	13.0
	Red fir	19	23.1	35.7	495	4.6
	White fir	37	50.0	75.1	1133	10.6
	Conifer	78	114.1	169.0	3059	28.7
	Total	**124**	**220.7**	**314.6**	**6195**	**58.1**
CV06	Aspen	18	30.7	44.5	810	7.6
	Lodgepole pine	26	50.0	69.9	1846	17.3
	Red fir	34	80.8	100.8	2727	25.6
	White fir	25	65.4	83.7	1851	17.4
	Conifer	85	196.3	254.4	6424	60.2
	Total	**103**	**227.0**	**298.9**	**7234**	**67.8**
SSP24	Aspen	49	67.3	103.5	2113	19.8
	Jeffrey pine	3	11.4	13.1	617	5.8
	Lodgepole pine	11	21.6	30.4	857	8.0
	Red fir	1	12.7	13.3	582	5.5
	White fir	142	187.5	274.7	5461	51.2
	Conifer	158	233.1	331.6	7517	70.5
	Total	**206**	**300.5**	**435.1**	**9630**	**90.3**
WA38	Aspen	21	28.7	44.3	638	6.0
	Lodgepole pine	25	64.6	84.6	2463	23.1
	Red fir	38	55.9	77.8	1533	14.4
	White fir	47	75.4	110.0	2043	19.2
	Conifer	110	195.9	272.4	6039	56.6
	Total	**132**	**224.6**	**316.7**	**6677**	**62.6**

Regeneration

The numbers of aspen root suckers or conifer seedlings per acre are listed for each study site (Table 12).

Table 12: Number of suckers or seedlings (trees <4 inches dbh) per hectare at each study site, LTBMU.

Site	Aspen/ac	Pine/ac	Red fir/ac	White fir/ac
CV05	1474	54	589	892
CV06	1544	67	311	356
SSP24	1605	0	7	344
WA38	1200	22	506	383

Saplings

The numbers of aspen or conifer saplings per acre are listed for each study site (Table 13).

Table 13: Number of saplings (trees 4-8 inches dbh) per hectare at each study site, LTBMU.

Site	Aspen/ac	Pine/ac	Red fir/ac	White fir/ac
CV05	14	25	4	119
CV06	6	11	45	11
SSP24	27	3	0	135
WA38	34	7	47	18