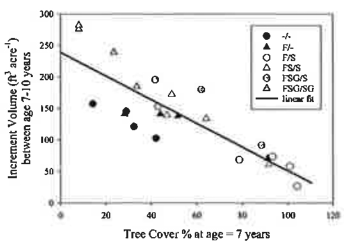
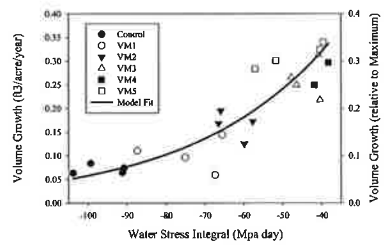
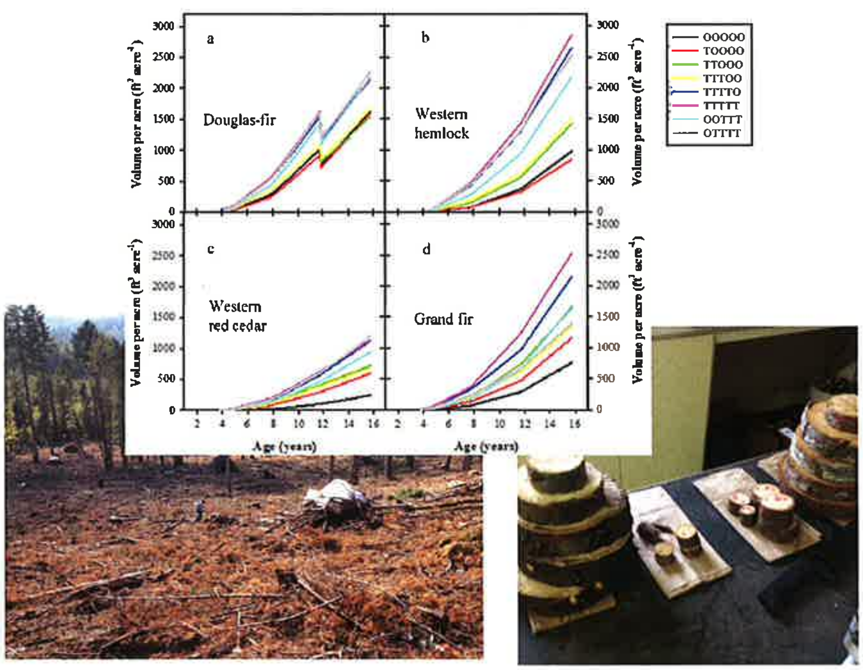
Vegetation Management Research Cooperative

2015 - 2016 Annual Report







December 2016

Staff

Director: Dr. Carlos A. Gonzalez-Benecke, Assistant Professor
Assistant Director: Maxwell Wightman, Faculty Research Assistant
M.S. Level Graduate Student: Herman Flamenco
M.F. Level Graduate Student: Christopher Hubbard

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Vegetation Management Research Cooperative
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Words from the Director

To: VMRC Cooperators

From: Dr. Carlos Gonzalez-Benecke

Date: December 2016

Subject: 2015-2016 Annual report

Dear friends, in your hands you have the first annual report from this new era of the VMRC. It has been a great pleasure working with you to conduct applied research on vegetation management and reforestation. Your enthusiasm and support have been critical to my successful transition into the role of VMRC director.

The current and historic VMRC studies are an extensive source of information that we are using at a maximum. These studies are maturing, allowing us to analyze them from different perspectives. Even though we are installing new trials, the heritage studies will continue to be the backbone of VMRC research in coming years.

This year we started the installation of the new set of studies called COmpetition and Site INteractions Experiment (COSINE). We installed plots on three sites owned by Cascade Timber Consulting, Hancock Forest Management and OSU. These companies were extremely helpful in the site selection process and I would like to thank them for their support. Next year we will expand this project to different zones diversifying the study inference area.

In January 2016, Herman Flamenco, a MS student started working at the CPT studies, analyzing them from a productivity and sustainability perspective. His work will produce important information regarding the long-term effects of vegetation management treatments on whole-ecosystem biomass partitioning. He is fully supported by FERM funding. I would like to thank Mark Gourley and Bill Marshall for their support on this project. In September 2016, a new MF student joined our team. Christopher Hubbard started working on our new COSINE study, conducting research on seasonal dynamics of biomass, soil moisture and water stress on competing vegetation and western hemlock seedlings. He is self-supported.

We are very lucky to have Maxwell Wightman serving as Associate Director of the VMRC. In addition to being a great person, Max is a great professional, dedicated 110% to conducting top level research. We are very thankful for all your support and enthusiasm. You should be confident that the VRMC, your cooperative, is in good hands.

Best regards,

Contents

Study Update: Evaluating Common Regimes

Maxwell Wightman and Carlos Gonzalez-Benecke

Highlights

At age 10:

- Treatments that did not include an early summer glyphosate release showed no effect on Douglas fir growth.
- There was a significant response to the spring release during growing seasons 1 and 2 + early-summer release with glyphosate treatment:
  + 2.5 m height;
  + 570 ft^3 $acre^{-1}$ stand volume.
- The F/S treatment (fall site preparation and spring release during year 2) had a negative effect on Douglas-fir growth due to a large number of hardwood trees becoming established in these plots.

Introduction

The Evaluating Common Regimes Study (ECR01) was designed to quantify the impact of six herbaceous vegetation control regimes on: 1) Douglas-fir seedling survival and growth, and 2) understory community dynamics. Previous VMRC annual reports have provided many early results from this study. A seedling morphology study conducted after two years of seedling development demonstrated that increasing the intensity of vegetation management treatments increased the stem, branch, needle, and root volume of Douglas-fir seedlings. A detailed description of the year two results can be found in Dinger and Rose (2009). After four growing seasons, the mean height and volume of the treatments were significantly different.

At this time the no action control (O/O) and fall site preparation only treatment (F/O) were significantly shorter than all other treatments (2.2 vs 2.7 m, $p = 0.008$). There were also significant differences in stand volume such that stand volume tended to increase with increasing intensity of vegetation management treatment. These differences in seedling volume and height were attributed to the more intense vegetation management treatments creating a larger reduction in the cover of competing vegetation, allowing tree seedlings to better capture site resources. This report provides an update of the study results, presenting data from the year 10 tree inventory and vegetation survey measurements.

Methods

A brief synopsis of the methods utilized in measuring the seedlings and vegetation are included in this report. For a more detailed description of the full suite of measurements taken on this study site, please refer to Dinger and Rose (2009) or to the 2006/2007 VMRC Annual Report.

Table 1. Description of treatment regimens tested.

Treatment		Year
1	O / O	No Control
2	F / O	Fall Site Prep
3	F / S	Fall Site Prep + Spring Release Year 2
4	FS / S	Fall Site Prep + Spring Release Year 1 + Spring Release Year 2
5	FSG / S	Fall Site Prep + Spring Release Year 1 + Glyphosate Release Year 1 + Spring Release Year 2
6	FSG / SG	Fall Site Prep + Spring Release Year 1 + Glyphosate Release Year 1 + Spring Release Year 2 + Glyphosate Release Year 2

Details on application date, method and chemicals applied can be found in Dinger and Rose (2009).

The Evaluating Common Regimes study contains six vegetation management treatments (Table 1) arranged in a randomized complete block design with four replications on 80 x 80 ft treatment plots. Bareroot 1 + 1 Douglas-fir seedlings (from an improved seed source) were planted on February 25, 2006 at a spacing of 10 x 10 ft. The study area was surrounded by a perimeter fence prior to planting to protect seedlings from ungulate browsing damage. Measurements of seedling height, ground line diameter, diameter at breast height (DBH) and crown radius were taken in the central 60 x 60 ft measurement plots allowing for a 1 tree buffer on all sides. Measurement plots contained 36 seedlings and tree inventories were conducted during the dormant season in years 0-4, 7 and 10. Crown area of each tree was determined from the crown radius measurements and the sum of crown areas of all trees in each plot was expressed as a proportion of the area of the plot (canopy closure). Surveys of understory vegetation cover were conducted on seven 1 m radius subplots per plot during July of growing seasons 0-4, 7 and 10. Understory cover was estimated visually by species. Analysis of variance was used to test the effects of treatments on stand growth and vegetation community dynamics and correlation analysis was used to test the effects of vegetation cover on Douglas-fir growth (PROC GLM and PRCO REG; SAS Institute Inc., Cary, NC, USA).

Results and Discussion

Table 2 provides a summary at age 10 for mean height (HT, m), diameter at breast height (DBH, cm), survival (TPA, trees acre^{-1}) and stand volume per acre (VOL, ft^3 acre^{-1}). The trend of increased tree growth with increasing vegetation management intensity observed at year 4 was no longer apparent in year 10 (Figures 1 and 2). In fact, the F/S treatment had the smallest mean height and DBH of all treatments and significantly differed from the control by 0.8 m ($p = 0.05$) and 2.7 cm ($p = 0.003$), respectively (Table 2). Tree survival was high across the study site and there were no significant differences in TPA among any of the treatments ($p = 0.52$).

Table 2. Treatment summary at age = 10 years for mean height (HT, m), diameter at breast height (DBH, cm), survival (TPA, trees acre^{-1}) and stand volume per acre (VOL, ft^3 acre^{-1}).

Treatment	HT (m)	DBH (cm)	TPA (trees acre^{-1})	VOL (ft^3 acre^{-1})
O / O	8.2	10.3	396	546.0
F / O	8.3	9.8	409	528.8
F / S	7.4	7.6	412	323.8
FS / S	8.4	10.1	415	603.5
FSG / S	8.8	11.4	403	743.2
FSG / SG	9.7	13.8	415	1,113.5

There has been a trend of curve separation among treatments as the stands have aged. Treatment with more intensive vegetation management (FSG/SG) showed positive separation from other treatments in DBH (Figure 1a), mean height (Figure 1c) and volume (Figure 3e). On the other hand, the F/S treatment showed negative separation from the other treatments, even the control. Furthermore, plots that received the F/S treatment were the only ones that did not reached canopy closure at age 10 years (Figure 2a and b)

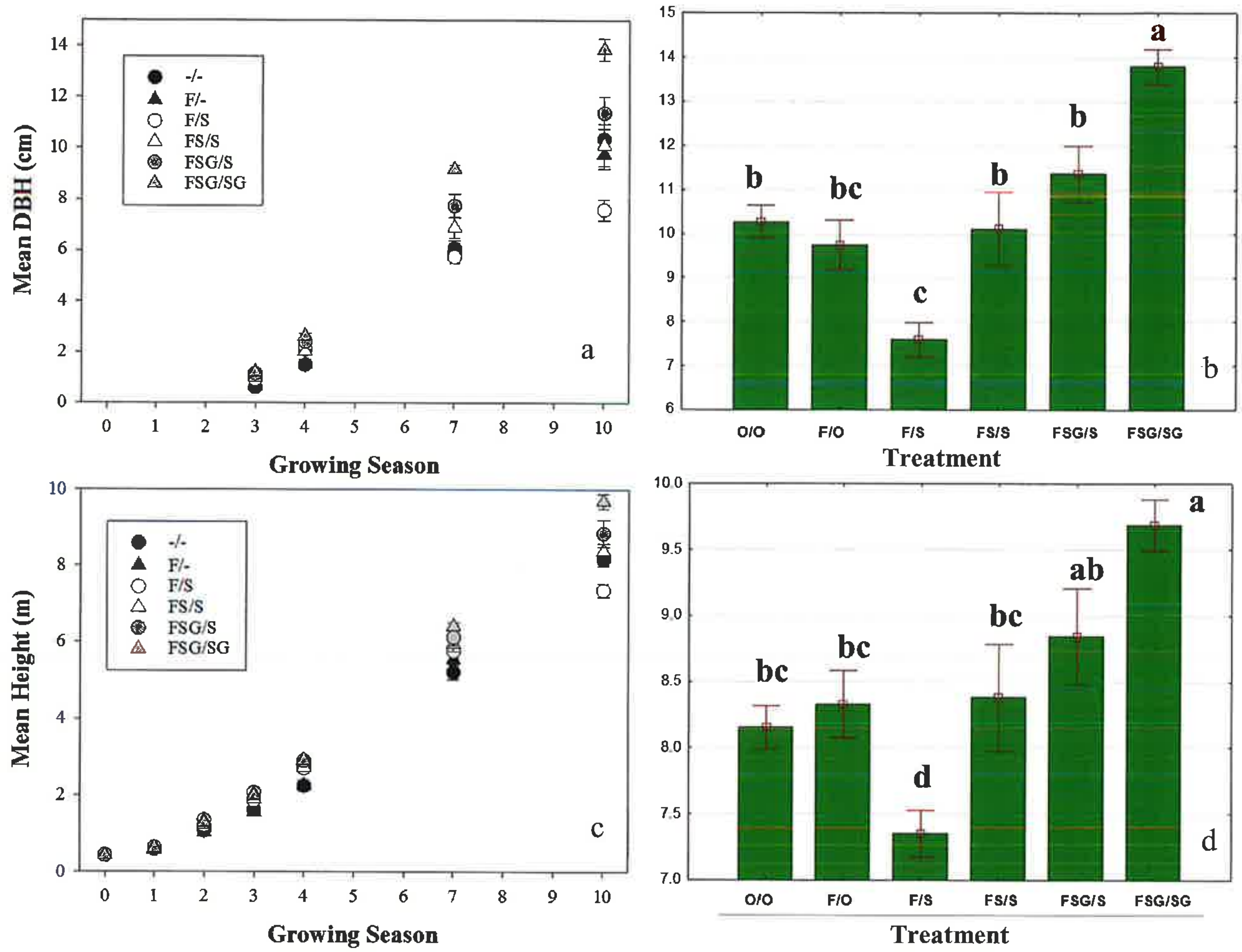

Figure 1. Vegetation management treatment effects on Douglas-fir diameter at breast height (DBH) (a ,b) and mean height (c, d) after 10 growing seasons. The left panel shows time series and the right panel shows yield at age 10 years.

The F/S treatment had 222 ft^3 $acre^{-1}$ less volume than the control, but this difference was marginally not significant (Figure 2 e and f). Meanwhile, the most intensive vegetation management treatment (FSG/SG) continued to have the highest mean height, DBH and volume per acre of all treatments in year 10. The mean height, DBH and volume of the FSG/SG treatment differed from the control by 1.5 m, 3.5 cm, and 568 ft^3 $acre^{-1}$, respectively ($p < 0.001$). There were no significant differences in the mean height, DBH or volume of the O/O, F/O, FS/S, and FSG/S treatments in year 10 ($p > 0.10$).

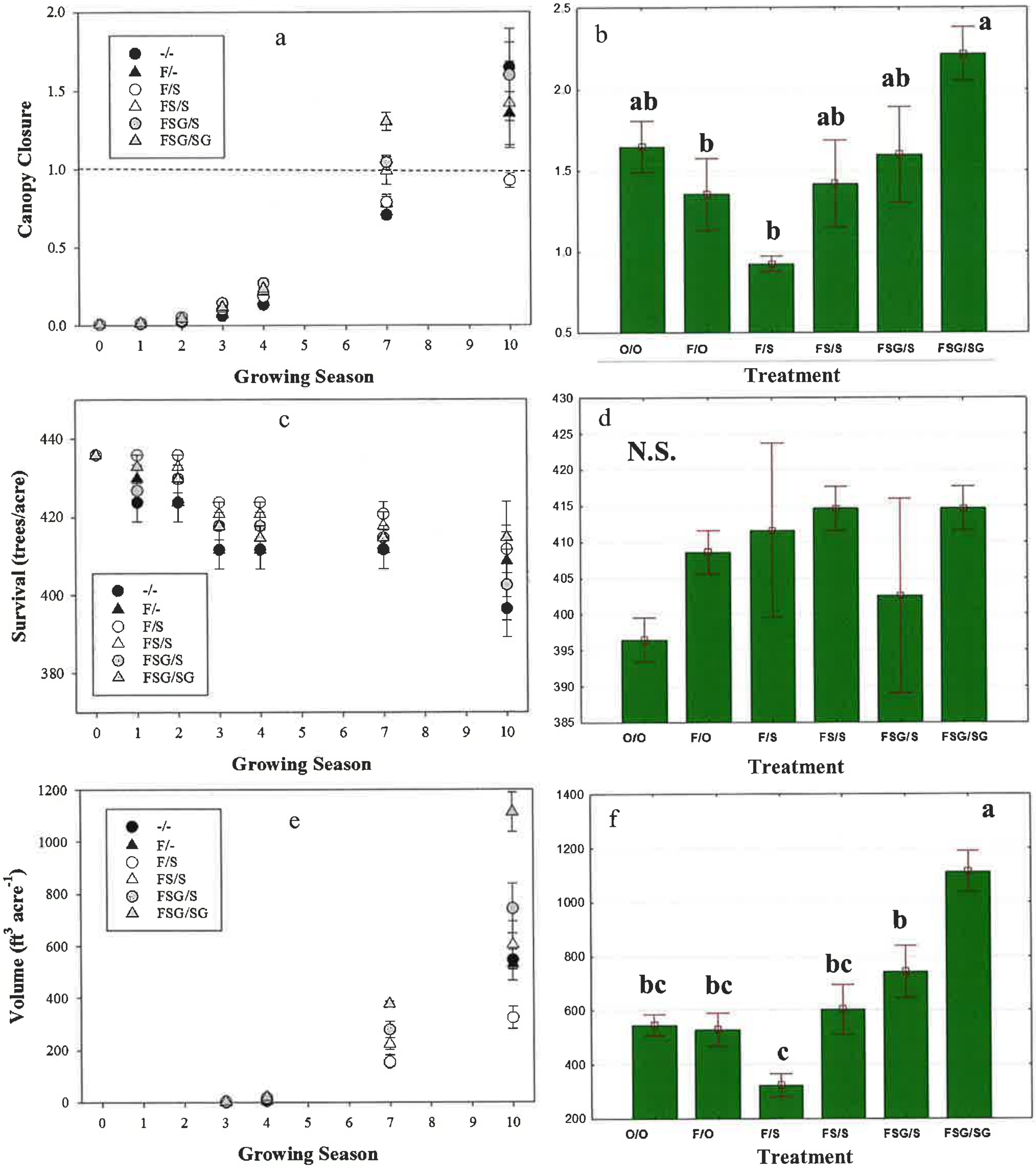

Figure 2. Treatment effects on Douglas-fir canopy closure (a, b), survival (trees per acre) (c, d) and volume (ft^3 $acre^{-1}$) (e, f) after 10 growing seasons. The left panel shows time series and the right panel shows yield at age 10 years.

Changes in the ranking of treatment means for stand growth parameters from year 4 to year 10 is likely due to differences in the amount and type of competing vegetation present in the treatment plots. The reduced growth observed in the F/S treatment is almost certainly the result of competing hardwoods, mainly bitter cherry (*Prunus emarginata*), becoming very abundant in plots receiving this treatment (Figure 3). The percent cover of tree species in the F/S treatment was greater than all other treatments in year 2 and this trend continued until year 10.

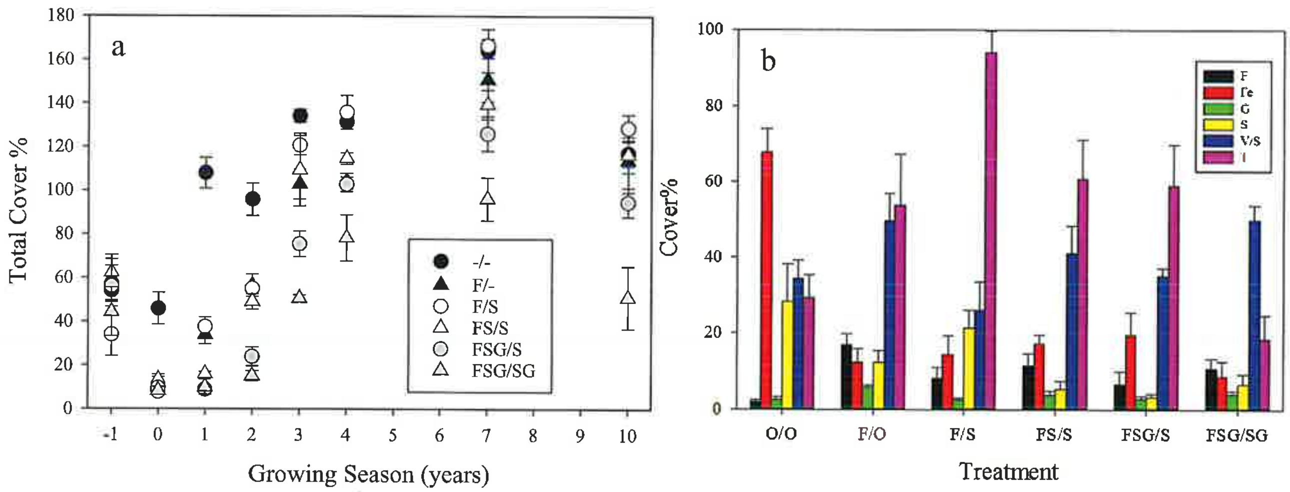

Figure 3. Time series of mean total percent vegetation cover by treatment (a) and mean percent vegetation cover by vegetative growth habit at age 10 years (b). Growth habits include forbs (F), ferns (Fe), graminoids (G), shrubs (S), vine/shrubs (V/S) and trees (T).

Volume growth from year 7 to year 10 was negatively correlated with the % cover of non-crop tree species in the vegetation survey subplots during year 7 ($R^2 = 0.72$, Figure 4) at which time the F/S treatment had 12% more cover than any other treatment and 48% more tree cover than the control (87% vs 39%) (Figure 3). The abundant hardwoods in the F/S treatment plots have severely competed with the Douglas-fir crop trees reducing growth to the extent that the F/S treatment is the only treatment to have not yet reached canopy closure (Figure 2).

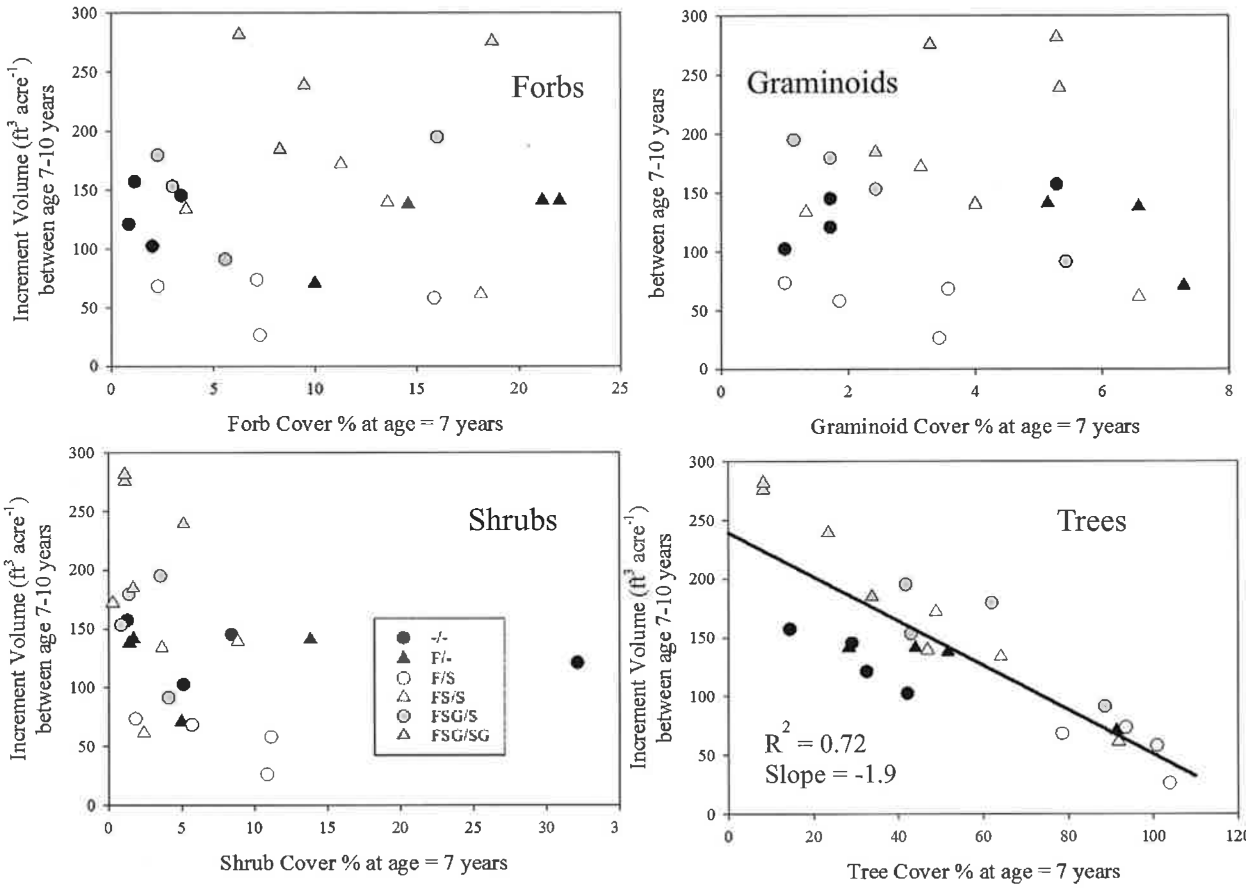

Figure 4. Relationship between vegetation cover at age 7 years and volume growth (ft^3 $acre^{-1}$) between age 7 and 10 years.

The negative effect of hardwood competition on tree growth was observed in all treatments. This effect can be observed in Figure 4 where all plots share the same general relationship between tree cover at age=7 years and volume growth. The FSG/SG treatment had the lowest % cover of tree species and continues to demonstrate the fastest growth rate of any of the treatments. Although the O/O treatment had the second lowest % cover of tree species in year 7, this treatment had significantly greater cover of fern species than all other treatments (68% vs 14%, $p < 0.001$; Figure 3).

The profound effect of hardwood competition on stand growth at the study site raises the question of why some treatments have higher levels of hardwood competition than others. The first point that should be made in this discussion is that the study site is fenced. Ungulates such as black tail deer (*Odocoileus hemionus*) find bitter cherry to be highly palatable and often preferentially browse this species across the landscape. Therefore, the exclusion of ungulates from the study area may have created an artificial condition that would not have occurred otherwise. The high levels of bitter cherry in the F/S treatment may be due to the fall site preparation without a spring release in the first year allowing the hardwood seedlings to become established. The subsequent treatment of atrazine and clopyralid during the spring of the second growing season then released these cherry seedlings allowing them to grow rapidly. This can be seen in the rapid increase in the cover of trees in the F/S treatment during the second growing season. This rapid increase in tree cover would continue until year 7 when tree cover peaked at 87% cover. The F/O, FS/S and FSG/S treatments followed a similar pattern, but with the % tree cover increasing at a slower rate.

The O/O and FSG/SG treatments both had relatively low tree cover, but this condition was the result of two different processes. The O/O treatment did not receive any vegetation management treatments and was quickly occupied by forbs, ferns, graminoids, shrubs, and vine/shrubs. At year 0 the O/O treatment had significantly more cover of competing vegetation than all other treatments (46% cover vs 10% cover). The rapid invasion of these plots by non-tree plant species likely limited the ability of hardwood seedlings to become established. The low tree cover in the FSG/SG treatment, on the other hand, is due to the vegetation management treatments applied. The glyphosate applied during the first and second summer releases prevented the hardwood seedlings from becoming established and after this point the Douglas-fir trees had occupied the site to the extent that they were able to out compete any hardwood seedlings that become established. The % cover of trees in the FSG/SG plots has continued to rise over time, but it is likely that this trend will not continue into the future due to canopy closure having recently occurred on these plots.

Conclusions

The early results of increased Douglas-fir seedling growth with increasing vegetation management intensity at the Evaluating Common Regimes study was no longer apparent after ten growing seasons. This lack of treatment response was attributed to many of the treatments having abundant hardwood competition and volume growth from year 7 to year 10 being negatively correlated with the % cover of competing tree species. The large amount of hardwood volunteers at the site is likely due to the exclusion of ungulate species that tend to heavily browse hardwood tree seedlings. The FSG/SG treatment, however, has maintained low levels of competing tree cover and continues to demonstrate significantly larger height, DBH, and volume growth then all other treatments. These results suggest that it may be important to apply early summer glyphosate release treatments in areas with extremely low ungulate populations in order to control hardwood seedlings.

References

Dinger, E.J., and R. Rose. 2009. The integration of soil moisture, xylem water potential, and fall-spring herbicide treatments to achieve the maximum growth response in newly planted Douglas-fir seedlings. Can. J. For. Res. 39, 1401-1414.

Study Update: Critical Period Threshold – Summit

Carlos Gonzalez-Benecke and Maxwell Wightman

Highlights

At age 16 years, on a Coastal Range site with chemical and mechanical site preparation (vegetation cover < 30% at planting):

There was a species x treatment interaction:
- Vegetation management treatments produced large growth responses in western red cedar, western hemlock and grand fir.
- The response of Douglas-fir to these same treatments was much less pronounced.

Maximum VOL response was attained with 4 to 5 years of spring release for all species:
- Douglas-fir: +560 ft^3 $acre^{-1}$
- Western hemlock: +1700 ft^3 $acre^{-1}$
- Western red cedar: + 880 ft^3 $acre^{-1}$
- Grand fir: +1400 ft^3 $acre^{-1}$

There was no effect of thinning (~20% BA removal) on the vegetation cover of Douglas-fir plots after three years.

Introduction

The Critical Period Threshold (CPT) study located on Starker Forests, Inc. property in the Coast Range (CPT01) is the oldest active VMRC study site and was the first of the three ongoing CPT studies installed. The Critical Period Threshold study series was established to: 1) analyze the effects of continuous vegetation management treatments on stand productivity and vegetation community dynamics, 2) determine the number of years of vegetation control required to maximize seedling growth, 3) determine the level of growth loss that results from delaying vegetation control for one or two years, and 4) compare the response of different crop-tree species to vegetation management treatments. In addition to being the oldest ongoing VMRC study, the CPT01 site also contains the largest number of crop-tree species including Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), and grand fir (*Abies grandis*). Early results from this study site have been reported in several publications including Mason et al. (2007), Maguire et al. (2009), and Rosner and Rose (2006). This report will summarize the results of the year 16 tree inventory.

Methods

The CPT01 study is located in the Coast Range on a site with a mean annual temperature of 51.9°F and mean annual precipitation of 72.2 inches. The soil is a Preacher-Bohannon complex which is defined as a well-drained fine-loam. Prior to study instillation, the site was subsoiled with an excavator equipped with a winged subsoiler. The entire study area received a fall site preparation treatment of 2 oz/ac sulfometuron and 0.5 oz/ac metsulfuron in October, 1999. Containerized (styro-15) Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), and grand fir (*Abies grandis*) seedlings were planted in January, 2000 at a spacing of 10 x 10 ft.

The Critical Period Threshold study contains eight vegetation management treatments (Table 1) arranged in a randomized complete block design with four replications on 80 x 80 ft treatment plots. The eight vegetation control treatments are the same as those used in the other two CPT studies; OOOOO, OOTTT, OTTTT, TOOOO, TTOOO, TTTOO, TTTTO, and TTTTT. An "O" signifies no vegetation control during that growing season while a "T" indicates a treatment year (Table 1). The spring release treatments were applied in either March or April of a given year and were designed to reduce the understory cover of treated plots below 25% cover. If this threshold was not met addition summer or fall applications were conducted.

Table 1. Description of treatment regimens tested.

Treatment	Description
OOOOO	No spring release
TOOOO	Spring release during year 1
TTOOO	Spring release during year 1 and 2
TTTOO	Spring release during year 1, 2 and 3
TTTTO	Spring release during year 1, 2, 3 and 4
TTTTT	Spring release during year 1, 2, 3, 4 and 5
OOTTT	Spring release during year 3, 4 and 5
OTTTT	Spring release during year 2, 3, 4 and 5

*: all plots received fall site prep treatment.

Measurements of seedling height and diameter were taken during the dormant season of years 1-5, 8, 12, and 16 in the central 60 x 60 ft measurement plots allowing for a 1 tree buffer on all sides. Measurement plots contained 36 seedlings. Vegetation assessments were conducted during July of growing seasons 1-5, 8, 12, and 16 on five 1 m radius subplots per plot. Vegetation assessments included visual estimates of understory plant cover by species. Douglas-fir plots received a pre-commercial thinning during the fall of 2013. Thinning intensity was about 25% of basal area. Analysis of variance was used to test the effects of treatments on stand growth and vegetation community dynamics, including Tukey adjustments (PROC GLM; SAS Institute Inc., Cary, NC, USA).

Results and Discussion

Table 2. Summary of stand yield at age 16 years for Douglas-fir, western hemlock, western red cedar and grand fir trees growing under different vegetation management treatments. The variables included are mean height (HT, ft), quadratic mean diameter (QMD, inch), stand volume per acre (VOL, ft^3 $acre^{-1}$), stand density index (SDI, trees $acre^{-1}$) and survival (TPA, trees $acre^{-1}$).

Species	Treatment	HT (ft)	QMD (inch)	VOL (ft^3 $acre^{-1}$)	SDI (trees $acre^{-1}$)	TPA (trees $acre^{-1}$)
Douglas-fir	OOOOO	47.0	7.3	1627	167	278
	TOOOO	47.4	7.1	1351	143	242
	TTOOO	46.5	7.1	1545	155	266
	TTTOO	49.3	7.3	1687	168	275
	TTTTO	51.2	8.0	2187	204	291
	TTTTT	51.1	8.1	2141	202	281
	OOTTT	50.3	8.0	2193	207	294
	OTTTT	51.6	8.2	2279	211	291
Western hemlock	OOOOO	35.5	5.6	975	137	348
	TOOOO	33.6	5.0	841	127	378
	TTOOO	39.7	6.1	1420	177	390
	TTTOO	40.1	6.1	1500	187	412
	TTTTO	46.3	7.8	2643	273	406
	TTTTT	46.7	8.0	2850	290	415
	OOTTT	44.2	7.7	2176	230	336
	OTTTT	45.2	7.9	2519	263	378
Western red cedar	OOOOO	15.6	3.4	243	57	315
	TOOOO	21.2	4.3	598	102	343
	TTOOO	25.8	4.8	722	122	395
	TTTOO	25.6	4.7	686	120	404
	TTTTO	26.8	6.0	1125	169	371
	TTTTT	27.1	6.1	1140	175	391
	OOTTT	24.3	5.6	945	146	339
	OTTTT	27.4	5.9	1201	182	420
Grand fir	OOOOO	29.1	4.8	761	117	375
	TOOOO	33.4	5.4	1157	160	424
	TTOOO	36.3	6.4	1644	202	404
	TTTOO	35.8	5.9	1341	175	412
	TTTTO	37.3	7.1	2149	254	436
	TTTTT	39.9	7.9	2524	278	404
	OOTTT	33.3	6.6	1684	216	424
	OTTTT	34.4	6.4	1390	181	367

Table 2 provides a summary at age 16 years for mean height (HT, ft), quadratic mean diameter (QMD, inch), stand density index (SDI, trees $acre^{-1}$), stand volume per acre (VOL, ft^3 $acre^{-1}$) and survival (TPA, trees $acre^{-1}$) for the eight treatments tested. In order to facilitate visual comparisons of the vegetation management treatment effects across species, figures are shown as time series for TPA, mean height, QMD, SDI and VOL, for all four species simultaneously. Nevertheless, the results are described separately for each species.

I. Douglas-fir

Douglas-fir exhibited the smallest treatment response of all species tested. Tree survival was not effected by treatment and averaged 281 trees per acre ($p = 0.445$, Figure 1a).This result is not surprising as the Douglas-fir plots were thinned to the same stocking level in 2013. It is worth noting, however, that there were no differences in tree survival among the treatments prior to the thinning operation ($p = 0.998$) and tree survival averaged 80%. This result suggests that only applying a fall site preparation treatment was sufficient to ensure adequate stocking at this site. Although there was a significant effect of treatment on mean height prior to thinning, mean height was not effected by any treatment at year 16 and averaged 48 ft ($p = 0.194$, Figure 2a). This lack of response may be due to the thinning operation removing the smallest trees from plots and thereby reducing differences between treatments.

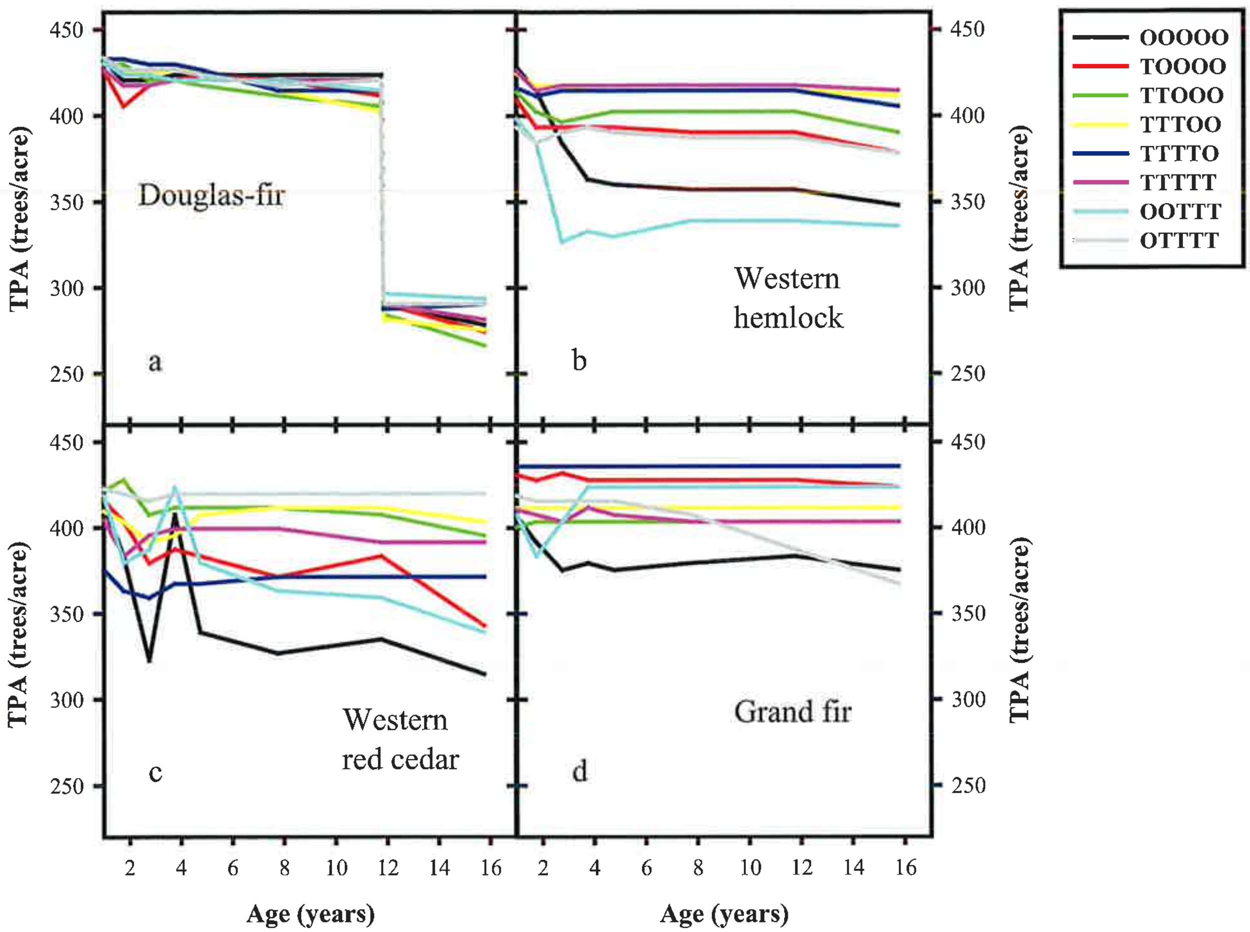

Figure 1. Time series of trees per acre (TPA) for Douglas-fir (a), western hemlock (b), western red cedar (c) and grand fir (d) stands growing under different treatments of vegetation control on a site located in the Coast Range.

There was a significant effect of treatments on QMD (Figure 4a), SDI (Figure 5a) and VOL (Figure 6a) such that two distinct groups became apparent. The QMD ($p = 0.002$), SDI ($p = 0.003$), and VOL ($p = 0.001$) of the TTTTO, TTTTT, OTTTT, and OOTTT treatments (group 1) did not differ from one another and were greater than all other treatments. There were also no significant differences in the QMD, SDI or VOL of the OOOOO, TOOOO, TTOOO, and TTTOO treatments (group 2). The treatments in group 1 increased QMD by 12% (0.9 in) and stand volume by 38% (563 ft^3 $acre^{-1}$) when compared to the treatments in group 2. Considering a maximum SDI (SDImax) of 520 trees $acre^{-1}$ for Douglas-fir, at the time of thinning SDI ranged between 0.25 (OOOOO) and 0.38 (TTTTT) relative density, reflecting that the thinning was carried out much sooner than the threshold of 0.60 - 0.65 suggested for Douglas-fir and other conifers (Curtis 1982; Dean and Baldwin, 1993; Dean and Jokela, 1992; Drew and Flewelling, 1979).

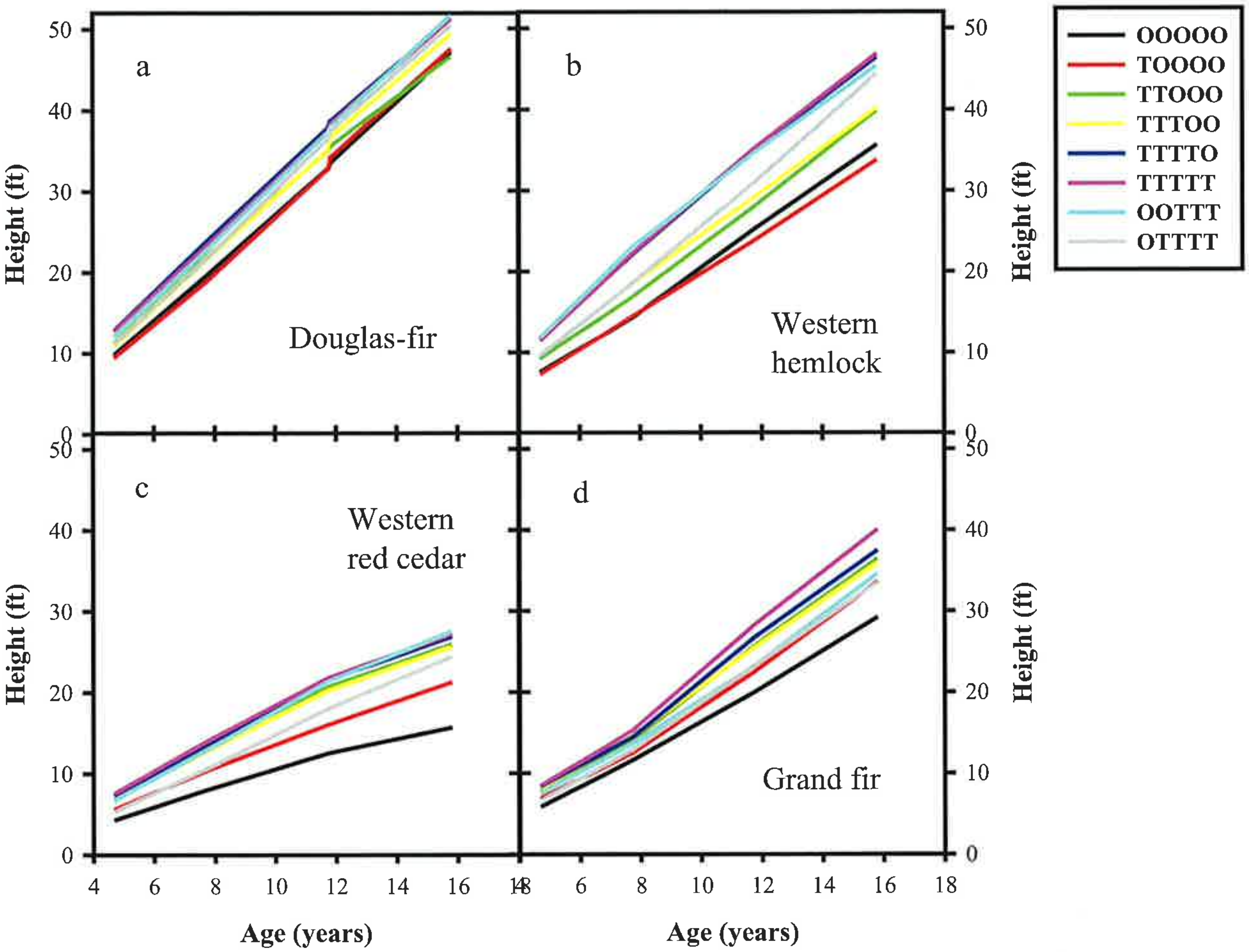

Figure 2. Time series of mean height for Douglas-fir (a), western hemlock (b), western red cedar (c) and grand fir (d) stands growing under different treatments of vegetation control on a site located in the Coast Range.

The lack of differences between the OOOOO and TTTOO treatments in this study suggests that a single fall site preparation treatment was sufficient to ensure good Douglas-fir seedling survival and growth at this site. The study site, however, was subsoiled prior to study establishment. This mechanical treatment likely influenced the pattern of understory development as the percent cover of understory species in the OOOOO treatment during the summer of the first and second growing seasons was only 32% and 78%, respectively (Figure 3a). It is likely that this condition influenced treatment responses. The large differences between the TTTOO and OOTTT treatments are also likely due to the pattern of understory development at the study site. The slow development of the understory resulted in the spring release treatments in the TTTOO treatment not reducing understory competition to the same extent as the spring release treatments in the OOTTT treatment. This effect can be seen in the sum of understory cover for the first five years. The TTTOO treatment had a summed understory cover of 303% whereas the OOTTT had a summed understory cover of only 189%. The thinning treatment conducted at year 13 did not impact the total understory cover of any treatment after three years ($p = 0.131$). When analyzed individual, there were no changes in the cover of forbs ($p = 0.228$), ferns ($p = 0.267$), grasses ($p = 0.157$), shrubs ($p = 0.822$), trees ($p = 0.605$) or vine shrubs ($p = 0.368$) for any treatment during this period.

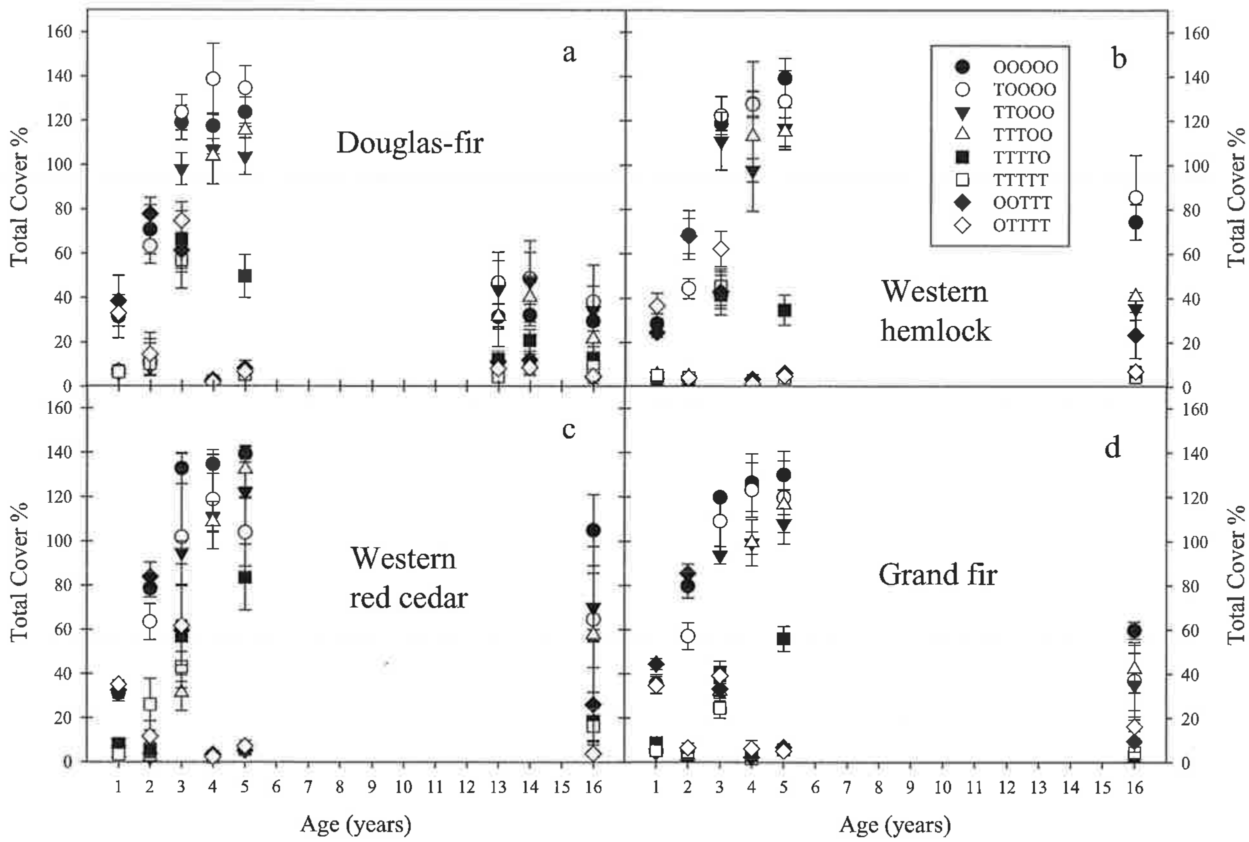

Figure 3. Time series of total vegetation cover for Douglas-fir (a), western hemlock (b), western red cedar (c) and grand fir (d) stands growing under different treatments of vegetation control on a site in the Coast Range.

II. Western hemlock

Western hemlock was more responsive to the treatments than Douglas-fir and grew well at the study site. Seedling survival rate was high and there were few differences in survival among the treatments (Figure 1b). There was, however, a significant effect of treatment on mean height such that three distinct groupings became apparent (Figure 2b). The groups were such that: 1) the OOOOO and TOOOO were shorter than all other treatments, 2) the TTOOO and TTTOO treatments were taller than the OOOOO and TOOOO, but shorter than all other treatments, and 3) the TTTTO, TTTTT, OTTTT, and OOTTT treatments were taller than all other treatments (Figure 2b). There were no significant differences among the treatments within any of these three groups. This pattern of treatment response was the same for differences in QMD (Figure 4b), SDI (Figure 5b) and VOL (Figure 6b), with the exception of the QMD of the TTOOO treatment not differing from the OOOOO or TOOOO treatment.

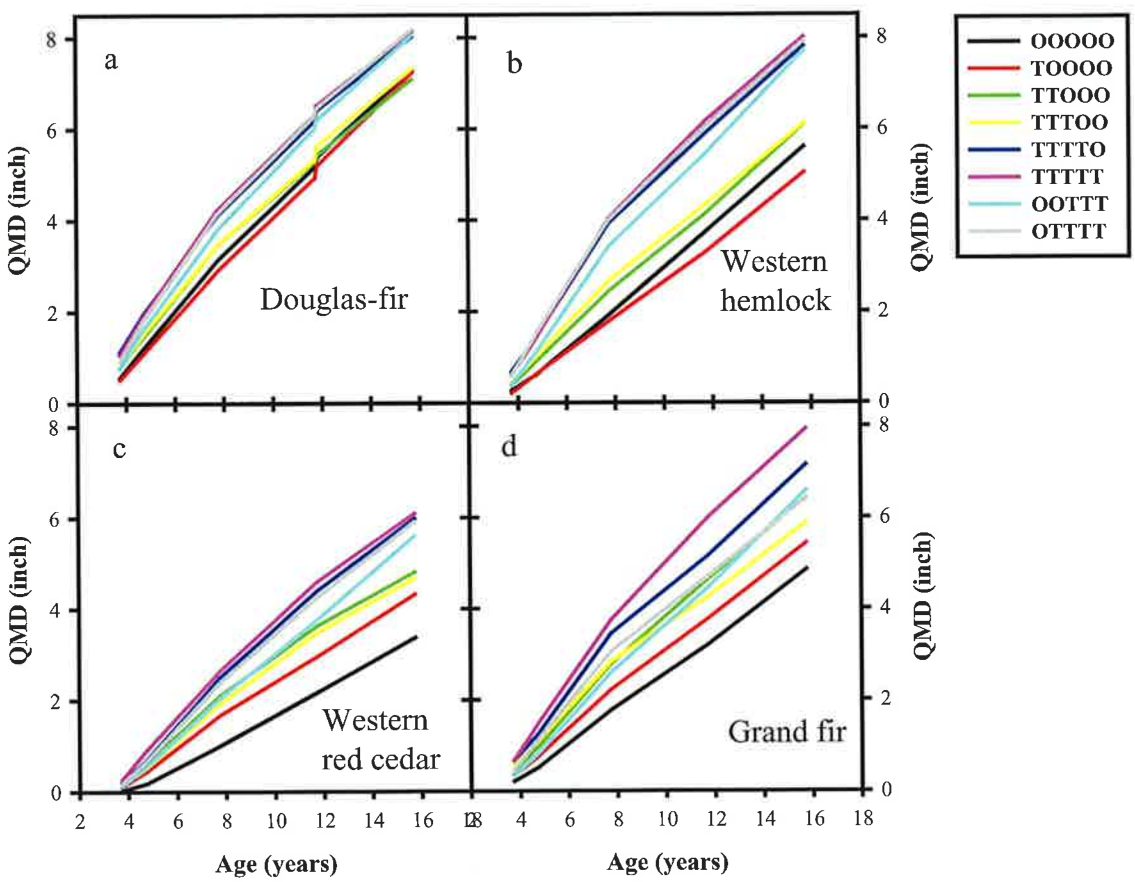

Figure 3. Time series of quadratic mean diameter (QMD) for Douglas-fir (a), western hemlock (b), western red cedar (c) and grand fir (d) stands growing under different treatments of vegetation control on a site located in the Coast Range.

Western hemlock was, on average, the second tallest of the species tested (Figure 2). The magnitude of treatment responses was such that the mean height of group 2 and group 3 were 1.6 m and 3.2 m greater than group 1, respectively. This represents a 15% increase in height growth for group 2 and a 30% increase in height growth for group 3. The impact of treatments on diameter growth were similar. When compared to group 1, the treatments in group 2 and group 3 increased stand QMD by 15% and 48%, respectively (Figure 4b). These significant differences in individual tree size combined with an absence of major treatment effects on tree survival resulted in large treatment differences in stand volume. Differences in stand volume between the treatments have been increasing through time and this trend continued through year 16 (Figure 6b). The treatments in groups 2 and 3 increased stand volume by an impressive 61% and 184%, respectively. The stand volume of 2455 ft^3 $acre^{-1}$ for group 3 was the highest standing volume of any treatment for any species at the site, although it is important to remember that the Douglas-fir plots have been thinned. The summation of all of these treatment differences resulted in differences in the SDI of treatments (Figure 5b). This suggests that group 3 is farther along in stand development than the other groups and that group 2 is farther along in stand development than group 1. The SDI of group 3, however, was only 264 trees $acre^{-1}$ which represents only 33% of the maximum SDI for the species (SDImax = 790 trees $acre^{-1}$). A thinning threshold of 65% of maximum SDI is commonly used which suggests these plots will not need to be thinned for several years.

The distinct grouping of treatment responses seen above was likely the result of the patterns of competing vegetation development within the treatments. The study site was subsoiled prior to study establishment. This mechanical treatment likely influenced the pattern of understory development as the percent cover of understory species in the OOOOO treatment during the summer of the first growing season was only 29% (Figure 3b). By the third growing season, however, the understory cover of the OOOOO treatment had increased to 118%. The slow development of the understory community during the first two growing seasons can help to explain the lack of differences between the OOOOO and TOOOO treatments as well as the large differences between the TTTOO and OOTTT treatments.

III. Western red cedar

Western red cedar was the slowest growing of all species tested. The survival of western red cedar seedlings was also the most sensitive to vegetation management treatments. Although not statistically significant, the mean survival of cedar seedlings in the OOOOO treatment was the lowest of all treatments and all species. For Western red cedar, there were no differences in the survival of any treatment that received at least one year of spring release. The OOOOO treatment, however, had significantly worse survival than the TTOOO, TTTOO, and OTTTT treatments (Figure 1c).

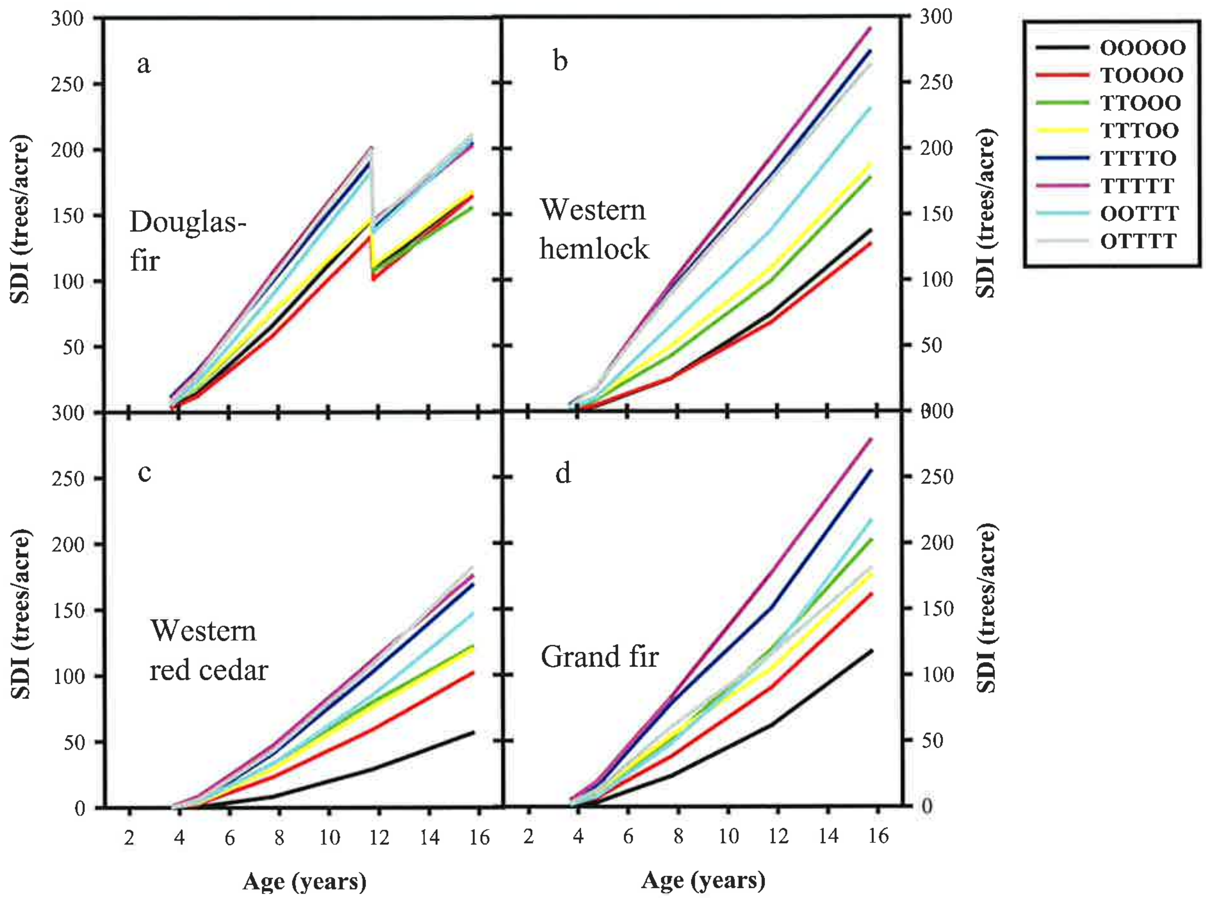

Figure 4. Time series of stand density index (SDI) for Douglas-fir (a), western hemlock (b), western red cedar (c) and grand fir (d) stands growing under different treatments of vegetation control on a site located in the Coast Range.

Similar to seedling survival, there were no differences in the mean height or QMD among any of the treatments that received at least one year of spring release. The mean height of the OOOOO treatment (15.4 ft) was shorter than all other treatments (25.2 ft), but this difference was only significant for treatments that received four or more years of spring release (TTTTO, TTTTT, and OTTTT) (Figure 2c). The QMD of the OOOOO treatment (3.4 in) was also smaller than all other treatments (5.4 in), but this difference was only significant for the TTTTTT treatment (Figure 4c).

The differences in stand volume among the Western red cedar treatments have continued to increase through time. The volume of the OOOOO treatment (207 ft^3 $acre^{-1}$) was significantly less than all other treatments except for TOOOO (Figure 6c). The volume of the cedar OOOOO treatment was only 14% of the volume of the Douglas-fir OOOOO treatment, even after the Douglas-fir plots were thinned. There were no differences in the volume of any of the treatments that received at least one year of spring release with the exception of the TTTTT treatment having significantly more volume than the TOOOO, TTOOO, and TTTOO treatments (Figure 6c). The volume of the TTTTT treatment at age 16 was only 1005 ft^3 $acre^{-1}$ which represents only 67% of the volume of the OOOOO Douglas-fir treatment. The patter of treatment differences for SDI was the same as the differences in volume and the SDI of the TTTTT treatment was 175 trees $acre^{-1}$ (Figure 5c). This represents only 25% of the maximum SDI for the species (SDImax = 722 trees $acre^{-1}$) and suggest that these plots will not need to be thinned for several years.

IV. Grand Fir

Grand fir grew better than western red cedar, but not as well as Douglas-fir. The survival of grand fir seedlings was high and there were no differences in survival among any of the treatments that received at least one year of spring release (Figure 1d). The survival of the OOOOO treatment, however, was less than the TOOOO, TTTOO, and OOTTT treatments, but was still high at 375 trees $acre^{-1}$. Grand fir was, on average, the third tallest of the species tested. For grand fir the mean height of the OOOOO treatment was significantly shorter than all other treatments. There were no significant differences in the mean height of any of the other treatments with the exception of the TTTTT treatment being taller than the TOOOO, OOTTT, and OTTTT treatments (Figure 2d). This result suggests that grand fir may have been more sensitive to the delayed spring release treatments (OOTTT and OTTTT) than the other species tested. The difference in height between the OOOOO treatment (28.5 ft) and the TTTTT treatment (39.7 ft) represents a 38% increase in height growth. The QMD of the OOOOO treatment was less than all of the treatments, but this difference was not significant for the TOOOO or TTTOO treatments. Conversely, the TTTTT treatment had the highest QMD of all treatments, but this difference was only significant for the OOOOO, TOOOO, and TTTOO treatments (Figure 4d). There were no other differences in the QMD of treatments. The pattern of treatment differences for stand volume was the same as for QMD with the exception of the volume of the TTOOO treatment not differing form the OOOOO treatment. The difference in the QMD and Volume of the OOOOO treatment (4.8 in, 676 ft^3 $acre^{-1}$) and TTTTT treatment (7.9 in, 2311 ft^3 $acre^{-1}$) represents a 64% and 240% increase in diameter and volume growth, respectively (Figure 6d).

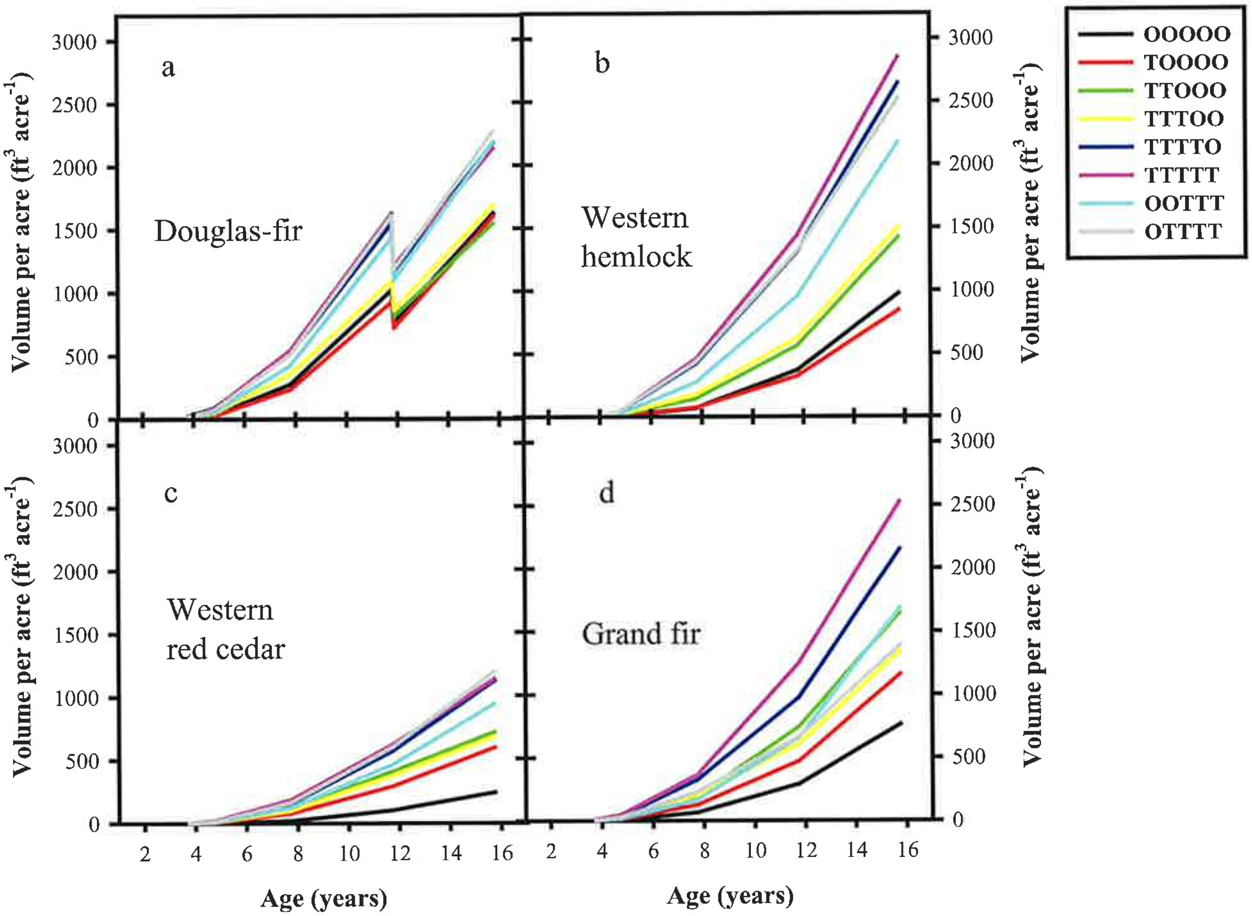

Figure 5. Time series of stand volume for Douglas-fir (a), western hemlock (b), western red cedar (c) and grand fir (d) stands growing under different treatments of vegetation control on a site located in the Coast Range.

The TTTTT grand fir treatment had the largest relative SDI of any treatment for any species (Figure 5d). The SDI of the TTTTT treatment was 278 trees $acre^{-1}$ or 50% of the maximum SDI for the species (SDImax=560 trees $acre^{-1}$). At age 12 the SDI of this same treatment was 101 trees $acre^{-1}$ suggesting that these plots are increasing in SDI at a rate of approximately 25 trees $acre^{-1} \cdot year^{-1}$. At this rate these stands will reach the thinning trigger of 65% SDI in approximately 3 to 4 years. The SDI of the TTTTT, TTTTO, and TTOOO treatments was higher than all other treatments and did not statistically different from one another. The OOOOO treatment had the lowest SDI of all treatments, but was not significantly different from the TOOOO or TTTTOO treatments. There were no other differences in the SDI of the treatments.

Table 2. Years of spring release that maximize height (HT), quadratic mean diameter (QMD) and stand volume (VOL) growth of Douglas-fir, western hemlock, western red cedar and grand fir trees on a site located in the Coast Range.

Species	HT	QMD	VOL
Douglas-fir	4	4	4
Western hemlock	4	4	4
Western red cedar	2	2	5
Grand fir	2	2	5

Conclusion

Growth responses to vegetation management treatments were species specific. Douglas-fir was the fastest growing species at the site, but also the least responsive to vegetation management treatments. Growth was maximized for Douglas-fir after four years of continuous spring release, but stand volume was only increased by 560 ft^3 $acre^{-1}$ (Table 2). Western hemlock was, on average, the second tallest species at the site and was much more response to treatments that Douglas-fir. The growth of western hemlock was also maximized after four continuous years of spring release and the volume increase of 1700 ft^3 $acre^{-1}$ was the largest of any species (Table 2). The OOTTT treatment out preformed the TTTOO treatment in both Douglas-fir and western hemlock and this was attributed to slow understory development at the site. Grand-fir was, on average, the third tallest species and was also the most sensitive to the delayed spring release treatments (OOTTT and OTTTT). The height and diameter growth of grand fir was maximized after two years of spring release, but volume growth was not maximized until five years of spring release (Table 2). The increase in volume of 1400 ft^3 $acre^{-1}$ for grand fir was the second largest of all species. Western red cedar was the slowest growing species at the study site. After 16 growing seasons the volume of the TTTTT western red cedar treatment was only 67% of the volume of the OOOOO Douglas-fir treatment, despite the Douglas-fir plots having been thinned.

Similar to grand fir, height and diameter growth was maximized after two years of spring release, but volume growth was not maximized until five years of spring release (Table 2).

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Study Update: Critical Period Threshold – South Bend

Maxwell Wightman and Carlos Gonzalez-Benecke

Highlights

At age 3 years:

- Little competition during first 3 years: vegetation cover < 30% in all plots.
- No responses to any vegetation management treatment.
- Delayed vegetation control may be a good strategy for sites represented by this study.
- The % cover of competing vegetation on control plots increased to 50% during growing season four. This suggests that competition is intensifying at the site which may lead to future treatment effects.

Introduction

The Critical Period Threshold study series was established to: 1) analyze the effects of continuous vegetation management treatments on stand productivity and vegetation community dynamics, 2) determine the number of years of vegetation control required to maximize seedling growth, 3) determine the level of growth loss that results from delaying vegetation control for one or two years, and 4) compare the response of different crop-tree species to vegetation management treatments. The Critical Period Threshold study site near South Bend, WA (CPT03) applies the critical period threshold study design to both Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*). The 2012/2013 VMRC annual report summarized the results of the initial seedling morphology and vegetation survey measurements. These measurements indicated that the seedlings were in good condition with an acceptable shoot to root ratio (generally under 2:1) and that competing vegetation was slow to respond to the open conditions created through timber harvest. This report will summarize the results of the year 3 tree inventory and year 4 vegetation survey.

Methods

The CPT03 study site is located in Pacific County, WA, at an elevation of 800 ft on a west-facing ridge within 13 miles of the Pacific Ocean. The site has a site index of 117 ft for Douglas-fir and 104 ft for Western hemlock. Rayonier Inc. owned the site until the summer of 2016 when it was sold to Forest Investments Associates (FIA). The VMRC has been in communication with FIA and they have been kind enough to allow us access to the study site for future measurements. The final spring release treatment and any other site maintenance costs, however, will be at the expense of the VMRC.

The Critical Period Threshold study contains eight vegetation management treatments (Table 1) arranged in a randomized complete block design with four replications on 80 x 80 ft treatment plots. The eight vegetation control treatments are the same as those used in the other two CPT studies; OOOOO, OOTTT, OTTTT, TOOOO, TTOOO, TTTOO, TTTTO, and TTTTT. An “O” signifies no vegetation control during that growing season while a “T” indicates a treatment year (Table 1). Two additional treatments were installed at the request of Rayonier Inc.: a true no-action control (NS) and a fall site preparation only treatment (FSP). This resulted in 8 additional plots (2 treatments x 4 replicates). The extra plots were installed adjacent to each other and were the same size as the other treatment plots. The additional plots, however, were split in half such that one half was planted with Douglas-fir seedlings and the other half was planted with western hemlock seedlings.

Styro-15 seedlings were planted at the study site on February 28th, 2012 at a spacing of 10 x 10 ft. The seedlings were grown as a “plug in plug” at Weyerhaeuser’s Rochester nursery. For both species, seeds came from 2 different seed zones: “Gray’s Harbor” and “Forks”. Trees from different seed sources were planted randomly and no marking of genetic source was possible. The study area was surrounded by a perimeter fence prior to planting to protect seedlings from ungulate browsing damage. All non-NS treatment plots received a fall site preparation treatment on September 11th, 2012 that consisted of 4 oz/ac Oust Extra®, 1.5 qts/ac Accord XRT®, and 8 oz/ac Polaris SP®. There have now been four spring release treatments applied at the site all of which consisted of a broadcast application of Atrazine L® at 4 qts/ac and Transline® at 10 oz/ac. All spring release treatments occurred in April of a given year.

Measurements of seedling height and basal diameter, were taken during the dormant season of years 0 (2012) to 3 (2015) in the central 60 x 60 ft measurement plots allowing for a 1 tree buffer on all sides. Measurement plots contained 36 seedlings. Vegetation assessments were conducted during July of growing seasons 1 through 4 on five 1-m radius subplots per plot. Vegetation assessments included visual estimates of understory plant cover by species. Analysis of variance was used to test the effects of treatments on stand growth and vegetation community dynamics, including Tukey adjustments (PROC GLM; SAS Institute Inc., Cary, NC, USA).

Table 1. Description of treatment regimens tested.

Treatment		Year
1	OOOOO	Fall Site Prep
2	TOOOO	Fall Site Prep + Spring Release Year 1
3	TTOOO	Fall Site Prep + Spring Release Year 1 and 2
4	TTTOO	Fall Site Prep + Spring Release Year 1, 2 and 3
5	TTTTO	Fall Site Prep + Spring Release Year 1, 2, 3 and 4
6	TTTTT	Fall Site Prep + Spring Release Year 1, 2, 3, 4 and 5
7	OOTTT	Fall Site Prep + Spring Release Year 3, 4 and 5
8	OTTTT	Fall Site Prep + Spring Release Year 2, 3, 4 and 5
9	NS	No Control
10	FSP	Fall Site Prep

Results and Discussion

Table 2 provides a summary at age=3 years for mean height (HT, m), ground line diameter (GLD, cm), height to ground line diameter ratio (H/D, cm cm^{-1}), individual tree volume (I_VOL, cm^3), survival (TPA, trees $acre^{-1}$) and stand volume per acre (VOL, ft^3 $acre^{-1}$). There were no significant differences among the treatments in any tree or stand-level attribute (Table 2, Figure 3, Figure 4).

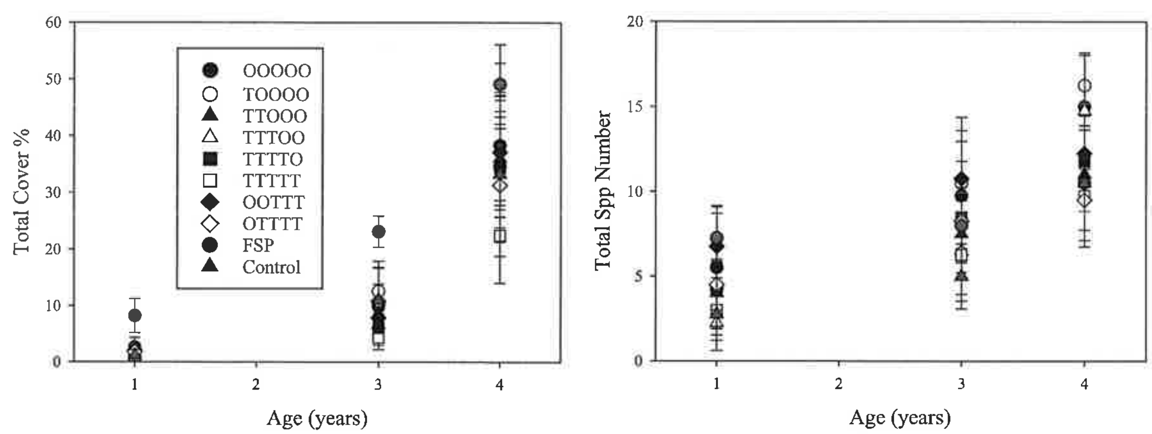

Figure 1. Total vegetation cover % and species richness for Douglas-fir plots growing under different vegetation management treatments.

Table 2. Treatment summary at age = 3 years for mean height (HT, m), ground line diameter (GLD, cm), height to ground line diameter ratio (H/D, cm cm^{-1}), individual tree volume (I_VOL, cm^3), survival (TPA, trees $acre^{-1}$) and stand volume per acre (VOL, ft^3 $acre^{-1}$). There were no significant effects of vegetation management treatment on any of the variables reported for either species.

Species	Vegetation Management	HT (m)	GLD (cm)	H/D (cm cm^{-1})	I_VOL (cm^3)	TPA (trees $acre^{-1}$)	VOL (ft^3 $acre^{-1}$)
Douglas-fir	OOOOO	1.7	3.6	48.4	683	427	10.4
	TOOOO	1.5	3.2	49.0	507	424	7.6
	TTOOO	1.5	3.3	47.3	536	421	8.1
	TTTOO	1.7	3.7	47.2	681	433	10.4
	TTTTO	1.6	3.6	45.9	673	412	9.8
	TTTTT	1.7	3.8	46.5	743	418	11.0
	OOTTT	1.5	3.3	48.0	516	430	7.8
	OTTTT	1.7	3.7	46.1	720	415	10.6
	NS	1.6	3.3	48.4	510	430	7.7
	FSP	1.6	3.5	47.4	577	436	8.9
Western hemlock	OOOOO	1.8	3.2	59.6	574	421	8.5
	TOOOO	1.6	3.0	57.6	483	390	6.7
	TTOOO	1.6	2.7	63.1	409	384	5.6
	TTTOO	1.8	3.2	59.5	590	384	7.9
	TTTTO	1.8	3.1	60.4	540	384	7.4
	TTTTT	1.9	3.5	56.8	682	396	9.6
	OOTTT	1.8	3.1	60.5	510	412	7.4
	OTTTT	1.7	3.1	56.7	544	403	7.8
	NS	1.8	3.2	61.1	610	406	8.9
	FSP	1.8	3.0	63.8	584	400	8.3

Understory development has been very slow at the CPT03 site, especially when compared to other VMRC studies. The vegetation survey conducted in July of 2016 indicated that the OOOOO treatment had an average understory cover of 40% after four growing seasons (Figure 1). Treatment did not have a significant effect on vegetation cover % ($p = 0.928$) or species richness ($p = 0.471$). For context, the OOOOO treatments at the Starker and Cascade CPT study sites both had ~126% understory cover after four growing seasons. The slow development of the understory at this site was also observed during the first growing season and discussed in the 2012/2013 VMRC annual report. "*The prior stand was a dense mixture of naturally regenerated western hemlock, Douglas-fir, and Sitka spruce. The closed canopy conditions may have limited the amount of understory vegetation and the potential buildup of a seed/bud bank. Due to the site's proximity to the coast and lack of repeatedly disturbed sites (e.g. construction, highway, farms, etc.) in the area, it is possible that the amount of seed rain may be reduced and could help explain some of the slow response to open conditions.*" In addition to these factors, the site contains a large amount of logging slash that may inhibit the ability for seeds entering the site to become established (Figure 2).

Figure 2. View of the study site at the time of the first spring release treatment (April 3, 2013). Note the low amount of competing vegetation and high amount of harvest residues.

The slow development of the understory community at the study site has limited crop-tree responses to vegetation management treatments. There were no significant differences among any of the treatments for either species. This lack of treatment response is almost certainly due to the understory community not having developed to the point at which competition has become significant enough to impact crop-tree growth. The cover of understory plants has been increasing in all treatments over time, however, and it is possible that treatment effects could become more pronounced in future years. The treatment means have been diverging over the past three years and it is likely this trend will continue (Figures 3 and 4).

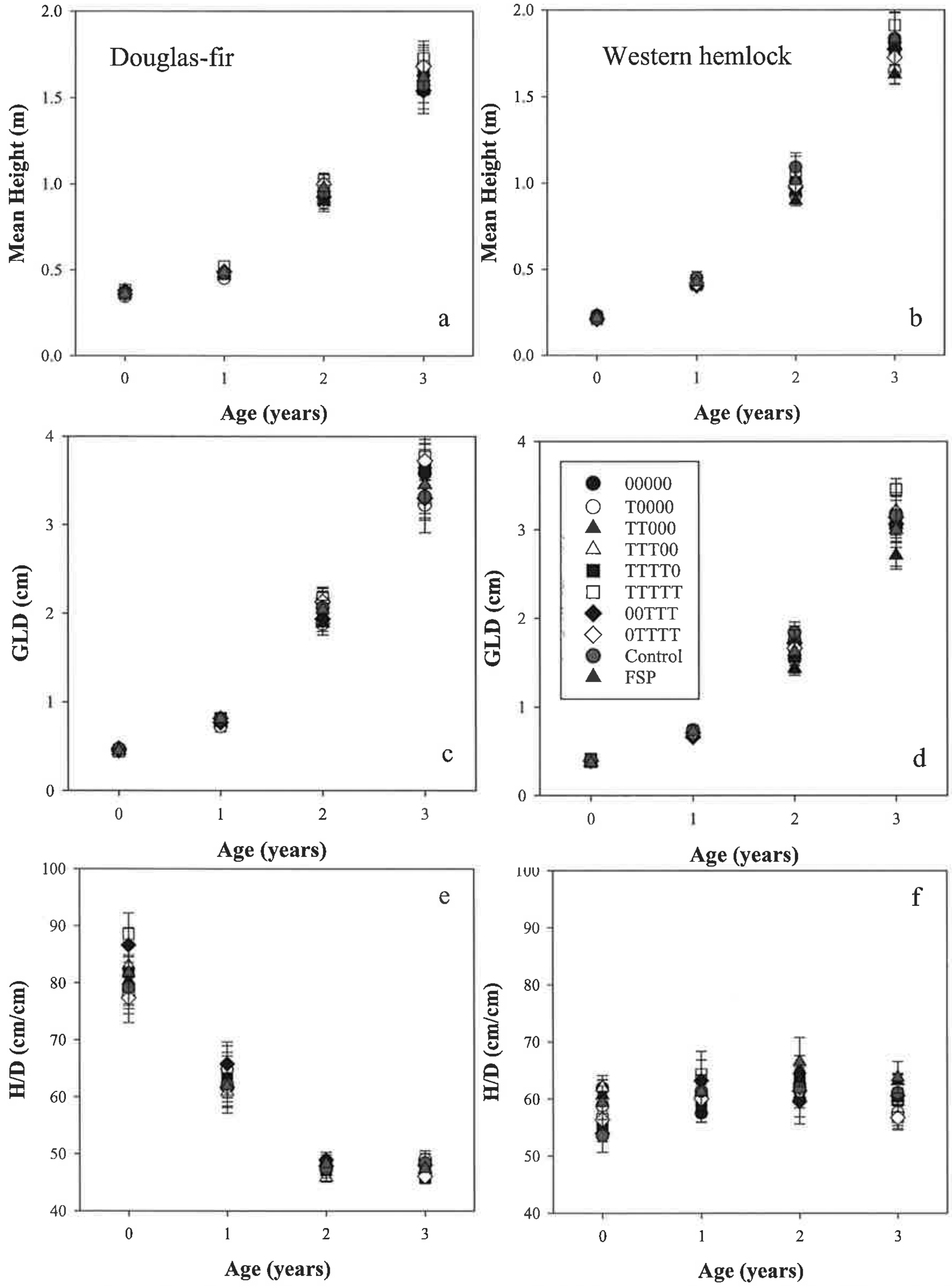

Figure 3. Time series responses for mean height (HT, m), ground line diameter (GLD, cm) and height to ground line diameter ratio (H/D, cm/cm) for Douglas-fir (left) and western hemlock (right) stands growing under different vegetation management treatments.

Despite the lack of treatment effects, the two species are growing differently. After three growing seasons the western hemlock seedlings are significantly taller than the Douglas-fir seedlings (1.77 vs 1.62 m, $p < 0.001$), but also have a smaller GLD (3.1 vs 3.5 cm, $p < 0.001$). This difference in growth characteristics results in the western hemlock seedlings having a significantly greater height to diameter ratio than the Douglas-fir seedlings (60 vs 47 cm cm^{-1}, $p < 0.001$) as well as significantly less volume per acre (7.8 vs 9.2 ft^3 $acre^{-1}$, $p = 0.04$).

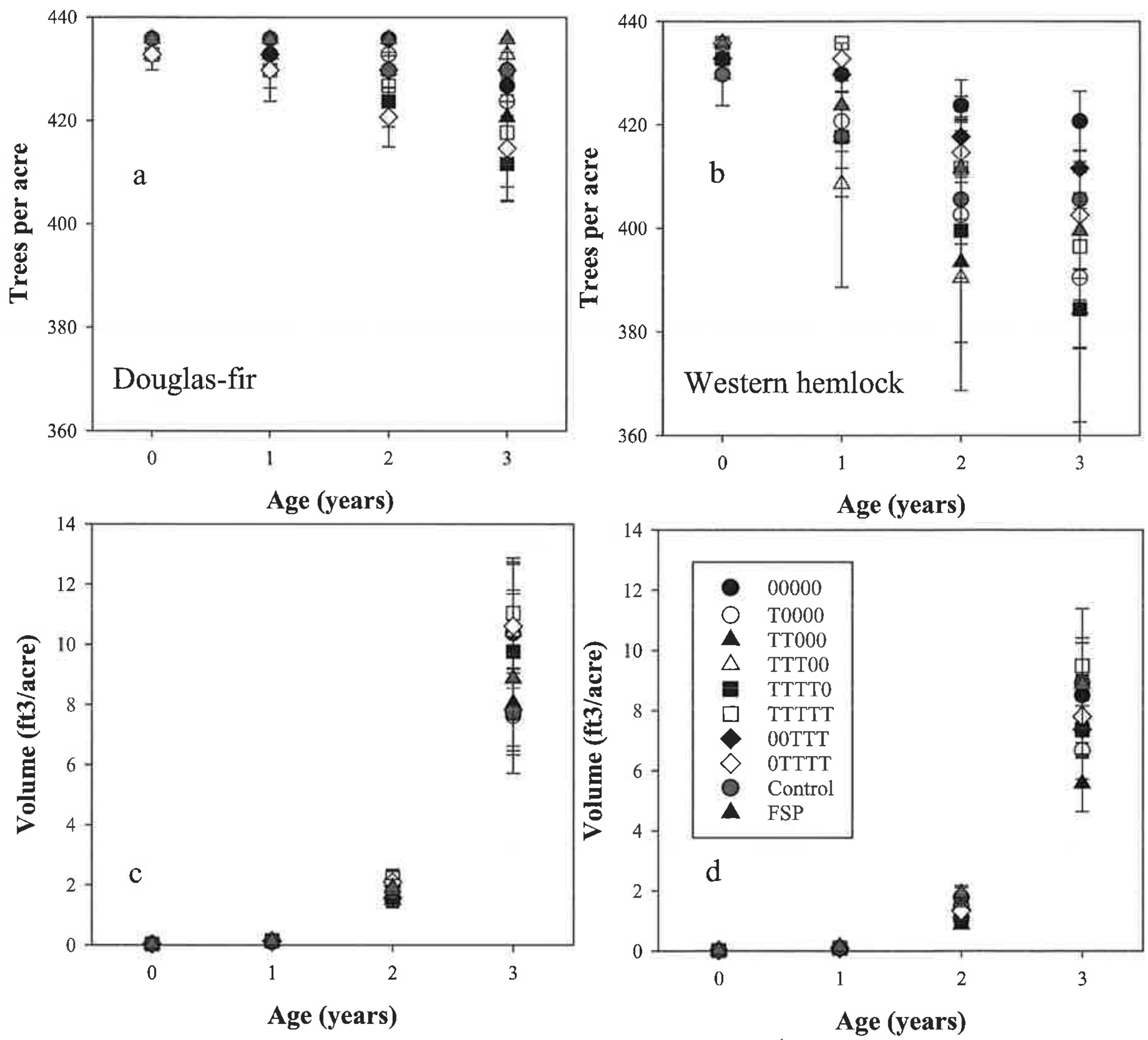

Figure 4. Time series responses for survival (trees·$acre^{-1}$) and stand volume per acre (ft^3 $acre^{-1}$) for Douglas-fir (left) and western hemlock (right) stands growing under different vegetation management treatments.

The vegetation community was relatively consistent across treatments and species during the fourth growing season (Figure 5). There were no significant effects of treatment on the cover or species richness of forbs, grasses, ferns, shrubs, trees, or vine/shrubs within the understory ($p > 0.32$), with the exception of the western hemlock FSP treatment having 10% more tree cover than all other treatments (12% vs 2% cover, $p < 0.001$). There were also no significant differences between the total understory cover of Douglas-fir and western hemlock plots even when analyzed by individual treatment ($p > 0.36$). The average cover of forbs, grasses, ferns, shrubs, trees, and vine/shrubs within the understory was 17.5%, 2.7%, 1.4%, 7%, 2.3%, and 3.9%, respectively. The most common species within the understory were foxglove (*Digitalis purpurea*), Salal (*Gaultheria shallon*), false dandelion (*Hypochaeris radicata*), pearly everlasting (*Anaphalis margaritacea*), and deer fern (*Blechnum spicant*).

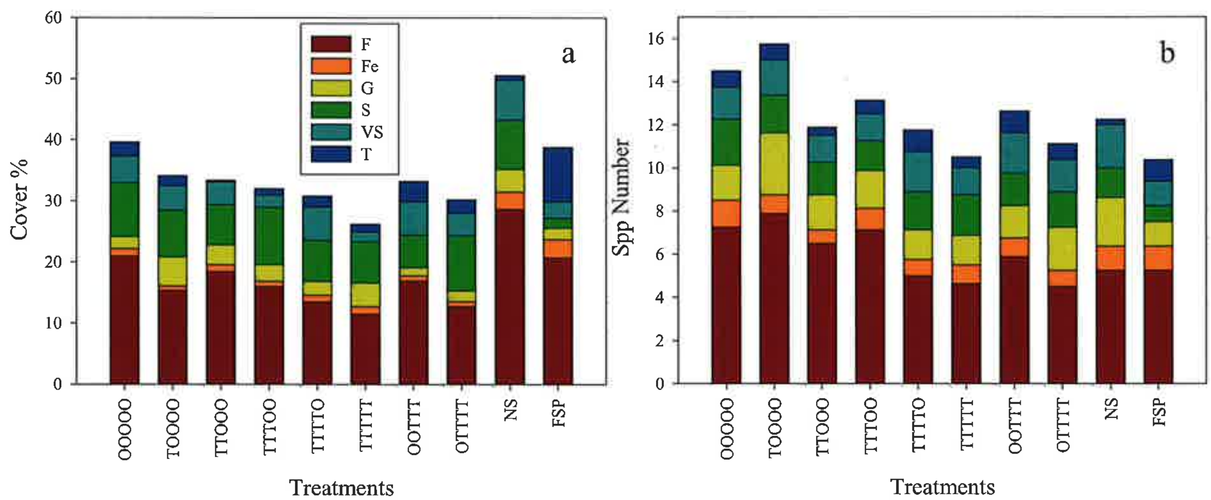

Figure 5. Vegetation cover % and species richness for forb (F), fern (Fe), graminoid (G), shrub (S), vine/shrub (VS) and tree (T) species on Douglas-fir plots growing under different vegetation management treatments. Data at growing season 4.

Conclusions

The slow development of the understory community at the study site has limited treatment effects on stand growth. The cover of the understory community, however, has been increasing through time and it is possible that treatment effects may become more pronounced in future years. There are some differences in the growth of the species such that western hemlock has a larger height to diameter ratio and lower volume per acre than Douglas-fir. The early results suggest that delayed vegetation management treatments maybe a good strategy on sites represented by this study, but this conclusion will need to be confirmed by future measurements.

This study is entering the fifth growing season and designated plots will receive the final spring release treatment this coming spring. The year 4 tree inventory will be conducted this winter and the year 5 spring vegetation survey will be conducted next summer. A large number of hemlock volunteers are beginning to invade the site and we are planning on cutting these volunteers this winter in order to protect the integrity of the study.

Study Update: Combining Weed Control Intensity and Seedling Stock Size Part II

Maxwell Wightman and Carlos Gonzalez-Benecke

Highlights

At age 4 years:

- There were no significant interactions between stock size and vegetation management regime suggesting all stock sizes responded to vegetation management treatments in a similar manner.
- Plots planted with the large stock size continued to have larger trees after four growing seasons, but differences in tree size are becoming less apparent over time.
- There was a strong and positive relationship between vegetation cover during year 1 and stand volume growth between year 1 and 4. This effect was increased on plots that received a spring release treatment at year 2.
- Plots that received more intensive vegetation control treatments had larger trees and the FTO treatment had larger trees than the FOT treatment. This suggests that a spring release during the first growing season is more effective than a delayed treatment for sites represented by this study.

Introduction

The survival and growth of planted tree seedlings has been shown to be affected by both chemical vegetation control treatments and seedling stock size (Driessche 1992; Haase et al. 2006; Wagner et al. 2006). Although these factors have often been studied independently, few studies have investigated how interactions between vegetation management treatments and seedling stock size affect seedling survival and growth. The Combining Weed Control Intensity and Seedling Stock Size Part II Study (CW201) was established by the VMRC in 2011 to evaluate the effects of different combinations of vegetation control and Douglas-fir bareroot stock size on stand productivity on a dry site. The year 4 results of this experiment are presented in this report.

Methods

A brief synopsis of the methods used in measuring the seedlings and vegetation are included in this report. For a more detailed description of the full suite of measurements taken on this study site, please refer to the 2012/2013 VMRC Annual Report.

The CW201 study was established in 2011 on a well-drained site approximately 7.5 miles southeast of Drain, OR. The mean annual temperature and precipitation of the site are 54.2°F and 47.9 inches, respectively. The soil series corresponds to Yoncalla-Jory complex which is described as colluvium and residuum derived from basalt mesic Xeric Palehumults, with a silty-clay-loam texture in the upper soil layers. The study design is a 3 x 4 factorial of treatments where factor 1 corresponds to seedling stock size and factor 2 corresponds to vegetation management regime. This study design results in 12 individual treatment types (Table 1).

Table 1. Description of vegetation control and stock size treatments. Vegetation control treatments include a fall site preparation (FSP), a spring release in year 1 (SR1) and a spring release in year 2 (SR2).

Treatment	Vegetation Control		Stock Size
1	FOO :	FSP	Small
2	FOT :	FSP + SR2	Small
3	FTO :	FSP + SR1	Small
4	FTT :	FSP + SR1 + SR2	Small
5	FOO :	FSP	Medium
6	FOT :	FSP + SR2	Medium
7	FTO :	FSP + SR1	Medium
8	FTT :	FSP + SR1 + SR2	Medium
9	FOO :	FSP	Large
10	FOT :	FSP + SR2	Large
11	FTO :	FSP + SR1	Large
12	FTT :	FSP + SR1 + SR2	Large

Note: A "T" under a given vegetation control treatment denotes receiving a treatment while an "O" denotes not receiving the treatment. All plots received fall site preparation

The three seedling stock size classes are small, medium, and large bareroot seedlings. Seedling stock size was determined by root collar diameter (RCD) such that small, medium, and large seedlings had RCDs of 5-7 mm, 8-10 mm, and 11-13 mm, respectively. Vegetation control treatments included a fall site preparation only (FOO), a fall site preparation with a spring release during the second growing season (FOT), a fall site preparation with a spring release during the first growing season (FTO) and a fall site preparation with a spring release during both the first and second growing seasons (FTT). The fall site preparation treatment was applied in September of 2011 and consisted of 3.5 l ha^{-1} Accord XRT®, 730 ml·ha^{-1} Chopper®, and 35.1 g ha^{-1} Escort®. Spring release treatments were applied on designated plots in April of a given year and consisted of 2.2 kg ha^{-1} Velpar DF® and 876.4 ml ha^{-1} Transline®. Each of the treatments was replicated four times for a total of 48 plots. Bareroot Douglas-fir seedlings were planted at the site in January, 2012 at a 10 x 10 ft spacing. Seedlings were protected from ungulate browsing by Vexar tubing. Treatment plots were set up to encompass 80 x 80 ft and measurement plots consisted of 36 measurement trees surrounded by a single buffer row.

Seedling height, ground line diameter (GLD), and, when available, diameter at breast height (DBH) were measured in March of 2012 to assess baseline conditions and repeated during the dormant season of years 1-4. The understory community was sampled during July of growing seasons 1-5 on 5 permanent 1 m radius survey points per plot. Vegetation surveys included visual estimates of percent cover by species. Understory plant species were classified as having one of the following growth habits: forb, fern, graminoid, shrub, tree, or vine/shrub. Analysis of variance and regression analysis were used to test the effects of treatments on stand growth and vegetation community dynamics, including Tukey adjustments (PROC GLM and PRCO REG; SAS Institute Inc., Cary, NC, USA).

Results and Discussion

Table 2 provides a summary at age=4 years for mean height (HT, m), ground line diameter (GLD, cm), height to ground line diameter ratio (H/D, cm cm^{-1}), individual tree volume (I_VOL, cm^3), survival (TPA, trees $acre^{-1}$) and stand volume per acre (VOL, ft^3 $acre^{-1}$). There were no significant interactions between seedling stock size and vegetation control regime found when analyzing the year 4 inventory data. The lack of significant interactions between seedling stock size and vegetation control regime suggests that all of the seedling stock size classes are responding to the vegetation control treatments in a similar manner. Therefore, the effects of stock size class and vegetation control regime on stand growth will be discussed separately in this report.

Table 2. Treatment summary at age = 4 years for mean height (HT, m), ground line diameter (GLD, cm), height to ground line diameter ratio (H/D, cm cm^{-1}), individual tree volume (I_VOL, ft^3), survival (TPA, trees acre^{-1}) and stand volume per acre (VOL, ft^3 acre^{-1}).

Vegetation Management	Stock Size	HT (m)	GLD (cm)	H/D (cm cm^{-1})	I_VOL (ft^3)	TPA (trees acre^{-1})	VOL (ft^3 acre^{-1})
FOO	Large	1.1	2.2	51.7	0.0062	309	1.9
	Medium	1.3	2.1	61.3	0.0061	333	2.0
	Small	1.1	1.7	61.0	0.0033	366	1.2
FOT	Large	1.4	2.7	51.9	0.0105	384	4.0
	Medium	1.3	2.3	57.3	0.0068	318	2.1
	Small	1.2	2.3	56.3	0.0067	363	2.4
FOO	Large	1.4	2.8	49.3	0.0117	345	4.0
	Medium	1.4	2.5	54.6	0.0089	415	3.7
	Small	1.4	2.4	56.1	0.0081	381	3.1
FOT	Large	1.5	3.1	49.6	0.0155	412	6.4
	Medium	1.4	2.7	51.9	0.0101	412	4.2
	Small	1.3	2.5	51.7	0.0082	396	3.1

The initial inventory of seedlings at the study site in March of 2012 verified significant differences in the GLD, height and volume of seedlings of different stock sizes (Table 3). This initial inventory was important to confirm that the stock size classes were significantly different at the beginning of the experiment. Differences in the GLD and height of the stock size classes, however, have been decreasing over the last four growing seasons (Figure 1). At the time of the year 4 inventory there were no longer any significant differences in the GLD, height, height to diameter ratio (H/D) or volume of trees in the small and medium size classes ($p > 0.1$).

Table 3. Initial (year 0) and current (year 4) ground line diameter (GLD), height and volume for different Douglas-fir seedling stock sizes. Lower case letters represent statistical significance within columns and years.

Year	Stock Size	GLD (mm)	Height (cm)	Volume (cm^3)
0	Small	6c	33c	2.7c
0	Medium	8b	58b	9.5b
0	Large	11a	62a	20.1a
4	Small	22b	123b	186.5b
4	Medium	24b	133ab	226.6b
4	Large	27a	137a	309.7a

The GLD and volume of trees in the large size class continued to be greater than both the medium and small size classes ($p < 0.001$), but the height of the large size class no longer differed from the medium size class ($p = 0.41$). The height of the large size class was still larger than the small size class, but the magnitude of this difference has been decreasing over time such that the large size class was 29 cm taller than the small size class at year 0 and only 14 cm taller at year 4 (Figure 1b). Stem volume was 66% ($p<0.001$) and 21% ($p=0.003$) bigger in the large and medium size classes when compared with the small size class seedlings (Figure 1c).

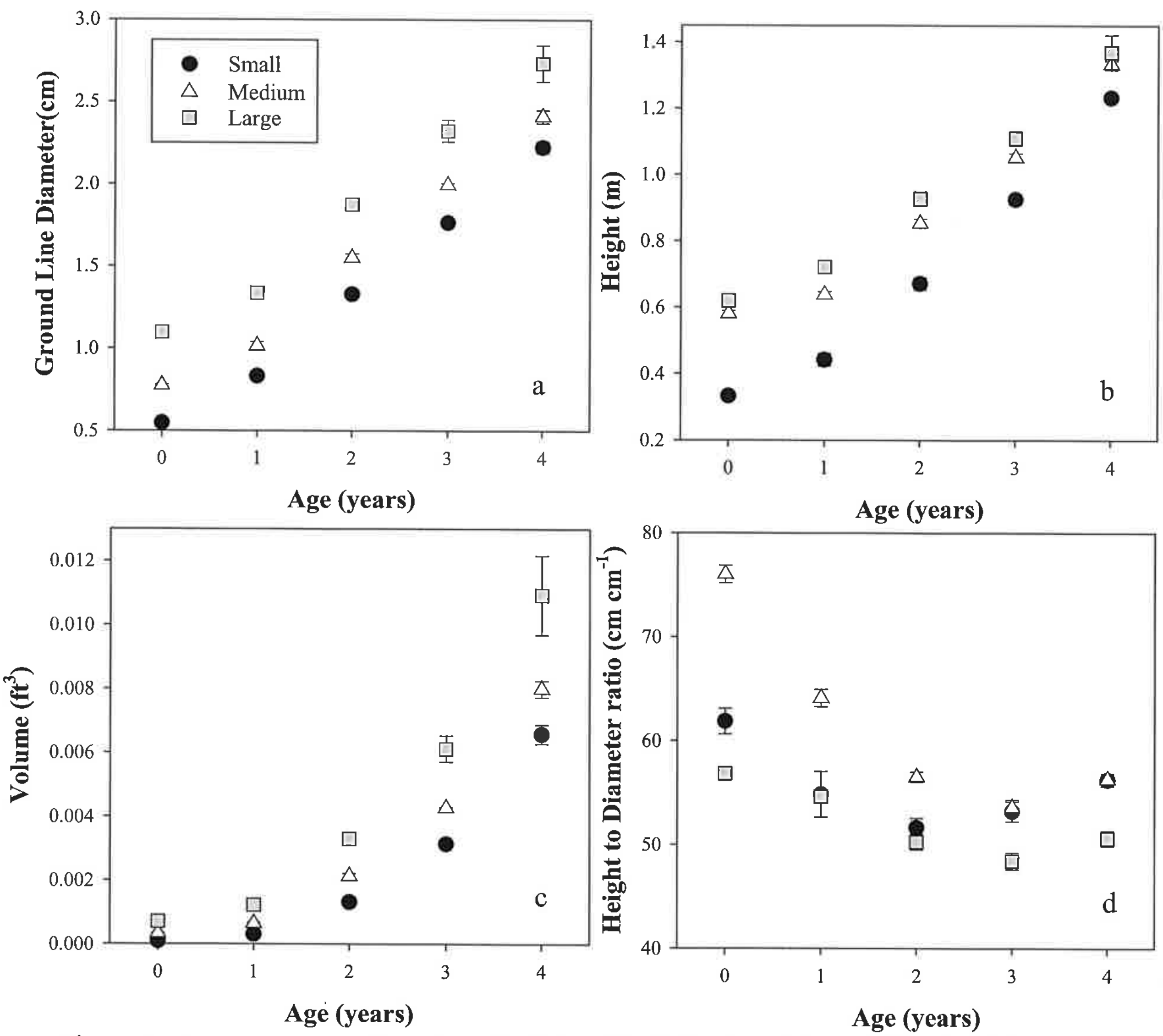

Figure 1. Average ground line diameter (a), height (b), stem volume (c) and height to diameter ratio (d) for Douglas-fir seedlings of different stock sizes.

There was a trend for volume per acre to increase with increasing stock size. At age 4, the large and medium stock sizes had 67% ($p<0.001$) and 23% ($p<0.001$) more volume per acre than the small stock size, respectively (Figure 2a). Survival was not affected by stock size class ($p=0.65$) and averaged 15% across all stock size classes (Figure 2b).

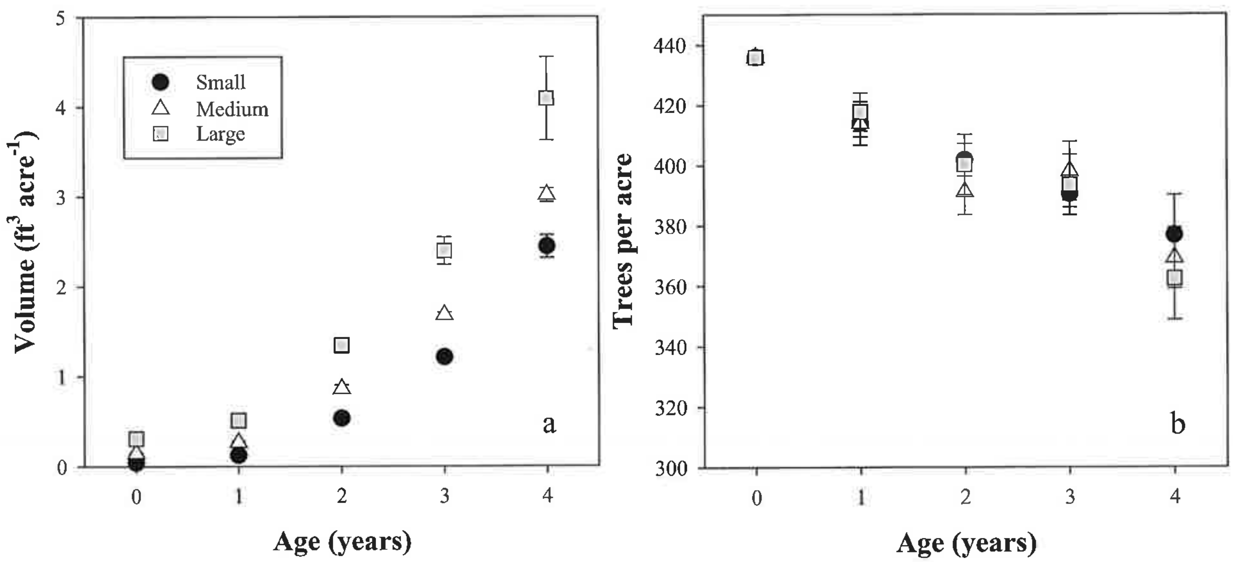

Figure 2. Average volume per acre (a) and trees per acre (b) for Douglas-fir seedlings of different stock sizes.

The differences between the stock size classes at year 4 suggest that planting a large seedling will produce four-year-old trees with larger individual volumes and GLDs than small or medium size seedlings. This difference in tree size at year 4, however, may not necessarily lead to long term volume gains. There were no differences in the survival of seedlings of different size classes suggesting that any of the stock sizes can be utilized in an operational setting. Additionally, differences in the height and GLD of the stock size classes have been decreasing over time. One important factor not considered in this study, however, is seedling damage produced through ungulate browsing. The larger stock size seedlings grow above the browse line faster than smaller seedlings possibly reducing tree mortality and defects such as forking. Growth assessments will continue in order to confirm long-term effects of initial stock size.

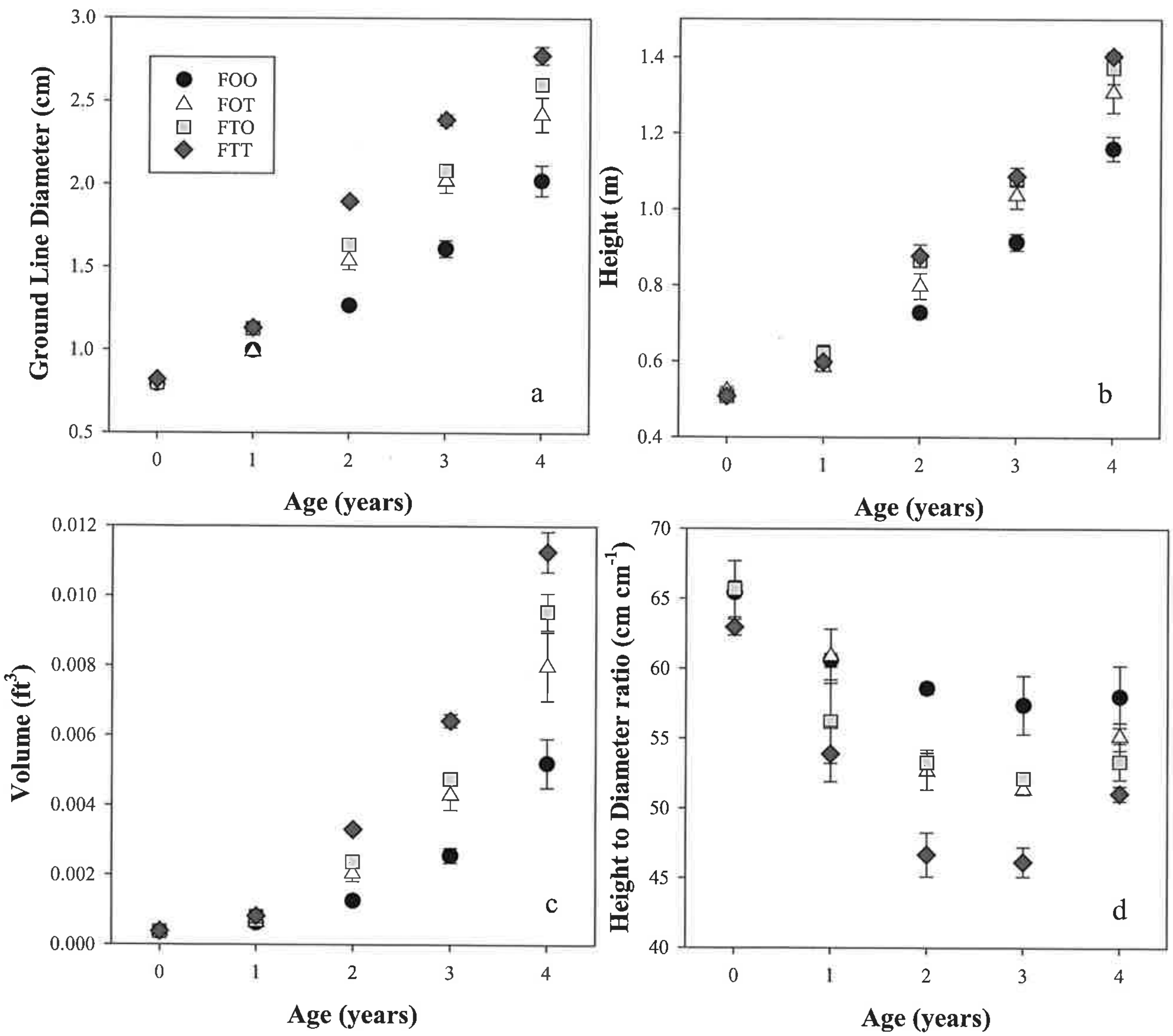

Figure 3. Average ground line diameter (a), height (b), stem volume (c) and height to diameter ratio (d) for Douglas-fir seedlings growing under different vegetation management treatments.

The effects of the vegetation management treatments on tree growth have become more pronounced over time. After four growing seasons, plots treated with more intensive vegetation management treatments tended to have larger trees, however these differences were not always significant (Figure 3). Trees in the fall site preparation only treatment (FOO) had significantly smaller GLDs, heights, and volumes than all other treatments ($p < 0.001$). Conversely, trees in the FTT treatment had larger GLDs, heights, and volumes than all other treatments, however these differences were not always significant. Trees in plots treated with a spring release during the first growing season (FTO) had larger GLDs, heights, and volumes than trees in plots treated with a spring release during the second growing season (FOT), but these differences were not statistically significant ($p > 0.14$).

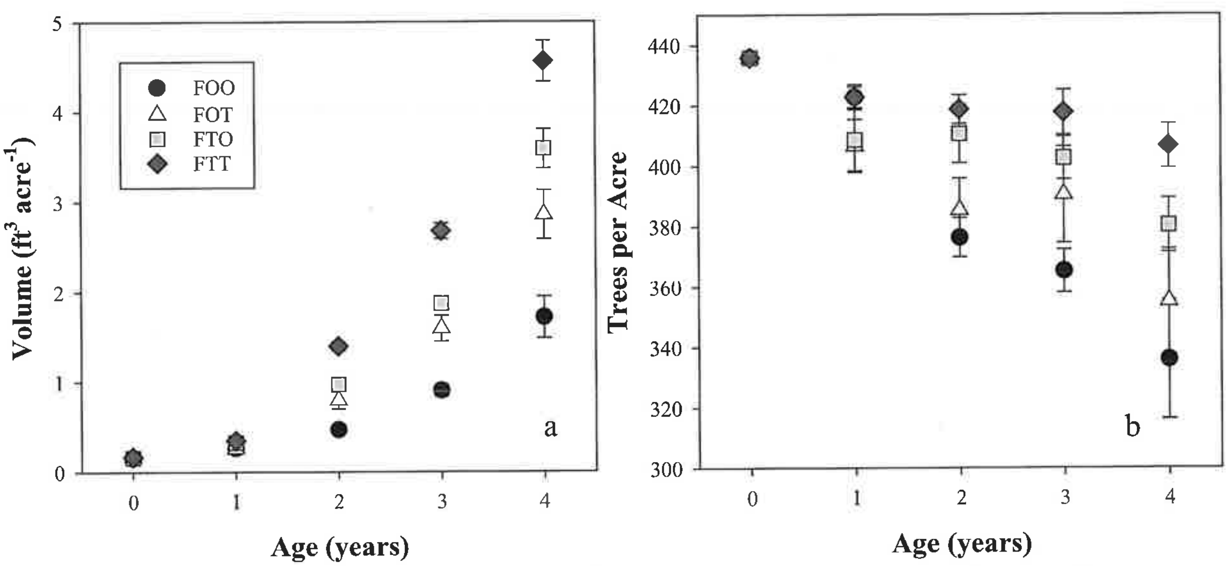

Figure 4. Average volume per acre (a) and trees per acre (b) for Douglas-fir seedlings growing under different vegetation management treatments.

When analyzed at the stand level, plots treated with more intensive vegetation management had better survival and stand volume (Figure 4). Plots with 2 years of spring release treatments (FTT) had 166% and 27% larger stand volume than plots with no (FOO) or one year (FTO) of spring release ($p<0.001$). The FTO treatment tended to have better survival and stand volume than the FOT treatment, but these differences were not significant (p=0.17 and 0.10, respectively).

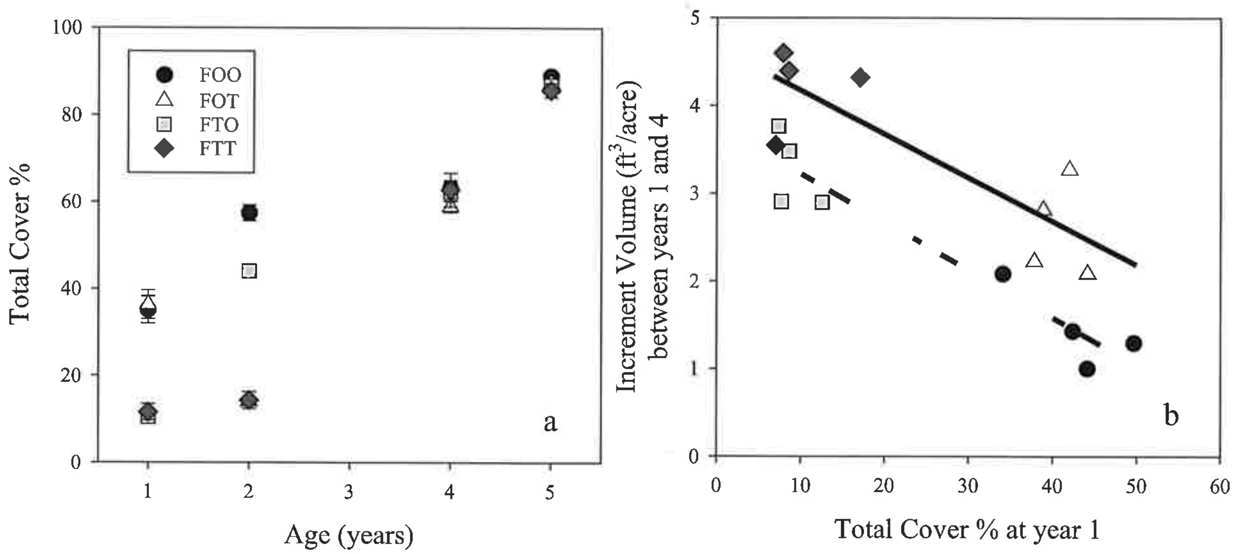

Figure 5. Time series of total vegetation cover (a) and relationship between total vegetation cover at year 1 and stand volume growth between years 1 and 4 (b) for plots with different vegetation management treatments.

The increase in tree growth with increasing vegetation management intensity observed in this study is consist with the results of other VMRC studies. This increase in growth is the result of decreased competition with understory species. During the first growing season plots treated with a spring release treatment (FTO and FTT) had 25% less understory cover than untreated plots (11% vs 36%) (Figure 5a). This reduction in understory cover decreased competition and as a result the soil moisture of treated plots was 21% greater than untreated plots during the 2012 growing season (2012/2013 VMRC annual report; data not shown). The spring release during the second growing season significantly affected vegetation cover. This treatment decreased the vegetation cover of the FOT treatment from 36% in year 1 to 14% in year 2 and held the vegetation cover of the FTT treatment below 20%. By the fifth growing season, however, there were no longer any differences in total understory cover among any of the vegetation control treatments.

There was a strong relationship between total vegetation cover at year 1 and stand volume growth between years 1 and 4 (Figure 5b). This relationship was different for plots that received a spring release treatment during the second year (FOT and FTT; $p<0.001$; $R^2=0.72$)

and those that did not (FOO and FTO; $p<0.001$; $R^2=0.92$). The second year spring release treatment increased stand volume growth by 29% for the FOT treatment and by 79% for the FTT treatment. This finding supports the positive effects of competing vegetation control on Douglas-fir seedlings growth. The FOT treatment tended to have less tree growth than the FTO treatment ($p=0.10$), suggesting that applying a spring release during the first growing season, when seedlings are becoming established, may be more effective than a delayed treatment.

Conclusions

There were no significant interactions between stock size and vegetation management treatment suggesting that all stock sizes are responding to the vegetation management treatments in a similar manner. After four growing seasons, plots planted with large seedling stock continued to have larger trees than plots planted with medium and small stock, but differences in tree size are becoming less apparent over time. There was a strong relationship between vegetation cover at year 1 and stand volume growth. Plots receiving more intensive vegetation control treatments had larger trees and the FTO treatment tended to have larger trees than the FOT treatment. This suggest that applying a spring release during the first growing season is more effective than a delayed treatment.

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Using Age-Shift Method to Estimate Long-Term Gains of Vegetation Management

Carlos Gonzalez-Benecke and Maxwell Wightman

Highlights

In studies testing number of years of competition release, age shift was maximized with 5 years of spring release in all species:

- Age shift response ranged between 0 to 7.7 years.
- On both sites, western red cedar showed larger age shift than Douglas-fir.
- One year of spring release showed no effect on Douglas-fir and western hemlock.
- Thinning boosted age shift responses in Douglas-fir.

In studies testing area of control:

- Age shift was maximized with > 4 ft radius vegetation to control.

Introduction

Age shift (or time gain) is an alternative method for analyzing long-term responses to silvicultural treatments that focuses on determining the number of years of advancement in growth realized at a given age (Lauer et al., 1993). The growth increment is expressed as the difference between the current age of the untreated stand and the age at which the treated stand had the same yield (Wagner et al., 2006). Because age-shift is independent of tree size, the age-shift method is more useful than percentage gain for evaluating long-term responses to silvicultural treatments, such as fertilizer application (Mason and Milne, 1999), vegetation management (Lauer et al. 1993; South et al., 2006; Wagner et al., 2006; Maguire et al., 2009; Watt et al., 2015) and even biosolid treatments (Kimberley et al., 2004).

In this study we analyzed long-term responses to vegetation management treatments using the age-shift approach. We selected 4 study sites that have the longest response periods in the VMRC dataset. The selected studies are the critical period threshold (CPT) studies installed in 2000 (CPT01) and 2001 (CPT02) and the HERB1 studies installed in 1993 (HER01 and HER02). A summary of the study sites selected for this analysis is provided in Table 1.

Table 1. Description of selected study sites.

Study	Study Name	Site	Land Owner	Planting Year	Final Age	Soil Texture	Annual Rainfall (mm)
CPT01	CPT*	Summit	Starker Forests	2000	15	fine-loamy	1707
CPT02	CPT**	Sweet Home	Cascade Timber	2001	14	silty-clay-loam	1179
HER01	HERB1	Marcola	Wayerhouser	1993	20	silty-clay-loam	1329
HER02	HERB1	Summit	Starker Forests	1993	20	fine-loamy	1726

Note: CPT: Critical Period Threshold
*: Include Douglas-fir, western Hemlock, western red cedar and grand fir.
**: Include Douglas-fir and western red cedar.

Methods

The four studies used for this analysis correspond to the oldest VMRC studies with available data. Two of the studies are part of the critical period threshold project, where the main objectives were to determine the number of years of vegetation control required to maximize tree growth and to determine the level of growth loss that results from delaying vegetation control for one or two years. The other two studies were part of the HERB1 project, where the main objectives were to determine the area of seedling-centered weed control required to maximize growth and to analyze the relative influence of herbaceous-only and woody-only vegetation control on Douglas-fir growth. Detailed descriptions of the studies selected for this analysis can be found in Mason et al. (2007), Maguire et al. (2009), Rose et al. (1999, 2006) and Rosner and Rose (2006). Table 2 shows details of the treatments applied at each study.

The age-shift method requires plotting stand volume over time for treated and untreated plots and then calculating the difference in time required to reach a selected yield, using the untreated stand as a reference (Figure 1). A non-linear model reflecting the relationship between age (years) and stand volume (ft^3 $acre^{-1}$) was fitted for each time series plot. Similar to Watt et al. (2015), several non-linear models were tested and the final model selected was:

$$\text{Vol} = a \cdot \text{age}^{b} \qquad \text{Eq. 1}$$

where Vol is stand volume (ft^3 $acre^{-1}$), age is stand age (years since planting) and a and b are curve fit parameters.

Table 2. Description of treatments tested.

Study Name	Treatment	Description
CPT*	OOOOO	No spring release
	TOOOO	Spring release during year 1
	TTOOO	Spring release during year 1 and 2
	TTTOO	Spring release during year 1, 2 and 3
	TTTTO	Spring release during year 1, 2, 3 and 4
	TTTTT	Spring release during year 1, 2, 3, 4 and 5
	OOTTT	Spring release during year 3, 4 and 5
	OTTTT	Spring release during year 2, 3, 4 and 5
HERB1**	Control	No control
	1 ft	Spot application 1 ft radius
	2ft	Spot application 2 ft radius
	3 ft	Spot application 3 ft radius
	4ft	Spot application 4 ft radius
	5 ft	Spot application 5 ft radius (Total Control)
	Herb	Selective control: Only herbaceous vegetation
	Woody	Selective control: Only woody vegetation

*: all plots received a fall site preparation treatment.
**: spring application in years 1 and 2

Within each block of each study, all treated plots were compared against untreated plots (OOOOO in CPT01 and CT02; control in HER01 and HER02) and the age at which the Vol of treated plots was equal to the Vol of the untreated plot was calculated for each measurement age. In the example shown in Figure 1, the T1 and T2 plots were compared with the Control plots at age=20 years and the age at which the Vol of T1 and T2 was equal to the Vol of Control was calculated. The same procedure was repeated for all treated plots within each block of each study for all measurement dates. Non-linear model fitting was used to estimate age-shift and analysis of variance was used to test the effects of treatments on age-shift (PROC NLIN and PRCO REG; SAS Institute Inc., Cary, NC, USA).

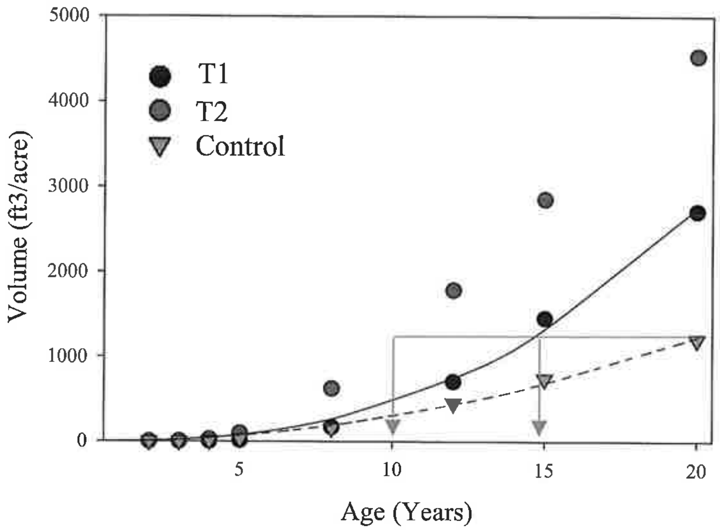

Figure 1. Example of age-shift calculation. In this example the age-shift for T1 was 10 years (20-10) and the age-shift for T2 was 5 years (20-15).

Results and Discussion

All model performance tests showed that volume per acre estimations using Eq. 1 agreed with measured values (Table 3). Across all sites and species, the bias ranged between 1.8 to 4.4% over-estimations. Estimated and observed values were highly correlated, with R^2 values larger than 0.99.

Table 3. Summary of evaluation statistics for volume per acre estimated with Eq. 1 for stands growing under different vegetation control treatments in the CPT and HERB1 studies.

Study	Species	$\overline{O}$	$\overline{P}$	n	RMSE	Bias (%)	R^2
CPT01	Douglas-fir	770.2	793.2	191	126.2	3.1	0.970
	Western hemlock	601.2	614.7	160	44.4	2.3	0.997
	Western red cedar	278.4	287.9	120	27.4	3.4	0.995
	Grand fir	505.2	514.5	120	26.1	1.8	0.998
CPT02	Douglas-fir	508.3	519.8	144	73.6	2.3	0.985
	Western red cedar	166.6	170.1	131	17.7	2.1	0.995
HER01	Douglas-fir	866.2	904.6	190	110.5	4.4	0.992
HER01	Douglas-fir	844.8	880.2	182	105.4	4.2	0.991

As was reported in Maguire et al. (2009) and Rose et al. (1999, 2006), vegetation management treatments had a strong effect on volume yield in VMRC studies. When volume gain was expressed as time gain (age-shift), the gain ranged between 0 to 10 years, depending on age of evaluation, species, site and vegetation control treatment applied (Figures 2 to 4).

For Douglas-fir, stands growing on the Coastal Range site (Summit; Figure 2), treatments with 4 or 5 years of consecutive spring release showed about 2 years of age-shift, while treatments with 1-3 years of consecutive spring release treatment showed no gain in age-shift. The age-shift gain changed over time with a trend to decrease until age = 12 years, when a pre-commercial thinning was carried out. After the thinning, the difference between the control (OOOOO) and treated plots increased, reaching quasi-stable values between 1 and 2 years of time gain. On the other hand, many of the western hemlock treatments had a trend of increasing age-shift gain over time. Western hemlock growing under any of the vegetation control treatments had an early gain of 2-3 years, but the long-term changes in age-shift were different for the different treatments (Figure 2b). After sixteen years, the age-shift of plots treated with 1 year of spring release was reduced close to 0, the early 2-3 years of age-shift was maintained in plots treated with 2 or 3 years of spring release and the age shift of plots treated with 4 or 5 years of spring release increased to between 6-7 years. Plots that received delayed control for 3 or 4 years also showed 6-7 years of age-shift. For western red cedar the age-shift of all treatments increased through time from 3.5 years of age-shift at age 4 to 5 to 8 years of age-shift at age 16 (Figure 2c). The response of grand fir was similar to western hemlock, but plots that received delayed control (OOTTT and OTTTT) showed a constant gain of about 3 years (Figure 2d).

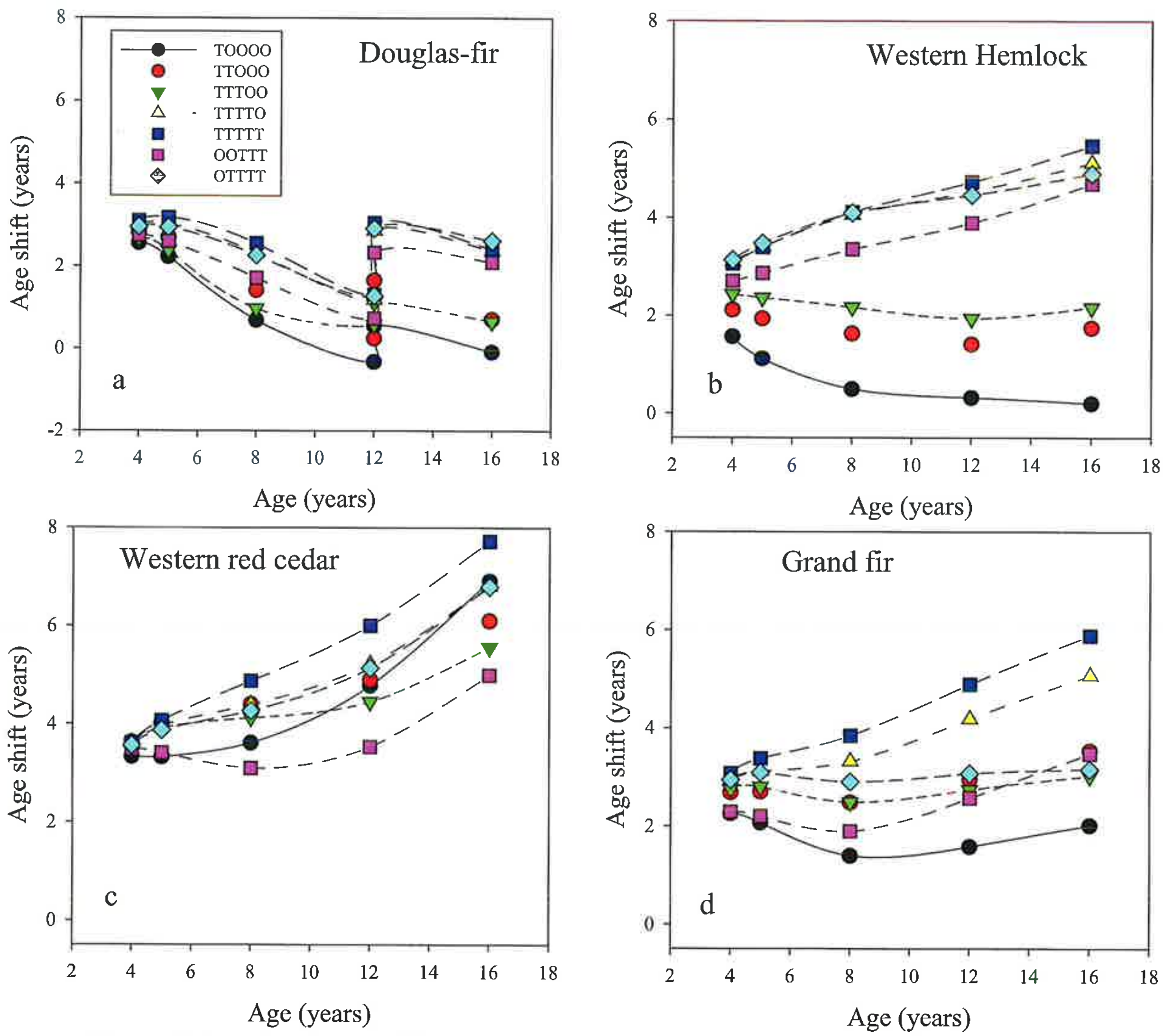

Figure 2. Predicted age-shift as a functions of age for Douglas-fir (a), western hemlock (b), western red cedar (c) and grand fir (d) stands growing under different treatments of vegetation control on a site located in the Coast Range (CPT01, Summit). Age shift is shown as a difference against treatment OOOOO.

For Douglas-fir stands growing on a site located in the foothills of the Cascade Mountains (Sweet Home; Figure 3a), treatments with 5 years of consecutive spring release showed about 4 years of age-shift, while treatments with 1-4 years of consecutive spring release treatment showed about 2 years of age-shift. Similar to the Coastal range site, plots with 1 year of spring release treatment showed less than one year of time gain (Figure 3a). Western red cedar was more responsive showing age-shifts between 2.5 to 4 years. Plots that received delayed spring release (OOTTT) showed lower response than plots that received one year of treatment (TOOOO). Plots that received 5 years of consecutive spring release continued separating showing age-shift of 6 years (Figure 3b).

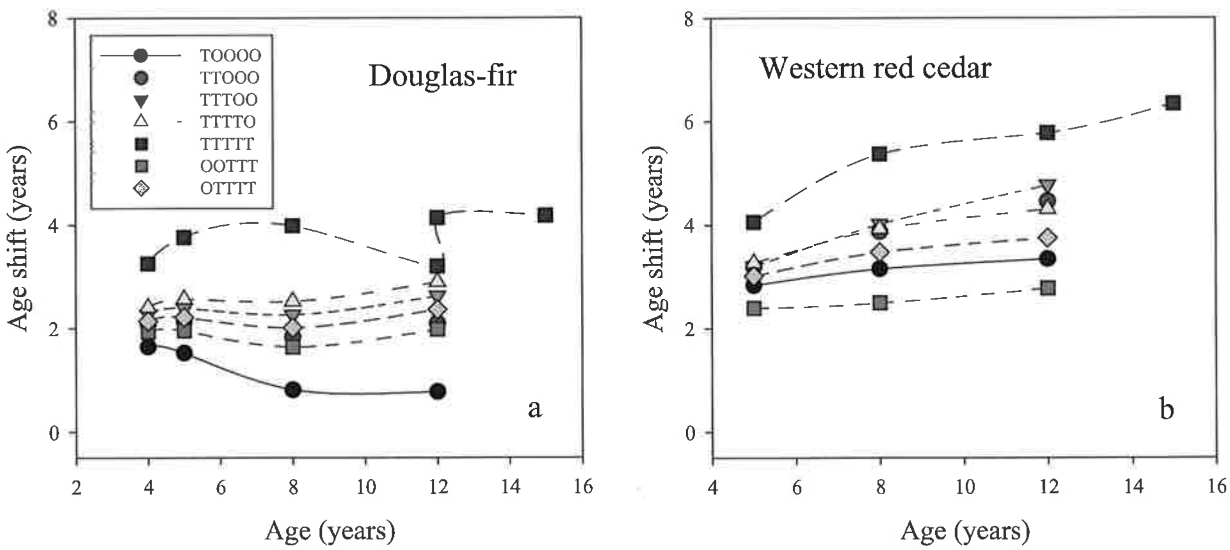

Figure 3. Predicted age-shift as a functions of age for Douglas-fir (a) and western red cedar (b) stands growing under different vegetation control treatments on a site located in the foothills of the Cascade Mountains (CPT02, Sweet Home). Age shift is shown as a difference against treatment OOOOO. Only plots with treatments OOOOO and TTTT were measured at age=15 years.

The age-shift response of treatments at the two HERB 1 study sites were very different. For the stand growing on the Coast Range site (Summit; Figure 4a), age-shift continued to increase as the stand aged for all treatments. For example, at age = 5 years, age-shift was between 2-3.5 years, while at age = 20 years, age shift was between 6 to 10 years. On the site located on the foothills of Cascade Mountains (Marcola; Figure 4b) early gains in age-shift were reduced from 2.5-3.5 years at age = 5 years to 0-2 years at age = 20 years. On both sites, treatments that included control only for woody species showed a smaller response than treatments that received herbicide control only for herbaceous species.

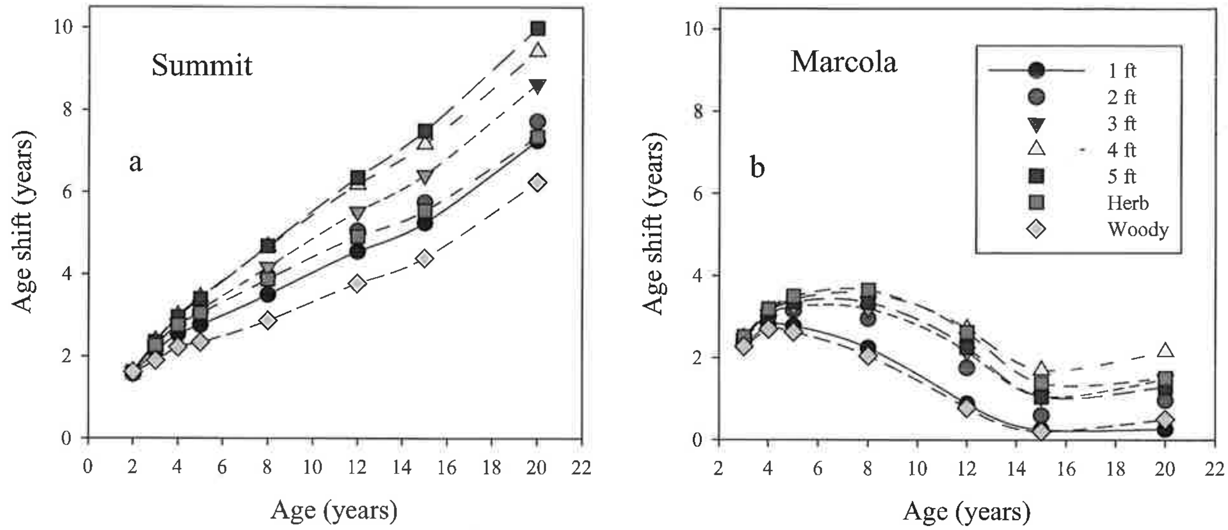

Figure 4. Predicted age-shift as a functions of age for Douglas-fir stands growing under different vegetation control treatments on sites located (a) in the Coast Range (HER01, Summit) and (b) in the foothills of the Cascade Mountains (HER02, Marcola). Age shift is shown as a difference against treatment control.

The summary of age-shift at the CPT studies is shown in Figure 5. The Coastal Range site was evaluated at an age of 16 years, while the site located at the foothills of Cascade Mountains was evaluated at an age of 12 years. For Douglas-fir growing at the Coastal Range site (Figure 5a), one (TOOOO) or two (TTOOO) years of spring release treatment did not produce a change in age-shift, while three (TTTOO) and four (TTTTO) years of spring release increased age-shift to 1.5 and 2.5 years, respectively. At the site located in the foothills of the Cascade Mountains (Figure 5b), Douglas-fir response was larger, increasing age-shift from 1 to 3.5 years as years of spring release increased from 1 (TOOOO) to 5 (TTTTT). The time gain in western red cedar was larger than Douglas-fir at both sites, averaging 5.5 and 7.5 years age-shift for plots that received 1 or 5 years of spring release at the Coastal Range site, while at the site located in the foothills of the Cascade Mountains the gain was between 3.5 to 6 years, respectively.

At an age of 16 years, western Hemlock showed a time gain that ranged between 2 to 6 years for plots that received one or five years of spring release, respectively. The age-shift response of grand-fir was similar to western hemlock for plots that received 5 years of spring release, but for plots that received one year of spring release, the age-shift was null. For grand fir, two years of spring release produced a time gain of 2 years.

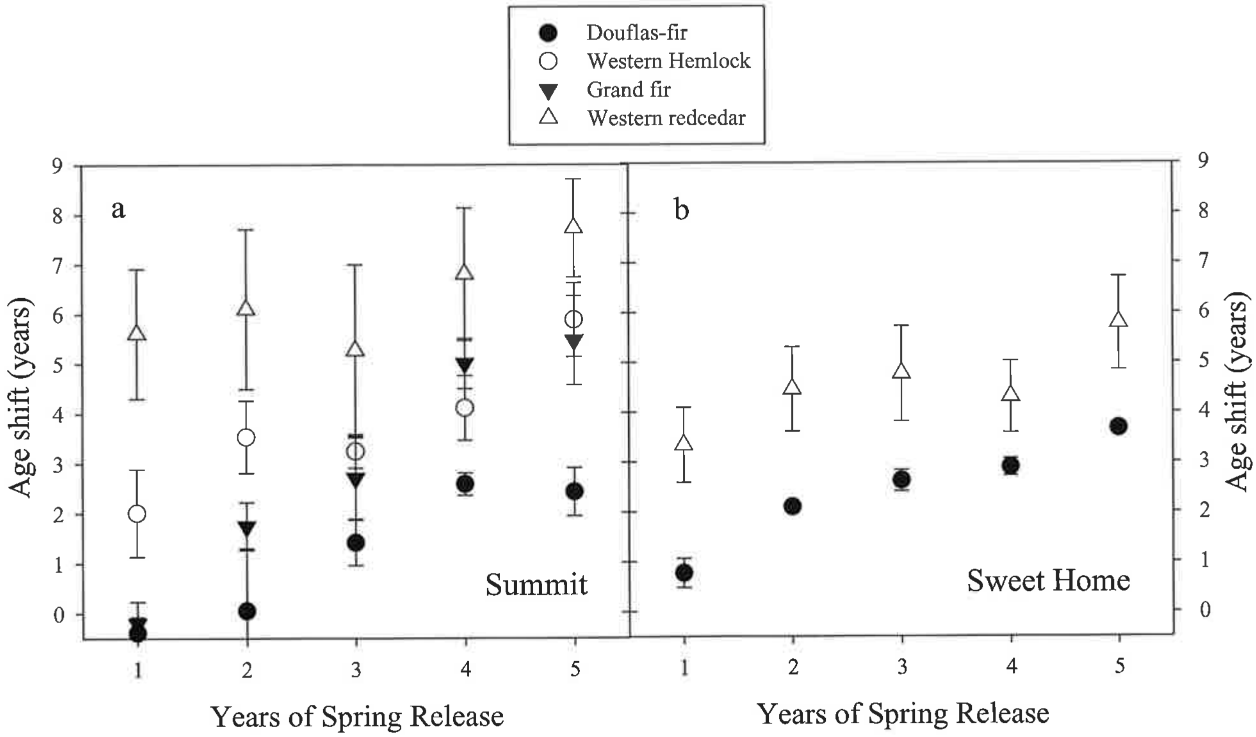

Figure 5. Predicted age-shift as a functions of age for Douglas-fir, western hemlock, western red cedar and grand fir stands growing under different treatments of vegetation control at the CPT studies located in (a) the Coast Range (CPT01, Summit, age=16 years) and (b) the foothills of the Cascade Mountains (CPT02, Sweet Home, age=12 years). Age shift is shown as the difference against treatment OOOOO.

The summary of age-shift at the HERB1 studies is shown in Figure 6. Both sites were evaluated at age=20 years. At the Coastal Range site (Summit), increasing radius of spot control from 1 to 5 ft, increased age-shift from 7 to 10 years. This large effect of vegetation control treatments contrasts with the results from a similar site evaluated in the CPT study. Aggressive invasion of cherry trees (*Prunus emarginata*) overtopped Douglas-fir seedlings that receive no vegetation management treatment (control) at the Summit HERB1 study and this effect was not observed to the same extent at the Summit CPT01 site. The cover of cherry trees in plots that received two years of spot herbicide application was drastically reduced (data not shown) at the HERB1 summit site. Further details of competing vegetation dynamics is shown in Rose et al.

(1999) and Rosner and Rose (2006). At the foothills of the Cascade Mountains site (Marcola), there was no effect of herbicide application at 1 ft treatment radius. Age-shift averaged 1, 1.5 and 2 years, for plots with treatment radius of spot control of 2, 3 and 4 ft, respectively.

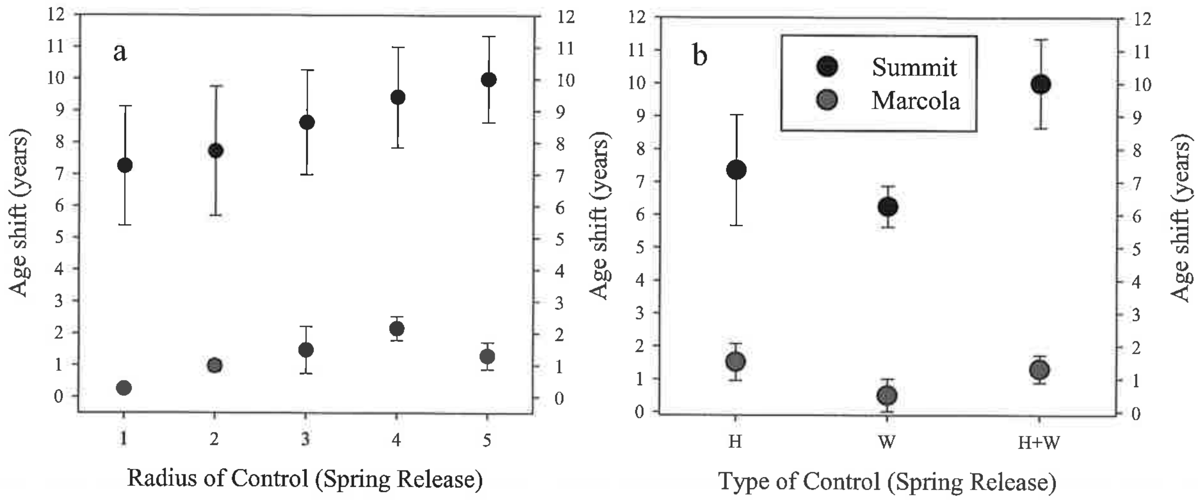

Figure 6. Predicted age-shift as a functions of age for Douglas-fir stands growing under different vegetation control treatments at the HERB1 studies located in the Coast Range (HER01, Summit, age=20 years) and in the foothills of the Cascade Mountains (HER02, Marcola, age=20 years). For type of control: H=Herbaceous; W=Woody. Age shift is shown as the difference between the treatment and the control.

On both sites woody-only control showed smaller response (6 years at Summit, 0.5 years at Marcola) when compared to herbaceous-only control (7.5 years at Summit, 1.5 years at Marcola). The application of a mix that controls both, herbaceous and woody vegetation, did not produce further gain in Marcola, but increased age-shift to 10 years at the Summit site (Figure 6b).

Conclusions

This study shows an alternative analytical approach to assess medium to long-term responses to vegetation management treatments. The results show that the responses are site-and-species dependent. Douglas-fir had age-shifts ranging between 0 to 10 years, depending on site and vegetation management treatment applied. When compared at the same site, western red cedar was more responsive to treatments and had age-shifts that were 2-6 years larger than Douglas-fir. Age-shift analysis can be used to support decision making about thinning and rotation length making it a useful tool in economic analysis. Further assessments are needed to corroborate these results for different sites and older stands.

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Use of Water Stress Integral to Evaluate Moisture Stress in Douglas-fir Trees

Carlos Gonzalez-Benecke and Eric Dinger

Highlights

For first two growing seasons:

- Water Stress Integral (WSI) is a practical index of seasonal water stress.
- WSI is correlated with tree growth.
- Xylem water potential evaluated in early August can be used as a surrogate of WSI and, therefore, of whole season productivity.
- Volumetric water content can be used as a surrogate of xylem water potential and, therefore, of WSI and whole season productivity.

Introduction

One of the main objectives of the Evaluating Common Regimes Study (ECR01) was to quantify the impact of six herbaceous vegetation control regimes on Douglas-fir xylem water potential and soil moisture dynamics (VMRC 2005/2006 report). Previous VMRC annual reports have provided early results from this study site analyzing differences in seedling growth, vegetation cover and species richness. In addition, Dinger and Rose (2009, 2010) reported seedling growth, xylem water potential and soil moisture dynamics during the first two growing seasons. They concluded that the initial fall-spring vegetation management regimes improve soil moisture and plant water relations conditions, increasing Douglas-fir seedling growth.

Water Stress Integral (WSI) corresponds to the summation of pre-dawn water potential measurements over a chosen period of time (Myers, 1988) and has been used as an index of seasonal plant water stress. WSI has been shown to be well correlated with productivity (Hanson et al., 2001; Fernandez 2010; De la Rosa, 2016), mortality (Hanson et al., 2001; Nepstad et al., 2007) and has even been used for irrigation management in agricultural crops (Ballester et al., 2013). Dinger and Rose (2009, 2010) used the xylem water potential and soil moisture dataset for ANOVA tests, but no correlations between Douglas-fir productivity and plant water stress or soil water availability were reported. In this study we tested the use of WSI as a tool to link plant water stress and growth in Douglas-fir seedlings growing under contrasting vegetation management treatments.

Methods

A detailed description of the full suite of measurements taken at this study site can be found in Dinger and Rose (2009, 2010) or in the 2005/2006 VMRC Annual Report. Briefly, the Evaluating Common Regimes study contains six vegetation management treatments (Table 1) arranged in a randomized complete block design with four replications on 80 x 80 ft treatment plots. Douglas-fir seedlings (bareroot 1 + 1) were planted on February 25, 2006 at a spacing of 10 x 10 ft. Measurements of seedling height and basal diameter were taken in October 2006 and 2007 (growing seasons 1 and 2) in the central 60 x 60 ft measurement plots allowing for a 1 tree buffer on all sides. The study area was surrounded by a perimeter fence prior to planting to protect seedlings from ungulate browsing damage. The average precipitation is 1450 mm (57.4 inch), with only 110 mm (4.3 inch) occurring between July and September. Soils are fine-loamy with an argillic horizon at 50-70 cm depth (Dinger and Rose, 2009).

Table 1. Description of treatment regimens tested.

Treatment		Year
1	O / O	No Control
2	F / O	Fall Site Prep
3	F / S	Fall Site Prep + Spring Release Year 2
4	FS / S	Fall Site Prep + Spring Release Year 1 + Spring Release Year 2
5	FSG / S	Fall Site Prep + Spring Release Year 1 + Glyphosate Release Year 1 + Spring Release Year 2
6	FSG / SG	Fall Site Prep + Spring Release Year 1 + Glyphosate Release Year 1 + Spring Release Year 2 + Glyphosate Release Year 2

Details on application date, method and chemicals applied can be found in Dinger and Rose (2009).

Xylem water potential (Ψ, MPa) was measured using a portable pressure chamber (PMS 600; PMS Instruments Co., Oregon, USA) biweekly from May to October in 2006 and 2007. Two seedlings per plot were measured at pre-dawn (4:00-6:00) and midday (12:00-14:00). On each selected seedling, one branch tip of 8 cm length was cut and measured within 3 minutes of shoot excision. After shoot excision samples were covered with wet towels, placed inside a plastic bag and stored inside an insulated box to minimize desiccation. On the same dates when xylem water potential was measured, soil volumetric water content (θv, $cm^3\ cm^{-3}$) was measured on seven points in each plot using a 20 cm-long time domain reflectometry (TDR) soil moisture probe (Hydrosense CS 620, Spectrum Technologies, Illinois, USA).

Following Myers (1988), water stress integral (WSI, MPA day) was computed as the summation of pre-dawn water potential (Ψ_{PD}) on every day during the period of interest (May to October). WSI was estimated from12 Ψ_{PD} measurements in 2006 and 9 Ψ_{PD} measurements in 2007 at intervals of n days as follows:

$$WSI = \Sigma(\Psi_{i,i+1} - c) \cdot n$$

where $\Psi_{i,i+1}$ is the mean Ψ_{PD} for any interval i,i+1, c is the datum values or maximum (less negative) Ψ_{PD} measured, and n is the number of days in each interval. In our dataset, c = -0.15 MPa.

Stem volume was computed from dormant season measurements of ground line diameter and height, assuming the stem as a cone. Analysis of variance was used to test the effects of treatments on stand growth, volumetric water content and xylem water potential and correlation analysis was used to test the relationship between WSI and Douglas-fir stand growth (PROC GLM and PRCO REG; SAS Institute Inc., Cary, NC, USA).

Results and Discussion

The data shown in Figure 1 was already reported in Dinger and Rose (2009, 2010). It is included in this report to reinforce the strong effect of rainfall and vegetation management on soil moisture and plant water stress dynamics in young Douglas-fir stands. The growing season of 2006 was dryer than that of 2007 and the total accumulated precipitation during these growing seasons (March 1st to October 31st) was 203 and 478 mm, respectively. During the summer (June-August) of 2006 the total precipitation was 46.4 mm, while during the summer of 2007 total precipitation was 82.0 mm (Figure 1a and b).

Vegetation management treatments created a large gradient in soil moisture and plant water stress (Figure 1 c to f). This effect was more accentuated in 2006 than in 2007 due to lower summer precipitation. For example, in 2006 (Figure 1 c and e), treatments that did not included a spring release (T1, T2 and T3) had lower θv and Ψ_{PD} than in 2007 ($p<0.001$). During 2007 (Figure 1 d and f), plots that received glyphosate during the summer of the first growing season (T5) and during the summer of the first and second growing seasons (T6) had higher θv and Ψ_{PD} ($p<0.001$). The control treatment (T1) continued to have lower θv and Ψ_{PD}, even though rainfall was high ($p<0.044$).

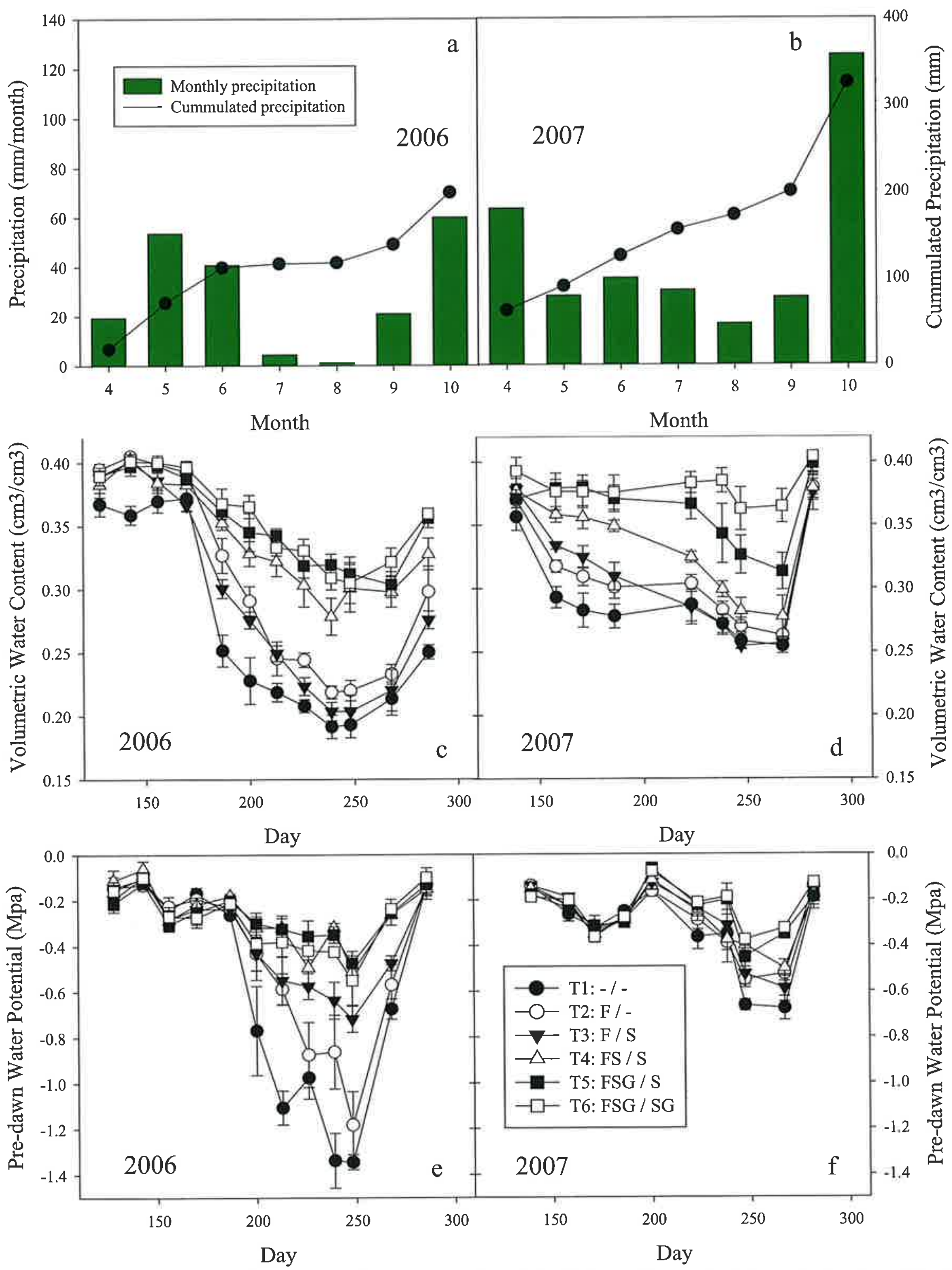

Figure 1. Monthly (green bar) and cumulated (solid line) precipitation between March 1st, 2006 and October 31st, 2007 (a, b), and treatment effects on volumetric water content (c, d) and pre-dawn water potential (e, f) for the 2006 and 2007 growing seasons. For panels c to f, each point is the mean of 4 plots (data from Dinger and Rose, 2009).

In 2006 the total WSI for T1 was -98 MPa day, while treatments that received a spring release reached a WSI of about -45 MPa day (Figure 2 a and b). Treatments started to separate by July 7th, and reached a difference of about -20 MPa day 15 days later. Similar to θv and Ψ_{PD}, this effect was more accentuated in 2006 due to lower precipitation. In 2007, T1 had the lowest total WSI, reaching -55 MPa day, while T5 and T6 reached a WSI of -37 MPa day. Similar to WSI, vegetation management treatments created a large gradient in stand volume growth. In both growing seasons, treatments that received more intensive vegetation management had larger volume growth and control plots (T1) showed the lowest volume growth (Figure 2 c and d).

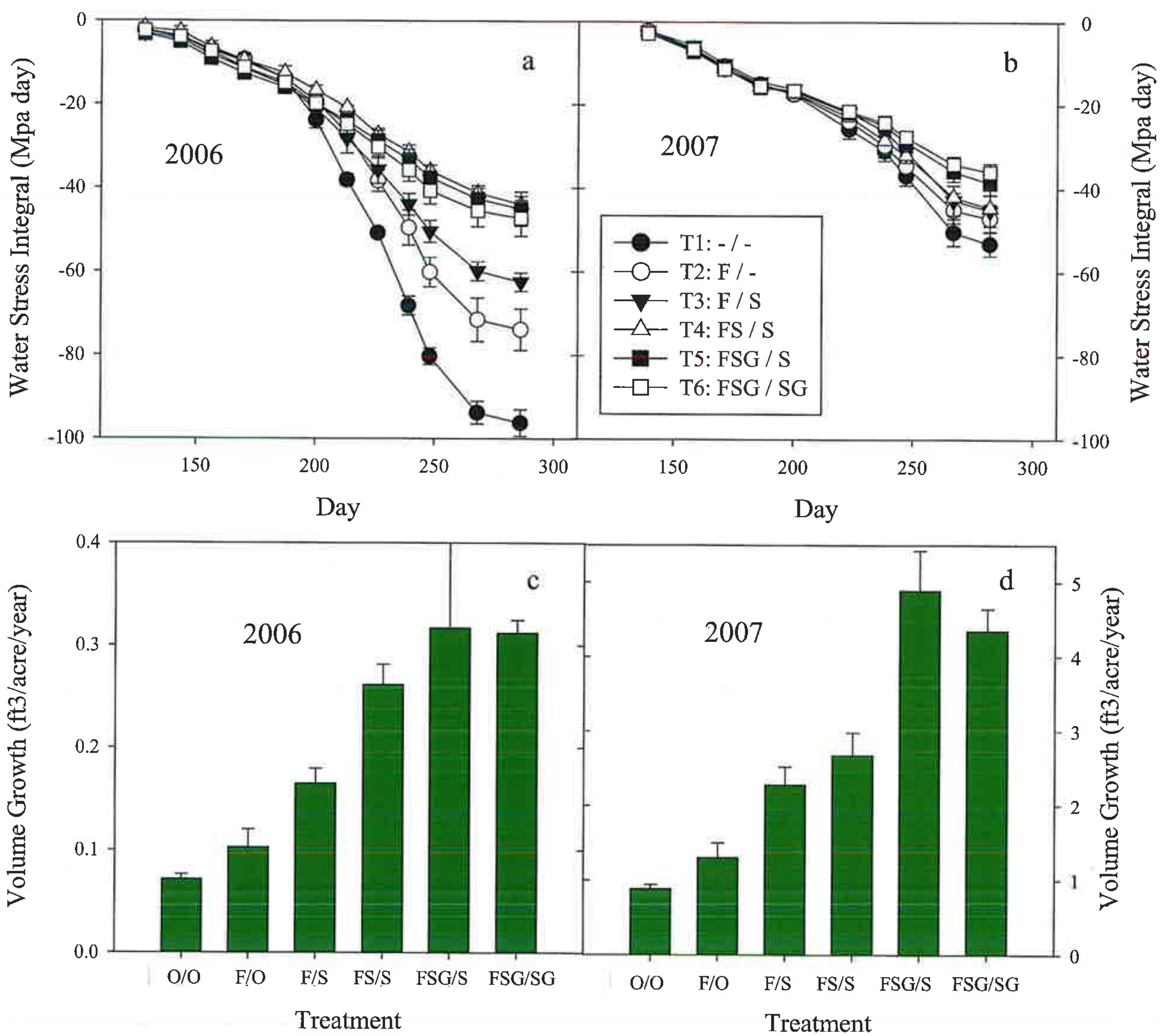

Figure 2. Treatment effects on water stress integral (WSI) (a) and volume per acre growth (b) for the 2006 and 2007 growing seasons. For panels a and b, each point is the mean of 4 plots. For panels c and d, each bar is the mean of 4 plots.

There was a strong relationship between WSI and volume growth during the growing seasons of 2006 ($p<0.01$; $R^2=0.77$) and 2007 ($p<0.01$; $R^2=0.69$). During the first growing season (year 2006, dry), 1 year-old seedlings that reached a WSI of about -40 MPa day had a volume growth of about 0.32 ft^3 $acre^{-1}$ $year^{-1}$. On the other hand, seedlings that reached a WSI of about -100 MPa day had a volume growth of only 0.08 ft^3 $acre^{-1}$ $year^{-1}$. During the second growing season (year 2007, higher precipitation), seedlings that reached a WSI of about -30 MPa day had a volume growth of about 5 ft^3 $acre^{-1}$ $year^{-1}$. On the other hand, seedlings that reached a WSI of about -60 MPa day had a volume growth of only 1 ft^3 $acre^{-1}$ $year^{-1}$. The functions that described these relationships are:

Growing season 1: $\text{Volume Growth } (ft^3\ acre^{-1}\ year^{-1}) = e^{0.0285 \cdot WSI}$ Eq. 1

Growing season 2: $\text{Volume Growth } (ft^3\ acre^{-1}\ year^{-1}) = 39.3 \cdot e^{0.0641 \cdot WSI}$ Eq. 2

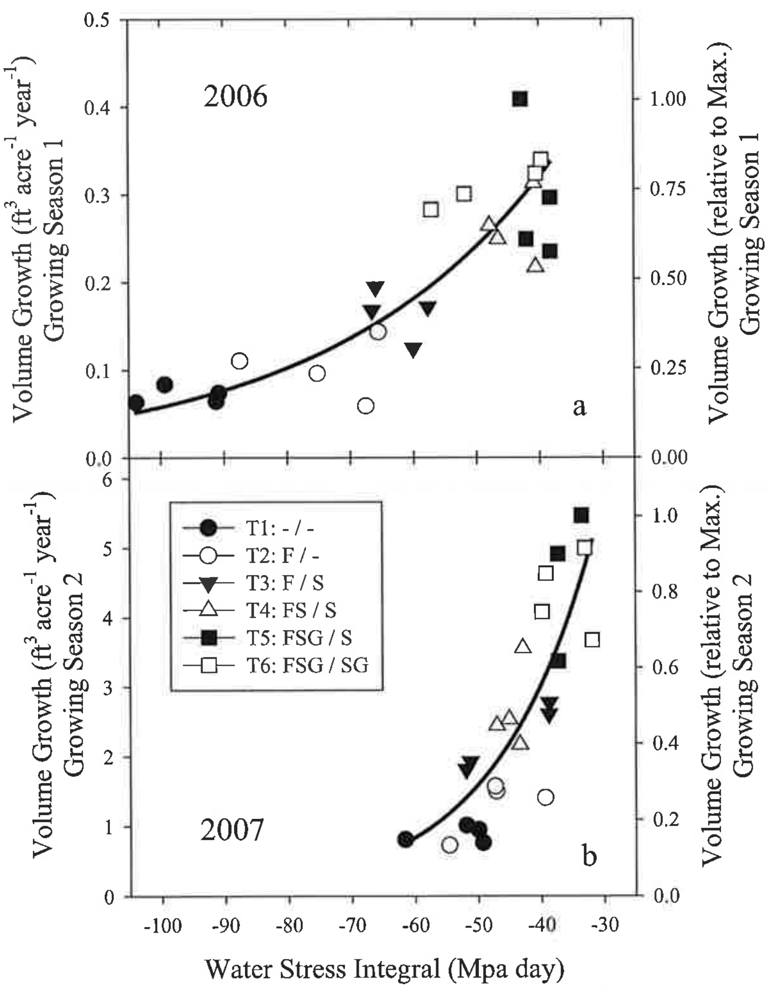

Figure 3. Relationship between water stress integral and volume growth for Douglas-fir seedlings growing under different treatments of vegetation control for the 2006 (a) and 2007 (b) growing seasons.

When volume growth was expressed as a fraction of the maximum observed for each growing season across all plots, Eq. 1 and 2 can be expressed as:

Growing season 1: Volume Growth (relative to maximum) $= 2.352 \cdot e^{0.0285 \cdot \mathrm{WSI}}$ Eq. 3

Growing season 2: Volume Growth (relative to maximum) $= 7.1869 \cdot e^{0.0641 \cdot \mathrm{WSI}}$ Eq. 4

In order to facilitate field evaluation and operational application of Eq. 1 to 4, WSI was correlated with Ψ_{PD} evaluated at different dates between May and October of each growing season. The best correlation was found between Ψ_{PD} measured during the first half of August ($\Psi_{PD\text{-}8}$; Aug 3 in 2006, Aug13 in 2007). When data from both years was pooled, a unique relationship was found (Figure 4; $p<0.001$; $R^2=0.82$) and the slope of each relationship was not different for each year ($p=0.25$, data not shown). On average, seedlings that had a $\Psi_{PD\text{-}8}$ of -0.5 MPa had a WSI of -50 MPa day, while seedlings that had a $\Psi_{PD\text{-}8}$ of -1.5 MPa had a WSI of -110 MPa day. The linear function that described that relationship was:

$\mathrm{WSI} = -19.15 + 61.056 \cdot \Psi_{PD\text{-}8}$ Eq. 5

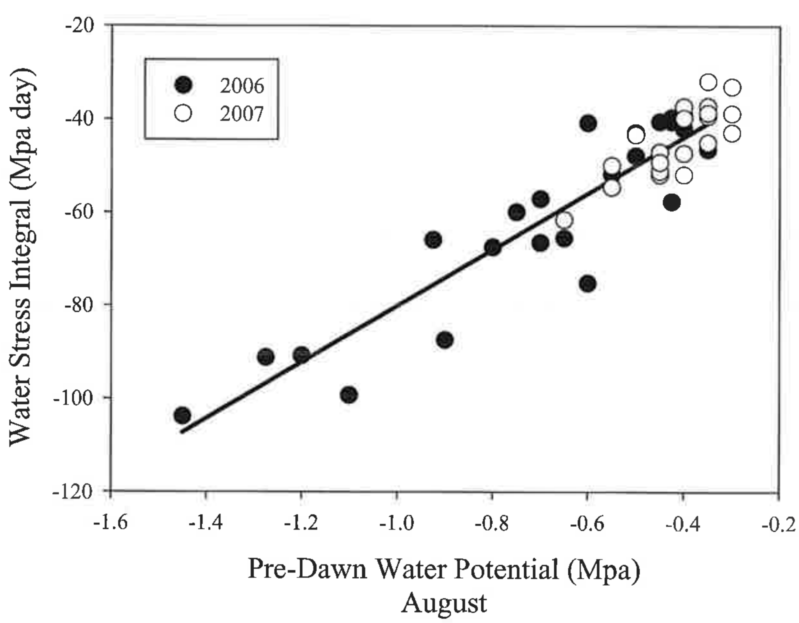

Figure 4. Relationship between pre-dawn water potential measured during the first half of August and water stress integral for the 2006 and 2007 growing seasons.

Further analysis was developed in order to facilitate operational use of Eq. 5. Using the data for 2006 and 2007 presented in Figure 1, a relationship between θv and Ψ_{PD} was developed (Figure 5a; $p<0.001$; $R^2=0.65$). This relationship resembled a water release curve as Ψ_{PD} can be used as a surrogate of soil matric potential. On average, when θv is larger than 0.35 $cm^3\ cm^{-3}$, Ψ_{PD} will have values between -0.2 and -0.3 MPa, and when θv is 0.15 $cm^3\ cm^{-3}$, Ψ_{PD} will be -1.25MPa. The function that described that relationship was:

$$\Psi_{PD} = -5.178 \cdot e^{-8.4159 \cdot \theta_v} \qquad \text{Eq. 6}$$

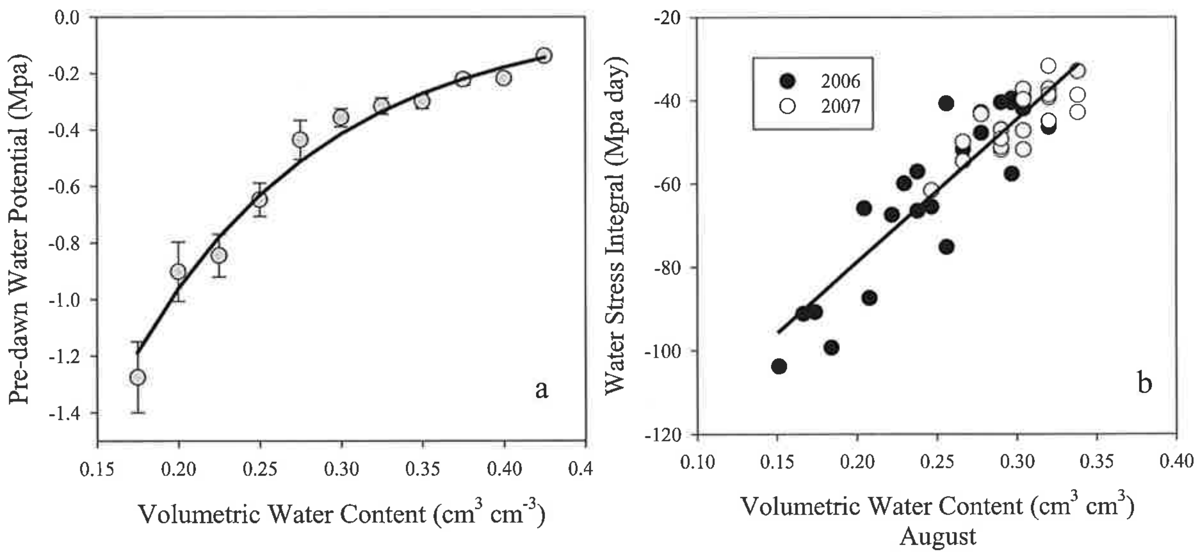

Figure 5. Relationship between volumetric water content and pre-dawn water potential (a) and volumetric water content measured during the first half of August and water stress integral (b) for the 2006 and 2007 growing seasons.

When Eq. 6 was combined with Eq. 5 the final relationship between θv measured during the first half of August ($\theta_{v\text{-}8}$) and water stress integral was determined (Figure 5b; $p<0.001$; $R^2=0.83$). This linear relationship can be used to estimate WSI and, therefore, volume growth ($ft^3\ acre^{-1}\ year^{-1}$ or relative to maximum) for seedlings during growing season 1 and 2 on sites represented by this study. The linear function that describes this relationship was:

$$WSI = -341.74 - 147.17 \cdot \theta_{v\text{-}8} \qquad \text{Eq. 7}$$

Conclusions and Management Implications

The results from this study reinforce the importance of competing vegetation management on soil water availability, plant water stress and stand growth for young seedlings. The results reported by Dinger and Rose (2009, 2010) have already shown this, but lacked correlations between observed data that can allow for further field estimations of productivity and plant-soil water relations. In this report we present an alternative methodology to correlate soil water availability, plant water stress and stand growth. The equations reported here are a useful tool for managers and researchers working on a site similar to this study, as using a single evaluation of soil volumetric water content during early August can be used as a predictor of stand productivity during the first two growing seasons. These results should be validated in the field under different site conditions. The new set of studies that the VMRC will install in the coming years will serve as an excellent source of validation and expansion of these results to different soil types across the PNW.

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Chemical Trail: Efficacy of Cleantraxx® and Esplanade® Tank Mix Treatments

Maxwell Wightman and Carlos Gonzalez-Benecke

Highlights

- On average, the Cleantraxx treatments reduced understory cover more than the equivalent Esplanade treatments.
- The vast majority of the Senecio plants found at the study site were found on the planting scalps. 97.5% of the Senecio cover measured in the Cleantraxx treatments were on the planting scalps.
- The most effective treatment at reducing the cover of Senecio was the low rate Cleantraxx + Accord XRT II + Induce applied in both the fall and spring. This treatment had an average Senecio cover of only 1%.

Introduction

Chemical vegetation control is a key management tool used by forest managers to succeed in the establishment of conifer plantations in the Pacific Northwest (PNW). The efficacy of a chemical vegetation control treatment can be influenced by several factors including: soil pH, soil organic matter and clay content, soil moisture content, weather conditions during application, rainfall occurring shortly after application, understory species composition and the type of chemicals applied. In the PNW a common chemical vegetation management regime includes a fall site preparation treatment prior to seedling planting followed by one or more years of spring release treatments. The fall site preparation treatment severely reduces the cover of plant species at the site allowing newly planted seedlings to better capture site resources. There are, however, other plant species that can take advantage of the open conditions created through fall site preparation and rapidly invade these areas if follow up herbicide applications are not carried out. Three such species are *Senecio sylvaticus*, *Senecio jacobaea* and *Cirsium vulgare*. There has recently been interest in the development of new pre-emergent herbicides that are able to control these species better than current products. Two newly developed pre-emergent herbicides are Cleantraxx® and Esplanade®. Cleantraxx is produced by the Dow Chemical Company and contains two active ingredients: **penoxsulam** and **oxyfluorfen**. Esplanade is produced by Bayer and contains the active ingredient **indaziflam**. In this study we tested the efficacy of the newly developed herbicides Cleantraxx and Esplanade on reducing the cover of understory species during the first growing season.

Methods

This study was installed on a site owned by Starker Forest, Inc. located southwest of Philomath, Oregon. The study site is located on a Jory-Gelderman soil complex which is characterized as a silty-clay-loam. When the fall site preparation treatments were applied, the vegetation community at the study site was sparse with 60-70% of the area consisting of bare ground. It was, however, noted that some bull thistle (*Cirsium vulgare*), *Senecio sylvaticus*, *Senecio jacobaea* and annual grass germinates were starting to develop. Table 1 shows a description of the herbicide treatments applied.

Table 1. Treatment descriptions

Treatment	Product and Rate per Acre	Timing
1	NON TREATED CONTROL	
2	3 QTS ACC XRT II[1] + 4 OZ INDUCE	FALL
3	3 PTS CLEANTRAXX + 3 QTS ACC XRT II + 4 OZ INDUCE	FALL
4	4.5 PTS CLEANTRAXX + 3 QTS ACC XRT II + 4 OZ INDUCE	FALL
5	5 OZ ESPLANADE + 3 QTS ACC XRT II + 4 OZ INDUCE	FALL
6	7 OZ ESPLANADE + 3 QTS ACC XRT II + 4 OZ INDUCE	FALL
7	2.25 PTS CLEANTRAXX + 3 QTS ACC XRT II + 4 OZ INDUCE	FALL/SPRING
8	3.5 OZ ESPLANADE + 3 QTS ACC XRT II + 4 OZ INDUCE	FALL/SPRING
9	4 OZ OUST EXTRA + 3 QTS ACC XRT II + 4 OZ INDUCE	FALL
10	4 OZ OUST EXTRA + 3 PTS CLEANTRAXX + 3 QTS ACC XRT II + 4 OZ INDUCE	FALL
11	4 OZ OUST EXTRA + 5 OZ ESPLANADE + 3 QTS ACC XRT II + 4 OZ INDUCE	FALL
12	2.25 PTS CLEANTRAXX + 3.5 OZ ESPLANADE + 3 QTS ACC XRT II + 4 OZ INDUCE	FALL

[1] ACC XRTII refers to ACCORD XRT II

This study utilized a randomized complete block design with 4 replicates (blocks) of twelve different treatments (Table 1). Treatment plots were 10 feet wide by 25 feet long and all treatments were applied by a single pass of a 10-foot-wide boom backpack sprayer. There was a minimum buffer of 5 feet between treatment plots. All of the tank mixes used contained 3 qrts per acre Accord XRT II (glyphosate) and 4 oz per acre Induce (surfactant). The 12 treatments were: 1) no action control, 2) Accord XRT II and Induce only, 3) low rate Cleantraxx (3 pts/acre), 4) high rate Cleantraxx (4.5 pts/acre), 5) low rate Esplanade (5 oz/acre), 6) high rate Esplanade (7 oz/acre), 7) low rate Cleantraxx (2.5 pts/acre) in both the fall and spring, 8) low rate Esplanade (3.5 oz/acre) in both the fall and spring, 9) Oust Extra (4 oz/acre), 10) Oust Extra (4 oz/acre) with low rate Cleantraxx (3 pts/acre), 11) Oust Extra (4 oz/acre) with low rate Esplanade (5 oz/acre) and 12) low rate Cleantraxx (2.25 pts/acre) with low rate Esplanade (3.5 oz/acre). The fall site preparation treatments were applied on October 29th, 2015 and the spring release treatments (T7 and T8) were applied on March 24th, 2016. Each plot was planted with both Douglas-fir and western red cedar seedlings in the winter of 2015/2016 at a spacing of approximately 3 feet resulting in 8 seedlings per species per plot.

A summertime assessment of treatment effects on understory cover and tree seedling health was conducted on June 7th, 2016. During this assessment the total cover of understory species across the entire plot area was estimated visually. The individual cover of bull thistle, Senecio species, and grasses was also estimated visually. Damage to tree seedling buds and needles was estimated on a 0 to 10 scale such that 0 indicated no damage and 10 indicated a dead bud or dead needle. The percent brownout and survival of tree seedlings was also assessed. Percent brownout refers to the percentage of needles that were necrotic. Analysis of variance was used to test the effects of treatments on stand growth and vegetation community dynamics (PROC GLM; SAS Institute Inc., Cary, NC, USA).

Results and Discussion

The cover of understory species in the no action control plots (T1) averaged 101% by June of the first growing season and was significantly greater than all other treatments except for the Accord XRT II and Induce only treatment (T2) (Figure 1). This result is not surprising as T2 did not contain any pre-emergent herbicides. All of the other herbicide application treatments had lower total understory cover than T1 and T2, but this difference was only significant for the full rate Cleantraxx treatment (T4), the low rate Cleantraxx in both the fall and the spring treatment (T7), the low rate Cleantraxx with Oust Extra treatment (T10) and the low rate Esplanade with Oust Extra treatment (T11).

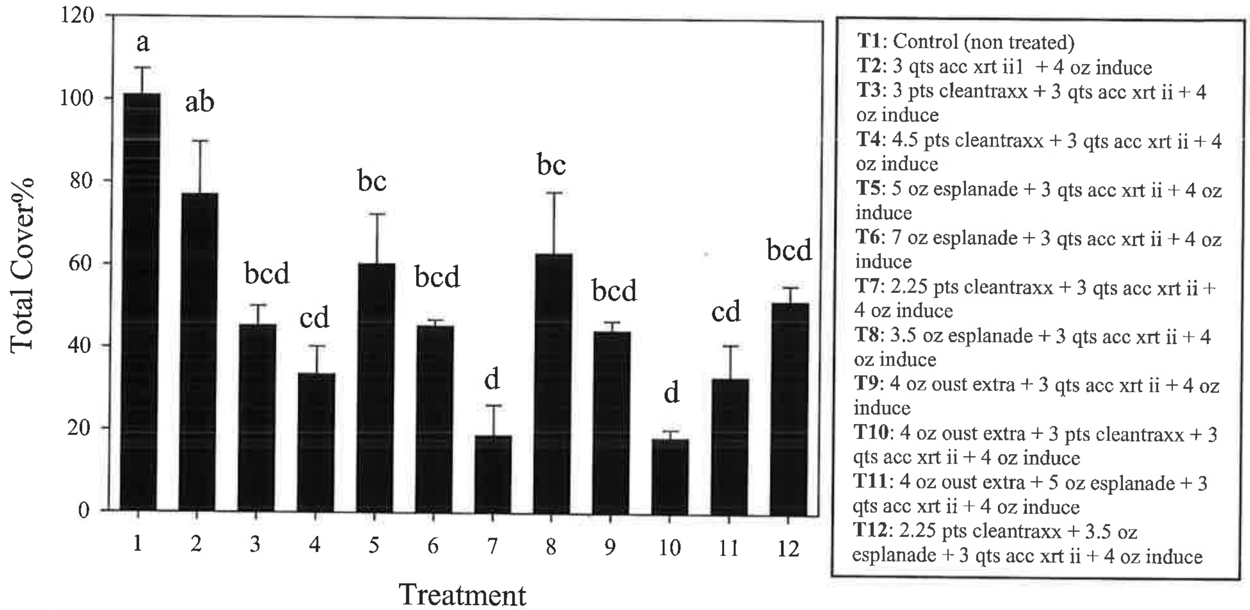

Figure 1. Effect of herbicide treatments on total understory cover during the summer of the first growing season. Treatments that share the same letter are not significantly different. Whiskers represent standard error. Treatments 7 and 8 received applications during fall and spring. All other treatments received only fall site preparation application.

There was a trend for the Cleantraxx treatments to have less percent cover than the equivalent Esplanade treatment, but this difference was not always significant. The average understory cover of the four Cleantraxx treatments (treatments 3,4,7 and 10) was 30% whereas the average understory cover of the four Esplanade treatments (treatments 5,6,8 and 11) was 50%. The only significant difference between the two products was in the low rate fall and spring treatments. The total understory cover of the low rate fall and spring Cleantraxx treatment (T7) was 19% whereas the total understory cover of the equivalent Esplanade treatment (T8) was 63%. The low rate Cleantraxx mixed with Esplanade treatment (T12) also had greater understory cover than if any of the Cleantraxx treatments was applied alone, although these differences were not significant. Finally, there was a trend for the low rate of each product with Oust Extra treatments (T10 and T11) having less understory cover than if the full rate of each product was applied without Oust Extra (T4 and T6).

One of the most interesting results of this study was the effect of treatments on the cover of Senecio species. When conducting the summertime vegetation assessment it was observed that a vast majority of the Senecio plants were growing in the planting scalp around the tree seedlings. When averaged across all treatments 84% of the Senecio cover measured occurred in the planting scalps. This effect was even more pronounced for the Cleantraxx treatments where 97.5% of the Senecio cover measured was in the planting scalp. It is possible that disturbing the soil during the planting process broke the pre-emergent herbicide barrier, allowing for Senecio plants to become established. The most effective treatment at reducing the cover of Senecio was the low rate Cleantraxx in the fall and spring treatment (T7) which had an average of only 1% Senecio cover. Additionally, this was the only treatment to have significantly less Senecio cover than the control. This suggests that the second low rate application of Cleantraxx was sufficient enough to prevent Senecio from becoming established in the newly exposed planting scalps. The Oust Extra treatment (T9) had 26% Senecio cover which was significantly greater than all other treatments. There were no other significant differences in the cover of Senecio among the treatments.

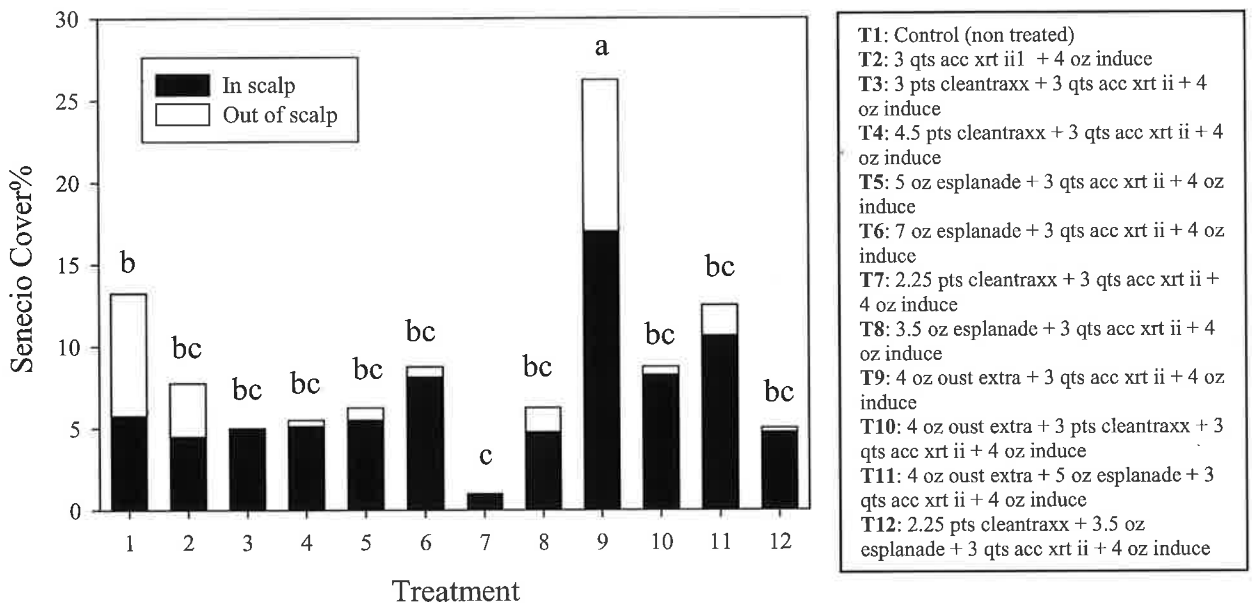

Figure 2. Effect of herbicide treatments on Senecio cover during the summer of the first growing season. Treatments that share the same letter are not significantly different. Treatments 7 and 8 received applications during fall and spring. All other treatments received only fall site preparation application.

All of the tank mixes used in this study were effective at reducing the cover of grass species when compared to the control with the exception of T2 (Accord XRT II and Induce only treatment). The average cover of grass species in the control, however, was only 6% which suggest that the study site did not have a large proportion of grass species developing in the understory. There was no effect of any of the treatments on reducing the cover of bull thistle, but bull thistle cover averaged only 3% across all treatments.

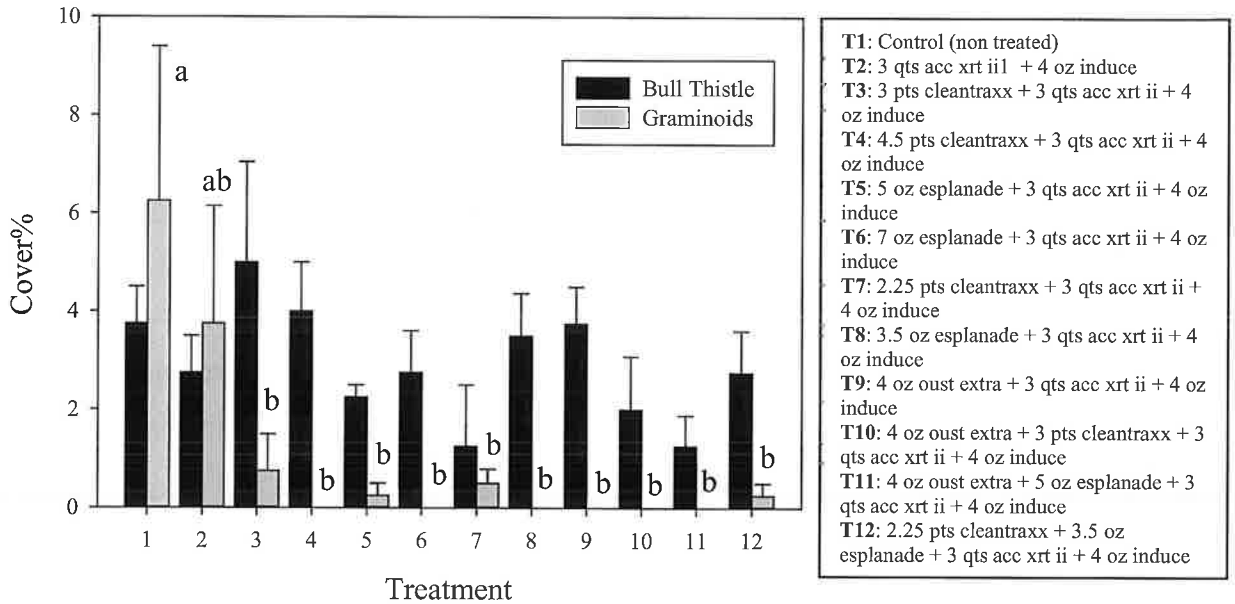

Figure 3. Effect of treatments on graminoid species and bull thistle cover during the summer of the first growing season. For graminoid species (grey bars), treatments that share thc same letter are not significantly different. There were no significant differences among treatments in the cover of bull thistle (black bars). The whiskers represent one standard error.

There was little effect of any of the treatments on tree seedling health during the summer of the first growing season (Table 2). There were no significant differences among treatments or species in bud or needle damage and these values averaged < 1 and 3, respectively. Seedling survival was also not affected by treatment and averaged 100% for Douglas-fir and 99% for western red cedar. The % brown out was high for western red cedar at 46%, but there was no effect of treatment on this variable and the control had the highest rate of brown out of any treatment. This suggests that the high rate of brown out among the western red cedar was due to factors other than herbicide damage such as site quality, seedling quality, drought stress or nutritional stress. The percent brown out for Douglas-fir was only 5%.

Table 2. Seedling damage by species. There was no effect of any treatment on any seedling damage.

	Species	
	Douglas-Fir	Western red cedar
Bud Damage	0.02	0.01
Needle Damage	2	2.6
% Brownout	5	46
% Survival	100	99

Conclusions

The results of this study suggest that the product Cleantraxx was more effective at reducing understory cover than Esplanade. The average understory cover of the four Cleantraxx treatments (treatments 3,4,7 and 10) was 30% whereas the average understory cover of the four Esplanade treatments (treatments 5,6,8 and 11) was 50%. A vast majority (97.5 %) of the Senecio cover in the Cleantraxx treatments was found in the planting scalps. This suggests that Cleantraxx is effective at controlling Senecio on undisturbed soils, but when the soil is disturbed, such as in planting, the chemical barrier is broken reducing the efficacy of pre-emergent treatments for Senecio control. When low rates of Cleantraxx are applied in both the fall and the spring, however, the chemical is able to persist in the newly exposed soils in the planting scalps and the cover of Senecio is dramatically reduced. The average cover of Senecio in the plots receiving this treatment was only 1%. There was no significant effect of either of the products on seedling health.

Project Update: COSINE-COmpetition & Site INteractions Experiment

Maxwell Wightman and Carlos Gonzalez-Benecke

Highlights

- 3 new study sites were identified. These include 2 Tier II Douglas-fir sites and 1 Tier 1 western hemlock site.
- Plots have been installed at all of the sites and the fall site preparation treatments have been applied.

Introduction

A new research project with a focus on how site conditions and chemical vegetation management treatments interact to effect seedling survival and growth was proposed to the VMRC cooperators at the 2015 annual meeting. Following the meeting a formal project proposal was develop entitled *Assessing Interactions between Site Conditions and Vegetation Management Treatments for Pacific Northwest Conifer Plantations*. After receiving comments from the cooperators a finalized version of the proposal was developed. It was decided that all of the experimental sites in this study will utilize a 2 x 2 x 2 factorial design, where factor 1 corresponds to fall site preparation, factor 2 corresponds to spring release during growing season 1, and factor 3 corresponds to spring release during growing season 2. This study design results in eight individual treatment types (Table 1).

According to the site deployment strategy outlined in the study proposal, one western hemlock (WH) Tier I site[1] and two Douglas-fir (DF) Tier II sites[2] would be established in the first year of the project. This project update will provide information on the location and site conditions of these three sites. We have also renamed the study as COSINE which stands for **CO**mpetition and **S**ite **IN**teractions **E**xperiment.

[1] Tier I are installed in 2 or 3 sites per species, with 4 replicates and detailed ecophysiological measurements.
[2] Tier II are installed in multiple sites across the region, with no replication in site.

Table 1. Description of the eight treatment types. Treatments with a 0 receive no action and treatments with a 1 will receive the indicated vegetation management action.

Treatment Type	Fall site Preparation	Spring Release Growing Season 1	Spring Release Growing Season 2
1 (000)	0	0	0
2 (010)*	0	1	0
3 (001)*	0	0	1
4 (011)	0	1	1
5 (100)	1	0	0
6 (101)	1	0	1
7 (110)	1	1	0
8 (111)	1	1	1

Treatments with an * will not be included in the Tier I WH Bulgogi site.

Figure 1 shows the location of the three selected sites across the PNW. Background colors represents the mean annual rainfall. The three selected sites vary in time of harvest, mean annual rainfall and competing vegetation species composition and abundance.

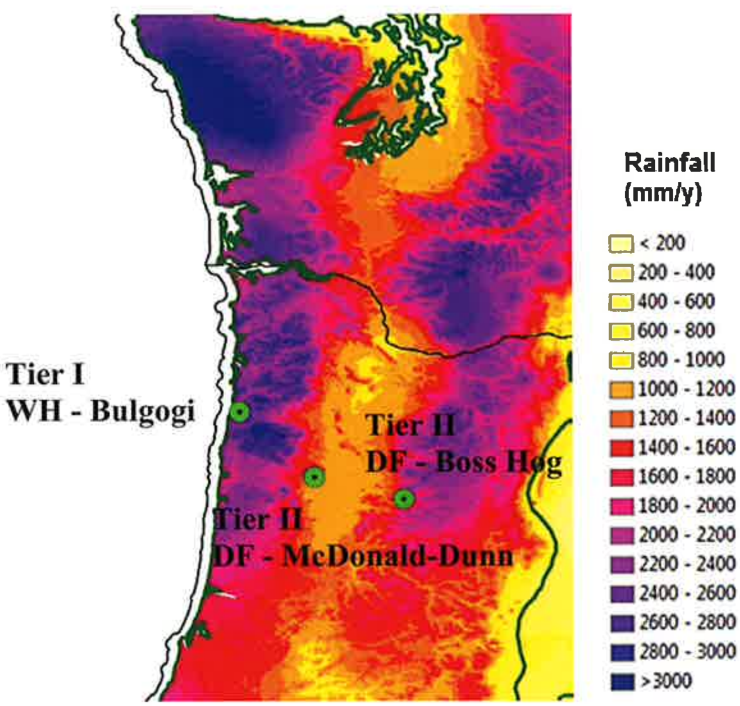

Figure 1. Site location for 2016 study installations.

Tier I WH – Bulgogi

The Tier I WH site is being installed on a unit name Bulgogi owned by Hancock Forest Management (Table 2). This site is located in Tillamook County approximately 4 miles from the coast (Figures 1 and 2). The harvest operation at the unit was completed in August of 2015.

Table 2. Tier I WH site description.

Site Name	Bulgogi
Land Owner	Hancock Forest Management
Site Location	45°07'09.9"N 123°54'09.0"W
State/County	Oregon / Tillamook
Harvest Date	August, 2015
Soil Type	Tolovana-Templeton
Soil Texture	Medial Silt Loam
Soil Drainage	Well drained
Annual Rainfall	78.7 inches
Average Daily Temperature	59.8°F Max – 44.4°F Min

Plots were installed at the site in September of 2016 and it became apparent that the unit did not have sufficient space for 4 replicates of all 8 of the treatments denoted in the original proposal (Table 1). The site, however, was in very good condition for study instillation so it was decided that the treatments 010 (treatment 2) and 001 (treatment 3) would be dropped. This resulted in 4 replicates of 6 different treatments for a total of 24 plots. The fall site preparation treatment was applied to the appropriate plots on September 14th, 2016. The prescription for this treatment was 2 qts/acre Roundup Custom, 24 oz/acre Polaris SP, 1 qt/acre MSO, and 1 oz/acre MSM 60.

Figure 2. View of the Tier I WH – Bulgogi site.

A vegetation survey was conducted shortly after the fall site preparation treatment had been applied. The survey was conducted on five 1 m radius subplots per plot and consisted of visual estimates of percent cover by species. The results of this survey showed that there were no significant differences in the total cover of understory species among the different treatments ($p = 0.298$; data not shown). The average total understory cover across all treatments was 32.8% cover. When broken down by habit the average cover was 21.2% forbs, 7.7% ferns, 2.6% grasses, 0.1% shrubs, 0.6% trees, and 0.6% vine/shrubs (Figure 3). The most common species at the study site were foxglove (*Digitalis purpurea*), miner's lettuce (*Claytonia perfoliata*), sword fern (*Polystichum munitum*), mint (*Stachys spp.*) and bracken fern (*Pteridium aquilinum*).

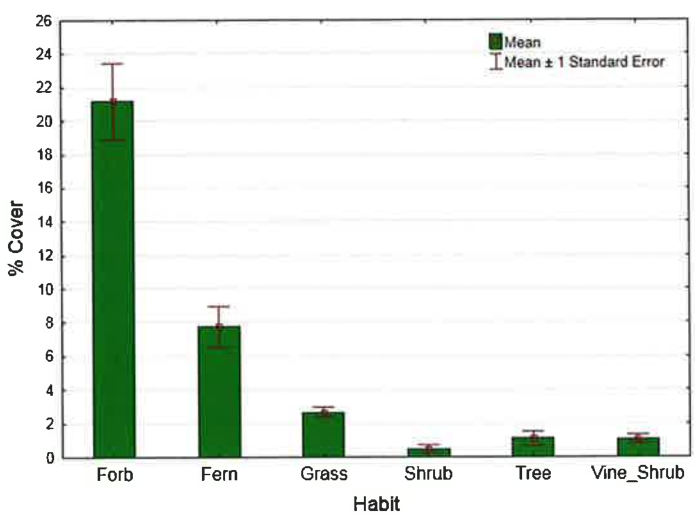

Figure 3. Cover percent at the time of fall site prep. at the Tier I WH – Bulgogi site.

Tier II DF – McDonald-Dunn Forest

The first Tier II DF site will be located in the McDonald-Dunn Forest owned by Oregon State University (Table 3). The site is located in Benton County approximately 5 miles from Corvallis (Figures 1 and 4). This site's close proximity to Oregon State University will make it an excellent resource for teaching students about reforestation practices. The VMRC has also discussed collaborating with other researches to install additional small scale studies in the school's forest to serve as both research and educational resources.

Table 3. Tier II DF McDonald-Dunn Forest site description

Site Name	McDonald-Dunn
Land Owner	Oregon State University
Site Location	44°36'36.8"N 123°19'33.6"W
State/County	Oregon / Benton
Harvest Date	September, 2016
Soil Type	Dixonville-Gellatly complex
Soil Texture	Silty clay loam
Soil Drainage	Well drained
Annual Rainfall	45 inches
Average Daily Temperature	63.4°F Max – 42.0°F Min

The heights of 10 dominant trees were measured prior to timber harvest and tree cores were taken from these same individuals in order to calculate site index, although this analysis has not yet been completed. The timber harvesting operation at the unit was completed in September of 2016 and treatment plots were installed in early October. The Tier II sites were designed to contain one replicate of each of the treatments described in Table 1, therefore a total of eight treatment plots were installed at the site. The fall site preparation treatment was applied to the appropriate plots on October 10th, 2016 and the prescription for this treatment was 3 qt/acre Accord XRT II, 4 oz/acre Oust Extra, and 4 oz/acre Induce.

Figure 4. View of the Tier II DF – McDonald-Dunn site.

A vegetation survey was conducted at the site shortly after the fall site preparation treatment had been applied. The survey was conducted on five 1 m radius subplots per plot and consisted of visually estimates of percent cover by species. The results of this survey indicated that there was almost no understory vegetation present at the site. The average understory cover across all plots was only 1% cover. This lack of understory cover is the result of a late timber harvest operation that removed the pre-harvest understory. The only understory species found at the site were false brome (*Brachypodium sylvaticum*), poison oak (*Toxicodendron diversilobum*), and sword fern (*Polystichum munitum*).

Tier II DF – Boss Hog

The second Tier II DF site will be located on a unit owned by Cascade Timber Consulting Inc. named Boss Hog. This site is located in Linn County approximately 6 miles northwest of Sweet Home (Figures 1 and 5).

Table 4. Tier II Boss Hog site description

Site Name	Boss Hog
Land Owner	Cascade Timber Consulting Inc.
Site Location	44°26'11.6"N 122°38'15.8"W
State/County	Oregon / Linn
Harvest Date	December, 2015
Soil Type	Honeygrove
Soil Texture	Silty clay loam
Soil Drainage	Well drained
Annual Rainfall	54.9 inches
Average Daily Temperature	63.9°F Max – 41.6°F Min

The timber harvest operation at the site was completed in December, 2015 and eight treatment plots (one for each of the treatments in table 1) were installed at the study site in September, 2016. The fall site preparation treatment was applied to the appropriate plots on October 25th, 2016 and the prescription for this treatment was 64 oz/acre glyphosate, 16 oz/acre Polaris SP, 4 oz/acre Oust Extra, and 8 oz/acre MSO. The vegetation survey at the site had not been completed by the time this report was written, however, early observations at the site suggest that the Boss Hog unit has the highest percent cover of any of the newly installed study sites outlined in this report. Early observations also suggest that this site has a high proportion of grasses, Senecio, bull thistle and Canada thistle in the understory.

Figure 5. View of the Tier II DF – Boss Hog site.

Preliminary Results: Long-term Effects of Vegetation Management on Biomass Stock and Net Primary Productivity of Four Coniferous Species in the PNW

Herman Flamenco and Carlos A. Gonzalez-Benecke

Highlights

During the summer of 2016 field measurements were taken at the CPT studies:
- Crop trees above ground biomass (foliage, branches, stemwood and bark)
- Forest floor biomass.
- Understory biomass.
- Top soil organic matter and fine roots biomass.

Monthly litterfall, starting on March 2016.

We developed species-specific biomass and volume functions.

Introduction

The Vegetation Management Research Cooperative (VMRC) has two Critical Period Threshold (CPT) studies with 15-16 years of monitoring data for different conifer species. One study site is located on land owned by Starker Forests Inc. in the central coast range (CR) and the other is located on land owned by Cascade Timber Consulting in the Cascade foothills (CF). The CR site has a fine loamy soil, a mean annual temperatures of 11.1 °C and mean annual rainfall of 1,707 mm. Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), and grand fir (*Abies grandis*) seedlings were planted at this site. The CF site has a silty-clay-loam soil, mean annual temperatures of 12.4 °C, and mean annual rainfall of 1,179 mm. This site was planted with Douglas-fir (*Pseudotsuga menziesii*) and western red cedar (*Thuja plicata*).

Both sites were treated with a fall broadcast herbicide application and seedlings were planted the following winter at a 10 ft x 10 ft spacing. Treatment plots are 80 ft x 80 ft consisting on 64 seedlings and the measurement plots contained 36 seedlings surrounded by a one tree buffer on all sides. The CPT studies were designed as a species x competition factorial design with three or four randomized complete blocks (Rosner and Rose, 2006). Three blocks were installed for western red cedar and grand fir at the CR site. In all other cases four blocks were installed. There were eight total treatments randomly assigned to each block: no spring release (SR) treatment (OOOOO), SR in the first year (TOOOO), SR in the first and second year (TTOOO), SR in the first, second, and third year (TTTOO), SR in years one through four (TTTTO), SR in years one through five (TTTTT), SR in years two through five (OTTTTT), and SR in years three, four, and five (OOTTT). The present study focuses on the two extremes treatments: OOOOO and TTTTT. Detailed descriptions of the studies used in this analysis can be found in Rosner and Rose (2006) and Maguire et al. (2009).

The responses of Pacific Northwest conifer stands to vegetation management treatments have been reported by several studies (Newton and Preest, 1988; Rose et al., 1999; Rose and Ketchum, 2003; Maguire et al., 2009), but no report has published long-term effects of vegetation management treatments on aboveground net primary productivity (ANPP) and total biomass accumulation of the whole ecosystem. Net primary production is the rate at which all the plants in an ecosystem produce net useful chemical energy and is one of the most used metrics of productivity in terrestrial ecosystems. The main objective of this study is to evaluate the long-term effects of vegetation management treatments on the ANPP (Mg ha^{-1} $year^{-1}$) and whole-ecosystem biomass stock (Mg ha^{-1}) of four coniferous species. A second objective is to create species specific biomass and volume equations at 15 and 16 years of age.

Methods

Aboveground net primary productivity (ANPP) is quantified as the sum of litterfall and aboveground biomass production over a specified time period (Waring and Runnig, 2007). In this study, five 0.5 m^2 litterfall traps per plot were used to estimate litterfall production. Litter was collected approximately every 4 weeks and dried at 70^{o} C for a minimum of 72 hours before being weighed. Aboveground biomass was separated into four separate pools: overstory (crop-tree), midstory (volunteers), understory, and forest floor (including coarse woody debris).

Figure 1. Field sampling. Litterfall was collected monthly using five 0.5 m^2 litterfall traps per plot (a); tree biomass was measured during the summer of 2016 (b).

In order to determine overstory biomass, four trees per species and treatment were destructively sampled at each site (32 trees at CR site, 16 trees at CF site). Sample trees were located in treatment buffers and were selected to cover the range of diameters found at each site using the winter 2015 inventory data. The four sample trees (i-iv) for each treatment and species were selected from diameter at breast height (DBH) percentiles as follows: i) 0-25th percentile, ii) 25th-50th percentile, iii) 50th-75th percentile and iv) 75th-99th percentile. Table 1 shows the range of DBH and total tree height for sample trees at the CR site. Branch, stem, and foliage samples were collected from each measurement tree in order to produce estimates of tree biomass.

Table 1. Minimum (Min) and Maximum (Max) diameter at breast height (DBH) and total tree height (HT) for sampled trees at the CR site.

Species	Treatment	Min DBH (cm)	Max DBH (cm)	Min HT (m)	Max HT (m)
Douglas-fir	OOOOO	13.8	22.2	14.3	17.2
	TTTTT	16.9	23.8	14.8	17.4
Western hemlock	OOOOO	3.8	18.3	4.6	14.5
	TTTTT	15.7	25.5	12.9	16.5
Western redcedar	OOOOO	4.8	17.1	4.5	10.6
	TTTTT	3.6	18.8	3.6	9.6
Grand fir	OOOOO	6.6	19.1	6.1	12.9
	TTTTT	8.1	23.5	8.6	14

The diameter at stem insertion point and position along the main stem of every branch on each sample tree was measured. Additionally, a subsample of two branches were collected from each third of the living crown (6 branches per tree) in order to determine branch and foliage biomass. If dead branches were present, two extra samples were collected at the dead crown section. After returning to the lab, all of the foliage of each live branch was removed, dried, and weighed. Functions to estimate the dry weight of dead branches (BD), foliage (BF) and wood+bark, (BW) in living branches, were determined using the following models:

$$\mathrm{BF, BW} = a \cdot D^{b} \cdot Hr^{c} \qquad \text{Eq. 1}$$

$$\mathrm{BD} = a \cdot D^{b} \qquad \text{Eq. 2}$$

where BF is foliage dry mass (g) and BW is wood+bark dry mass (g), D is branch insertion diameter (mm), Hr is relative height in the living crown, and a, b and c are curve fit parameters. Total foliage and branch biomass was determined for each sample tree by applying Eq. 1 and 2 to all branch diameter and Hr measurements for that tree.

After conducting the branch measurements, stem diameter and bark thickness was measured every 2 m along the trunk for stem volume (VOL) calculations (Figure 1b). Five cross sections (5 cm thickness) were cut at: i) stump height (0.5 m height), ii) DBH (1.37 m height), iii) live crown base, iv) mid-point between DBH and live crown, and v) mid-point between live crown and top for specific gravity (SG) determinations. In the lab, the volume of all samples was determined by measuring disk thickness and diameter with and without bark on 4 points by rotating 45 degrees clockwise. All samples were oven-dried at 70^{o} C for a minimum of 72 hours and weighed and SG of wood and bark was determined as the ratio between mass and volume of each sample. Later, for each sampled tree, the SG was assigned to the corresponding section in the stem in order to determine stemwood and stem bark dry mass. Whole-tree SG of stemwood and stem bark was determined as the ratio between whole tree volume and whole tree dry mass of stemwood and stem bark.

Once the field and lab measurements had been completed, species-specific models were developed to predict total tree stem wood, bark, branch and foliage biomass (kg) from tree DBH and height (Eq 3). Before model fitting, a logarithm transformation was carried out and stepwise procedure was used on the resulting linear model with a threshold significance value of 0.15 as variable selection criteria and the variance inflation factor (VIF) was monitored to detect multicollinearity between DBH and Height (Gonzalez-Benecke et al., 2012). Any variable included in the model with a VIF larger than 5 was discarded, as suggested by Neter et al. (1996).

$$\text{Wood, Bark, Dead Branch, Living Branch, Foliage} = a \cdot \text{DBH}^{b} \cdot \text{Height}^{c} \qquad \text{Eq. 3}$$

Understory, forest floor and coarse woody debris biomass were measured on six, 0.6 m x 0.6 m square subplots (clip-plots) per plot (Figure 2a). The understory was destructively sampled by cutting all vegetation at ground level. Coarse woody debris and forest floor, including moss, was also removed from each clip-plot. In the lab, all vegetation was separated by living habit (forb, fern, graminoid, shrub or tree) and oven-dried. Soil organic matter and fine root biomass was sampled at the center of the 0.6 m x 0.6 m square subplots using a 5 cm diameter PVC core of 25 cm length (Figure 2b). For all dry mass determinations, samples were oven-dried at 70° C for at least 72 hours.

Figure 2. Field sampling. Example of a sampling point before (a) and after (b) understory, forest floor, fine root, and soil organic matter measurements.

In some control plots there were volunteer trees (Douglas-fir and hardwoods). The diameter of all volunteer trees was measured in the winter of 2016 and will be measured again in the winter of 2017. The biomass production of volunteer trees we will be calculated using the biomass functions obtained in this study for Douglas-fir and species-specific functions reported in literature for hardwoods. The Douglas-fir plots were pre-commercially thinned (PCT) in 2013 at both sites. The downed wood created through this treatment will be included in the coarse woody debris estimates. The DBH and height of the cut trees prior to PCT are known and the initial biomass can be estimated using the biomass functions determined in this study. In order to correct for decomposition, a subsample of the downed trees will be carried out next summer (2017) to determine changes is SG and to determine bark, wood and branch decay rates.

Non-linear model fitting was used to estimate volume and biomass functions and analysis of variance was used to test the effects of treatments on total litterfall and above ground biomass (PROC NLIN and PRCO REG; SAS Institute Inc., Cary, NC, USA).

Preliminary Results

The results presented in this report are based on litterfall and crop tree aboveground biomass measurements collected during the summer of 2016 at the CR site.

Table 2 shows the accumulated foliage litterfall, from February 15 to October 27, 2016 for the four crop species at the CR site. Douglas-fir foliage litterfall was not affected by treatment ($p=0.726$) and averaged 1.98 and 2.07 Mg ha^{-1} for the OOOOO and TTTTT treatments, respectively (Table 2). Foliage litterfall from other species was negligible in the Douglas-fir plots, averaging 0.01 Mg ha^{-1}. For western hemlock, plots treated with 5 years of sustained spring release had 55% more crop tree foliage litterfall than plots that did not receive spring release treatments ($p=0.094$). Nevertheless, when litterfall from other species was included, total foliage litterfall was larger in the OOOOO plots ($p=0.065$). The western red cedar OOOOO plots showed negligible crop species foliage litterfall (0.02 Mg ha^{-1}) but a large amount of litterfall from other species (2.52 Mg ha^{-1}). Total foliage litterfall was small for both crop trees (0.39 Mg ha^{-1}) and all other species (0.58 Mg ha^{-1}) in the TTTTT western red cedar plots. The grand fir TTTTT plots had 1.3 times more crop species foliage litterfall than OOOOO plots, but 0.82 Mg ha^{-1} less total foliage litterfall. This was due to the OOOOO treatment having a large amount of litterfall from other species (1.64 Mg ha^{-1}).

Table 2. Accumulated foliage litterfall (Mg ha^{-1}) between February and October, 2016 for 16-year-old Douglas-fir, western hemlock, western red cedar and grand fir trees growing under contrasting vegetation management treatments on a site located in the Oregon Coast Range.

Species	Treatment	Crop Trees	Other Vegetation	Total	p < F*	p < F**
Douglas-fir	OOOOO	1.98	0.01	1.99	0.726	0.721
	TTTTT	2.07	0.01	2.08		
Western hemlock	OOOOO	1.28	1.48	2.76	0.094	0.065
	TTTTT	1.98	0.09	2.08		
Western red cedar	OOOOO	0.02	2.52	2.54	0.013	0.047
	TTTTT	0.39	0.58	0.97		
Grand fir	OOOOO	0.61	1.64	2.25	0.096	0.199
	TTTTT	1.43	0.002	1.43		

*: test for treatment effect on crop trees foliage litterfall.
**: test for treatment effect on total foliage litterfall.

Figure 3 shows the monthly foliage litterfall dynamics at the CR site. The pattern of monthly litterfall production was similar for the OOOOO and TTTTT Douglas-fir plots (Figure 3 a and b), peaking at about 500 kg ha^{-1} $month^{-1}$ during October. For western hemlock, the OOOOO plots peaked at 380 kg ha^{-1} $month^{-1}$ during September, while TTTTT plots peaked at 600 kg ha^{-1} $month^{-1}$ during October (Figure 3 c and d). The monthly foliage litterfall of western red cedar was small, ranging between 0 and 7 kg ha^{-1} $month^{-1}$ for OOOOO and 19 and 120 kg ha^{-1} $month^{-1}$ for TTTTT (Figure 3 e and f). Grand fir showed a similar pattern to Douglas-fir, peaking in September at 200 and 500 kg ha^{-1} $month^{-1}$ for the OOOOO and TTTTT plots, respectively (Figure 3 g and h).

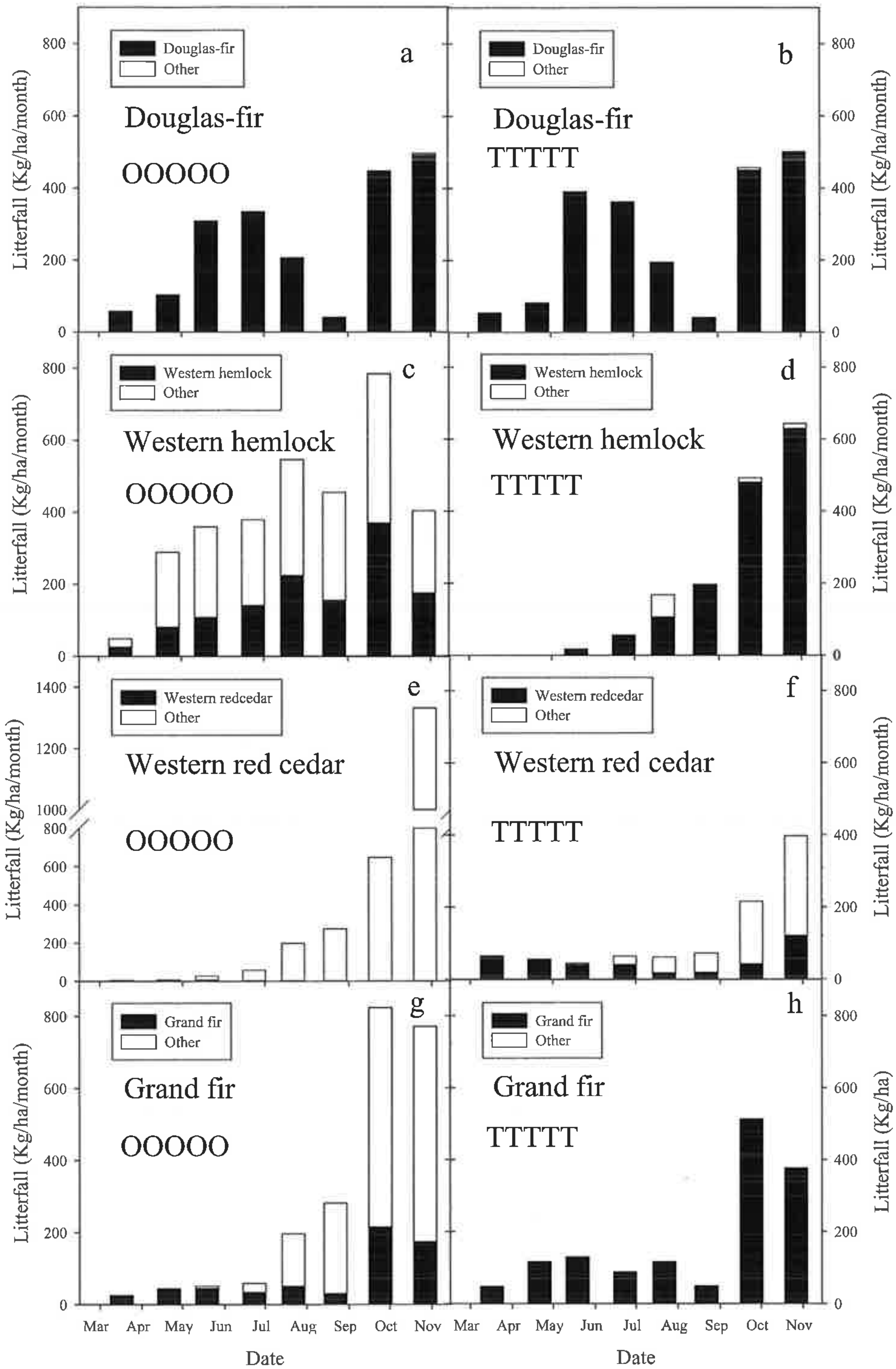

Figure 3. Monthly foliage litterfall for Douglas-fir (a, b), western hemlock (c, d), western red cedar (e, f) and grand fir (g, h) stands growing under contrasting vegetation management treatments on a site located in the Oregon Coast Range. Left panel shows foliage litterfall for treatment OOOOO; right panel shows foliage litterfall for treatment TTTTT. Foliage litterfall from crop species is shown as black bars and foliage litterfall from understory and mid-story species is shown as white bars.

Douglas-fir and western hemlock had denser stem wood than grand fir and western red cedar (Figure 4; $p<0.05$). Average whole-tree SG for Douglas-fir, western hemlock, western red cedar and grand fir was 0.40, 0.39, 0.34 and 0.33, respectively. Whole-tree SG was not dependent on tree size (data not shown).

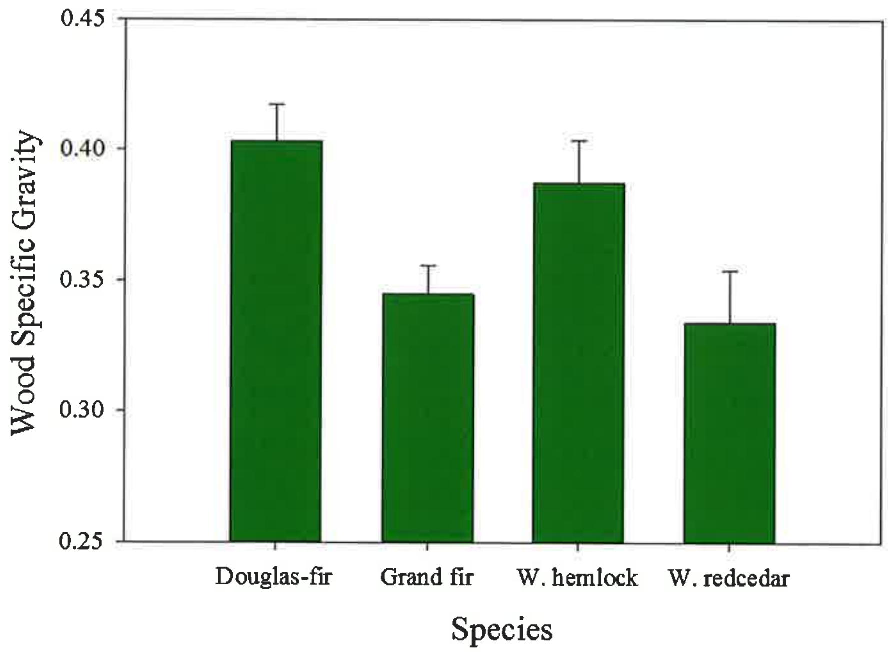

Figure 4. Mean whole-tree specific gravity of wood for 16 year-old Douglas-fir, western hemlock, western red cedar and grand fir trees growing on a site located in the Oregon Coast Range. Error bars represents standard error.

Using the 48 sampled trees, species-specific equations were developed to estimate stem volume inside (VIB, m^3) and outside (VOB, m^3) bark (Table 3). We observed differences in volume allometry by species, with Douglas-fir having the highest volume at a given DBH and western red cedar the lowest (Figure 5a). We also observed a linear relationship between outside bark stem volume and inside bark stem volume (Figure 5b). The slope of this relationship shows, across all species, an average bark volume fraction of 0.1615.

Table 3. Parameter estimates and fitted statistics of equations for predicting stem volume outside bark (VOB) and stem volume inside bark (VIB) for 16-year-old Douglas-fir, western hemlock, western red cedar and grand fir trees growing on a site located in the Oregon Coast Range.

Species	Variable	Parameter	Parameter Estimate	MSE	R^2	RMSE
Douglas-fir	VOB = a*(DBH^b)*(HT^c)	a	0.000102	0.000117	0.9639	0.0161
		b	1.838524	0.2893		
		c	0.830752	0.6083		
	VIB = a*(DBH^b)*(HT^c)	a	0.000054	0.000066	0.9601	0.0139
		b	1.788427	0.3071		
		c	1.037427	0.6468		
			0.000102	0.000117		
Western hemlock	VOB = a*(DBH^b)*(HT^c)	a	0.000027	0.000019	0.9926	0.00967
		b	2.026993	0.0996		
		c	1.083372	0.2422		
	VIB = a*(DBH^b)*(HT^c)	a	0.000018	0.000016	0.9873	0.0108
		b	1.890745	0.1297		
		c	1.335215	0.3084		
Western red cedar	VOB = a*(DBH^b)	a	0.000256	0.00011	0.9915	0.00449
		b	2.141848	0.1534		
	VIB = a*(DBH^b)	a	0.00024	0.000104	0.9913	0.00389
		b	2.10864	0.1536		
Grand fir	VOB = a*(DBH^b)*(HT^c)	a	0.000039	0.00001	0.9978	0.00443
		b	2.047817	0.0756		
		c	0.923092	0.105		
	VIB = a*(DBH^b)*(HT^c)	a	0.000017	0.000007	0.9967	0.00567
		b	2.257184	0.119		

VOB: stem volume over-bark (m^3); VIB:stem volume inside bark (m^3) DBH: diameter at breast height (1.37 m), HT: tree height (m), SE: standard error, R^2: coefficient of determination, RMSE: root mean square error

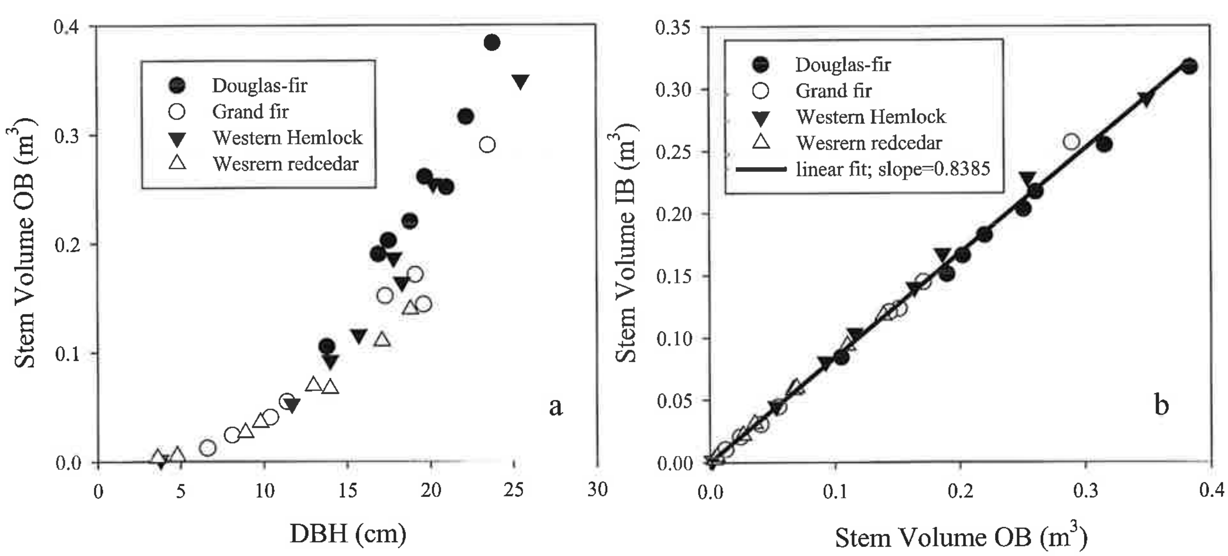

Figure 5. Relationship between diameter at breast height (DBH) and stem volume over bark (a) and the ratio between stem volume over bark and inside bark (b) for Douglas-fir, western hemlock, western red cedar, and grand fir trees growing on a site located in the Oregon Coast Range.

The branch samples collected were used to create branch wood and foliage biomass equations. There was good agreement between observed and predicted foliage and wood + bark branch biomass. Species and treatment-specific functions were determined and can be provided upon request. Figure 6 shows the relationship between DBH and foliage (a), stemwood (b), live branch (c) and stem bark (d) for Douglas-fir, western hemlock, western red cedar, and grand fir trees. For a given DBH, western red cedar had more foliage and branch biomass than the other conifer species, but less stem wood and bark biomass. Douglas-fir had more stemwood and bark biomass than the other species for a given DBH (Figure 6).

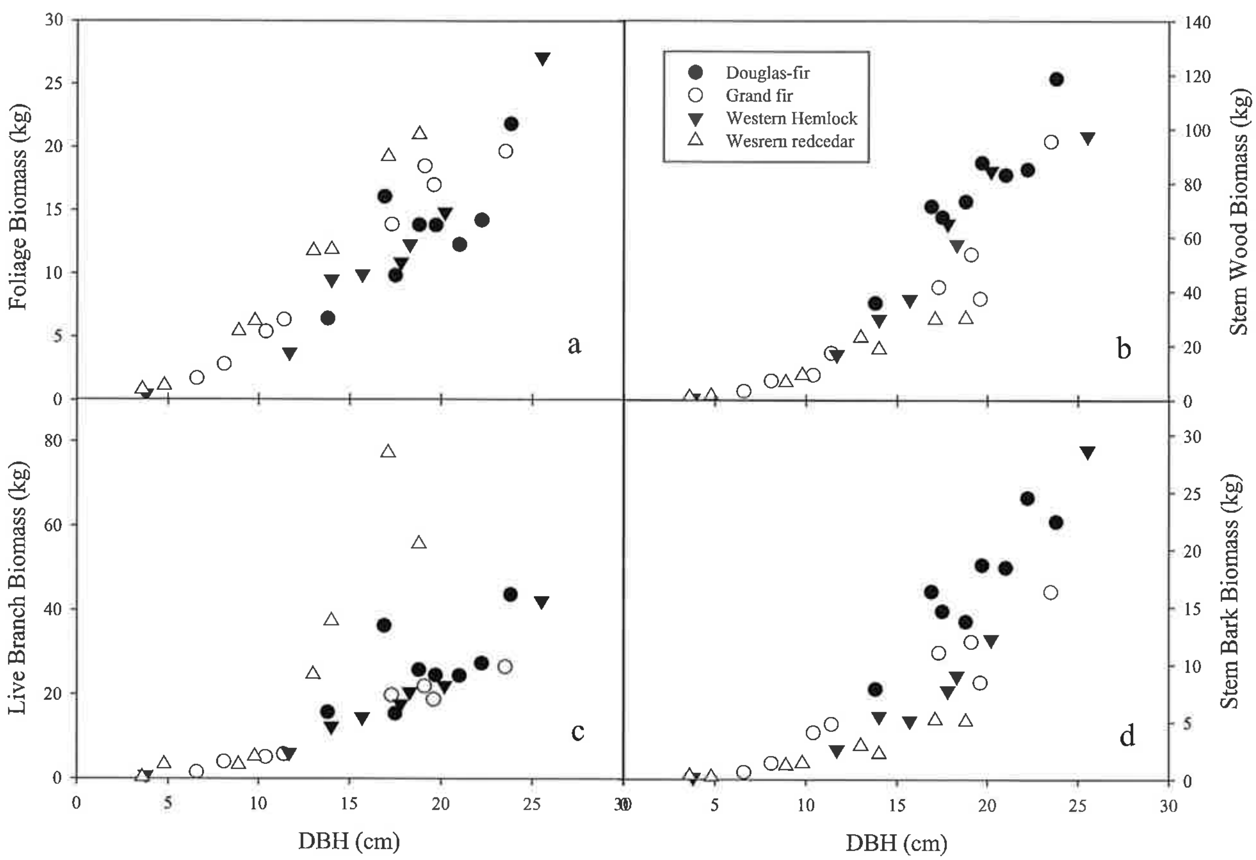

Figure 6. Relationships between DBH and foliage (a), stemwood (b) live branch (c) and stem bark (d) biomass for Douglas-fir, western hemlock, western red cedar and grand fir trees growing on a site located in the Oregon Coast Range.

Parameter estimates for biomass functions to estimate the dry weight of stem wood, bark, live branch, dead branch and foliage trees are shown in Table 4. For 16 year-old Douglas-fir and western red cedar trees, biomass functions of all components were dependent only on DBH. For grand fir, stem wood, bark and live branch biomass depended on DBH and height. No dead branches were observed on Douglas-fir and western red cedar trees.

Table 4. Parameter estimates and fitted statistics of equations for predicting dry weight (kg) of wood, bark, live branch, dead branch and foliage for 16-year-old Douglas-fir, western hemlock, western red cedar and grand fir trees growing on a site located in the Oregon Coast Range.

Species	Model	Parameter	Parameter Estimate	SE	R^2	RMSE
Douglas-fir	Wood = a*(DBH^b)	a	0.499537	0.4474	0.8695	9.0720
		b	1.703376	0.2964		
	Bark = a*(DBH^b)	a	0.115333	0.1190	0.8334	2.3021
		b	1.686987	0.3416		
	Branch Live = a*(DBH^b)	a	0.391757	0.8860	0.3902	8.0636
		b	1.425189	0.7511		
	Foliage = a*(DBH^b)	a	0.126875	0.2210	0.5891	3.1129
		b	1.576986	0.5774		
Western hemlock	Wood = a*(DBH^b)	a	0.286328	0.2428	0.9284	9.6557
		b	1.826283	0.2794		
	Bark = a*(DBH^b)	a	0.000498	0.000253	0.9913	0.8883
		b	3.381199	0.1616		
	Branch Live = a*(DBH^b)	a	0.02632	0.00993	0.9888	1.4186
		b	2.273879	0.1228		
	Branch Dead = a*(HT^b)	a	0.12627	0.4896	0.7580	1.2729
		b	1.906506	1.4412		
	Foliage = a*(DBH^b)	a	0.021115	0.0114	0.9759	1.3344
		b	2.203772	0.1764		
Western red cedar	Wood = a*(DBH^b)	a	0.216346	0.1600	0.9443	3.0450
		b	1.71132	0.2664		
	Bark = a*(DBH^b)	a	0.01526	0.00430	0.9480	0.4803
		b	2.002787	0.1225		
	Branch Live = a*(DBH^b)	a	0.039079	0.0547	0.8533	11.8770
		b	2.557727	0.1071		
	Foliage = a*(DBH^b)	a	0.093557	0.0271	0.9923	0.7244
		b	1.85748	0.1040		
Grand fir	Wood = a*(DBH^b)*(HT^c)	a	0.00179	0.00153	0.9887	3.9087
		b	2.367062	0.2385		
		c	1.292648	0.3312		
	Bark = a*(DBH^b)*(HT^c)	a	0.009587	0.00453	0.9919	0.5905
		b	1.285332	0.1361		
		c	1.292751	0.2193		
	Branch Live = a*(DBH^b)*(HT^c)	a	0.040547	0.0335	0.9713	1.9567
		b	1.526975	0.2545		
		c	0.66422	0.3832		
	Branch Dead = a*(DBH^b)	a	0.000036	0.28	0.8353	2.4969
		b	4.564436	1.1497		
	Foliage = a*(DBH^b)	a	0.137147	0.0816	0.9569	1.6534
		b	1.607244	0.2000		

DBH: diameter at breast height (1.37 m), HT: tree height (m), SE: standard error, R^2: coefficient of determination, RMSE: root mean square error

There was a significant increase in tree above ground biomass when sustained SR treatments are used. Average gain was 8.0, 34.6, 22.6 and 35.1 Mg ha^{-1}, for Douglas-fir, western hemlock, western red cedar and grand fir, respectively (Figure 7). Differences in biomass allocation were observed. Douglas-fir and western hemlock tend to have more biomass in the stem wood and stem bark than the other two species. Western red cedar has more biomass in foliage and live branch than any of the other species.

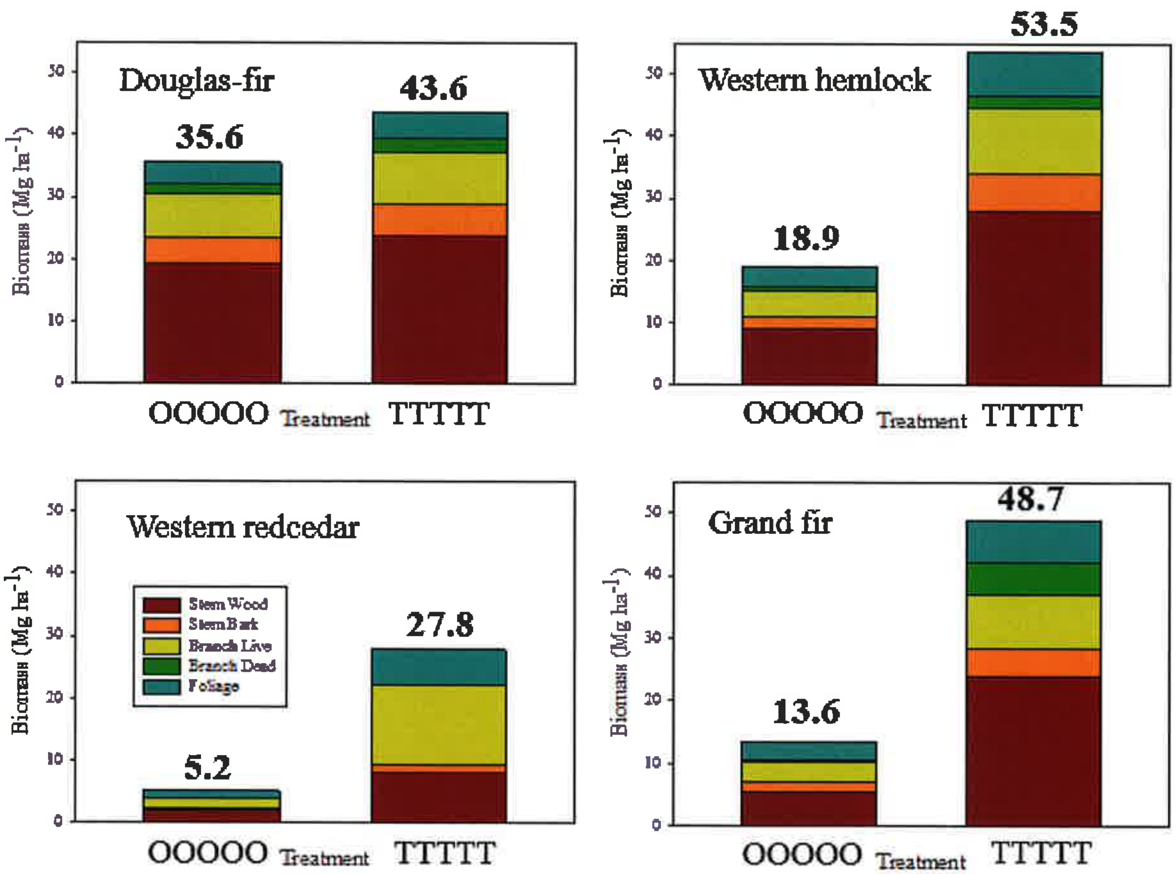

Figure 7. Above ground tree biomass of 16 year-old Douglas-fir, western hemlock, western red cedar and grand fir stands growing under contrasting vegetation management treatments on a site located in the Oregon Coast Range. Total above ground biomass is separated into stem wood, stem bark, branch live, branch dead, and foliage.

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