

**An evaluation of Douglas-fir leave-tree retention practices in central
British Columbia**

**FSP Contract Number: Y051089
Final Technical Report**

April 29, 2005

Prepared by:

University of British Columbia

**Bruce Rogers
Nicole Balliet
and
Chris Hawkins**

**Mailing address:
3333 University Way, Prince George, BC
V2N 4Z9**

Telephone: 250.960-5614

FAX: 250.960-5845

Email: hawkinsc@unbc.ca

Website: www.mixedwood.unbc.ca

Douglas-fir Leave-tree Mortality: A temporal and spatial assessment of water relations under pre and post harvest conditions in the sub-boreal spruce (SBS) biogeoclimatic zone

Abstract

Mature interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) leave trees show inconsistent survival when retained after harvest in the Sub-Boreal Spruce biogeoclimatic zone of BC. Government policy is to maintain appropriate levels of leave-trees on cut blocks to meet biodiversity objectives. Douglas-fir is utilized because populations are naturally fragmented, at the northern edge of their natural distribution, and potentially sensitive to adverse management practices. Dominant and veteran trees that survive fire persist while new cohorts of spruce, lodgepole pine, and sub-alpine fir come and go beneath them. Such stands have unique vertical structure and provide habitat for numerous wildlife species: ungulate winter range for mule deer. Studies in 2002 provided knowledge on the geographical range where leave tree mortality is occurring and revealed potential factors related directly to mortality. In 2003, we assessed possible changes in pre and post harvest water relations around large and/or old Douglas-fir leave-trees, and the potential stresses such changes place on them. Douglas-fir trees may be functioning at the maximum limit of their hydraulic conductance potential in this latitude. If this is true, sudden changes in moisture availability may exert lethal stresses. Plant moisture stress (twig water potential), soil water content, soil water potential, carbon isotope discrimination and micro climate data were collected in 2004 for typical Douglas-fir leave-trees in harvested ('cc') and unharvested ('un') treatment units on five sites. In the SBSmk1 and wk1 subzones cutblocks harvested the previous winter and 5-6 years previously were sampled while in the SBSvk1 subzone, a cutblock harvested 1 year previously was sampled. 2003 and 2004 data indicate differences in water relations between 'cc' and 'un' treatments. Twig water potential and stable carbon isotope ratio values indicating possible water stress were seen most often in trees in the 'cc' treatments with the most extreme values observed in the wettest subzone. Vapor pressure deficit around leave-trees in harvested cutblocks is substantially greater than in the unharvested stand. Sample trees in harvested treatments, in some cases, reach water potentials that may potentially be lethal. Some of the responses are due to genetic variability among trees. Although not as frequently as in the 'cc', some 'un' trees reached lower water potentials than expected. This suggested their post harvest survival rate may be marginal. These trees could be identified by a Douglas-fir Leave Tree Risk Index.

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Background

Maintaining the distribution of Douglas-fir across the landscape remains one of the key issues for strategic and operational planners within Natural Disturbance Type 3 (NDT3). The concern is being addressed in a number of different ways. Although planting Douglas-fir addresses some long term goals for this species, it does not address the preservation of existing forest structure or the longevity of large old Douglas-fir trees that contribute to natural regeneration and wildlife habitat. In order for regional objectives to be realized, the ecological processes and factors affecting survival rates of Douglas-fir leave-trees must be investigated, and the resulting recommendations implemented by forest managers.

Objectives of the Ministry of Forests Regional Douglas-fir management guidelines (BC Ministry of Forests, 1999) are:

1. No net reduction/loss of area of Douglas-fir leading, major or minor forest types in a landscape unit, which implies adequate regeneration of Douglas-fir after harvest; and;
2. Retain a post harvest range of Douglas-fir stand structure and age classes representative of the range present in the pre-harvest conditions.

More specifically, the intent of the regional guidelines was to retain live Douglas-fir leave-trees in a windfirm undamaged condition within areas to be harvested under operational plans. This includes: (1) adequate levels of large old Douglas-fir trees, either in individual-tree or group reserves, and (2) adequate levels of a representative range of younger and older age class of residual Douglas-fir. Licensees are operating within these policies. However, if they are to meet their intended objectives regarding biodiversity guidelines, forest managers need information that will aid them in ensuring that Douglas-fir leave tree survival is realized. Forest companies and government agencies which operate in Douglas-fir timber types are willing to use the results of this research in order to improve Douglas-fir management strategies. This project addresses our lack of success and ecological understanding of factors affecting the viability of Douglas-fir leave-tree silviculture systems in central BC within the SBS. The aim of this research is to provide much needed information to aid foresters and habitat biologists in central BC in the management of Douglas-fir for biodiversity and wildlife objectives. For several years, experts have been puzzled by Douglas-fir die-back when they have prescribed single tree retention in mature stands of scattered Douglas-fir (Stevenson, 2000, Pers. Com.).

At the start of this project (January, 2002), the apparent problem or extent of Douglas-fir leave-tree die-back in the SBS had not been documented or addressed. Field observations to date had been widespread, but largely anecdotal in nature (Jull, 1999). Similar observations were being made for spruce in the boreal forest (Lieffers, 2003 Pers. Com.) For example, in the past it has been thought that leave-trees are more susceptible to Douglas-fir beetle, root rots, etc. Therefore, the need existed to document the level and distribution of Douglas-fir leave-tree die-back across the SBS. This work will provide insights into the ecological processes affecting Douglas-fir leave-tree stress response and/or potential mortality following variable retention or clearcut with reserve harvest treatments. This is an issue which has been little studied or documented in the scientific or operational literature.

Low rates of Douglas-fir leave-tree survival in areas of the SBS have led some to question the ecological viability of partial cut Douglas-fir retention systems. In order to maintain biodiversity in managed stands, forest managers need to know how to preserve acceptable levels of post harvest leave trees in numbers similar to those present after natural disturbance. Improved knowledge of the expected performance of retention systems in relation to variable ecological conditions and Natural Disturbance Types (units) will allow for more effective stand, forest, and landscape level planning.

Data collected during the investigative field season of 2002 were examined to determine if trends in mortality existed in relation to site factors on cutblocks. However, due to the potential complexities affecting the actual mode of tree death ranging from postharvest changes in soil characteristics to root disease, the possibility for this approach to be confounded was realized. In 2002 many observations of post harvest crown characteristics such as top dieback and crown thinning were made. This was the basis for a decision to pursue water relations as a key study parameter in 2003, and subsequently across a broader range of subzones in 2004. It is likely that variability in site conditions contribute in part to variation in the actual modes of tree mortality. However, these processes may be accelerated when considering additional stress placed on the leave-trees by increases in transpirational demand as a result of increased exposure from logging.

Introduction

Water relations for Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), and differences in local hydrology between pre and post harvest conditions may play a role in the mortality of Douglas-fir leave-trees. Pre and postharvest hydrological characteristics may also vary across a range of biogeoclimatic subzones.

Douglas-fir reaches its northern limits in regions of British Columbia that are transitional between the dry warm climatic regions of the central interior plateau, where Douglas-fir forms the dominant forest cover; and, the moist cold climatic regions of the sub-boreal plateau, where lodgepole pine, trembling aspen and white spruce form the dominant cover (DeLong, 1999). Within this transitional area, Douglas-fir is most commonly found on coarser soil deposits or where bedrock occurs close to the soil surface. Data from two 14,000 ha areas, one in a drier warmer biogeoclimatic unit (SBSdw3) and one in a wetter cooler unit (SBSwk1) demonstrate typical Douglas-fir distribution in terms of aspect and slope. These data show that Douglas-fir were most abundant on south westerly slopes greater than 20% at mid elevations (DeLong, 1999).

Altitudinal distribution of both varieties of Douglas-fir (*menziesii* or *glauca*) increases from north to south, reflecting the effect of climate on distribution of the species. Mid to low elevations, with Douglas-fir at its northern limit, are similar climatically to species distribution ranges that include higher elevations in the south. The principal limiting factors are temperature in the north of the range and moisture in the south (Hermann and Lavender, 1988). Consequently, Douglas-fir is found mainly on southerly slopes in the northern part of its range, and on northerly exposures in the southern part. At high elevations in the southern Rocky Mountains, however, Douglas-fir grows on the sunny slopes and dry rock exposures (Hermann and Lavender, 1988). This is a very broad description and more needs to be known about the sensitivity of Douglas-fir leave trees to changes in local hydrology.

Plants can respond to soil conditions in ways that cannot readily be explained in terms of the ability of the roots to take up water and nutrients and roots sense difficult conditions in the soil and in turn send inhibitory signals to the shoots (Passioura 2002). That plants have developed such responses if water supply is at risk seems a good evolutionary strategy. Once soil water potential has fallen to a level that directly effects leaf water potential there is typically so little available water left in the soil that the plant is in danger of severe wilting. (Passioura 2002). For example, when a soil dries, many changes take place within it. It not only holds water more strongly, but it also gets harder and it transmits solutes less readily so that deficiency of poorly mobile nutrients such as phosphorous is more likely. Plants eventually respond to the falling water potential of their leaves by slowing there growth and closing their stomata (Passioura 2002).

Large and/or old Douglas-fir trees may be functioning at the maximum limit of their hydraulic conductance potential when growing in forests. If this is the case, sudden changes in moisture availability may exert intolerable stresses upon them. Philips et al. (2002) tested for reductions in water transport with increasing tree size in young, mature, and old Douglas-fir trees. The hypothesis that canopy conductance and leaf-specific hydraulic conductance vary simply as the inverse of tree height was not supported in this study. However the effect of low soil water content on stomatal and hydraulic conductance was found to be most pronounced for the tallest (60 m) trees, suggesting some differential influence of soil water limitation with tree height. Reductions in stomatal or crown conductance have been shown to been associated with increased hydraulic resistance (Philips et al. 2002). Other studies have shown whole tree estimates of leaf-specific hydraulic conductance to be lower in larger older trees than in smaller younger trees in several species. These studies support the hydraulic limitation hypothesis proposed by Ryan and Yoder (1997), which stated that tree height growth and productivity decline because of stomatal limitation induced by increased hydraulic path-length resistance and gravity (Phillips et al. 2002).

In an old growth (approx. 460 years) Douglas-fir/western hemlock (*Tsuga heterophylla*) forest, dominants and saplings were compared for water potential or whole tree water relations at the Wind River Canopy Crane site, Carson, Washington, USA. Lower stomatal conductances were observed in the old growth trees (Bauerle et. al. 1998). It was hypothesized there are limits to the maximum heights that trees can achieve and that these limits are most often set by stem hydraulic conductivity (Ryan and Yoder, 1997). There also is clear evidence that Douglas-fir seedlings, saplings, and large trees react very differently to both natural and anthropogenic stresses in terms of stem hydraulic conductivity Bauerle et al. (1998).

A number of studies have identified hydraulic limits as the cause of partial or complete foliar dieback in response to drought. The regulation of plant water potential by stomatal control and leaf area adjustment may be necessary to maximize water uptake on the one hand, while avoiding loss of hydraulic contact with the soil on the other (Sperry et al. 2002). Transpiration and plant water potential must be regulated to stay within acceptable physical limits or else canopy desiccation will occur. The existence of a hydraulic limit means that pulling harder on the water column does not necessarily mean that leaves get more water. Plants may need to regulate their rate of water uptake to stay within the hydraulic limits of their supply lines (Sperry et al. 2002).

During preliminary data collection for this project, top dieback of Douglas-fir leave trees was observed on numerous occasions. Work examining damage to Douglas-fir trees throughout Oregon

State showed that dead branches, dead tops and dead Douglas-fir trees were unusually abundant and widespread (Kanaskie, et al. 1999). The primary cause of this branch and tree death is water stress inside the tree. Most water stress in trees results from a lack of available soil moisture due to drought. Water stress inside a tree also can result from excessive soil moisture. In waterlogged or flooded soils, tree roots are deprived of oxygen and may be killed or damaged to the point that they can no longer absorb water and nutrients efficiently (Kanaskie, et al. 1999).

We propose that differences in whole tree water relations exist between harvested and unharvested treatments and in 2003 asked the following questions. Do hydrological relationships around large Douglas-fir trees under pre and post-harvest conditions vary temporally and spatially in the sub-boreal spruce zone? More specifically, we propose that; 1) trees in harvested treatments will attain lower (potentially damaging) water potentials than those in the unharvested treatments under predawn and midday conditions, 2) these differences are more pronounced when atmospheric demand (temperature, relative humidity and vapor pressure deficit) is greatest during the growing season, and 3) $^{13}\text{C}/^{12}\text{C}$ stable isotope ratios will be higher (more positive) in harvested versus unharvested treatments. In 2004 the same response variables were examined across a wider range of subzones to determine if they would yield the same treatment responses seen in the SBSdw3 in 2003.

1.0 Methods

1.1 Study area and site description

All sites were chosen in the Prince George Forest District. In addition the two sites in the SBSdw3 that were examined the previous year, five new sites in the SBSmk1, wk1 and vk1 were also examined (Table 1.1.1).

Table 1.1.1 Site description

Subzone	Time since harvest	Soil Texture	Land form	Surface shape	Slope (%)	Exposure
SBSdw3	0 year	Sandy loam	Glacial till	Flat	0	0
SBSdw3	5 year	Sandy loam	Glacial till	Flat	0	0
SBSmk1	0 year	Sandy clay loam	Glacial till	Flat	0	0
SBSmk1	5 year	Sandy loam	Glacial till	Hummocky	0 - 5	0
SBSwk1	0 year	Sandy loam	Glacial till	Flat		0
SBSwk1	5 year	Silty clay loam	Glacial till	Hummocky	0 - 10	0
SBSvk1	1 year	Silt loam	Glacial till	Benching	30 - 40	SW

1.2 Data Collection

Data for plant moisture stress, percent volume soil moisture, bole temperature, carbon isotope discrimination and micro climate, were collected for large, old Douglas-fir leave-trees in harvested and unharvested treatment units. Principal methods for evaluating leave-tree treatment response included measurement of plant moisture status (stress or twig and soil water potential) and carbon (C) isotope discrimination ($^{13}\text{C}/^{12}\text{C}$ ratio). Two trees per harvested and unharvested treatment were randomly chosen within representative areas and were characteristic of those typically retained in this silviculture system. Candidate trees had no obvious pathological or harvest damage.

1.3 Plant moisture Status/Twig water potential

Plant moisture stress, or tension created within the tree that results from inadequate water uptake between the roots and the surrounding soil environment, can be measured to determine a plant's response to water availability (Wilson, 1984). This tension results from leaf transpiration processes and the plant's failure to acquire water quickly enough to balance the water loss from the leaves (Waring, et al 1967). Commonly, measured water stress can be higher during the day than at night due to diurnal changes in stomatal response (Burns et al, 2003). Waring and Cleary (1967), describe the technique that was used to measure the primary variable in this study (twig water potential). It is a well established and accepted method that has seen wide application since the early 1960's with the use of a "pressure bomb" (Scholander and Hammel, 1965, Kaufman, 1968, Duniway, 1971, Ritchie and Hinckley, 1975 Cleary and Zaerr, 1980, Meron and Grimes, 1987).

Drought stress always restricts the growth of trees (Tyree and Sperry, 1988). The immediate factor most influencing growth response to drought is turgor pressure which is the force causing plastic enlargement of cells, leaves and stems. Reduced shoot and leaf growth in one dry season can reduce the vigor and growth potential of trees for several subsequent years (Tyree, 1989). Water transport in woody plants is limited by the hydraulic sufficiency of the xylem. When xylem water potential becomes sufficiently negative, cavitation occurs with air introduced into the tracheids or vessels forming an embolism (Crombie et al. 1985, Sperry and Tyree, 1990). The introduction of air into the sapwood of a woody plant increases resistance to water flow resulting in stomatal closure (Sperry and Pockman 1993, Sperry et al. 1993), foliage loss (Kavanagh and Zaerr 1997), and eventually mortality (Tyree and Sperry, 1988).

Using a 12 gauge shot gun with number 2 shot, twigs were removed from within the top 5 meters of each sample tree. Two trees were randomly selected in each treatment (clearcut, unharvested, and patch retention). An attempt was made to approximate a sampling schedule of weekly midday and biweekly predawn measurements. However after predawn trends were determined the frequency of these measurements was reduced. Predawn measurements were taken anywhere from midnight to early dawn, revealing the water potential of the tree when at approximate equilibrium with the soil, while stomata are open and respiration is taking place. Midday measurements were usually taken between 11:30 am and 2:00 pm (PDT) revealing twig/leaf water potential at the time of stomatal closure. Three twig samples at a time were measured for each tree. Care was taken to ensure that there was no leakage in the pressure-bomb, therefore, Teflon tape was wound around the twigs before they were placed in the instrument. Differences in shooting heights for each sample tree

were established using a laser height finder, and field measurements of plant moisture status were corrected for gravitational height effects during data summation.

1.4. Soil moisture/water potential

At the time of midday sampling, soil moisture was measured at each tree with a MP-16 soil moisture meter using Time Domain Reflectometry (TDR) technology. Soil water content is a means of expressing the quantity of water in the soil. This can either be expressed as a weight fraction or a volume fraction. These expressions are related via the soil bulk density. In soil almost all of the hydrogen is present as water (Coombs, et al. 1985). TDR depends on discontinuities in the energy storage mechanisms which are available. Combined with knowledge of the propagation velocities of the waves in the medium being used, these discontinuities can be located by observing the change in energy levels at fixed points in the media. Energy which does not become dissipated returns to its source. The probe tips of a TDR appliance present a discontinuity in the wave propagation path of the energy initiated at the signal source (Sowac, 2002).

Four, 30 cm soil moisture probes were fixed under the drip line around each sample tree. Each point sample consisted of recording 3 volumetric water content soil moisture measurements with a time delay reading. Soil samples were taken at each sample tree and sent to the BC Ministry of Forests Research Laboratory in Victoria for pressure plate analysis of soil water retention capacity. Retention curves generated from this process can then be used along with daily soil % volume water content data collected at the time of twig water potential sampling to calculate soil water potential, which can then be related to twig water potential.

Equations for soil water potential are currently being developed. Therefore, results for this section are not presented here, but will be included in subsequent publications and a UNBC Masters Thesis.

1.5 Stable carbon Isotope discrimination

Photosynthesis by terrestrial C_3 plants discriminates against CO_2 with ^{13}C relative to CO_2 with ^{12}C , because ^{13}C has a lower diffusivity through the stomatal pore and lower reactivity with the photosynthetic enzyme Rubisco. This discrimination results in a decrease in ^{13}C of plant matter of approximately 20 % below that of atmospheric CO_2 (McDowell et. al. 2002). Although it is not possible to estimate exact fluxes of assimilated carbon during water deficit, carbon isotope discrimination represents an easy to use tool to study integrated plant adaptations to drought stress because the $^{13}C/^{12}C$ ratio ($\delta^{13}C$) does reflect variability under extreme conditions. (Arndt and Wanek, 2002).

Sampling in 2004 occurred across a range of progressively wetter BEC subzone. 0 year and 5-6 year sites were sampled for the SBSmk1 and wk1 and a 0 year site in the SBSvk1. In Late September, at the close of the 2004 growing season, twig samples were removed from within the top 5 m of all sample trees using a shot gun and sent to the stable isotope lab at the University of British Columbia for mass spectral analysis for $\delta^{13}C$. Samples were freeze dried, ground up and

were then sent to the laboratory. To avoid ecophysiological differences in samples, all needles collected were sun leaves from typical older Douglas-fir dominant in these forest canopies. Needles were selected from close to the current year's growth node to ensure that they were the first to emerge at bud break and had been active the longest. We expect to see more positive (indicative of higher stress) $\delta^{13}\text{C}$ values in postharvest 'cc' treatments than in preharvest or 'un' treatments. Vapor pressure deficit was measured at the SBSmk1 0 year site from June to September.

1.6 Climate station variables

The level of transpiration taking place at the tree level is of interest when considering water *input and output* as it cycles from the soil, through the tree, and into the atmosphere. Temperature plays an important role in this process. The temperature of the aerial parts of plants is determined by the balance between energy gain by interception of radiation and the energy losses by the re-radiation, convection or sensible heat loss and transpiration (Coombs, 1985). The water content of air is known as the absolute humidity and is the density of water vapour in the air. The importance of humidity to the plant is two fold. First, it determines the rate of water loss in transpiration and second, it has a direct effect on the stomata of many plants, so that stomata tend to close in dry air restricting water loss but also reducing CO_2 assimilation. Relative humidity is the ratio of the actual vapour pressure to the saturated vapour pressure at dry bulb temperature. However, plants do not respond directly to relative humidity. Saturation deficit or vapour pressure deficit is the difference between the saturation vapour pressure and the actual vapour pressure at the same temperature. It is an index of the drying power of the air; the higher the deficit the greater the evaporation rate (Coombs, 1985).

Climate stations were established in the 'cc' and 'un' treatments in the SBSmk1 0 year site with air temperature, relative humidity, vapor pressure deficit and soil temperature measured at the base of a sample tree.

1.7 Statistical analysis

Based on consultation with a UNBC statistician, a 2-way fixed factorial ANOVA was initially used for analysis to examine the variability around the twig water potential for trees within and between treatments. The main factors were to be Site and Treatment and their interaction S*T; the error term is Tree (S, T, replicate). It became evident that due to high tree to tree variability and differences in daily environmental conditions which preclude the pooling of samples to attain acceptable sample size, that non parametric statistical methods may have to be used. These methods are currently being investigated and will be presented in subsequent publications and a UNBC Master's Thesis.

2.0 Results

2.1 Twig water potential

Daily Twig Water Potential

Midday

Due to minimal data points for the 5-6 year old sites, only the 0 -1 year old sites which were sampled more often are included in this summary. Mean midday water potential values ranged from around -1 MPa in spring and fall to almost -4.0 MPa during the hot demanding parts of the summer. These sites showed a general trend for 'cc' trees to have lower water potentials more often throughout the season (Figures 2.1.1 – 2.1.3). However, this varied as some of the 'un' trees did at times reach lower water potentials than the 'cc' trees. At one site in particular (Figure 2.1.2), a 'un' tree was constantly more water stressed than all other trees. At the wettest and coldest site (Figure 2.1.3), early spring water potentials were more negative for both 'un' trees with the 'cc' trees reaching lower levels in relation to the 'un' trees as the season progressed.

Predawn

Mean predawn water potentials for the SBSmk1 and vk1 (Figure 2.1.4 – 2.1.5) also showed the same treatment trend as the midday measurements, with the 'cc' trees consistently having more negative values. However at the SBSwk1 site, the same 'un' tree as seen in the midday measurements had the lowest values throughout the season.

Figure 2.1.1 Daily midday mean twig water potential for the SBSmk1 0 year old site

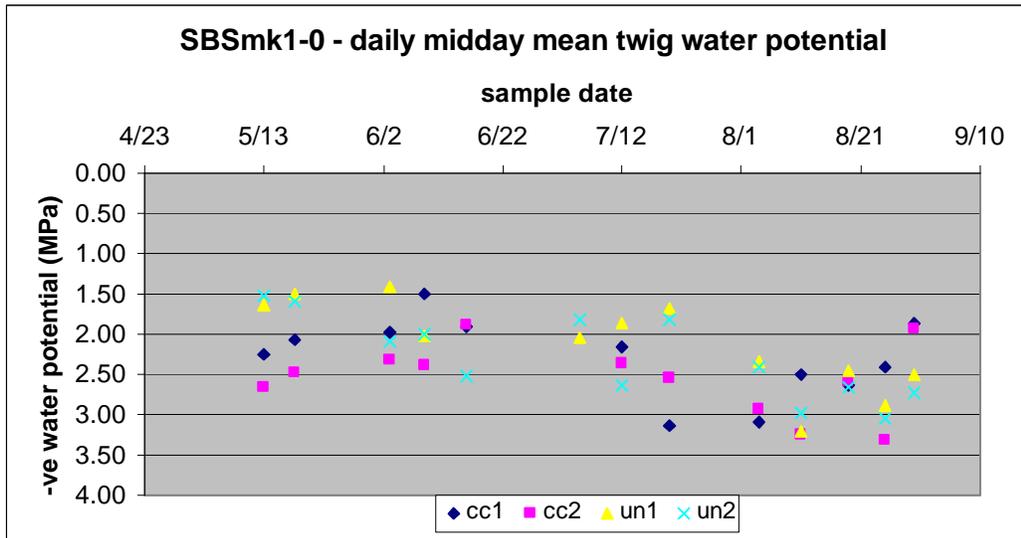


Figure 2.1.2 Daily midday mean twig water potential for the SBSwk1 0 year old site

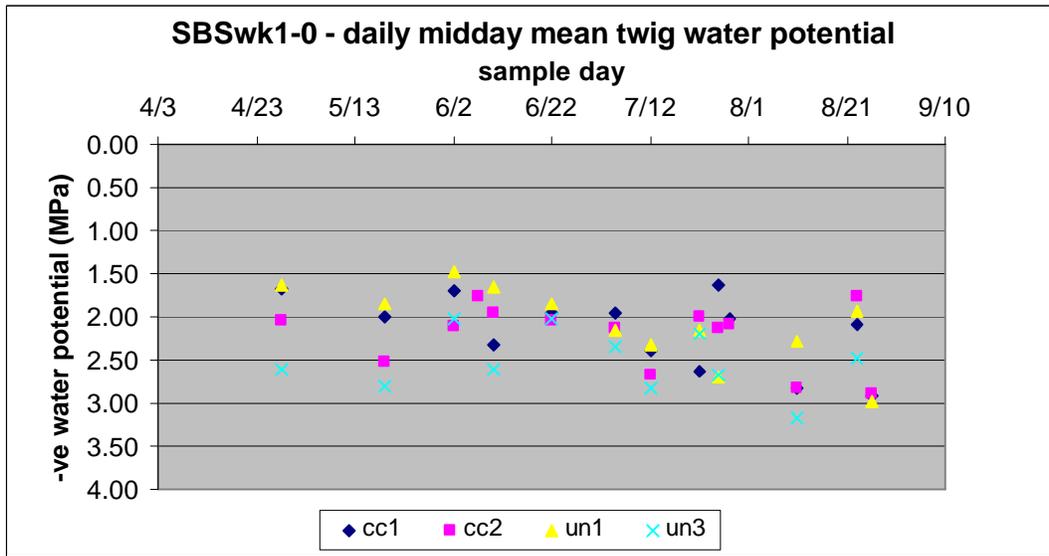


Figure 2.1.3 Daily midday mean twig water potential for the SBSvk1 1 year old site

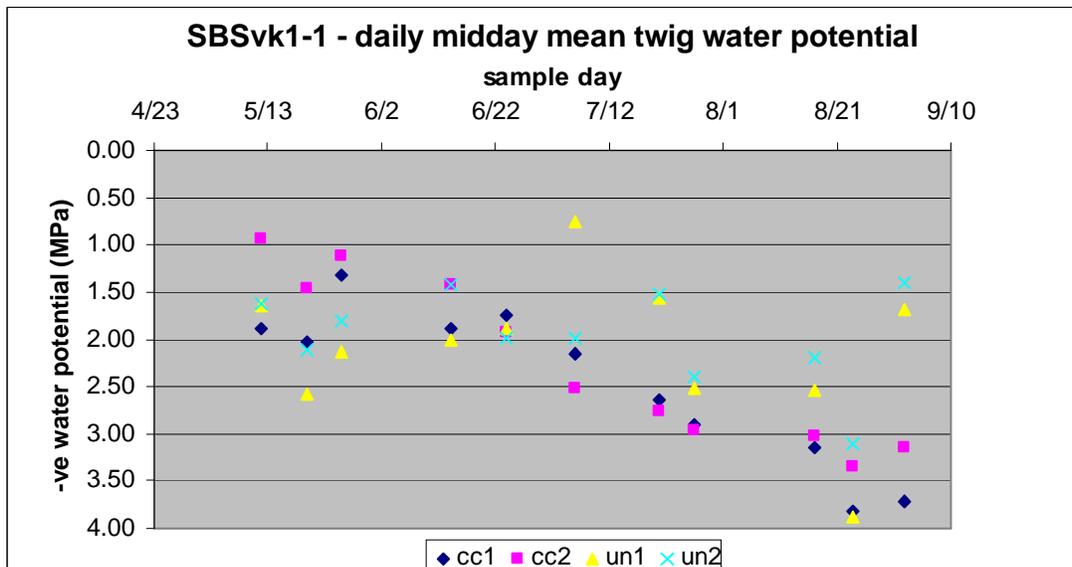


Figure 2.1.4 Daily predawn mean twig water potential for the SBSmk1 0 year old site

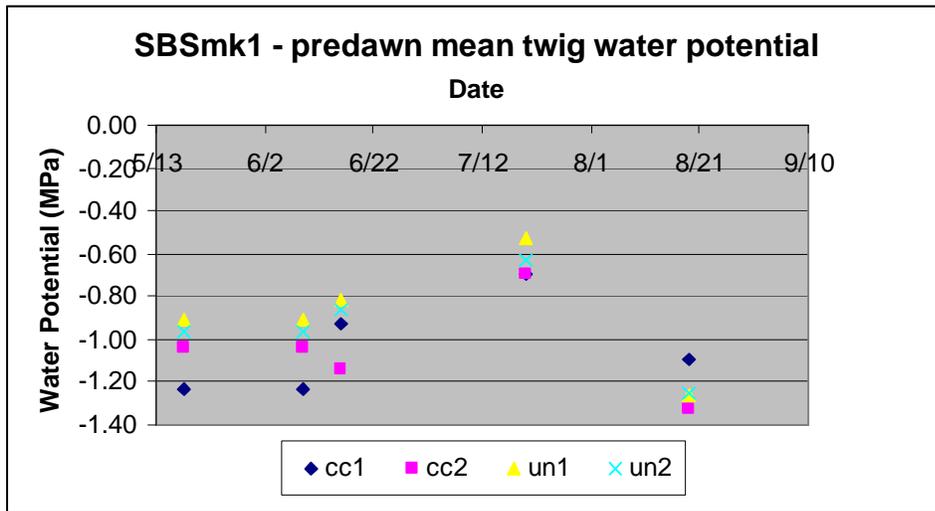
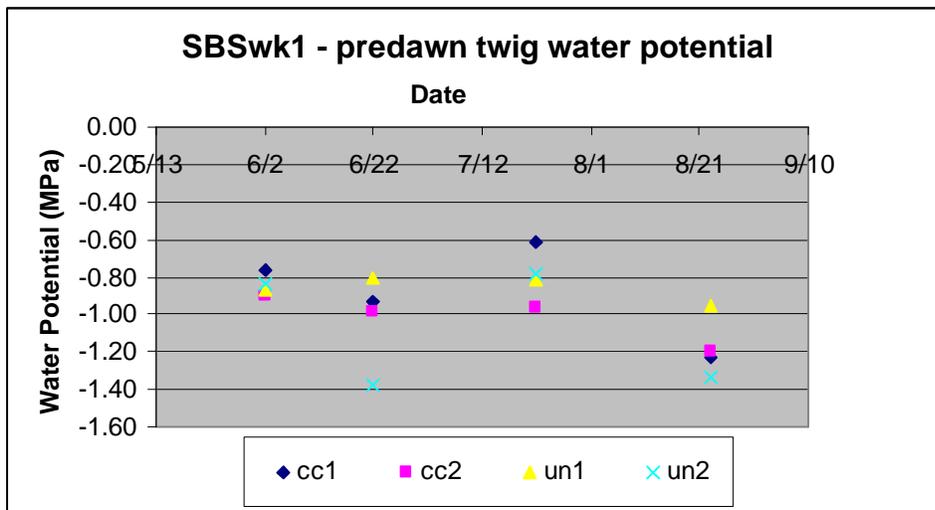


Figure 2.1.5 Daily predawn mean twig water potential for the SBSwk1 0 year old site



Cumulative twig water potential

Seasonal cumulative individual twig water potential sums for each tree had to be balanced for each site. Because each site was limited to the use of only sample days where all trees were sampled (e.g. trees 1 and 2 in cc and un) with equal sample size (3 twig measurements per tree per day), the number of sample days used at each site varies (e.g. if on a sample day only one tree was sampled in a treatment and/or one tree had less than 3 twigs measured, these data were not included in the seasonal cumulative sums. Therefore, comparisons of cumulative sums are limited to within sites and cannot be compared across sites as absolute values. Some sites due to logistics and/or sample days that had to be removed in the sample balancing process only had 1, 2 or 3 data points and were subsequently not included in this summary.

All sites but (Figure 2.1.6 – 2.1.8) the SBSwk1 0 year had trees in the ‘cc’ treatments with the greatest cumulative midday values. Consistent with the daily water potential data, one of the ‘un’ trees at the SBSwk1 site was much more water stressed than the other ‘un’ tree and the ‘cc’ trees. The two ‘cc’ trees at this the site consistently had greater values than one of the other ‘un’ trees.

Predawn values (Figure 2.1.9 – 2.1.10) for ‘cc’ trees at the SBSmk1 0 year site were consistently greater that of those in the ‘un’ treatment. As with the midday daily and cumulative water potential values, the same ‘cc’ tree at the SBSwk1 0year site had greater cumulative values.

Table 2.1.1, Frequency of occurrence for twig summed growing season values in 3 designated “Risk Categories”, further illustrates the distribution of individual twig measurement values that occurred throughout the season in three Risk Categories (Low, Moderate, High). The three sites represented are those that had sufficient data points. Sample size is also listed in the table. At the SBSmk1 and vk1 sites the proportion of twig samples relative to the total number of values over the season that occurred in the high risk category (≤ -2.9 MPa) was much higher in the cc than in the un, and conversely in the low risk category (≥ -2.5 MPa) for the un treatments.

Figure 2.1.6. Cumulative midday seasonal twig water potential/Plant moisture stress (PMS) sample value for the SBSmk1 0 year site

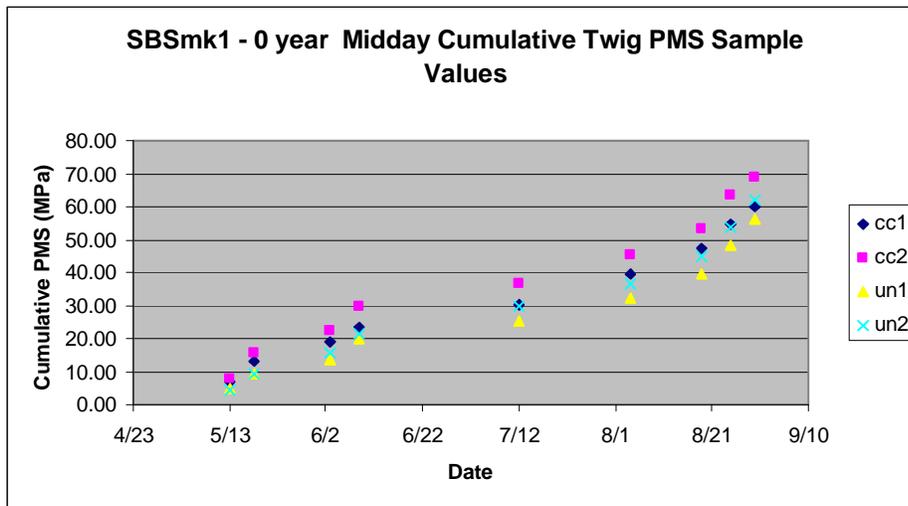


Figure 2.1.7. Cumulative midday seasonal twig water potential/Plant moisture stress (PMS) sample value for the SBSwk1 0 year site

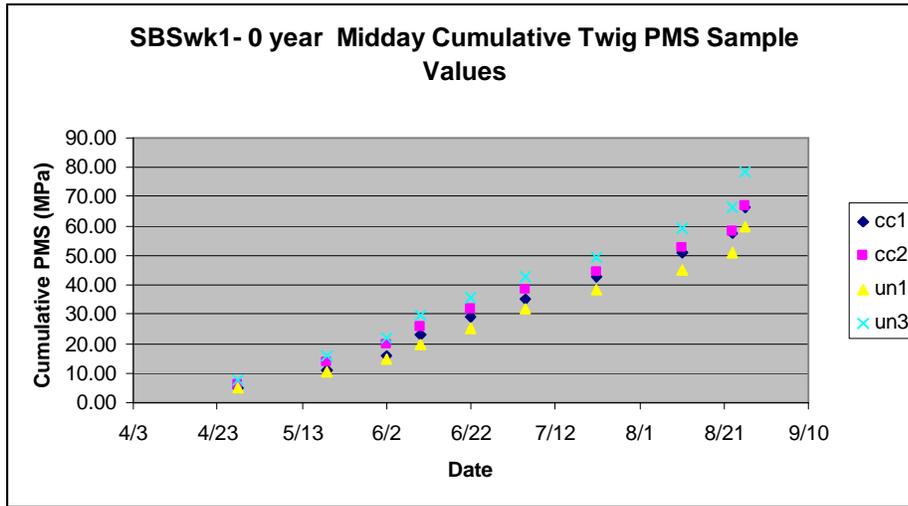


Figure 2.1.8. Cumulative midday seasonal twig water potential/Plant moisture stress (PMS) sample value for the SBSvk1 5 year site

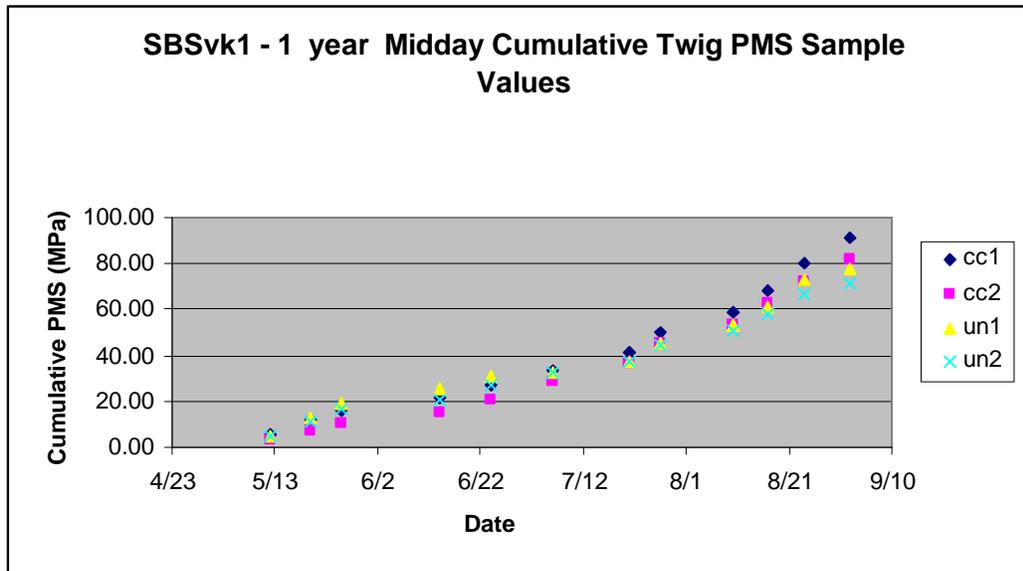


Figure 2.1.9 Cumulative predawn seasonal twig water potential/Plant moisture stress (PMS) sample value for the SBSmk1 0 year site

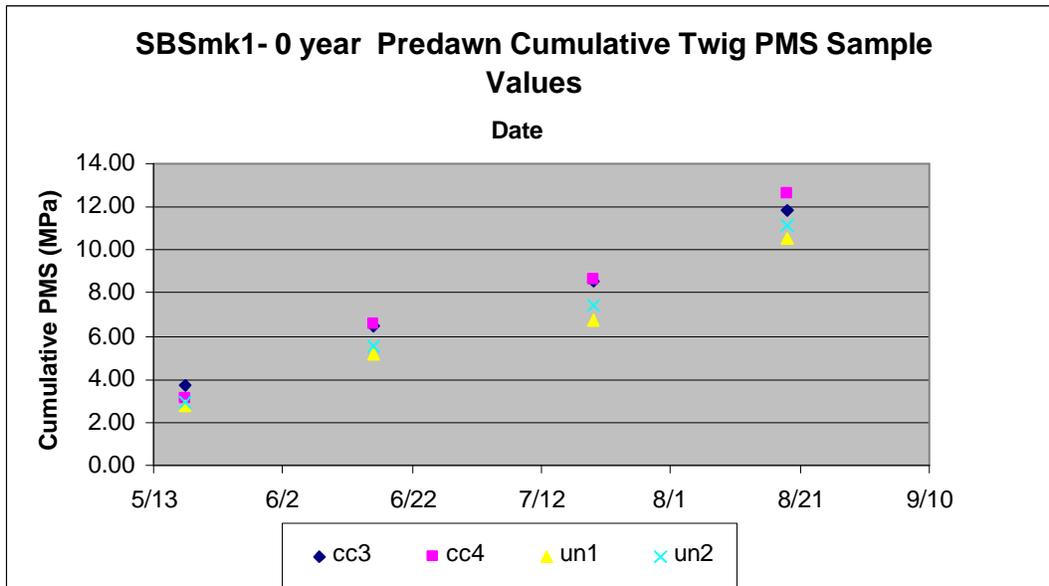


Figure 2.1.10 Cumulative predawn seasonal twig water potential/Plant moisture stress (PMS) sample value for the SBSwk1 0 year site

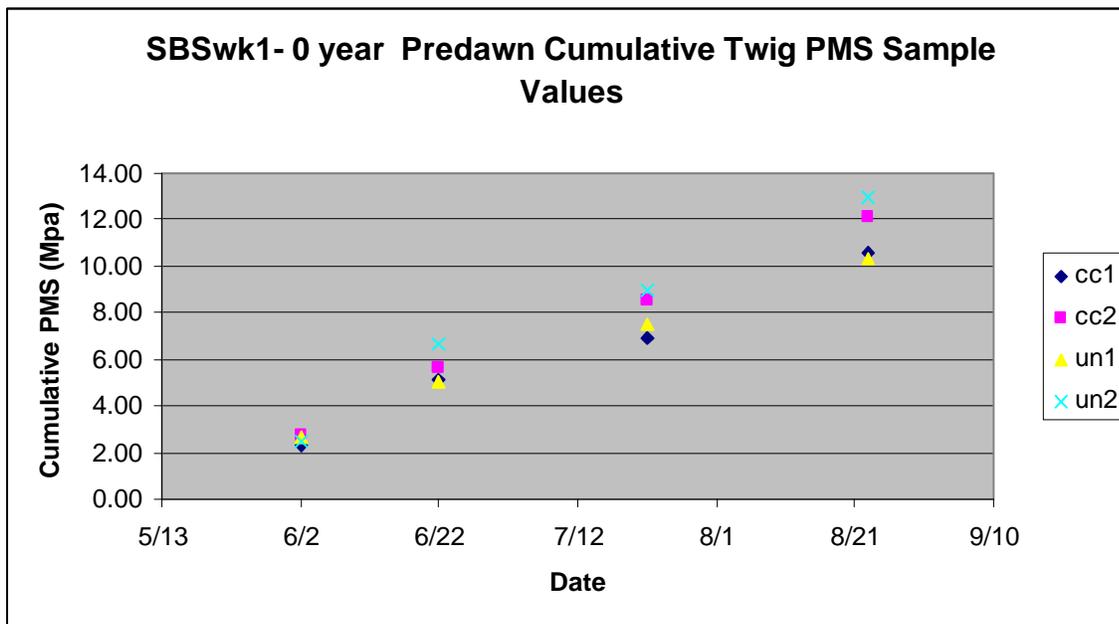


Table 2.1.1 Frequency of occurrence for twig summed growing season values in 3 designated Risk Categories

Subzone	Moisture class	Time since harvest (yrs)	Treat	Tree #	(n) twig	(n) day	Risk Zone Frequency (absolute count)			Risk Frequency % (MPa) Category		
							freq good	freq low	freq high	≤-2.5	≥2.51 ≤ -2.9	≥ -2.91
SBSmk1	moist	0	cc	1	39	13	27	5	6	69	13	15
SBSmk1	moist	0	cc	2	35	13	17	7	12	49	20	34
SBSmk1	moist	0	un	1	39	13	30	5	3	77	13	8
SBSmk1	moist	0	un	2	38	13	22	14	3	58	37	8
SBSwk1	wet	0	cc	1	39	14	31	5	3	79	13	8
SBSwk1	wet	0	cc	2	42	14	33	7	3	79	17	7
SBSwk1	wet	0	un	1	40	14	32	6	2	80	15	5
SBSwk1	wet	0	un	2	40	14	16	15	9	40	38	23
SBSvk1	very wet	1	cc	1	39	11	21	5	13	54	13	33
SBSvk1	very wet	1	cc	2	41	11	21	10	11	51	24	27
SBSvk1	very wet	1	un	1	41	11	31	5	5	76	12	12
SBSvk1	very wet	1	un	2	39	11	35	2	2	90	5	5

2.2 Carbon isotope ratio (d13C)

2004 Leaf Sample

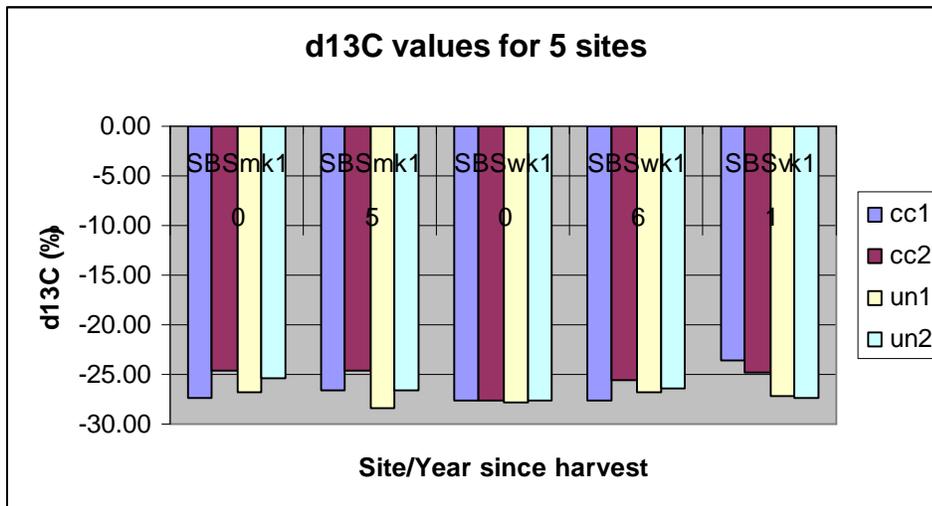
Measurement error and needle variability for d13C was taken for one tree. Variability within and between needle samples is presented in Table 2.2.1.

Figure 2.2.1 Leaf d13C values for cc and un treatments for all sites. At all five sites at least one tree in the cc treatment had the most positive (indicative of stress) d13C values. Values ranged from -23.51 ‰ in the cc treatment for the wettest SBSvk1 subzone to -28.40 ‰ in the un treatment of the driest SBSmk1 subzone. Trees in the cc treatment at the 1 year since harvest SBSvk1 site were substantially more positive than those in the un treatment. The recently harvested 0 year site in the SBSwk1 also showed more positive values in the cc treatment. Although the most positive value was found in the cc treatment at the SBSwk1 5 year site, the other tree in the cc treatment also showed the most negative (least stressed) d13C). In the SBSmk1 0 year site cc treatment one tree had the most positive while the other had the most negative d13C of both treatments. Finally, in the SBSmk1 5year site the most positive value was measured in the cc while the most negative value was seen in the un.

Table 2.2.1. Measurement error and needle variability for d13C.

Site	Treatment	Tree	Comparison	Mean (‰)	n	SD	SEM
mk1-0 year	un	2	between needles	-24.92	6	0.33	0.13
mk1-0 year	un	2	within needle	-24.48	3	.46	0.26
vk1-0 year	cc	1	within needle	-24.17	3	0.64	0.37
wk1-0 year	cc	2	within needle	-27.69	3	0.27	0.16

Figure 2.2.1 Leaf d13C values for cc and un treatments for all sites



2.3 Climate variables

Soil Temperature

Seasonal maximum and minimum values are presented in Table 2.3.1 and Figure 2.3.1 – 2.3.3 illustrates a trend for warmer soil temperature in the cc compared to the un treatments and overall cooler temperatures at depth.

Table 2.3.1 Seasonal maximum and minimum values for cc and un soil temperature

Treatment	Temp (C)
Max of 10 cm cc	17.16
Min of 10 cm cc	12.2
Max of 10 cm un	14.9
Min of 10 cm un	10.33
Max of 30 cm cc	15.93
Min of 30 cm cc	10.82
Max of 30 cm un	12.92
Min of 30 cm un	8.89
Max of 60 cm cc	14.66
Min of 60 cm cc	9.76
Max of 60 cm un	12.51
Min of 60 cm un	8.05

Figure 2.3.1 Seasonal daily maximum soil temperature at 10 cm for the SBSmk1 0 year old site

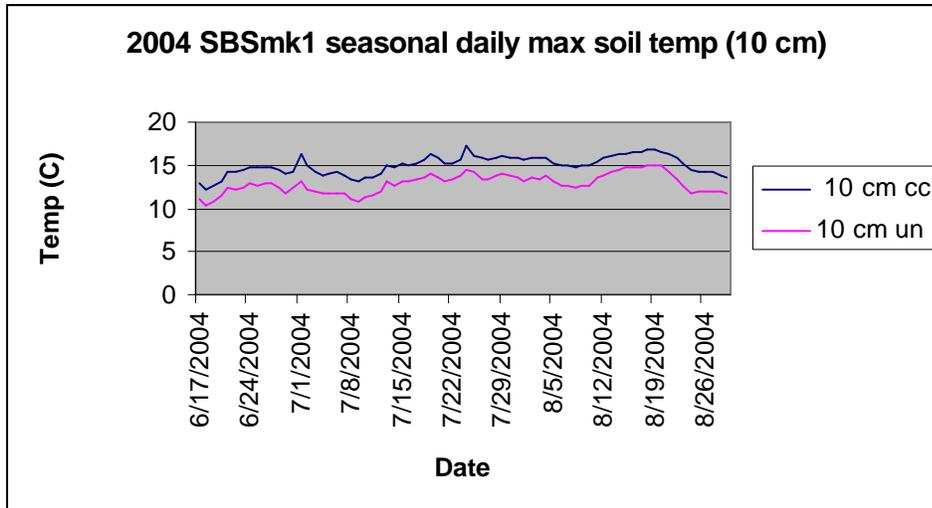


Figure 2.3.2. Seasonal daily maximum soil temperature at 30 cm for the SBSmk1 0 year old site

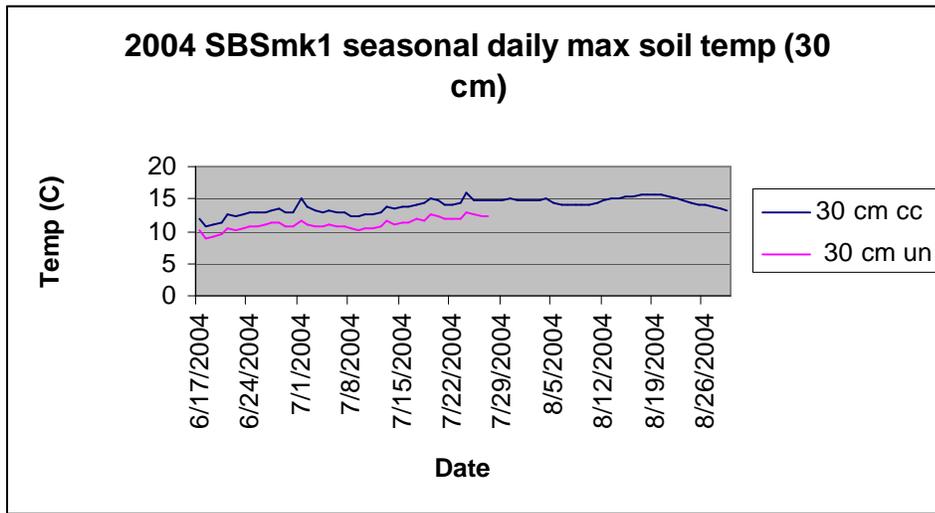
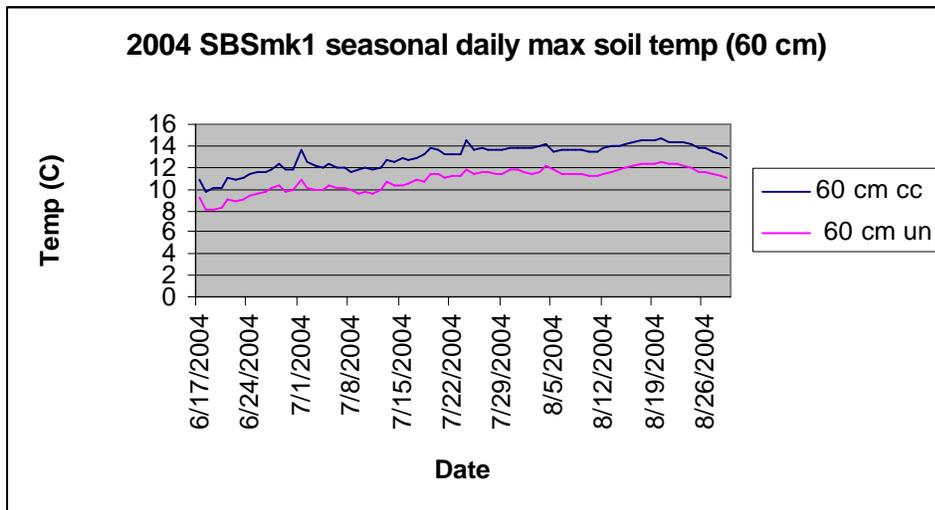


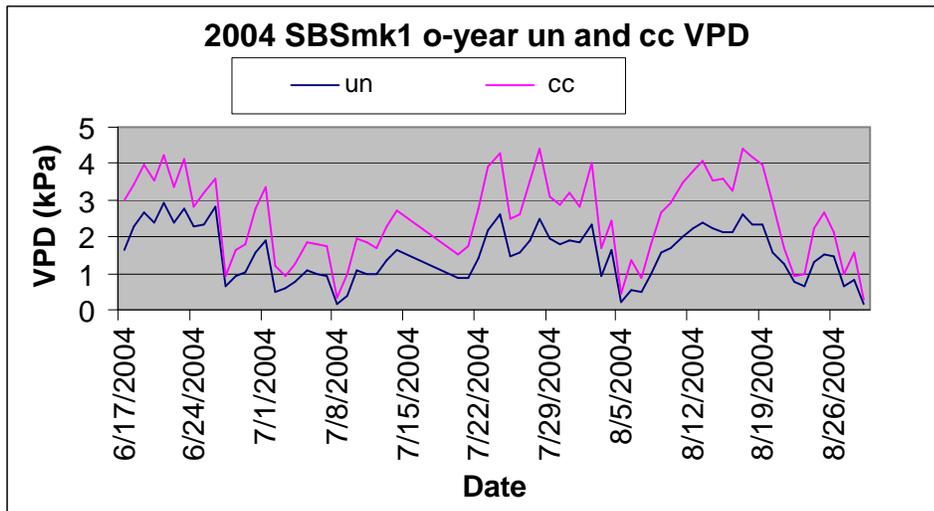
Figure 2.3.3 Seasonal daily maximum soil temperature at 60 cm for the SBSmk1 0 year old site



Vapor Pressure Deficit

Vapor pressure deficit was consistently higher over all in the 'cc' treatment compared to the 'un' treatment.

Figure 2.3.4. Seasonal vapor pressure deficit in the ‘cc’ and ‘un’ treatments for the SBSmk1 0 year old site.



3.0 Discussion

Although it is difficult to make statistical comparisons of moisture stress between subzones due to the inability to control for site factors and genetic variability and having low sample sizes, the most extreme water potential and $\delta^{13}C$ values indicating moisture were seen in the wettest subzone. In this subzone, Douglas-fir is truly at its range limit being only found on exposed slopes and coarse textured soils. A common trend seen across all sites for predawn and midday measurements, was that the lowest (most water stressed) daily values and the greatest Cumulative values (cumulative loading) for the most part always occurred for a tree in the ‘cc’ treatments. However, variability between trees was substantial and in one case a tree in the ‘un’ treatment spent most of its time at physiologically dangerously low water potentials in comparison with the other trees at that site. This may be due to natural genetic variability with some trees having greater capacity to tolerate water stress. It is also possible that root rot such as *Inonotus tomentosus* may be involved, as although it prefers spruce over Douglas-fir, it is known to infect the latter as well. Thus, it is possible that trees such as this are operating right on the edge in terms of their respiratory and photosynthetic compensation points and would be the likely candidates for mortality after removal of the surrounding forest and increased vapor pressure deficit acting on what were once shade leaves protected by the other tree crowns.

Daily water potential graphs describe the response of individual trees to variable daily environmental conditions. However, it may be more useful to know the frequency at which individual trees were found to be within given water potential categories (Table 2.1.1). These categories (Risk Categories) form the basis for the development of the Risk Index. Furthermore, describing the negative water potential load on individual trees with the use of cumulative water potentials (Figures 2.1.6 – 2.1.9) allows for another method of exploring the degree to which each of the trees responded over a whole growing season in relation to one another. Trends seen with cumulative water potential values are parallel with that of the daily water potential values as expected. Another useful feature of cumulative values is that sometimes trees for numerous reasons ranging from response to seasonal changes to variable microsite conditions within a treatment may

have very low water potentials from time to time throughout the season, yet spend most of their time at relatively normal levels.

Stable carbon isotope ratios also show the same trend as water potential values, having more positive (higher tree stress) values over all in at least one 'cc' tree at a site and site to site comparisons can also be difficult due to local environmental differences. Greater productivity in these populations indicates that their lower discrimination against $^{13}\text{CO}_2$ probably results from higher photosynthetic capacity, not lower stomatal conductance (Guy and Holowachuk, 2001). Thus, although stomatal conductance has a major influence on carbon isotope discrimination and hence $\delta^{13}\text{C}$, we must also consider genetic differences associated site conditions and their interactions (GxE). Therefore, differences in values between sites cannot be conclusively attributed to any treatment effect without first controlling for site effects. There did not appear to be a subzone moisture gradient affect between sites. However, with few sample trees and high tree to tree variability within treatments it cannot be ruled out. The SBSvk1 (the wettest site) did have very positive $\delta^{13}\text{C}$ in the 'cc' treatment compared to the other sites measured in 2004 and this zone is likely the most limiting for Douglas-fir.

In the unharvested stand, leaves of the older dominant and co-dominant Douglas-fir are typically 1/2 to 2/3 shaded. Due to differences in ecophysiology of sun and shade leaves (Nippert and Marshal 2003), it is conceivable that when the canopy is opened up around these trees exposing the understory shade leaves to a new more water demanding microclimate, that water stress may occur. It has been demonstrated that vapor pressure deficit is considerably higher for the shade leaves in the 'cc' treatment. Increasing vapor pressure deficit typically causes a reduction in stomatal conductance (Cowan, 1994; Hinckly and Braatne, 1994; Montieth, 1995; Oren et al., 1999) and consequently the supply of atmospheric CO_2 to the stomatal pore is reduced, thereby causing the ratio of atmospheric to internal or sub-stomatal CO_2 to decline (McDowell, et al. 2004). Re-fixing of respired carbon can affect the carbon isotope signal of understory foliage. In forest stands, CO_2 concentrations increase near the ground due to efflux of soil respired CO_2 . The isotopic composition of respired air differs from the bulk atmosphere. The extent to which vertical gradients of $\delta^{13}\text{C}$ exist in foliage depend on a number of stand and climatic factors (Cregg and Zhang 2000). The greater the mixing and turbulence within the stand the less opportunity for gradients to develop. Open stands or stands in exposed areas will have greater air mixing and less likely to have $\delta^{13}\text{C}$ gradients. Brooks et al. estimated that 20% of the variation in $\delta^{13}\text{C}$ gradient in a canopy of boreal conifers was due to variation in the isotopic composition of the source air (Cregg and Zhang 2000).

4.0 Conclusion and Management Implications

4.1 Conclusion

There may ultimately be numerous modes of mortality for Douglas-fir leave-trees after harvest ranging from root damage, disease and soil compaction to water inundation and fine root die back. Many may be operating on the edge physiologically in terms of their productivity and ability to store reserves to meet basic metabolic needs. Over two seasons of sampling Douglas-fir leave-trees, it is clear that there are differences in water relations between the harvested and unharvested treatments and that although trees in unharvested treatments also reach low water potentials, most do not do so as frequently nor to the same extent. This may be a function of having a closed

canopy. For the past five years both observation and data have also lead to the conclusion that the level of mortality seen in cutblocks in the Prince George and Fort St. James Forest Districts is greater than what occurs naturally in unharvested forests.

It is understood that the silvics of Douglas-fir limit its establishment on wet cold sites and that this is a major factor behind the patchy distribution of this species seen in the central interior. Furthermore, it is also evident that nature provides its own leave-trees that survive for hundreds of years through stand replacing wildfires, as we observe many large old fire veteran Douglas-fir in younger stands. What is not clearly understood is the survival rate of these trees.

Having an understanding of the stress levels of these large old trees through out their northern extent may give landscape planners a better idea of leave-tree survivability, so that expected mortality can be factored into the success of intended long term green-tree retention strategies and target goals. Data provided through this research forms the basis for the creation of a Risk Index that would provide planners with knowledge that would help them meet their objectives. However, due to minimal samples, statistical inference is limited. Therefore, the inventorying of plant moisture stress levels at the landscape level along with work examining fine scale physiological responses to more specific harvesting and wildfire treatments should continue if questions regarding the success of long term management strategies are to be addressed.

4.2 Management Implications

Douglas-fir provides unique stand structure at its northern reaches. Although stand age may provide some useful information when classifying wildlife habitat, and is available on B.C. Ministry of forests inventory forest cover maps, it is the structure of a particular stand that dictates its understory light. During the process of forest ecosystem change at one location which includes species composition and structural changes, recognizable community stages will occur, known as seral stages (Perry, 1994). Typical seral stages after timber harvest include grass, shrub-sapling, pole, mature and old growth (Edmonds et. al., 2000).

Winter can be a critical period for mule deer, and Douglas-fir (*Pseudotsuga menziesii*) trees in north central British Columbia provide extensive canopy cover (Whittaker, 1996). Douglas-fir is associated with steeper more southerly slopes in the northern part of its range. This relationship becomes more pronounced under the influence of wetter colder climates (DeLong, 1999). Because Douglas-fir's occurrence can be limited in such a manner, its distribution at northern latitudes is fragmented and patchy in some cases resembling landscape islands. Armleder and Dawson (1992), found that Douglas-fir present in uneven aged stands provide unique canopy structural characteristics and offer better forage for mule deer. Canopy characteristics in these forest types create snow interception and thermal cover, allowing mule deer to forage with less energy output during cold winters with high snow fall (Whittaker, 1996).

To manage a landscape attribute such as ungulate winter range (UWR) effectively in a resource extraction setting, government policy must be clearly defined at a local level, and include enough detail so that successful operational outcomes will be realized. Currently, older age class forests with a Douglas-fir component are considered an indicator of optimal UWR. Operational recommendations in the Fort St. James District include maintaining a minimum of 40% winter

range in age class 8 (140 yr+), with crown closure >56% Douglas-fir and Spruce (varies with UWR unit) (Vinnedge, 2004). In the Prince George Forest District, wildlife managers propose maintaining species composition as Douglas-fir leading, with a minimum of 50% Douglas-fir, considering age class, shrub species composition and abundance, stand structure, overstory tree species composition and crown closure (Brade, 2003). Crown closure is the most important factor controlling understory light availability, and is influenced to a large extent by the vertical structure of the forest. Although older age classes of forest are in many cases associated with this vertical structure, seral stage, because it describes forest structure in more detail than age class, may ultimately serve as a more appropriate indicator of optimal UWR.

Observation has led to the conclusion that trees retained in significantly large patches do not appear to be affected by harvesting their mortality is less than for individual leave trees. It may be that there is no way to avoid mortality after harvesting. In this case the knowledge of expected mortality given local data could dictate retention levels. Leaving patches with large old Douglas-fir in them that are large enough to maintain the microclimate around these trees is the logical approach. However, for this to take place it must be recognized as government policy. Currently, forest companies are leaving many of these trees to meet biodiversity objectives set out by the Forest and Range Practices Act. With respect to Douglas-fir retention, policies around patch retention characteristics should also be included.

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