Extension Note

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Assessing the Fertilization Response Potential of Subalpine Fir (*Abies lasiocarpa*): A Retrospective Study

Rob Brockley
Research Branch
Kalamalka Forestry Centre
B.C. Ministry of Forests and Range
3401 Reservoir Road
Vernon, BC V1B 2C7

Abstract

Pre- and post-fertilization tree growth in unfertilized and fertilized thinned stands was used to estimate the 7-year radial growth response of operationally fertilized subalpine fir (*Abies lasiocarpa*). Despite large stem growth variability in thinned, and thinned and fertilized stands, the 7-year growth increment of fertilized trees was apparently 51–57% larger than the estimated growth that would have occurred had the stand not been fertilized. These results are consistent with the favourable fertilization responses reported for other *Abies* species. Reliable growth and yield data from well-designed fertilizer experiments are needed to provide a stronger basis for statistical inference of fertilization response and to provide area-based growth response estimates for subalpine fir. In the interim, however, some operational fertilization of subalpine fir may be justified, especially in vigorous, well-spaced (i.e., not overly dense) immature stands with a moderate component of nutrient-deficient interior spruce.

Introduction

Forest nutrient deficiencies are widespread throughout the British Columbia Interior, and the growth benefits of fertilizing with nitrogen (N) and other nutrients have been well documented for several conifer species (Brockley and Simpson 2004; Brockley 2006, 2008). By accelerating stand development and reducing rotation age, large-scale fertilization may be helpful in mitigating the effects of catastrophic mortality on future timber supply caused by the mountain pine beetle (*Dendroctonus ponderosae*). Several aerial fertilization projects have recently been completed in immature Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) and interior spruce (*Picea glauca, Picea engelmannii,* and their hybrids) stands. Operational fertilization of young lodgepole pine (*Pinus contorta* var. *latifolia*) will likely proceed after the current mountain pine beetle outbreak has subsided. However, given the predominance of extensive stands of immature subalpine fir on the forested landscape, accelerating their development by fertilization may also be a useful timber supply mitigation strategy in several Interior forest management units. However, information is currently lacking on the potential responsiveness of subalpine fir forests to nutrient additions.

The fertilization response potential of several other *Abies* species, including white fir (*Abies concolor*) (Miles and Powers 1988; Cochran 1991; Powers 1992), grand fir (*Abies grandis*) (Cochran et al. 1986; Shafii et al. 1989; Chappell and Bennett 1993), noble fir (*Abies procera*) (Chappell and Bennett 1993), and red fir (*Abies magnifica*) (Powers 1992; Zhang et al. 2005), is well documented. Given these results, subalpine fir is likely also responsive to fertilization. However, reliable growth and yield data from well-designed, area-based research field installations are needed to justify large investments in operational fertilization of this species. In the interim, a semi-operational project previously undertaken by Pacific Inland Resources (a division of West Fraser Timber Ltd.) provided an opportunity to obtain preliminary information for forest planners and practitioners who may be contemplating fertilization of subalpine fir as a timber supply mitigation strategy.

Methods

The Blunt Fire Incremental Silviculture Project was initiated in 1996 to document the responsiveness of immature, high-elevation subalpine fir forests in the Bulkley Timber Supply Area to thinning and fertilization.[1] The project area is located 65 km north of Smithers at an elevation of 1000 m. The biogeoclimatic classification of the area is transitional between the Moist Cold subzone of the Engelmann Spruce–Subalpine Fir (ESSFmc) zone and the Babine variant of the Moist Cold Sub-Boreal Spruce (SBSmc2) zone (Banner et al. 1993). The 950-ha project area is comprised of a naturally regenerated subalpine fir forest (approximately 65 years old) with a minor component of interior spruce. The forest regenerated naturally following a wildfire in the 1930s.

In 1997, twelve 0.01-ha permanent sample plots (PSP), consisting of three replications of an untreated control plot and each of three post-thinning regimes (800, 1200, 1600 trees per hectare [tph]), were established in portions of the project area approximating each of the two pre-treatment density levels (approximately 3000 and 8000 tph). Extensive areas surrounding the PSPs were subsequently operationally thinned in 1997 and 1998.

Operational fertilization activities were conducted within the project area in the fall of 2000, 2002, and 2003. All of the PSPs (including unthinned controls) and large portions of the surrounding thinned and unthinned stands were fertilized in one of these three years. A fertilizer blended to deliver 204 kg N/ha and 66 kg sulphur/ha was aerially applied to all targeted blocks.

The 8-year remeasurement of the Blunt Fire PSPs indicated that the post-treatment growth increment of subalpine fir in the thinned and fertilized PSPs was substantially larger than the growth in the control (i.e., unthinned) plots.[2] In September 2008, further field sampling was undertaken in operationally thinned and thinned and fertilized portions of the project area in an attempt to separate the effects of thinning from the effects of fertilization.

Definitions

The symbols used to describe fertilization response are defined as follows (from Ballard and Majid 1985):

- A – growth increment after date of fertilization
- B – growth increment before date of fertilization
- E – estimate, for a fertilized tree, of the growth increment that would have occurred after the date of fertilization had fertilizer not been applied
- I – an index of response
- R – absolute magnitude of growth response
- av – the average for all replicates
- f – fertilized
- u – unfertilized
- k – a specific fertilized tree
- l – a specific unfertilized tree

Theory

Tree growth response following fertilization (R_{fk}) is the difference between the post-fertilization growth of a fertilized tree (A_{fk}) and the growth that would have occurred had it not been fertilized (E_{fk}).

$$R_{fk} = A_{fk} - E_{fk} \quad (1)$$

Measuring A_{fk} is rather straightforward. However, obtaining a reliable estimate of E_{fk} can be difficult. This is especially true in operational settings, where the elements of sound experimental design (e.g., replication and randomization) are often not rigorously employed. Because E_{fk} can only be estimated (i.e., cannot be measured), some simple alternatives to estimate fertilization growth response are:

$$R_{fk} = A_{fk} - A_{ul} \quad (2)$$

$$R_{fk} = A_{fk} - B_{fk} \quad (3)$$

In Equation 2, the post-fertilization growth of a tree in a nearby, unfertilized stand (A_{ul}) is used to estimate E_{fk}. However, because of possible site variability between the fertilized and unfertilized stands, A_{ul} may be a poor

1 Laing and McCulloch Forest Management Services Ltd. 1998. Blunt Fire incremental silviculture project establishment of permanent sample plots. Unpublished report.

2 Silvicon Services Inc. 2007. Response of subalpine fir (*Abies lasiocarpa*) to thinning and fertilization in the ESSFmc: results of 8-year re-sampling of permanent sample plots. Forest Investment Account Land Based Investment Project 2502004. Unpublished report.

estimate of E_{fk}, even if trees l and k share similar tree and stand characteristics (e.g., size, competition class). In Equation 3, the pre-fertilization growth of a fertilized tree (B_{fk}) is used to estimate E_{fk}. Unfortunately, B_{fk} may be a very poor estimate of E_{fk} due to ageing effects (i.e., decline of growth rate with increasing age) and fluctuating weather patterns between the periods to which A and B data apply (Ballard and Majid 1985). Other silvicultural treatments (e.g., thinning) undertaken in conjunction with fertilization would also reduce the reliability of Equation 3.

Where soil conditions and climate between a fertilized and unfertilized stand are similar, estimation of E_{fk} may be improved by multiplying B_{fk} by the average ratio of post- to pre-fertilization tree radial increment in a nearby unfertilized stand $av(A_u/B_u)$ (Ballard and Majid 1985).

$$R_{fk} = A_{fk} - (B_{fk}) \cdot av(A_u/B_u) \qquad (4)$$

Average response for several trees may then be calculated as follows:

$$av(R_f) = av(A_f) - av[(Bf) \cdot av(A_u/B_u)] \qquad (5)$$

Variability of $av(A_f)$ and $av(B_f)$ can be reduced by confining sample selection to representative trees that share similar characteristics (e.g., size, competition class).

Provided substantial differences in soil moisture regime and climate do not exist, A_u/B_u tends to be fairly insensitive to most site and stand dissimilarities (Ballard and Majid 1985). Therefore, a relative index of response (I) can be calculated that will indicate whether a fertilization response has occurred.

$$I = av(A_f/B_f) - av(A_u/B_u) \qquad (6)$$

Many variations of the so-called "quotient method" have been used in the analysis of European fertilization experiments (Lipas 1979; Pettersson 1994). Equations 5 and 6 were used to assess the radial growth response of operationally fertilized lodgepole pine (Brockley and Yole 1985). The same assessment methodology is used in this paper to estimate the fertilization response of thinned subalpine fir.

Blunt Fire assessment

Field sampling

Field sampling was conducted in a thinned stand (T) and in a nearby thinned and fertilized stand (TF) in September 2008. The selected stands were supposedly thinned (T and TF) and fertilized (TF) in 1997 and 2002 (fall), respectively. This would enable assessment of 5-year pre-fertilization (1998–2002) and 5-year post-fertilization (2003–2007) bole radial increment in both the T and TF stands. The possible confounding effects of thinning on fertilization growth response would be minimized by confining the pre- and post-fertilization assessment periods to the post-thinning period. Unfortunately, supplemental information that was obtained following the completion of field sampling indicated that thinning in T and TF stands actually occurred in 1998 and 1997, respectively. Moreover, fertilization of the TF stand occurred in fall 2000 (not 2002 as previously thought). Based on this new information, pre- and post-fertilization response periods were increased to 7 years (1994–2000 and 2001–2007, respectively). Unfortunately, analysis and interpretation of results may be partially confounded by these deviations from the planned assessment protocol.

A total of 30–40 sampling points were located at paced intervals along transect lines within both the T and TF stands. A nearby healthy, codominant subalpine fir tree was selected at each sampling point. The selected trees had a mean diameter at breast height (dbh) of 13.0 cm (range 11–15 cm) and shared similar stand and site characteristics (i.e., pre- and post-thinning density, slope, aspect, and BEC site series). A 2-cm wide disc was cut at breast height from each selected tree that was felled.

Disc measurement

The largest inside bark diameter (D1) and the inside bark diameter (D2) of the perpendicular bisector of D1 were measured on each disc. From these measurements, two average radii, measured from the pith to the inside of the bark, were located and marked on each disc. On each of these two radii, the following distances were measured:

- distance from pith to the other edge of the 1993 annual growth ring, X;
- distance from pith to the outer edge of the 2000 annual growth right, Y; and
- distance from pith to the outer edge of the 2007 annual growth ring, Z.

For discs sampled from the T stand, the difference between distances X and Y is B_u in Equations 5 and 6. Likewise, the difference between distances Z and Y is A_u. For discs sampled from the TF stand, the difference between distances X and Y is B_f in Equations 5 and 6. Likewise, the difference between distances Z and Y is A_f.

Data analysis

A paired t-test was used to retain or reject the hypothesis that the population means of $av(A_f)$ and $av[(B_f) \cdot av(A_u/B_u)]$ in Equation 5 are the same. A two-sample t-test was used to test for differences between $av(A_f/B_f)$ and $av(A_u/B_u)$ on the right side of Equation 6. However, in neither case is there any basis for statistical inference of fertilization response since there is only one true replicate of the unfertilized and fertilized treatments (i.e., the unfertilized and fertilized treatments were assigned to two different stands and the individual trees were sub-sampled from within these two stands).

Results and Discussion

The 7-year pre-fertilization mean radial increment in the unfertilized and fertilized stands (B_u and B_f, respectively) indicates that 1994–2000 growing conditions were similar in the two stands (Table 1). Thinning was undertaken one year earlier in the fertilized (TF) stand than in the unfertilized (T) stand (1997 vs. 1998), which may explain why mean B_f was slightly larger than mean B_u.

Comparison of the pre- and post-fertilization radial increments in the unfertilized stand (B_u and A_u, respectively) indicates that the unfertilized stand (T) likely responded positively to the operational thinning in 1998 (Table 1). However, the large coefficient of variation (CV) (31%) for mean A_u/B_u (Table 2) indicates that the radial growth response to thinning in the unfertilized stand was quite variable. Variable and delayed radial growth response of subalpine fir following release cutting has been previously reported (Herring 1977). The larger CV for A_f/B_f (39%) indicates that variability was exacerbated by fertilization (Table 2).

As shown in Table 2, $av(A_f)$ is considerably larger than $av[(B_f) \cdot av(A_u/B_u)]$ and the hypothesis that the two means are equal (H_o) is rejected. The CVs for both variables are large (37% and 24%, respectively), which may reduce the level of confidence that the observed growth differences are due to fertilization. However, A_f was larger than $(B_f) \cdot av(A_u/B_u)$ for 29 of the 32 fertilized trees. Likewise, $av(A_f/B_f)$ is substantially larger than $av(A_u/B_u)$ and H_o is also rejected (Table 2). Using Equations 5 and 6, relative 7-year fertilization response is estimated to be 51% and 57%, respectively (Table 2). The results are consistent with the 29% increase in needle mass (g/100 needles) of fertilized trees relative to unfertilized trees that was measured one year after fertilization.[3] A positive correlation between first-year needle mass response and subsequent growth of fertilized trees has been reported for balsam fir (*Abies balsamea*) (Timmer and Stone 1978) and other species (Valentine and Allen 1990; Brockley 2000).

TABLE 1 *Mean radial increment (cm) of thinned (T) and thinned + fertilized (TF) stands during the pre- and post-fertilization periods.*

	Radial increment period			
	1994–2000		2001–2007	
	T (B_u)	TF (B_f)	T (A_u)	TF (A_f)
n	34	32	34	32
Mean (cm)	0.43	0.46	0.74	1.24
CV[a]	0.33	0.24	0.38	0.37
No. samples[b]	5	3	21	56

Note: *B*, growth increment before date of fertilization; *A*, growth increment after date of fertilization; *u*, unfertilized; *f*, fertilized
a Coefficient of variation
b Number of samples necessary to achieve a precision of ± 0.10 cm at the 90% confidence level

TABLE 2 *Estimating 7-year fertilization response using pre- and post-fertilization stem radial growth measurements from fertilized and unfertilized trees.*

	A_f (cm)	$B_f \cdot av(A_u/B_u)$ (cm)	A_f/B_f	A_u/B_u
n	32	32	32	34
Mean	1.24	0.82	2.76	1.76
CV[a]	0.37	0.24	0.39	0.31
Difference	0.42[b] (51%)		1.00[b] (57%)	
Parameter	$av(R_f)$		I	
Equation[c]	5		6	

Note: *B*, pre-fertilization stem radial growth increment (1994–2000); *A*, post-fertilization stem radial growth increment (2001–2007); *u*, unfertilized; *f*, fertilized
a Coefficient of variation
b Reject H_o
c Equation 5: $av(R_f) = av(A_f) - av[(B_f) \cdot av(A_u/B_u)]$; Equation 6: $I = av(A_f/B_f) - av(A_u/B_u)$

Summary and Management Implications

Despite the large observed variability in pre- and post-fertilization radial growth in T and TF stands, representative subalpine fir trees apparently responded positively to fertilization in the Blunt Fire project area. The estimated 7-year growth increment of fertilized trees was 51–57% larger

3 Ibid.

than the growth that would have occurred had the stand not been fertilized. These results are consistent with the favourable fertilization responses reported for other *Abies* species. However, fertilization response potential of subalpine fir growing under different site or stand conditions is still unknown. Also, reliable growth and yield data from well-designed fertilizer experiments are needed to provide a stronger basis for statistical inference of fertilization response and to provide area-based growth response estimates. Foliar nutrient interpretative criteria must also be developed to reliably diagnose nutrient deficiencies in subalpine fir forests. In the interim, however, some operational fertilization of subalpine fir may be justified, especially in vigorous, well-spaced (i.e., not overly dense) immature stands with a moderate component of nutrient-deficient interior spruce (for which fertilization response is better documented).

It is difficult to reliably evaluate growth response following operational fertilization by using traditional area-based permanent sample plots since there is no basis for statistical inference of treatment response where control and fertilized units are not randomly allocated or replicated. Reliable assessment is even more difficult when stand and site conditions vary between fertilized and unfertilized stands and where fertilization response is partially confounded by response to accompanying silvicultural treatments (e.g., thinning). Under these conditions, the single-tree assessment methodology described in this paper may be useful for estimating relative treatment response in operationally fertilized stands. Growth ring analysis using increment cores (two cores at 90° per tree), in conjunction with an electronic tree-ring measuring system, might be a practical modification of the described sampling methodology.

Similar methodology may also be useful for assessing the fertilization response potential of other tree species for which information is currently lacking. For example, previously operationally fertilized lodgepole pine or Douglas-fir stands could be used (along with representative unfertilized stands) to obtain preliminary fertilization response estimates for western larch (*Larix occidentalis*), which often grows in mixture with these other species in southeastern British Columbia.

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