Modelling vegetation management treatments with the Tree and Stand Simulator¹

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ABSTRACT

The Tree and Stand Simulator (TASS) has been used for over 20 years in British Columbia to generate yield tables for managed stands. In order to explore the impacts of weed control on site productivity we chose two vegetation management research trials where 10- to 15-year post-treatment data were available (Boston Bar and Mica research sites). Tree survival and height growth results were used to adjust the TASS input parameters to simulate the various brushing treatments. At the Boston Bar site, all vegetation reduction treatments shortened the Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) physical rotation age by up to 10 years and culmination mean annual increment (cMAI) was increased 8% to 11% relative to the untreated control. At the Mica site, the glyphosate and all repeated manual cutting treatments resulted in a shortening of the Engelmann spruce (*Picea engelmannii* Parry) rotation age by seven years and increased cMAI by approximately 11% to 12%.

Key words: growth and yield modelling, vegetation management, *Pseudotsuga menziesii*, *Picea engelmannii*

RÉSUMÉ

Le Tree and Stand Simulator (TASS) (simulateur d'arbre et de peuplement) est utilisé depuis plus de 20 ans en Colombie-Britannique pour produire des tables de rendement pour les peuplements aménagés. Dans le but d'explorer les effets du contrôle de la végétation indésirable sur la productivité de la station, nous avons choisi deux essais de recherche sur le contrôle de la végétation pour lesquels les données 10 et 15 ans après le traitement étaient disponibles (site expérimental de Boston Bar et de Mica). Les données sur la survie des arbres et la croissance en hauteur ont été utilisées pour ajuster les paramètres intrants du simulateur afin de reproduire les différents traitements de dégagement. Dans le cas du site de Boston Bar, tous les traitements de contrôle de la végétation ont réduit l'âge physique de la révolution du sapin Douglas (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) d'un maximum de dix ans et l'accroissement annuel moyen cumulé (AAMc) a augmenté entre 8% et 10% par rapport au témoin non traité. Sur le site de Mica, les traitements au glyphosate et tous les traitements répétés de débroussaillage manuel ont réduit l'âge de la révolution de l'épinette d'Engelmann (*Picea engelmannii* Parry) de sept ans et augmenté l'AAMc d'environ 11% à 12%.

Mots clés :: modélisation de la croissance et du rendement, contrôle de la végétation, *Pseudotsuga menziesii*, *Picea engelmannii*

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Introduction

Vegetation management treatments have been widely used in British Columbia to control non-crop vegetation in order to maintain plantation survival, enhance seedling growth and to help meet standards for free-growing plantations. A significant amount of research has been published documenting the response of vegetation species and crop trees to various treatment methods including the use of herbicides, manual brushing, sheep browsing, and mulch mats (Biring *et al.* 1996, Comeau *et al.* 1999). However, for many reasons much of this research has not provided the long-term data on crop tree response needed to help quantify stand yields.

Many vegetation management research trials have not been designed to provide long-term, stand-level information. The design and establishment of research trials that have spatial and temporal longevity is expensive, time-consuming and requires a significant long-term commitment of land, personnel, and financial resources. However, without these datasets we lack the information to support science-based management decisions. Long-term data help provide the statistical confidence to apply quantitative predictions from growth and yield models to the forest landbase.

In British Columbia, the Tree and Stand Simulator (TASS) (Mitchell 1975) has produced yield tables for second-growth managed forests for over 20 years (e.g., Mitchell and Cameron (1985)). TASS-generated yield tables are also made available via the software TIPSYP (Table Interpolation Program for Stand Yields) (Mitchell *et al.* 2004). Together, these two systems provide access to reasonable predictions of managed-stand yields for most coniferous species and two broadleaf species.

TASS operates as a spatially explicit, individual-tree-based model driven by height growth, crown expansion and bole increment (Mitchell 1975). Individual TASS trees grow crowns and foliage that are represented by concentric shells that compete for three-dimensional computer space. Each tree is assigned a rate of crown expansion relative to height growth. Annual bole increment is applied as a function of the amount of foliage volume individual tree crowns occupy. TASS has been calibrated using a database of 15 000 permanent sample plots and has been validated against independent thinning experiments (Goudie 1998).

In this paper, we present the results from TASS simulations of vegetation management treatments from two separate research trials where continuous crop tree data was available for 10 and 15 years post-treatment. The 10-year post-treatment results from these two trials have been previously published (Biring *et al.* 2003, Harper *et al.* 2005) and represent some of the oldest stand-level, vegetation management datasets presently available from British Columbia. The objectives of this paper are to explore the long-term growth and yield predictions for the various vegetation management treatments and to compare the TASS results in terms of merchantable volume, physical rotation age and stand productivity.

Methods

The two vegetation management research studies chosen were located near Boston Bar and Mica in southern British Columbia. Vegetation and crop tree response data have been published for both these research sites (Harper *et al.* 1998,

Comeau *et al.* 2000, Biring *et al.* 2003, Harper *et al.* 2005). For more detailed information please refer to these publications.

The Boston Bar research site was established during 1993 within a Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) plantation located in the warm and dry, south-western interior of British Columbia. The experiment consisted of a completely randomized design (CRD) with five treatments replicated four times. Planted Douglas-fir seedlings were assessed for up to 10 years post-treatment within 20, 144-m² treatment plots (12 × 12 m plus 3-m buffers). The five treatments were two rates of pre-plant glyphosate (2.1 and 1.0 kg ai/ha), one rate of pre-plant hexazinone (2.1 kg ai/ha), a mulch mat application (90 × 90 cm) and an untreated control (Table 1). Treatments were applied to examine the effectiveness of controlling grass, herbs, and shrubs. Vegetation competition and soil moisture deficit were considered the main factors influencing the survival and growth of Douglas-fir plantations in the Boston Bar area. Significant improvement in the Douglas-fir diameter and height growth was found up to seven years post-treatment within the hexazinone and glyphosate treatments. Survival and growth was improved to some extent by all vegetation control treatments by enhancing soil moisture availability on this dry site (Harper *et al.* 2005).

The Mica research site was established in the south-eastern interior of British Columbia near the Mica Dam on the Columbia River (Comeau *et al.* 2000). The study was established during 1991, and used a CRD consisting of eight treatments replicated three times. Tagged Engelmann spruce seedlings (*Picea engelmannii* Parry) were followed up to 15 years post-treatment within 24 900-m² treatment plots (30 × 30 m). The eight treatments comprised six combinations of spring and summer, annual and repeated manual cutting, a single application of glyphosate (2.1 kg ai/ha), and an untreated control (Table 1). The treatments were applied to examine the effectiveness of repeated manual cutting within a mixed shrub-herb community. On this site, vegetation develops rapidly in response to moist, productive growing conditions. If left untreated this mixed-shrub complex can reduce survival and growth of planted spruce through reduction in light levels and induced vegetation and snow press. Significant improvement in spruce survival was noted for the repeated manual brushing and glyphosate treatments; however, significant height growth differences were limited to years 4 to 5 and diameter growth to years 3 to 7 post-treatment (Biring *et al.* 2003).

Model input parameters

For each of the two research sites, top height was calculated for each treatment plot and measurement year (mean height of the largest basal diameter 100 trees per hectare (tph)) (Fig. 1). Mean site index was determined from treatment top height and breast height age (BHA) using the site curves of Thrower and Goudie (1992) for Douglas-fir and, Chen and Klinka (2000) for Engelmann spruce (Table 1). The results of previous height growth analysis (Biring *et al.* 2003, Harper *et al.* 2005) were used to determine if unique treatment site indices were justified assuming any increase in the rate of early stand height development followed a type I response associated with weed control (Snowdon and Waring 1984).

Table 1. Treatment means and TASS simulation statistics by research site.

	Site Index estimate ^a	Field DBH (cm) ^b	TASS DBH (cm) ^b	TASS Density (tph) ^b	TASS age (yr) @ 90% crown closure	cMAI (m ³ /yr/ha)	Stand Age @ cMAI (yr)	Merch- antable Volume @ cMAI (m ³ /ha)	DBH @ cMAI (cm)	% increase in cMAI relative to untreated control	% increase in Merch. Volume ^c
<i>Boston Bar site – planting density 1300 tph Interior Douglas-fir</i>											
Untreated control	22.9	1.8	1.1	650	35	5.56	100	523	33.4	0	0
Glyphosate @ 2.1 kg ai/ha pre-plant	30.9	3.0	3.0	1202	20	6.16	90	509	25.1	10.8	10.4
Glyphosate @ 1.0 kg ai/ha pre-plant	31.6	2.5	2.4	1138	21.5	6.15	93	528	26.0	10.6	10.4
Hexazinone 2.1 kg ai/ha pre-plant	27.5	3.7	2.8	975	24.5	6.05	95	533	27.6	8.8	8.9
Plastic mulch mats (90 × 90 cm)	26.5	2.5	2.4	910	26.5	5.99	98	547	28.9	7.7	8.0
<i>Mica site – planting density 1600 tph Engelmann spruce</i>											
Single spring cutting	35.8	8.9	9.2	1248	22	12.61	44	506	26.4	8.3	14.9
Single summer cutting	32.7	7.9	9.1	1280	21	12.69	44	509	26.2	9.0	15.7
Repeated spring cutting for 3 years	31.8	8.7	8.7	1600	15.5	13.05	42	492	23.9	12.1	18.6
Repeated summer cutting for 3 years	35.4	9.4	8.9	1467	17.5	13.03	42	492	24.4	11.9	18.6
Cutting twice in a year for 3 years	38.6	9.9	8.9	1520	16.5	13.04	42	492	24.1	12.0	18.6
Cutting twice in a year for 2 years	35.6	9.8	9.0	1387	19	12.89	42	488	24.8	10.7	17.6
Glyphosate @ 2.1 kg ai/ha post-plant	33.2	9.0	8.8	1547	16.5	13.05	42	492	24.0	12.1	18.6
Untreated control	32.9	9.0	9.5	907	37	11.64	49	530	30.6	0	0

^aSite height estimate (m) at breast height age 50.

^bAt 11 years age for Boston Bar site and 16 years age for Mica site.

^cRelative to untreated control at minimum rotation age: 90 years for Boston Bar and 42 years for Mica.

Individual treatment site curves and density were used as inputs for TASS simulations (Mitchell 1975, Goudie *et al.* 2005). Initial plantation densities in TASS were arranged on a square planting spatial distribution. TASS mortality was adjusted to follow the treatment density calculated from plot area, plantation spacing, and treatment survival rates. The smallest trees were chosen first when additional mortality was required. TASS output included total mean annual increment (tMAI), average diameter at breast height (DBH), total volume, merchantable volume (minimum 12.5 cm DBH, 10 cm top diameter inside bark, and a stump height of 30 cm) and stand density from one to 150 years of age (Table 1).

At the Boston Bar site, height growth statistics supported differentiation of the treatments by site index (Harper *et al.* 2005). As a result, we created custom site index curves for all treatment simulations including the untreated control by adjusting the height-age trajectory to follow the treatment top height data up to and including the 10-year post-treatment measurement (Fig. 2). Thereafter the height-age curve

followed the untreated control site index (23 m) with an adjustment for the top height difference noted at 10 years post-treatment and a “phase in” period of three years to allow a smooth transition to the 23-m site index trajectory. This technique captured the early post-treatment height differences assuming the differences were due to a short-term gain in the rate of stand development (type I response).

At the Mica site, there was insufficient statistical evidence to support treatment height growth differences (Biring *et al.* 2003) and therefore, individual treatment site index estimates could not be justified even though visually there was an apparent differentiation. An average site index of 34.5 m (Chen and Klinka 2000) was used for all TASS model simulations based on the average top height and breast height age of all treatment plots 15 years post-treatment (Fig. 1). Treatment survival data were used to guide early mortality up to 15 years post-treatment similar to the Boston Bar treatment projections (Fig. 3). No other model input parameter adjustments were made for the various treatments at Mica.

Fig. 1. Tree top height over breast height age for the various treatments at the Boston Bar and Mica sites with select site indices (SI) for comparison. Not all treatments shown.

Fig. 2. Boston Bar site Douglas-fir data for treatment top height over age. Customized treatment site curves used by TASS shown. Glyphosate 1.0 kg ai treatment not shown.

Fig. 3. TASS density projections shown (lines) for the various treatments at the two research sites. Symbols indicate observed treatment densities. Not all treatments shown.

Results

Boston Bar site

The treatment survival differences noted in the field (Harper *et al.* 2005) were incorporated into the modelling of early mortality. This resulted in significant stocking differences between the untreated control and treated (glyphosate, hexazinone and mat treatments) scenarios (Fig. 3). The greater early mortality in the untreated control simulation delayed canopy closure (90% crown closure) by 15 years as compared to the glyphosate 2.1 kg ai/ha treatment (Table 1).

Stand physical rotation age (culmination of mean annual increment (cMAI)) was recorded from the TASS output for each treatment (Table 1, Fig. 4). The cMAI results indicated stand productivity reached a maximum at approximately 100 years for the untreated control treatment, 90 years for the glyphosate 2.1 kg ai/ha treatment, and 93 to 98 years for the other treatments. The 10.8 % increase in cMAI of the glyphosate 2.1 kg ai/ha treatment over the untreated control resulted in an approximate 10% increase in merchantable volume at 90 years. The untreated control treatment was found to require an additional eight years to reach the merchantable volume level of the glyphosate 2.1 kg ai/ha treatment (untreated control 509 m³/ha at 98 years).

TASS DBH projections were found to be similar to the observed treatment means at 10 years post-treatment; however, the model appeared to under-estimate DBH for the untreated control and the hexazinone treatments (Table 1).

TASS DBH was found to be related to early stand density with the untreated control scenarios resulting in the largest DBH at cMAI.

Mica site

TASS output from the various manual cutting (single and repeated) and glyphosate scenarios indicated the significantly lower Engelmann spruce survival in the untreated control delayed crown closure (90%) by 15 to 21.5 years (Table 1). The model results suggested the glyphosate and all repeated manual cutting treatments shortened the physical rotation age by seven years and increased cMAI by approximately 11% to 12% when compared to the untreated control. The increased cMAI of the glyphosate and repeated manual treatments resulted in an approximately 18% increase in merchantable volume at 42 years compared to the untreated control.

At 15 years post-treatment, TASS appeared to over-estimate the spruce DBH of the untreated control and the single cutting treatments and, under-estimated the spruce DBH of the glyphosate, repeated manual summer and multiple season cuttings (Table 1). However, the noted difference in DBH was 1.3 cm or less, which could be accounted for by plus or minus one year in the simulation results (data not shown).

Discussion

Only at the Boston Bar site were we able to justify using unique treatment site curves for TASS treatment simulations

Fig. 4. Mean annual increment over stand age for select treatments at the two research sites. Arrows indicate culmination age for the glyphosate and untreated control treatments. Not all treatments shown.

based on significant height growth differences between treatments (Harper *et al.* 2005). Our method of site curve customization assumed a type I growth response based on the treatment height data combined with a three-year smooth transition period followed by equivalent treatment site trajectories. The three-year period was chosen to provide a short-term transition having no expectation on how long the height response may continue. Given the lack of large shrubs and broadleaf competitors at the Boston Bar site, the probability that the crop trees will continue to dominate the weeds (grass, herbs and low shrubs) remains high. Therefore, a type I growth response assumption appears reasonable for this site, since there exists no broadleaves or large shrubs as long-lived competitors that may impact crop yields (Balandier *et al.* 2006, Mason and Dzierzon 2006). Future measurements are required to assess how long the period of height growth gain may continue. However, the Boston Bar plots were not designed for long-term re-measurements (only 144 m²). The establishment of larger plots would have increased the re-measurement longevity of this research trial but not without a significant increase in financial and technical resources.

TASS results suggested all the vegetation reduction treatments at Boston Bar reduced the Douglas-fir rotation age and increased cMAI by varying degrees dependent on the density and height growth response. Model output indicated all brushing treatments resulted in a merchantable volume gain of approximately 8% to 10% at 90 years relative to the untreated control with the glyphosate 2.1 kg ai/ha treatment

resulting in the greatest response with a time gain of 10 years and a 10% increase in wood volume. These changes in treatment stand productivity and rotation age indicate the sensitivity of the TASS model to changes in density (seedling survival) and dominant height growth (customized site curves). We did not attempt to model the tree spatial arrangement and vegetation competition environment of the individual seedlings even though TASS is capable of using tree map data and individual tree height, diameter and crown size information (Goudie *et al.* 2005). No allowances were made for possible treatment differences in tree taper (Snowdon and Waring 1984). As more data become available for the Boston Bar site the degree, duration and shape of the height-age response curves will become more evident and more accurate assumptions of growth response may be required. Treatment impact on soil moisture availability may diminish as the trees develop more extensive root systems able to access greater soil resources.

The TASS results from the Mica site indicated treatment differences were solely related to differences in spruce survival (density). The high mortality of the spruce in the untreated control required 37 years before canopy closure was reached. During this time the unoccupied growing space resulted in a significant loss in stand productivity (Fig. 4). The lower productivity of the untreated control was somewhat compensated over the rotation by growing larger DBH trees. Due to the high spruce productivity on this site (SI 34.5 m), the model results suggested it would only require an additional

five years for the untreated control to reach a similar merchantable volume as the glyphosate and repeated manual cutting treatments reached at cMAI (Table 1, Fig. 3). However, consideration of wood volume alone is not definitive of timber management success. Consideration must be given to treatment differences in stand and stock tables (number of trees and volume by DBH class, data not shown) and wood quality at rotation (wider spaced trees such as in the untreated control would have longer live crowns, larger branches and high proportion of juvenile wood) (B.C. Ministry of Forests 1999). The TASS results from the glyphosate and repeated manual cutting treatments suggested these brushing treatments would result in similar levels of merchantable volume at a similar rotation age. Clearly maintaining survival of the planted spruce through effective brushing will enhance the long-term stand productivity (cMAI) and potentially shorten the rotation age relative to doing nothing.

The TASS results from both these two research sites indicated all vegetation reduction treatments have the potential to reduce rotation age and increase stand productivity in large part due to increased plantation survival. The use of customized treatment site curves needs to be further explored. With only short-term field data available (in this presentation only 10 and 15 years post-treatment) the link to long-term model output is tenuous. Simple variation in TASS model input parameters such as stand age or spatial distribution can result in a significant change in results. For example, it was noted that varying stand age plus or minus one year could vary the DBH by at least 0.5 cm at 10 years post-treatment, indicating the need to align the TASS model input parameters with field data. Changing the spatial distribution of trees in TASS may impact crown competition, tree size distribution, mortality and site productivity (Mitchell 1975).

Using growth and yield modeling techniques to account for the effects of vegetation management treatments is a natural advancement in the field of forest vegetation management (Mason and Dzierzon 2006, Wagner *et al.* 2006). However, before the application of enhanced yield estimates to operational timber supply analysis can be justified we must be able to clearly link field observations with model results. Without supporting long-term data the link between field treatments and computer simulations is questionable.

All growth and yield models have inherent strengths and weaknesses. It is incumbent upon the user to be aware of the strengths and weaknesses in their growth and yield decision support tools. A greater awareness of the levels of inherent risk and confidence in model output will ensure that reasonable expectations prevail in model interpretation.

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