

Final Technical Report – April 2008

**Project Title: - TASS III: Simulating the management, growth and yield of
complex stands**

Project Number: Y083088

Project Start Date: April 2005

Project Completion: March 2008

Project Purpose

The Tree and Stand Simulator (**TASS II**) is a biologically oriented model that simulates the growth of crowns and stems of individual trees in a 3-D growing space. Since the early 1980s, yield tables generated by TASS have provided most of the yield projections used in BC for Timber Supply Analysis and the evaluation of silviculture options. The Table Interpolation Program for Stand Yield (**TIPSY**) was developed in the early 1990s to manage and rapidly manipulate a large database of TASS tables to meet the needs of yield analysts and silviculturists (Mitchell *et al.* 2000). However, the potential of **TASS II** and **TIPSY** to address complex stands is limited to certain applications (e.g., variable retention (VR) in even-aged stands, Di Lucca *et al.* 2004).

This project integrates and calibrates new and revised modules (already developed) into a new version (**TASS III**) designed specifically for the complex structures found in uneven-aged and mixed-species stands, and the complex treatments now being designed and implemented in BC. We expect to deliver the following new features:

- Improved and expanded biological fidelity;
- Realistic and accurate predictions for complex stand structures (e.g., multi-species, multi-cohort, spatially heterogeneous), and complex treatments (e.g., Variable Retention, partial cutting, clearcutting-with-reserves) ;
- Capacity to assess light levels (e.g., light maps before and after partial cutting);
- User friendly front end similar to **TIPSY** interface;
- Visual display of thinning/partial harvesting with the capacity to view the trees from different positions above or within the stand, and to zoom in on stand components of interest.

Methods overview and results

This project had numerous aspects and a single final report organized in a strict scientific structure was not possible. Scientific structure is followed in the uploaded associated files mentioned in the text that are targeted for journal publications.

The project team was organised into the following five sub-groups to address different components of the project:

- 1) **TASS III Growth relationships**
 - a. Light/Growth relationships
Address the effects of light levels on height growth, crown lift, mortality, and crown description (e.g. leaf area density).
 - b. TASS Functionality
Modify TASS internal modules to accommodate additional complex stand dynamics.
- 2) **Light model tRAYci** Optimize, verify and evaluate the light model.
- 3) **Graphical User Interface** Develop and modify user friendly modules that both collect commands from users and link to VISTAS to display graphics and control activities.
- 4) **Model Evaluation** Collect, compile and display PSP data; calibrate (estimate parameters and verify model against simple and complex data) and validate (evaluate model performance against independent data).

- 5) **Extension** Develop context-sensitive help, document crown simulation, perform alpha testing and write quarterly and annual progress reports.

The methods differ for each sub-group.

1) TASS III Growth relationships

a) Light/Growth relationships

Height Growth Modifiers

Work continued on the relationships between height growth of trees and light environment, characterized as the proportion of above canopy light (PACL). We developed methods that account for the influence of factors other than light on height growth (such as the intrinsic variation due to height and age). This height index (HI) allows us to pool observations from trees that vary widely in height or age. We evaluated three functional forms to describe the relationship between HI and PACL in a mixed effects framework, and expressed the results as relative height rate (HR). Examples for western hemlock (Hw) and lodgepole pine (PI) are shown (**Figure 1**).

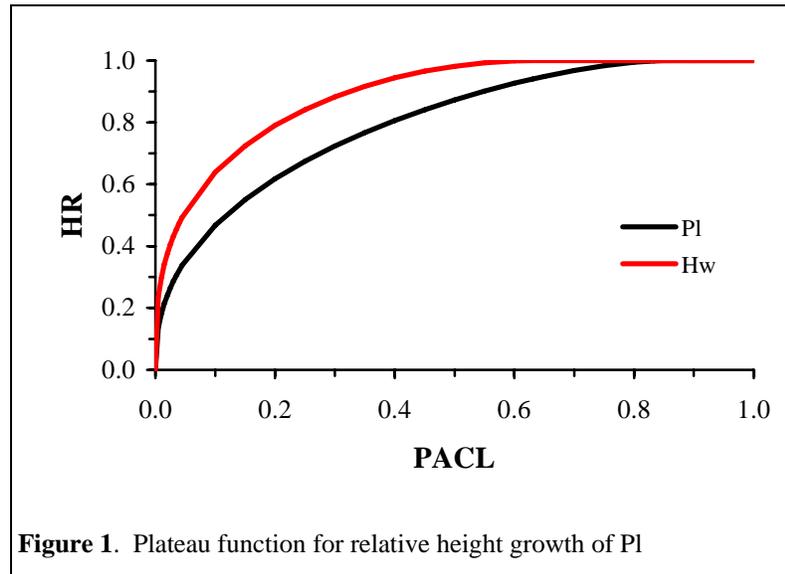


Figure 1. Plateau function for relative height growth of PI

Mortality

Work on a new mortality routine involved analyses of mortality in permanent sample plots and research experiments (e.g., EP 703); and evaluation of alternative algorithms and implementations in TASS.

With EP data, we explored various fitting techniques and functional forms of logistic regression and proportional hazards models. This work will be continuing in 2008-09. We also collated data and conducted exploratory analysis of maximum-size density limits for some combinations of single-species and mixed-species stands. This lays the groundwork for fitting stochastic frontier functions single-species and mixed-species, extending the work of de Montigny and Nigh (2007).

We also explored some options for predicting mortality by examining the behaviour with simulated output from TASS II. This helps to determine which types of algorithms might be successfully applied in the modelling environment and provides some feedback on how candidate algorithms might extrapolate to stand conditions that don't exist in the PSP data but can be simulated with TASS II.

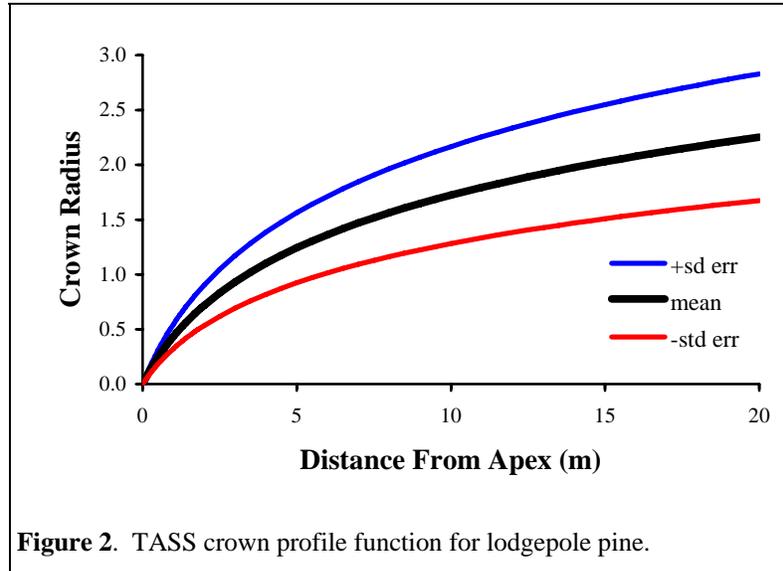
For the released version of TASS III, we developed an interim mortality routine that has had preliminary calibration and rudimentary testing. In the interim routine, as in the routine in TASS II, the probability of mortality for individual trees is related to the degree of overtopping and the size of the crown, but without the limitations that made the TASS II unsuitable for complex stands. The purpose of this interim routine is to allow full functionality of the GUI, which facilitates testing of model components and permits users to

provide feedback on the GUI, model features and capabilities. Further development, calibration, and testing will be undertaken in the coming year

b) TASS Functionality

Crown Profile

The crown profile functions for TASS have been updated, incorporating new data collected since the last major calibration. The fitting procedure now uses a mixed effects framework and provides better estimates of the tree-to-tree variation in the profile.



Crown length.

Simulations of complex forest types require realistic depictions of canopy structure. This investigation analysed two aspects of tree crown morphology required for TASS III, the length of the zone of interaction (CL_I) between neighbouring trees and the maximum crown length (CL_{MAX}) of open grown trees. **Figure 3** shows the key independent variables used in the analysis ($CL_I = CL_B - CL_C$, where CL_B is the distance from the tree top to crown base and CL_C is the distance from tree top to upper point of crown contact). Existing data from 493 trees on file at the BC Ministry of Forests and Range were used in the CL_I analysis and a subset of 44 trees in the CL_{MAX} . Models for CL_I are developed for lodgepole pine (*Pinus contorta* var *latifolia* Engelm. ex S. Wats.), interior spruce (Sx, *Picea glauca* (Moench) Voss X *Picea engelmannii* Parry ex Engelm.), interior Douglas-fir (Fdi, *Pseudotsuga menziesii* var *glauca* (Beissn.) Franco) and trembling aspen (At, *Populus tremuloides* Michx.), coastal Douglas-fir (Fdc, *Pseudotsuga menziesii* (Mirb.) Franco) and coastal western hemlock (Hwc, *Tsuga heterophylla* (Raf.) Sarg.).

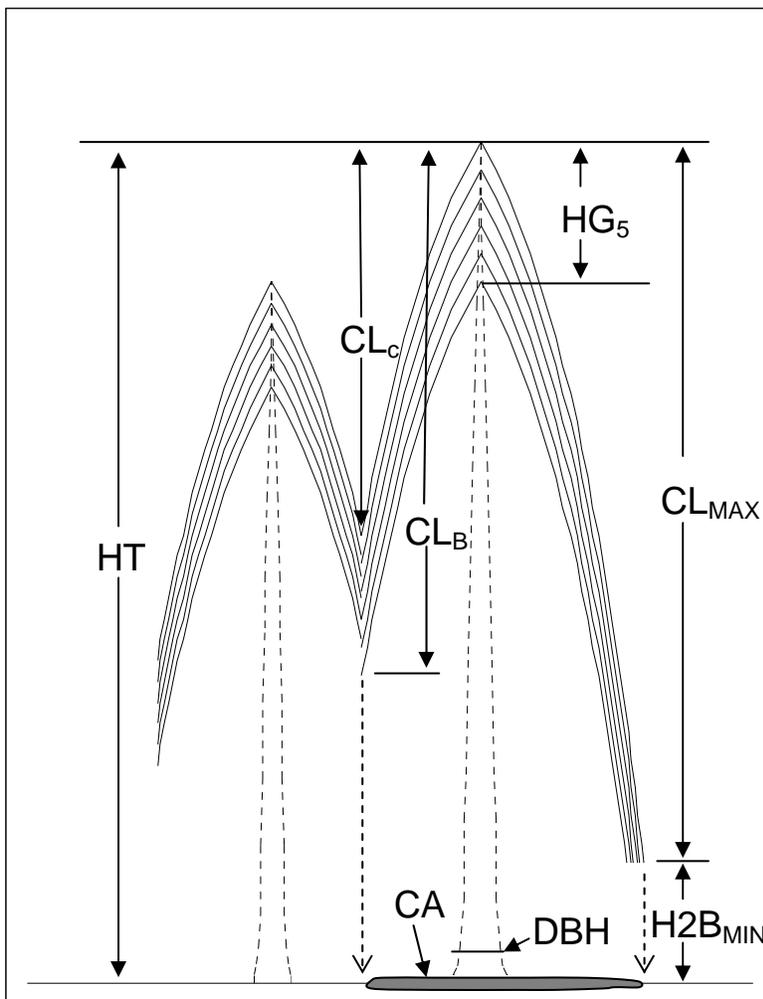


Figure 3. Variables used in the determination of CL_I and CL_{MAX} .

We fit CL_I prediction models with specific formulations for each species, as well as six models with the same formulation (Eq. 1) (see the draft manuscript **TASSIII_crown_length.doc** on file at the MOFR repository)

$$CL_I = \beta_0 \cdot CA^{\beta_1} \cdot e^{(\beta_2 CL_C)} \cdot HT^{\beta_3} \quad 1)$$

where :

CA = projected crown area (m^2)

CL_C = crown length to contact (m)

HT = total height (m),

$\beta_0, \beta_1, \beta_2, \beta_3$ = regression coefficients (see below)

Species	β_0	β_1	β_2	β_3
Fdi	0.222	0.770	-0.329	0.997
Pli	0.188	0.064	-0.078	1.046
Sx	0.041	1.136	-0.184	1.051
At	1.289	0.900	-0.567	0.354
Hwc	0.749	0.333	-0.100	0.523
Fdc	0.613	0.526	-0.110	0.345

Figure 5 compares the results for the six species. The variables CA and CL_C were fixed at mean values of $14.9m^2$ and $7.5m$, respectively.

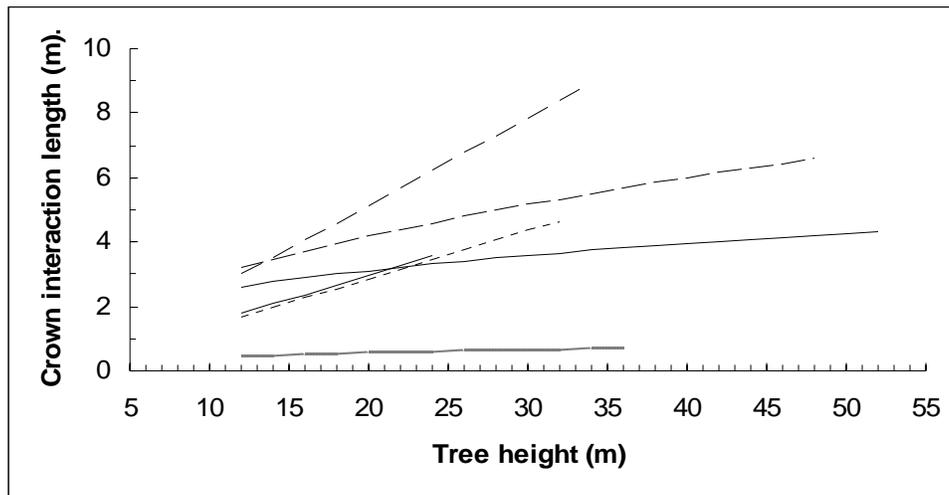


Figure 5. Comparison of predicted CL_I for six species using equation 1.

Models for CL_{MAX} were also developed for Pli, Fdc and Hwc using the same model form as Mitchell (1975). (Eq. 2). **Figure 6** shows the results for each species

$$CL_{MAX} = \beta_0 \cdot HT^{\beta_1} + \varepsilon \quad 2)$$

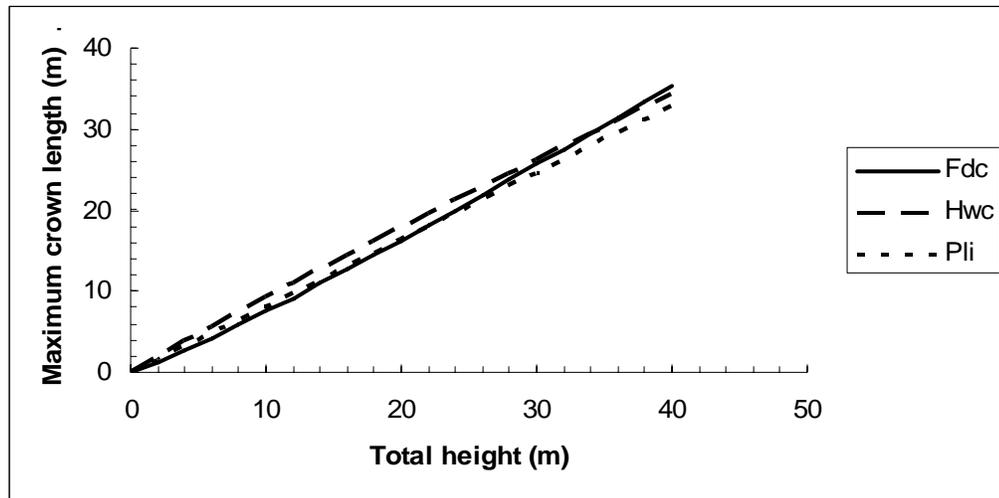


Figure 6. Comparison of predicted CL_{MAX} for three species for equation 3. See text for species abbreviations.

Crown Shyness

Crown shyness or canopy disengagement—a phenomenon wherein gaps around trees develop from swaying, whipping and shading—has been identified in the literature since the 1920s. Explicit models of crown shyness are sparse in the literature but are required for accurate simulations of crown structure and understory light. We developed empirical models of crown shyness in lodgepole pine for British Columbia (BC). We measured crown area and neighbour locations on 60 trees growing in 13 stands in central BC. We estimated potential crown area (A_V) using stem maps and Voronoi polygons constrained by estimates of maximum crown width, and then related observed crown area (A_C) to A_V and additional individual tree variables. One of the nine prediction equations (Eq. 3) was coded into a TASS to evaluate the effects of crown shyness at the stand level (see the draft manuscript **TASSIII_crown_shyness.doc** submitted to Forest Ecology and Management on file at the MOFR repository for details).

$$A_C = \beta_0 \cdot A_V^{\beta_1} \cdot S_R^{\beta_2} \cdot D_{BH}^{\beta_3} \cdot e^{\beta_4(H_T - 1.3)} \quad 3)$$

Where :

D_{BH} = diameter (cm) inside bark at breast height (1.3m)

H_T = total height (m)

S_R = slenderness ratio $((H_T - 1.3) / D_{BH})$

$\beta_0 - \beta_4$ = regression coeffs.

Equation 3 explained 93% of the variation in A_C . **Figure 7** shows the trends with height class and diameter.

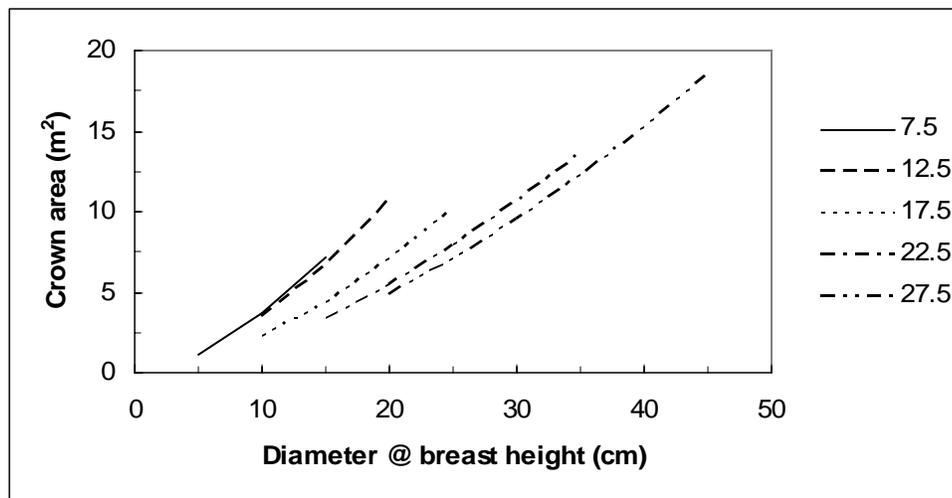


Figure 7. Crown area predictions from equation 3 by height class and diameter.

Crown shyness models validated well against two independent sources and when implemented linked with a light model tRAYci (Brunner, 1998), increased the below-canopy light by 0.07 to 0.11.

Crown competition

We designed and coded a new algorithm to simulate the crown competition between neighbouring trees. Mitchell's (1975) algorithm, used in TASS II, allowed only one tree to occupy a grid column. As the simulated crowns expanded, adjacent trees would compete for the same grid column. Mitchell's algorithm awarded the grid column to the tree whose crown entered that column at the highest location above the ground (**Figure 3**). This algorithm conserved computer memory and provided an effective representation of crown dynamics in even-aged, single-species stands.

The TASS III grid allows multiple crowns to share the occupancy of each column, even overlapping in the same vertical portion of the column. In the new competition algorithm, crowns compete probabilistically for shared space in the column (See **Figure 8**; see also the video file **TASSIII_crown_simulation.wmv** uploaded to the MoFR repository). In the TASS II image, the vigorous red tree surpasses the slower-growing green neighbour and all foliage on the right side of the green tree disappears. In the TASS III algorithm, the crowns intermingle and occupancy is determined with a complex probabilistic algorithm. Species-specific probabilities are determined by comparing model results with available PSP data in pure and mixed stands. Note that while **Figure 8** is a demonstration of the crown interaction algorithm, it does not display the foliated shells used in both TASS II and TASS III.

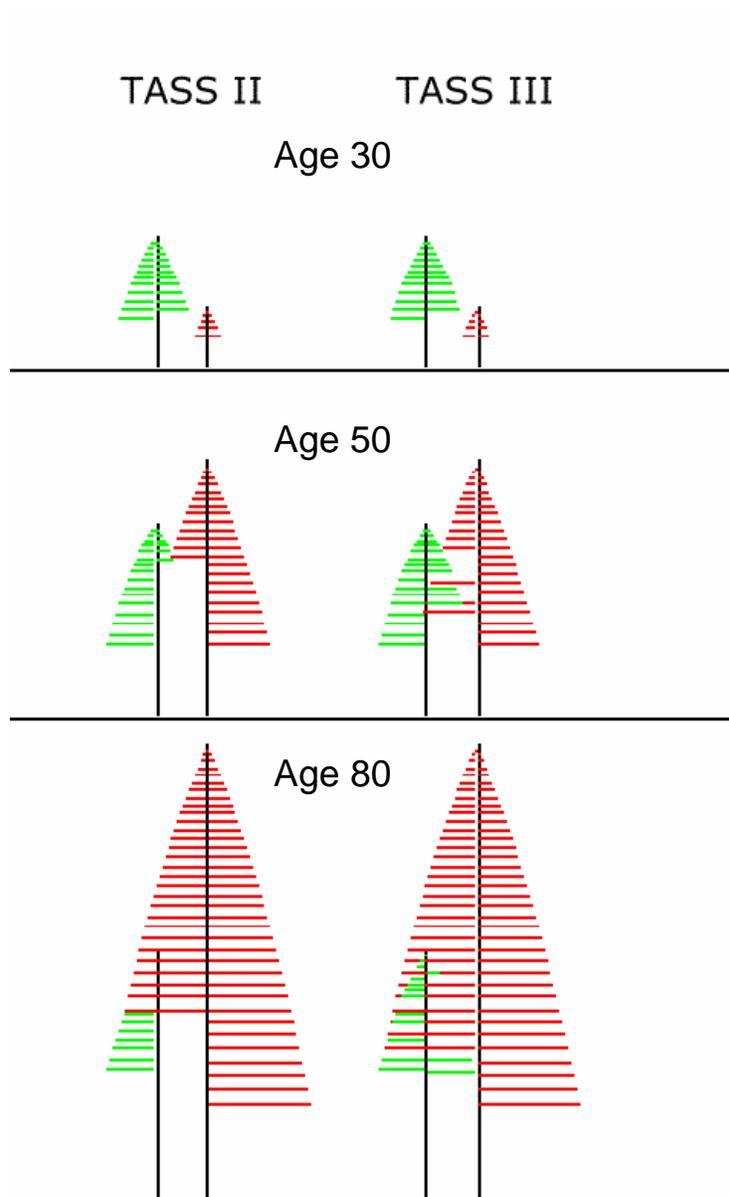
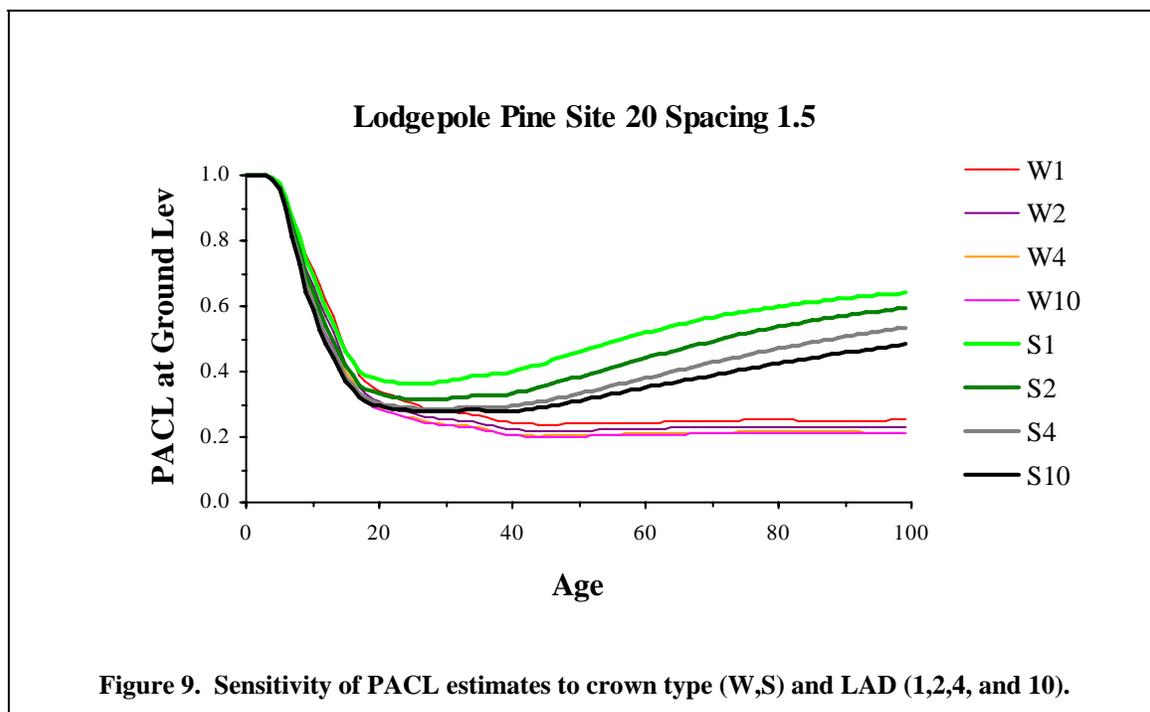


Figure 8. Comparison of TASS II and TASS III crown simulation.

Light Model Sensitivity Analysis

We examined the sensitivity of the PACL estimates from the tRAYci light model to the parameters for Leaf Area Density (LAD). We tested two options for TASS crown depiction—whole crown (W) versus foliated shell (S). We simulated various crown configurations for coastal Douglas-fir (Fdc), trembling aspen (At), and lodgepole pine (Pl) to evaluate the impact on predicted values of PACL at ground level. LAD values ranged from 1 to 99 for each crown type. In addition to species and LAD, other factors in the simulated experiment were site index and initial tree density. The results (**Figure 9**) show that for ray tracing, PACL estimates are much more sensitive to LAD values when crowns are depicted as a foliated shell versus the whole crown abstraction.



Top Height Estimation

Top height is a common reporting statistic in growth and yield models. In BC, the definition specifies users to choose the largest tree in a 0.01 ha reference area. There are a number of options for estimating top height in plots that exceed the reference area. To evaluate these methods, we must calculate the expected value of the top height statistic (i.e., the ‘true’ top height). We examined alternative approaches for determining the expected top height values and compared different algorithms to compute the expected values in large plots.

Interior Douglas-fir

Using the data sets prepared last year, we developed crown profile and bole area increment models using mixed effects fitting techniques. See report on file in the MoFR repository named **TASSIII_FDi_model.doc** for details.

2) Light model (tRAYci)

Changes to the implementation of tRAYci within TASS have greatly improved simulation efficiency. Test run times have been reduced by 67%. To test the light model, we evaluated light availability estimated by prototype versions of TASS III using arrays of fixed quantum (light) sensors in the field, which continuously recorded data over longer periods of the growing season, as well as mobile light sensors, which operate for single days. Percent (of) above canopy light (PACL) was found to vary substantially, with the result that measurements of average daily PACL accurate to only within +/- 10 to 20% , at best. Evaluation of TASS III PACL estimates was further confounded by possible errors in surveys and by representing real trees as virtual shapes in the model. These limitations aside, the TASS III model as presently configured appears to provide PACL estimates that are spatially reasonable and consistent with measurements made in partially cut Douglas-fir forests. Further improvements may be obtained with additional calibration with data from light sensors or hemispherical photographs.

3) Graphic User Interface (GUI).

Research Branch staff assumed the ongoing development of the TASS GUI at the beginning of 2007. The following improvements were implemented in 2006-07:

- clumped and multi-species natural regeneration can now be established,
- planting can take place at any point in the stand rotation,
- trees can be selected by species for user-specified operations,
- thinning can be applied to selected trees,
- snags can be removed optionally,
- yield tables can be output with custom-specified columns and at specified age steps,
- wind risk is now indicated in the graphics,
- multiple output windows can be displayed,
- images can be saved in BMP format,
- the GUI is now linked to the Help system and to VISTAS for 3-dimensional viewing,
- added ForestGales windthrow model, to check wind risk or trees and optionally remove them (for associated project Y083169 Windthrow in TASS & TIPSYP),,
- added ability to graph yield table variables via a DDE link to the Plot program,
- changed link to VISTAS from an external file to an internal DDE link,
- 3D graphic view now includes slider bars and a quick preview mode,
- added ability to save and load stand specifications,
- make multiple selections of tree types or areas for event processing,
- added mortality summary table,
- added image views of light in horizontal and vertical slices through stand,
- added dead tree list,
- added fertilization,

- added ability to save and load a yield table format,
- added ability to save and load an existing stand file format,
- added ability to plant from file (custom tree x/y coordinates),
- can generate natural regeneration in clumped or random distributions,
- added regeneration preview image of tree layout,
- when thinning, can select to cut or leave the selected trees,
- added ability to re-size many output view windows.

Refer to the uploaded document **TASSIII_GUI_Functionality.doc** uploaded to the MOFR repository to get an overview of the functionality. The TASS III GUI was distributed to approximately 30 professionals for alpha testing.

4) Model Evaluation

Field Data

We completed analyses and summarizations of data from five key research trials. Permanent and temporary sample plot data from the MoFR Forest Analysis and Inventory Branch database was procured and added to our summary database. See **TASSIII_psp_summary.doc** uploaded to the MOFR repository for further details.

Volume-Height Limits

We analysed permanent (PSP) and temporary (TSP) sample plot data to estimate the upper limit of volume production, a benchmark useful for model evaluation. We also developed and tested methods to estimate the stochastic frontier for volume-height relationships in a mixed effects framework, and examined the variation in the upper limits among biogeoclimatic subzones (**Figure 10**). Lodgepole pine volume-height data were used for development and the procedures will now be applied to other species.

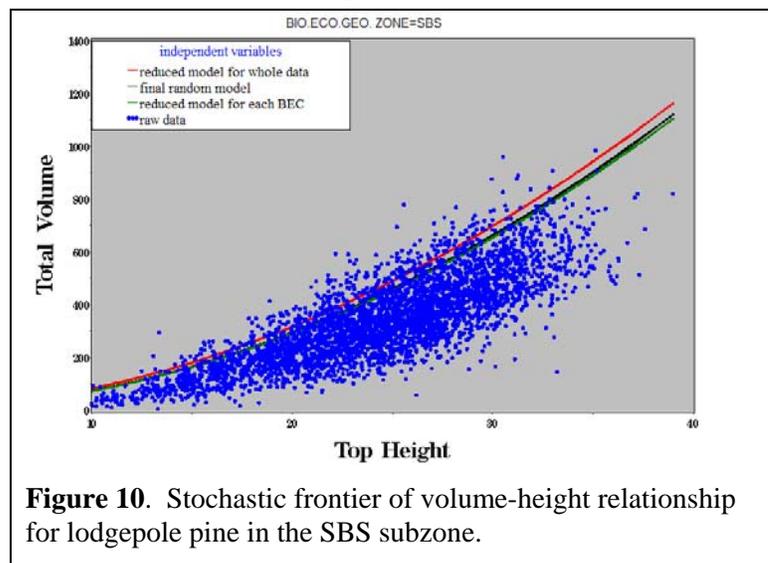


Figure 10. Stochastic frontier of volume-height relationship for lodgepole pine in the SBS subzone.

Lodgepole Pine

New lodgepole pine relationships developed in another project were also tested using the updated PSP data. We revised and improved a SAS program to automatically read TASS yield tables and PSP data to compare model output with data and facilitate model evaluation.

5) Extension.

- *Help.* As new features are added to the user interface, new Help topics are created. A glossary is now included in the online documentation. Definitions were copied from other MOFR documentation, then reviewed for their applicability to TASS.
- Updated web pages with TASS III content are currently in draft form, awaiting approval for the launch of a redesigned Research Branch Growth and Yield Modelling web site.
- A draft extension note describing the TASS III system. See **TASSIII_Extension_Note_draft.doc** uploaded to the MoFR repository.
- Presentations on TASS III development were made throughout the project to a wide range of audiences, including
 - staff at the Roslyn Forestry Commission Station in Edinburgh, Scotland (February 14 to 21, 2007);
 - faculty and students at UBC (January 2007);
 - the growth and yield committee of the Timber PAC in Vancouver (February 2007);
 - a conference on Complex Stand Management in Smithers (February 2007);
 - an invited paper at Western Mensurationists Conference in Penticton, BC on June 26, 2007
 - a presentation to the Fibre Centre team at the Canadian Forestry Service on July 17, 2007
 - a keynote address to an International of Forest Research Organization (IUFRO) conference in Sault Ste. Marie, ON between July 30 and August 3, 2007;
 - an invited paper on crown shyness at an IUFRO conference in Portland, OR between August 7 and 10, 2007;
 - a presentation to the Fibre Centre team at the Canadian Forestry Service on September 11, 2007
 - a presentation to Washington State DNR personnel who want to use TASS III for projecting complex stands in Washington state on September 18, 2007;
 - a meeting with FPInnovations personnel who invited us to take part in a new project calibrating TASS III to balsam fir on the coast (funded by FPInnovations);
 - a presentation of TASS III to a delegation from China who are interested in forest management and forest management tools in BC;
 - a presentation to the Timber Growth and Value conference in Smithers, BC on February 7, 2007
 - a meeting with and presentation to First Nations representatives interested in the western redcedar aspects of the new 2008-2011 TASS III upgrade project that continues the work started on this project.
- A training session on the TASS III functionality attended by 15 professionals in Victoria, BC who are providing feedback on the design. Refer to **TASS_III_exercises.doc** for the exercises that the attendees performed at the training session.
- A demonstration of TASS III to approximately 200 practitioners at the Southern Interior Silviculture Committee (SISCO) meeting in Penticton, BC between March 31 and April 2, 2007.
- A User Guide for designing simulated experiments with TASS III was prepared.
- Drafts of reports for submission as journal articles (Year 3) and research reports were prepared.

Project Scope and Regional Applicability

TASS II is a growth and yield model that is applicable for managed, even-aged stands throughout BC. The new version, TASS III, will include this functionality, but based on redesigned and new modules and features appropriate for a wider range of stand types, species mixtures and complex treatments. Improvements have initially focussed on a select number of high priority tree species (lodgepole pine, coastal and interior Douglas-fir, western hemlock, interior spruce and trembling aspen) and stand types (mixed cedar-hemlock and uneven-aged dry-belt Douglas-fir in the Southern Interior Region; pine-spruce and aspen-spruce mixtures in the Northern Interior Region; coastal Douglas-fir and western hemlock variable retention stands in the Coast Region) for which sufficient calibration and validation data sets can be located.

Summary of deliverables

Extension product, activity or deliverable	Status as of 2007/08 year end	File name on MoFR repository	Target journal
Extension note – Availability of TASS III Extension note – Overview of capabilities and limitations of TASS III	Draft Complete (combined into one note)	TASSIII_Extension_Note_draft.doc	
First-approximation functional version of TASS III for Fdi–Pl and Fdc–Hw mixtures	Complete – distributed to alpha testers	N/A	
An electronic presentation that outlines the operation of the model in easily understood biological terms	Complete	TASS_III_powerpoint_presentation.pdf	
Two training sessions on use of TASS III – one coast, one interior	Complete	TASSIII_Training_exercises.doc	
Distribute working software	Complete	N/A	
Make web-based help facility available.	Initiated	N/A	
Journal article: An empirical model of crown shyness in lodgepole pine	Submitted to For. Ecol. & Manage.	TASSIII_Crown_shyness.doc	For.Ecol.& Mange.
Journal article: Modelling the effect of light on height growth using stochastic frontier functions	In internal review	TASSIII_Light_height_growth.doc	CJFR
Journal article: The effect of initial density on dominant height growth.	In internal review	TASSIII_Density_height_growth.doc	WJAF

Other uploaded files.

Extension product, activity or deliverable	File name on MoFR repository	Target journal
Demonstration of crown competition algorithm	TASSIII_crown_simulation.wmv	
Potential journal article or station publication titled “Predictions of crown length for British Columbia species”	TASSIII_Crown length.doc	WJAF
Potential journal article or station publication on FDi model parameterization titled “Improved TASS Model Parameters for B.C. Interior Douglas-fir”	TASSIII_FDi_model.doc	WJAF
Description of PSP summarization	TASSIII_PSP_Summary.doc	

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