

Demonstrating growth and yield adjustments (TIPSY OAFs) for Armillaria root disease in a timber supply analysis

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March 2004

With funding from:
BC Forest Investment Account, Research Program
2003-04 FII Project # RO4-008
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ABSTRACT

Application of newly developed operational yield adjustment factors (OAFs) for *Armillaria ostoyae* (DRA) was demonstrated in a timber supply analyses for the Arrow Timber Supply Area in the southern interior of British Columbia. The OAFs are specific to the managed stand yield table generator known as the Table Interpolation Program for Stand Yields (TIPSY). OAFs were developed for and applied only to Douglas-fir within managed stands in the Interior Cedar-Hemlock Biogeoclimatic Zone. The impacts of three DRA severity distributions were examined in a sensitivity analysis. Since managed stands do not contribute to short-term harvest levels, these DRA OAFs mainly affected the long-term harvest projections. The OAF for medium severity DRA infections reduced long-term harvests by 7.2%. Sources of uncertainty were explored which a decision maker may wish to consider when evaluating the risks associated DRA and application of these OAFs. The analysis highlighted opportunities for mitigating some of the disease's impact on timber supply by continuing to refine management practices and acquiring more information about the disease and its distribution across the landscape.

INTRODUCTION

Forest pathology research continues to help forest managers better understand the effects that root diseases have on forest productivity and timber supply. *Armillaria ostoyae* is a common root disease endemic to the forests of southern of British Columbia. Historically, the fungus was mainly associated with Douglas-fir mortality losses. A growing body of research now indicates Armillaria root disease (DRA) infects all commercial species. In addition to mortality, growth losses from chronic sub-lethal infections further reduce merchantable timber yields. Long-term growth losses up to 40% have been documented in Douglas-fir (Cruickshank 2000). With only 25% of the infected trees exhibiting visual above-ground indicators (Morrison et al 2000), DRA is likely more pervasive than once thought. Forest managers have begun taking steps to actively manage the disease in order to capture more of the forest's productive potential. Expressing DRA impacts in terms of growth and yield (G&Y) enables forest managers to better assess the cost-effectiveness of various management options and the disease's potential impacts on timber supply.

Managed stand yield tables from the Tree and Stand Simulator (TASS) G&Y model are routinely incorporated in timber supply analyses in British Columbia via the Table Interpolation Program for Stand Yields (TIPSY; Mitchell et al, 2000). G&Y predictions from both TASS and TIPSY approximate the productive potential for a given combination of species, density and site. Consequently, their yield predictions need to be adjusted for various operational realities such as forest health losses and stocking gaps. TIPSY initially incorporated a two-stage system of Operational Adjustment Factors (OAFs) for this purpose. OAF2 can be used to approximate forest health losses in the absence of better information. The default OAF2 yield multiplier of 0.95 (at 100yrs) is intended to account for endemic stem decay losses only.

The growing awareness of DRA lead British Columbia's Chief Forester to identify the need for better accounting of DRA in timber supply analyses within the province's southern interior region. On-going research by Canadian Forest Service (CFS) pathologists provided data for the creation of TIPSY OAFs specific to DRA for Douglas-fir in the Interior Cedar-Hemlock (ICH) Biogeoclimatic Zone. This paper documents the first application of these DRA OAFs in an operational timber supply analysis setting.

DRA BIOLOGY AND OAFs

The fungus appears to thrive in moisture and temperature conditions typical of the ICH ecological zone. Yet it appears to have a low tolerance for extremes found in some areas of neighbouring eco-zones such as the IDF (hot, dry) and ESSF (cold, wet). The incidence of DRA in the ICH is high with some level of infection present in nearly every stand.

The abundance and distribution of inoculum in a stand will determine disease severity. However, severity assessments generally miss 75% of the infected live trees that do not exhibit visual above-ground symptoms. Stand history largely determines the amount and distribution of inoculum carried forward to the next stand. When a tree dies, fungal growth is no longer restrained by the tree's natural defences. DRA can live for decades in decaying root systems as long as conditions remain favourable. Stumping encourages root desiccation which kills the fungus.

In young stands, faster growing trees tend to reach inoculum sources first and re-initiate the cycle. Mortality peaks initially at 15-20 years, then increases again late in the rotation when trees sustain repeated infections from the fungus. Here again, bigger trees with larger root contact zones tend to have higher infection rates. It is not clear yet if larger trees die more frequently, but some literature suggests this. Douglas-fir is particularly susceptible to late rotation mortality, although infected trees of all species are likely to experience growth loss.

Infected tree roots provide a chronological record of their infection. CFS scientists are conducting a multi-year study excavating Douglas-fir root systems in stands across the ICH. Data from thousands of trees show that growth loss begins to accumulate at the time of infection. The longer trees have been infected, the larger cumulative growth loss becomes relative to healthy trees.

Data from the multi-year study is being used to calibrate the root rot simulation (ROTSIM) model attached to TASS. ROTSIM will eventually be used to refine TIPSY OAFs for DRA. Meanwhile, first-approximation DRA OAFs were estimated using the existing data augmented with professional opinion. Table 1 shows that incidence and growth loss data are concentrated in young stands, primarily plantations. Excavation and sampling costs along with the lack of older managed stands limit sampling to a few older natural stands. Mortality is always one of the most difficult G&Y parameters to predict given the scarcity of long-term data. For DRA, data from two long-term sites together

with professional experience indicated average annual mortality rates of 0.5 to 2.0% represented plausible estimates for low and high severity.

Stand Age (yrs)	Incidence Data			Growth Loss Data		
	No. of stands	No. of trees	Ave. Incidence	No. of stands	No. of trees	Ave. Growth Loss
14-27	11	2000	30% ± 10	5	800	6%
55	1	388	80%	1	125	13%
80-100	2	285, ¹ 144	80%, ¹ 90%	4	108	² 20%

Table 1. Distribution of data used in the creation of DRA OAFs.

¹Partially cut stand, ²For the 80-100 year period.

TIPSY's simple OAF2 model could not reflect these data, so custom DRA OAF functions were developed and incorporated in TIPSY (ver 3.2). The OAFs integrate both growth and mortality losses for three levels of infection severity (low, med, high) (Table 2). Functions were fit to these values enabling OAF estimation at any age.

Severity Class	OAF - Age 20			OAF - Age 50			OAF - Age 80			OAF - Age 100		
	G.L.	M.L.	Total	G.L.	M.L.	Total	G.L.	M.L.	Total	G.L.	M.L.	Total
Low	.95	.94	.893	.93	.90	.837	.89	.85	.757	.88	.80	.704
Med	.94	.91	.855	.90	.80	.720	.89	.70	.623	.90	.60	.540
High	.93	.85	.791	.88	.70	.616	.91	.55	.501	.93	.40	.372

Table 2. DRA-OAFs by severity class including growth loss (G.L.) and morality loss (M.L.) components. OAFs are expressed as a yield multiplier consistent with TIPSY application.

CONDUCTING THE SENSITIVITY ANALYSIS

Timber supply data for this demonstration comes from a timber supply analysis data package prepared for the Arrow Timber Supply Area (TSA) near Castlegar, British Columbia (Timberline, 2004). DRA OAF's where incorporated as a sensitivity analysis, a timber supply analysis tool commonly used to evaluate risk associated with information uncertainty.

Timber supply analysis techniques require some estimate of DRA severity for each analysis unit to provide a spatial linkage with the landbase. Severity ratings for DRA are based on the number of disease centres observed in juvenile stands. Since severity estimates were not available for existing and future managed stands, three separate sensitivity runs were conducted using three hypothetical severity distributions for the entire TSA (Table 3).

		Severity weighting factors			
Severity Distribution		% Low severity	% Med severity	% High severity	Weighted OAF equivalent
LowD		50	25	25	0.58
MedD		25	50	25	0.54
HighD		25	25	50	0.50

Table 3. Hypothetical DRA severity distributions tested in sensitivity analyses.

Reflecting development, DRA OAFs were applied only to Douglas-fir within the ICH. They were applied in combination with the standard default OAFs (OAF1=0.85; OAF2=0.95) specified in the Arrow data package. These standard OAFs account for other yield reduction factors besides DRA, such as stocking gaps, decay, etc.

Consistent with current practice, the Arrow data package specified TIPSY yields for existing and future managed stands. The Variable Density Yield Prediction (VDYP) model used for existing natural stands does not use similar OAFs. Table 4 indicates DRA-OAFs were initially applied to 2.5% of the current timber harvesting land base. This area increased to about 20% once all natural stands within the timber harvesting landbase were converted to managed stands. Mixed species planting strategies, a tool for managing DRA impacts, are embodied in Douglas-fir targets for ICH analysis units (Table 4, column b).

Ecosystems within the Timber Harvesting Land Base (THLB)			Managed Stands in the ICH containing Douglas-fir (Fd)			
Subzone	Site Series	(a) (%)	(b) % Fd in AUs	(c) % of current THLB	(b*c) Existing Fd as % of THLB	(a*b) Potential Fd as % of THLB
Entire ESSF		25.08				
Entire IDF		0.08				
ICHmw2	4,5,9	11.04	0			
ICHxw	1,3	0.43	50	0.07	0.035	0.22
ICHdw	01a	11.32	30	1.30	0.389	3.39
ICHdw	01b	8.33	35	0.14	0.048	2.92
ICHdw	2	0.51	20	0.01	0.001	0.10
ICHmw2	1,3	41.48	33	5.89	1.944	13.69
ICHwk1	1,4	1.63	20	0.29	0.059	0.33
TOTALS				7.70	2.477	20.64

Table 4. (a) Ecosystem composition of the timber harvesting landbase (THLB), (b) Douglas-fir (Fd) species composition specified for managed stands in ICH analysis units (AUs), (c) proportion of existing managed stands containing Fd in the current THLB, (b*c) the proportion of Fd (pure stand equivalent) in managed stands within the existing THLB and (a*b) future potential proportion of Fd assuming complete conversion of the THLB to managed stands.

Figure 1 compares yield curves for one of the Arrow analysis units. In addition to reducing yields, DRA OAFs lower the culmination age for mean annual increment, which defines minimum harvest age in this timber supply analysis. Consequently, DRA OAFs initially triggered earlier harvesting. For consistency, minimum harvest ages were fixed at base case levels in the final analysis.

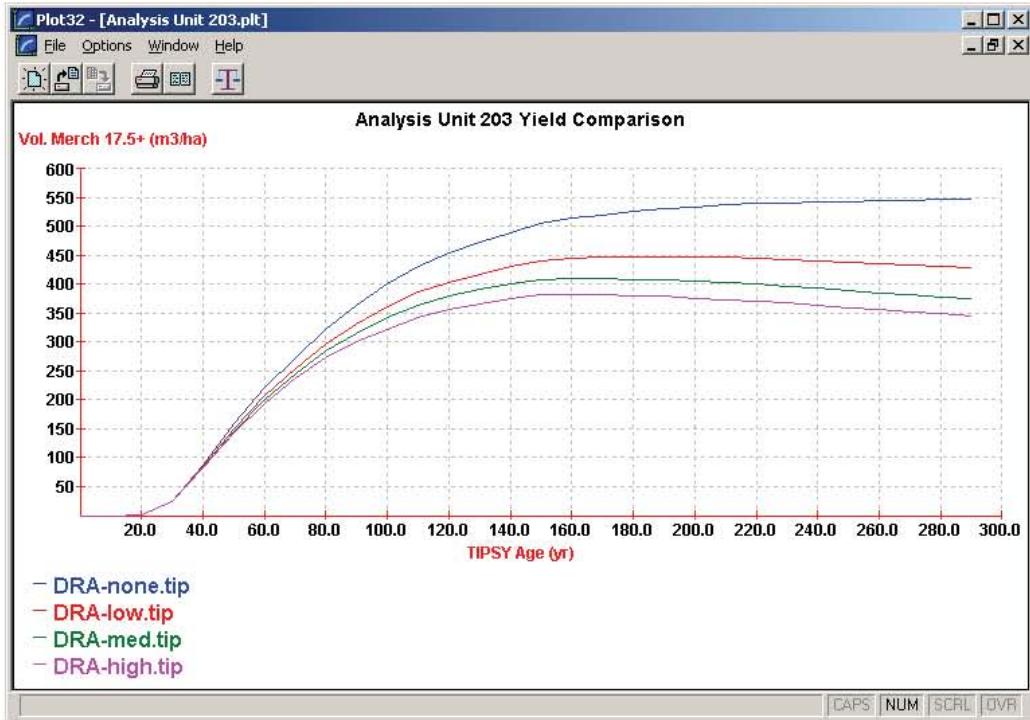


Figure 1. A comparison of TIPSY (ver 3.2) yield curves for Analysis Unit 203 (ICHmw2 01) consisting of Douglas-fir, western larch and lodgepole pine in equal portions with a base case minimum harvest age of 70 years.

SENSITIVITY ANALYSIS RESULTS

Figure 2 compares projected harvest flows under the three DRA severity distribution scenarios against the base case with no DRA OAFs. The three symmetrical severity distributions, in effect, narrowed the spread of high and low around medium severity. As expected, DRA OAFs had little effect on the short-term harvests, which are dominated by natural stands. DRA OAFs for medium severity reduced long-term harvests by 7.2%. A small mid-term harvest decline appears from 60-70 years with increasing DRA severity. This reflects the underlying reliance on managed stands to bridge an age-class gap in this critical transition period.

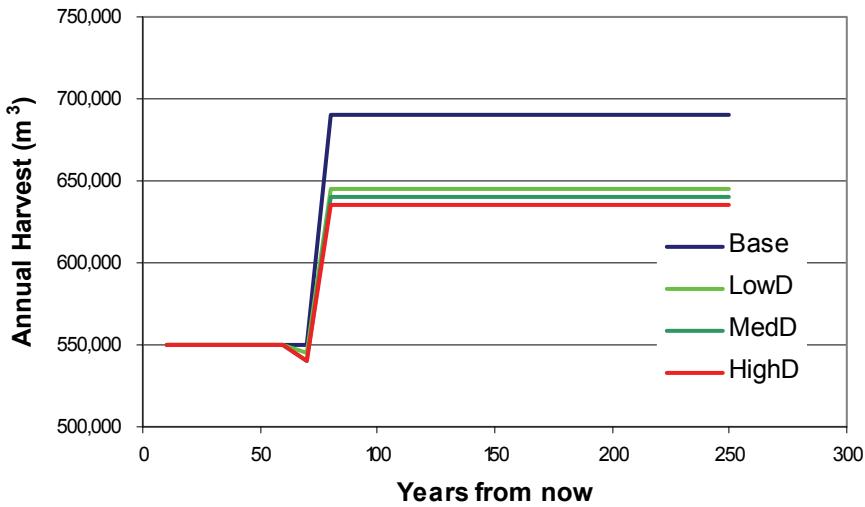


Figure 2. Sensitivity analysis of projected harvest flows for the Arrow TSA under the three alternative DRA severity distribution scenarios.

INTERPRETATIONS AND CONCLUSIONS

The sharp harvest flow increases at 70 years correspond to the harvesting transition from natural stands to managed stands. The impact of DRA OAFs parallels this same trend since the OAFs only applied to managed stands. Long-term harvest projections increased from the previous analysis five years ago due to the first-time inclusion of managed stand site index adjustments and genetic gain in the base case. Like DRA, these represent factors that had been previously excluded due inadequate information. Some factors will increase yield predictions and other reduce them, but the overall effect is a more realistic prediction based on the best available information.

A sensitivity analysis indicates how sensitive a given timber supply forecast is to different estimates of some factor. Known sources of uncertainty are considered when weighing the associated risks. Sources of uncertainty in this analysis relate to the following points:

- These particular DRA OAFs apply only to Douglas-fir in the ICH. However, pathologists consider DRA's impact to be broader, including other species and portions of other eco-zones.
- Little is currently known about potential disease interactions with genetic improvement. To date, genetic selections for growth have not included disease resistance. Faster growing trees appear to contact larger amounts of inoculum sooner.
- TIPSY does not account for natural in-fill following mortality. However, any effects related to late-rotation mortality in particular should be minimal.
- Some DRA effects may already be incorporated in TIPSY through data sources used to calibrate TASS. This is thought to be minimal given that TASS calibration techniques selectively emphasize potential growth.

Incidence and severity have not been statistically sampled (in an inventory sense) in the Arrow. Data from extensive sampling in young managed stands and a few older natural stands indicates incidence and growth loss are consistent and predictable. Incidence appears to be continuous in the ICH. The high and low severity OAFs bound observed growth loss and mortality ranges for infected stands. The medium severity OAF would approximate the landbase average if severity has a normal distribution. The two skewed severity distributions tested were not drastic enough to deviate far from the medium severity OAF. Opportunities exist for enhanced monitoring of existing managed stands for DRA incidence and severity in order to further refine our landscape-level understanding of the disease.

DRA OAFs used in this analysis are similar in magnitude to the DRA OAFs developed using different methods for Kootenay Lake TSA's second Timber Supply Review (Norris, 2000). Using the Western Root Disease Extension of the Prognosis G&Y model, Norris produced a TIPSY OAF2 yield multiplier of 0.71 (at 100 yrs) for Douglas-fir analysis units with site index greater than 18m.

Since managed stand yields do not have a large effect on short-term harvest levels, there is still a window of opportunity to advance DRA knowledge. Root disease obviously has an effect on natural stands, too. But unlike TIPSY, the impact is assumed to be included in VDYP yield tables already. Root disease reduces a stand's growth potential; hence there are no salvageable losses. Furthermore, the fungus survives in stumps after harvesting and infects the next stand, continuing the cycle. By continuing to improve our understanding and management of this naturally occurring disease, future timber supply analyses will be able to capture more of the forest's productive potential.

Trends observed in sensitivity analysis help the Chief Forester evaluate a balance of pressures on the AAC, both upward and downward. In this way, the best available information on DRA impacts is considered while recognizing that some uncertainty still exists.

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