Boundary TSA Young Stand Monitoring Program

Overview

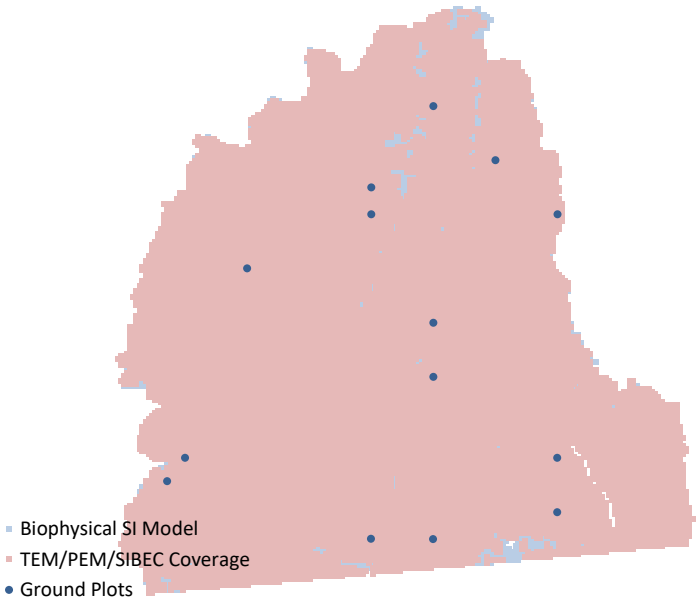
Young Stand Monitoring (YSM) programs have been established across a number of management units in BC. This handout provides a high-level technical summary of results compiled by FAIB for the Boundary TSA YSM program.

The target population for TSA-based monitoring programs is defined as 15-50 year old Crown forested stands in the Vegetation Resources Inventory (VRI) Vegcomp rank 1 layer. TFL-based monitoring programs may use other criteria (eg., harvest history).

Ground samples (dots on map, right) are established on a 10km X 5km grid, with trees tagged in 0.04ha permanent plots with a planned five-year re-measurement cycle.

Some key YSM objectives are to: describe the characteristics and structure of young stands, report on forest health, assess the accuracy of predicted attributes and spatial coverages, and compare against growth models to help evaluate if young stands will meet future timber supply expectations.

The TSA map (right) includes the source of site index found in the latest Provincial Site Productivity Layer (PSPL) : either TEM/PEM & SIBEC (pink), or Biophysical Site Index Model (blue).



Meas	# Ground Samples by Year (end of growing season)				
#	2016	2020	2021	2022	Total
1	11	2		1	14
2		9	2		11

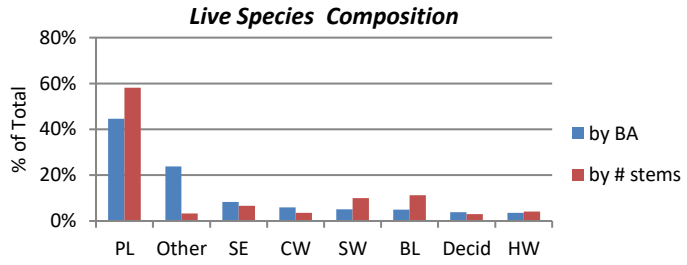
Summary of Key Findings for Existing Young Stands in the Boundary TSA related to Timber Supply

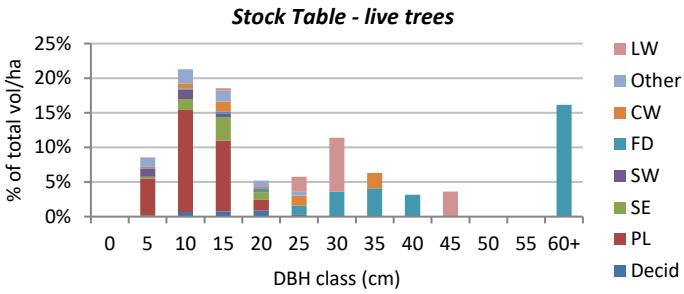
1)	The leading species from YSM ground samples is compared to the interpreted leading species in the Vegetation Resources Inventory forest inventory coverage (VRI). The leading species percent agreement is:	***36%*** *(% agreement)*
2)	Species composition from YSM ground samples is compared against TSR inputs (ie., regeneration assumptions used in modeling existing stands in Timber Supply Review [TSR]). The overall species composition overlap is:	***46%*** *(% overlap)*
3)	The Provincial Site Productivity Layer (PSPL), one of the TSR inputs used for modeling existing managed stands, is assessed for bias from YSM ground based site index data. If significant, site index bias (in percent) is listed by species, where a positive percent is an under-estimate in the PSPL, and a negative percent is an over-estimate:	***None***
4)	YSM sample measurements include conifer and deciduous tree species. The deciduous proportion in the YSM samples (% of total volume) is:	***3%*** *(% of m^3/ha)*
5)	YSM sample measurements include separate tracking of both managed vs. residual cohorts. The residual proportion in the YSM samples (% of total volume) is:	***25%*** *(% of m^3/ha)*
6)	The periodic annual increment (PAI) of TSR yield tables are compared against re-measured YSM samples over the same remeasurement period, to test if TSR projections are significantly different from YSM growth rates:	***no significant difference between the two***
7)	The PAI of YSM TASS projections are compared against re-measured YSM samples over the same remeasurement period, to test if TASS projections are significantly different from YSM growth rates:	***no significant difference between the two***
8)	For YSM measurements since 2017, the impact from stem rusts can be directly modeled in TASS using GRIM / CRIME. The volume impact of TASS YSM projections by age 100 (in addition to default OAFs) is:	***0.8%*** *(% of m^3/ha)*
9)	To address forest health risks from all other damage agents, an interim simplistic approach is applied to estimate future impacts of all known forest health agents, and results in an impact by age 100 (in addition to default OAFs) of:	***2.0%*** *(% of m^3/ha)*
10)	TSR yield tables are compared against YSM TASS projections, to test if TSR assumptions will meet future expectations of young stands by rotation age. Reported outputs include the maximum percent difference of TSR volume relative to YSM (a negative % is where TSR is lower than YSM, positive % is where TSR is greater than YSM); the projected age this occurs at; and a test to determine if the differences between the two is significant.	***Max % vol diff*** ***18%*** ***Age @max vol diff*** ***100*** ***Significant?*** ***No*** ***TSR bias?*** ***No***

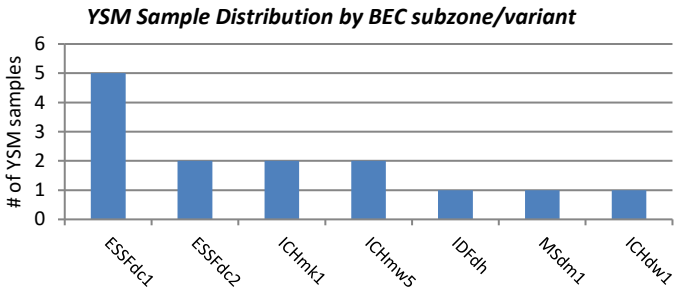
Young Stand Description

Stand summaries (all species combined) are compiled and summarized for all samples in the target population at the time of the latest measurement. Compilations are for all standing trees >=4cm DBH, except net merchantable volume (i.e., PL >= 12.5cm DBH, & all other species >=17.5cm DBH, excluding 30cm stump height, 10cm top diameter, & decay). Species code names are listed on page 7.

	n	Live				Dead
		Avg	Min	Max	SD	Avg
Basal Area (m^2/ha)	14	13.5	0.0	32.4	9.2	0.6
Total Stems (#/ha)	14	1,746	0	5,779	1,706	14
Quadratic Mean DBH (cm)	14	9.9				23.7
Whole Stem Vol. (m^3/ha)	14	72	0	203	69	2
Net Merch Vol. (m^3/ha)	14	39	0	180	64	2
Total age all site trees (yrs)	13	34	18	151		







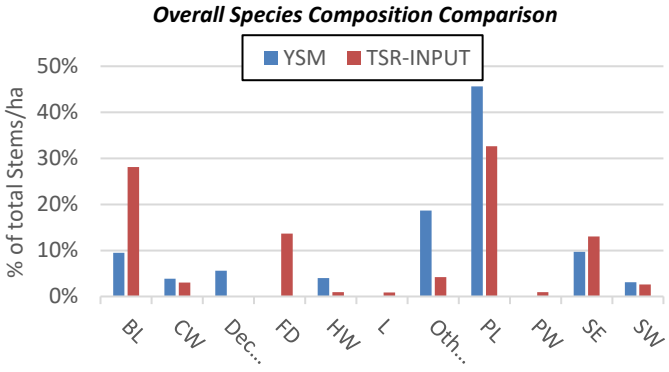
Leading Species vs. VRI, & Overall Species Composition vs. TSR Inputs

Leading species (by basal area) is compared between YSM & VRI where the *'correct leading species classification rate* ' is a percent of all YSM samples with matching inventory leading species at latest measurement (table left). A separate assessment of overall species composition is also compared between YSM and TSR modeled regeneration inputs (table right). Overall species composition overlap is a rough index, and expressed as the ratio between the minimum in common relative to the maximum in common that could have been. The planted & natural densities used in TSR inputs are combined as part of the overall species composition comparison.

Leading species cross-table comparison (sum of the # of YSM plots)

VRI \ YSM	BL	Decid	Other	PL	SE	SW	Total
BL	1		1	2			4
CW						1	1
FD			2				2
PL		1	1	4			6
SW					1		1
Total	1	1	4	6	1	1	14

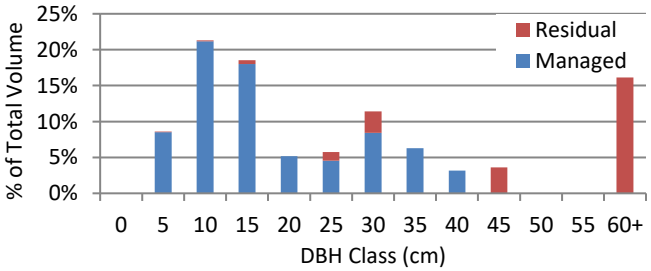
Correct Leading Species Classification Rate = ***36%***



Overall Species Composition Overlap = ***46%***

Post-Harvest-Regenerated vs. Residual Trees

Young stands may include older residual trees which have important ecological, management, and growth implications. Residual trees are identified in the field using standard measurement protocols. Depending on the analysis, it may be necessary to separate the residual from post-harvest-regenerated trees in young stands. The contribution of the residual cohort in the measured YSM samples is reported (chart right).



Percent of total volume comprising residuals = ***25%***

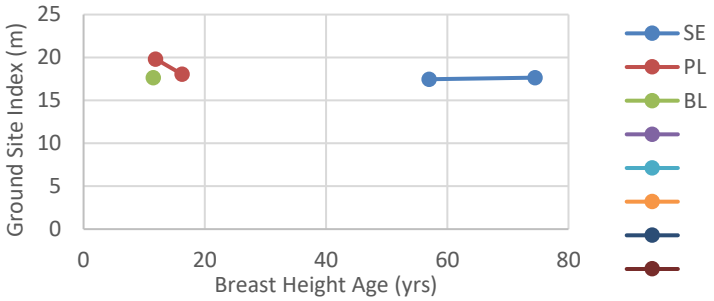
Site Index vs. Provincial Site Productivity Layer

Site index (SI) is an estimate of a stand's potential productivity by species. Predicted SI is from the Provincial site productivity layer (PSPL v7.0) that uses either ecological mapping plus SIBEC tables or SI biophysical model where no ecological mapping is available. YSM ground SI is from up to four site trees per species. The average SI and ratio of means (ROM) between ground and predicted SI are compared at the time of latest YSM measurement (table right). For those species with a least 10 paired observations, a region of practical equivalence (ROPE) assesses for practical SI differences, defined here as 5% ROPE (ie., ratio limits of 0.95 to 1.05). A practical difference (Y) is when the ROM confidence interval (CI) is entirely outside the ROPE, no practical difference (N) is when the ROM CI is entirely within the ROPE; all other situations are inconclusive (I).

Spc	#Pairs	YSM	SI (m)		Ratio of Means			ROPE
	n	BHAge	YSM	PSPL	ROM	L95%	U95%	test
BL	2	12	**17.7**	**16.2**	1.09	-	-	-
PL	8	16	**18.1**	**18.6**	0.97	-	-	-
SE	3	57	**17.5**	**16.0**	1.09	-	-	-

Trends in Site Index Estimates over Time

The average site index vs. breast height age from all valid site trees is plotted for each species and sample measurement (graph right; joined dots are for repeated measurements). Subsequent measurements may not always include the same site trees (due to changes in site tree suitability, or height by DBH crossovers), site index and breast height age may also change over time. The most reliable site index estimate for a given species and YSM plot is the measurement closest to breast height age 50.



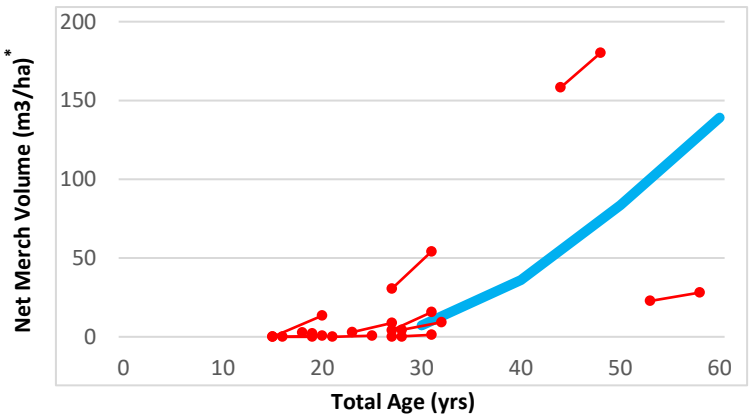
Comparing Current Volumes: TSR Predicted Yield Tables vs. YSM Actual Measurements

Field measured YSM volumes are compared to predicted volumes developed for FAIB's TSR analysis. FAIB's TSR yield table development process has three types of yield curves developed for stands less than 50 years of age:

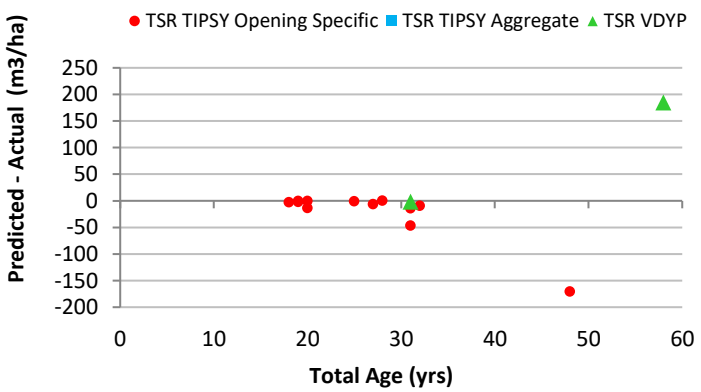
1) TSR TIPSY Opening Specific – where the VRI feature links to a RESULTS opening record that contains the minimum required yield table inputs. These features are projected in TIPSY ver 4.4 using RESULTS opening specific records as inputs.
2) TSR TIPSY Aggregate – where the VRI feature links to a RESULTS opening record that does not contain the minimum required yield table inputs. These features are projected in TIPSY ver 4.4 using the average of many RESULTS opening specific yield curves within the same management unit and Biogeoclimatic subzone.
3) TSR VDYP – where the VRI feature does not spatially match a RESULTS opening record. These features are projected in VDYP ver 7 using VRI inventory rank1 attributes.

TSR predicted volumes are compared to YSM volumes using the TSR input age adjusted to the year of ground sampling. The left graph plots YSM actual volume (points are joined where re-measurements are available), plus the average of all spatially intersected TSR predicted yield tables (solid blue line). The right graph illustrates the total bias (predicted minus actual volume) at each individual YSM sample location, at the latest measurement. TSR predicted volumes underestimate current YSM volume when the bias is negative, and overestimate current YSM volume when positive.

YSM Sample Remeasurements vs Average of TSR Yield Tables spatially matched to each YSM location



Total volume bias at each YSM location (Predicted TSR yield table volume - Actual YSM volume)



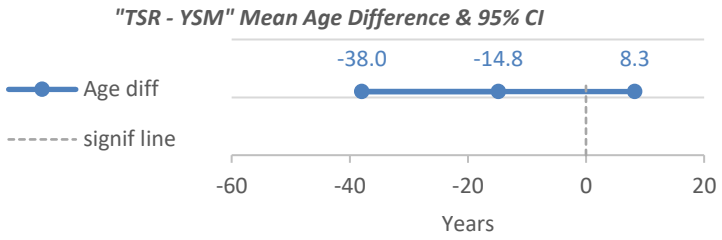
Test to Compare TSR Total Age vs. YSM Ground Sample Age

TSR uses the RESULTS age (for managed stands) or VRI age (for unmanaged stands) as the starting age in timber supply forecasts. This reference age (adjusted to the year of ground sampling) is critical as it is used to compare the TSR predicted volume at the reference age against the actual measured YSM volume. T-tests of the paired age differences (TSR - YSM) provides a check for significant differences between TSR and YSM ages (highlighted when significant @ alpha=0.05, middle chart). Note that YSM sample tree ages may include a combination of both managed and (sometimes) older residual cohorts depending on the sample tree data collection criteria; this may increase the average YSM ground age compared to the TSR reference age.

Results below show that the TSR reference age is not different from YSM ground age

TSR vs. YSM Age		
attr.	**# obs**	**Mean Age**
TSR	13	26.8
YSM	13	41.7

Age diff (m^3/ha/yr)			
p-val	**Diff**	**L95**	**U95**
0.187	-14.8	-38.0	8.3



Test to Compare Modeled vs. YSM Re-measured Periodic Annual Increment

Periodic annual increment (PAI) in units of m3/ha/yr, is computed from all re-measured YSM ground samples, and compared against predicted PAI from TSR yield tables and from YSM TASS projections, separately over the same re-measurement period. Paired T-tests check for significant differences in PAI (highlighted when significant @ alpha=0.05, middle chart). The first test helps evaluate if the TSR growth assumptions from bare ground are in line with actual YSM growth rates. The second test provides an accuracy assessment of TASS projections that start from an existing tree list, compared to actual YSM growth rates.

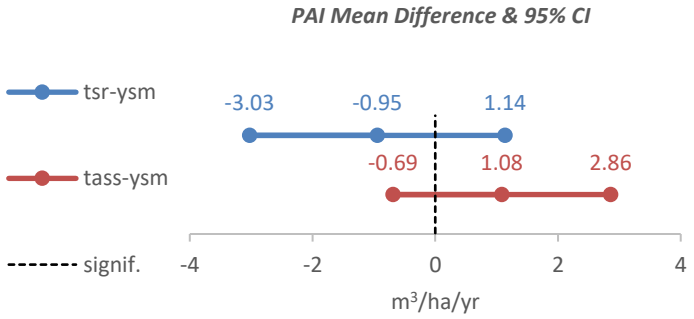
Results of test 1 (TSR yield tables vs. YSM) show no significant difference between the two

Results of test 2 (TASS tree list projection vs. YSM) show no significant difference between the two

Test 1: Compare YSM actual growth vs. TSR yield table projections

YSM vs. TSR MSYTs			
attr.	**# obs**	**Yrs**	**PAI**
YSM	11	4	1.94
TSR	11	4	1

TSR-YSM diff (m^3/ha/yr)			
p-val	**Diff**	**L95**	**U95**
0.335	-0.95	-3.03	1.14



Test 2: Compare YSM actual growth vs. TASS YSM tree list projections

YSM vs. TASS projections			
attr.	**# obs**	**Yrs**	**PAI**
YSM	11	4	1.94
TASS	11	4	3.02

TASS-YSM diff (m^3/ha/yr)			
p-val	**Diff**	**L95**	**U95**
0.204	1.08	-0.69	2.86

Quantifying Change in Growth and Mortality

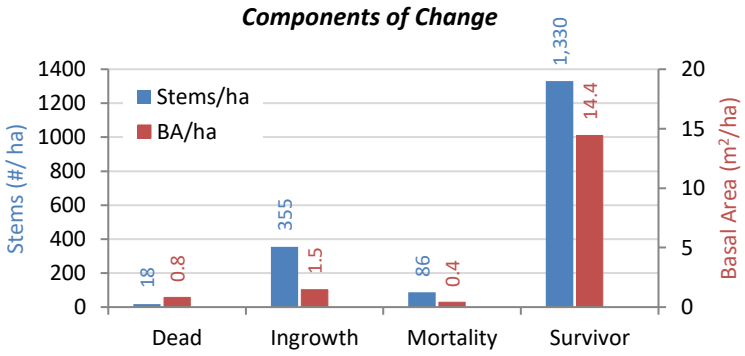
Growth and mortality of the (n=11) re-measured YSM ground samples are summarized into components of change for all tagged trees over an average re-measurement period of 4 years (fig right). The components of change include:

Survivor *Trees that are alive at both measurements*

Mortality *Trees that died between measurements*

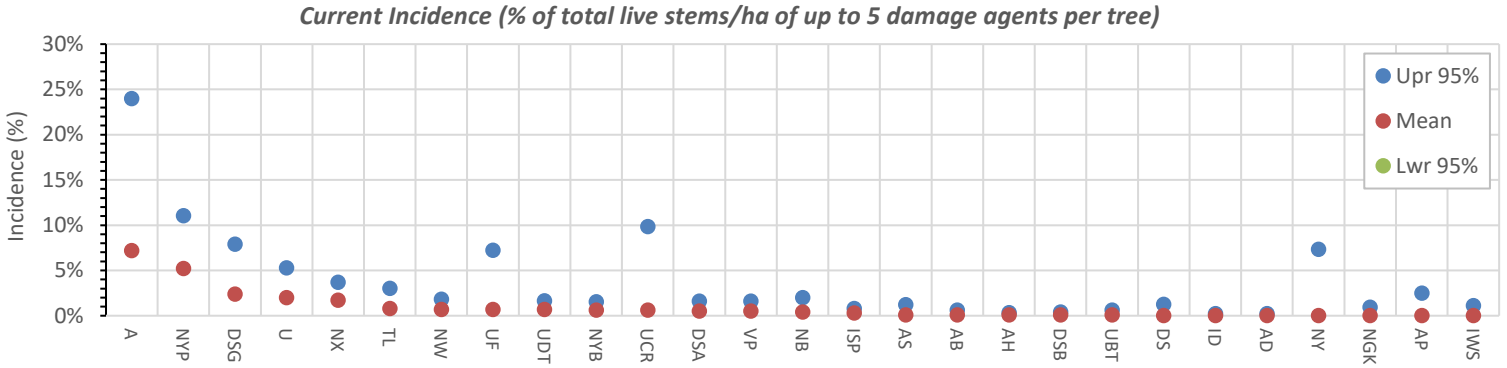
Ingrowth *New trees that grow into the minimum tagging limit*

Dead *Trees that are dead standing at both measurements*



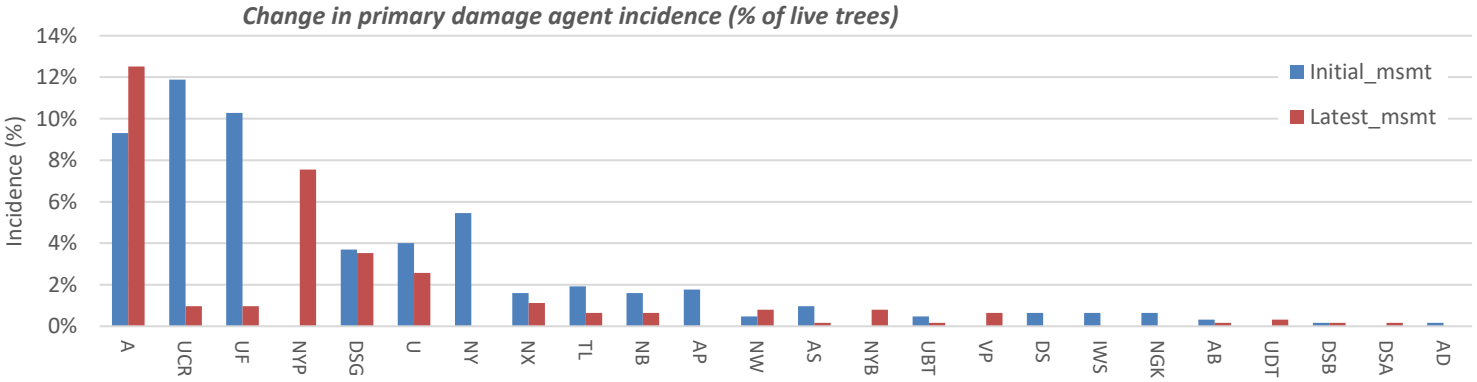
Current Forest Health Incidence

All tagged trees are assessed for up to five forest health damage agents per tree. The mean incidence and 95% confidence intervals by damage agent (expressed as a percent of total live stems/ha of all damage agents recorded per tree) are computed at the latest measurement. Note that up to the 2020 field season, all fork and crook occurrences were recorded regardless of size and severity. Starting in the 2021 field season, those forks and crooks with very small (<10%) offsets in stem diameter (expected to have negligible/no impact on stem form) are no longer recorded; therefore, earlier recorded incidences of forks and crooks prior to 2021 were likely over-estimated. In addition fork and crook severity is now further classified into minor (<50%) vs. major (>=50%) diameter offsets. A full list of recorded damage agents is on page 7.



Comparing Change in Forest Health Incidence

Change in forest health incidence of the (n=11) re-measured YSM samples are compared across the last measurement period averaging 4 years. Incidence across both measurements is relative to the primary damage agent (first recorded and most significant) and from the same trees that were alive at the begining of the period (graph below).



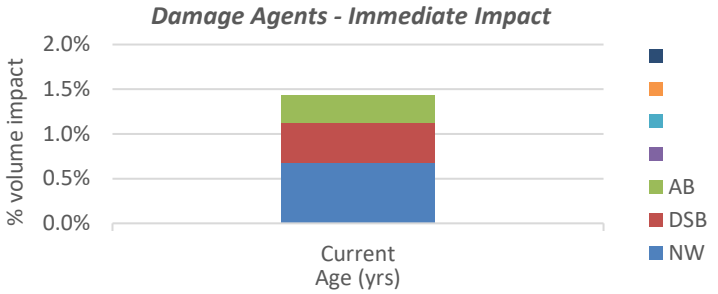
All trees that were alive at the beginning of the period, have either survived or died between measurements. The table on the right summarizes the components of change (# of survivor & mortality) for those trees affected by primary damage agents with highest percent incidence. In addition, the probability of trees getting infected by a given damage agent and subsequently dying from it, is also calculated.

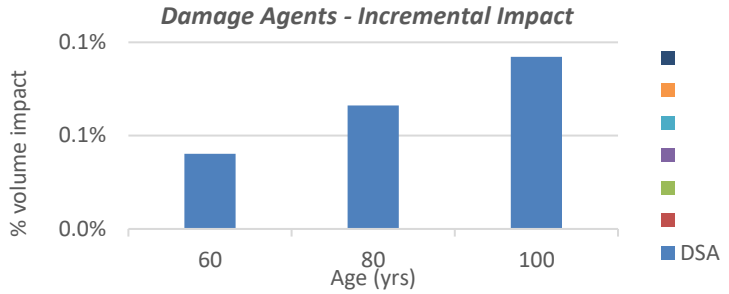
Live trees at period start [a] (#/ha)	Primary Damage Agent	Incidence [b]=e/a (%)	Number of Affected Trees by Primary Damage Agent				Prob. Getting Infected & Dying [g]=b*f (%)
			Survivor trees [c] (#/ha)	Mortality trees [d] (#/ha)	Total affected [e]=c+d (#/ha)	Mortality [f]=d/e (%)	
1,417	O	66.1%	932	5	937	0.5%	0.3%
	A	12.5%	175	2	177	1.3%	0.2%
	NYP	7.5%	61	45	107	42.6%	3.2%
	DSG	3.5%	41	9	50	18.2%	0.6%
	U	2.6%	27	9	36	25.0%	0.6%
	NX	1.1%	16		16		
	UCR	1.0%	14		14		
	UF	1.0%	14		14		
	NYB	0.8%	9	2	11	20.0%	0.2%
	NW	0.8%	2	9	11	80.0%	0.6%
	NB	0.6%	9		9		
	TL	0.6%	5	5	9	50.0%	0.3%
	VP	0.6%	9		9		
	Rest	1.1%	16		16		
	Total	100%	1,330	86	1,417	6.1%	6.1%

Approximating Future Forest Health Risks

Forest health impacts are currently modeled in TASS using the forest health modules GRIM & CRIME that quantify volume impacts of a specific group of stem rusts (DSC, DSG, DSS). YSM sample measurements collected since 2017 include the necessary tree detail information to run these modules. However, to address forest health risks from all other damage agents (and for those sample measurements collected before 2017), an interim simplistic approach is applied to estimate future impacts of all known forest health agents. This involves creating two groups of damage agents: 1) those expected to result in immediate mortality vs. 2) those causing incremental mortality or growth loss through to rotation. For the first group, 90% of the current measured incidence is assumed to cause immediate mortality (left graph). For the second group, the impact is modeled as a product of the current measured incidence times a mortality rate of 2.5% volume loss per decade (right graph). Their combined impact is applied as an additional reduction factor to each YSM TASS projection up to rotation age.

These interim forest health factors resulted in an additional 2% volume impact on YSM TASS projections by age 100. The GRIM/CRIME forest health modules (affecting DSC,DSG,DSS) resulted in a further 0.8 % volume impact on YSM TASS projections by age 100.



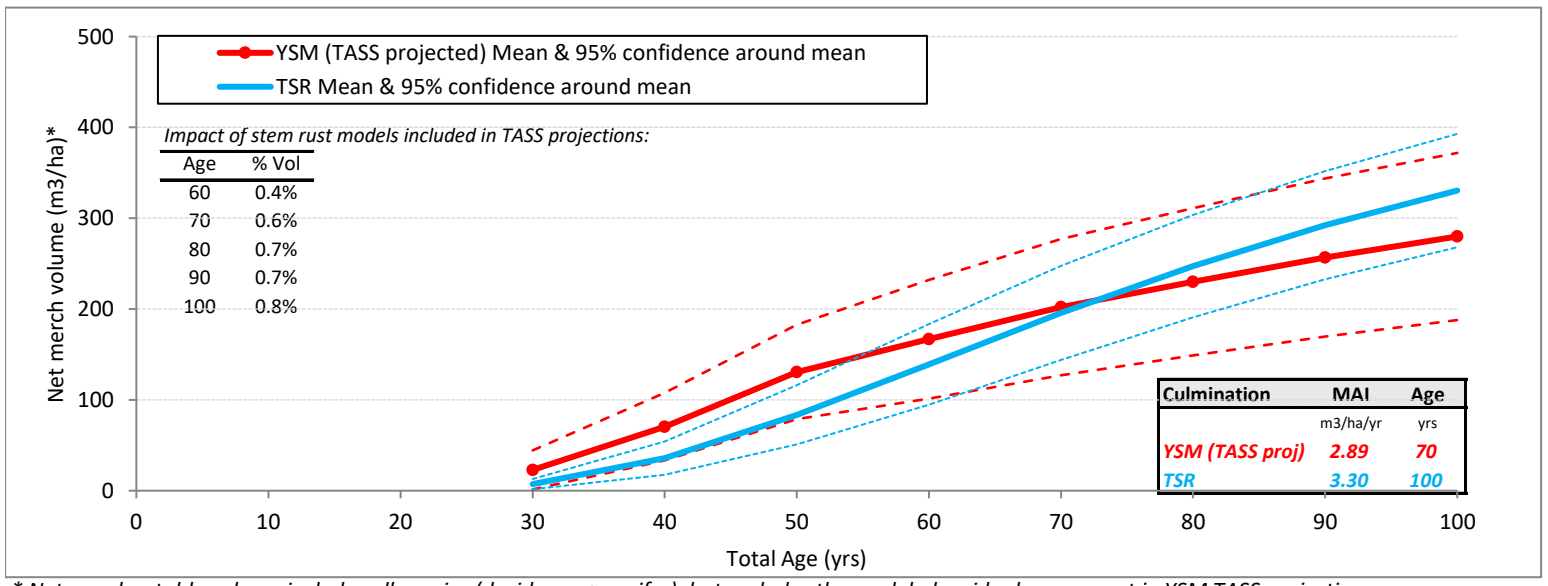


Will Existing Young Stands Meet Expectations at Rotation?

To assess if young stands will meet future volume expectations, each YSM tree list is projected in TASS from its latest measurement date to rotation, and compared against each spatially matched TSR yield table. TASS3 is run for all YSM ground samples comprising at least 80% (by basal area) of PL & SW combined, while TASS2 is run for all other YSM ground samples. No genetic gain estimates are applied, since ground based SI estimates are used for all YSM TASS projections.

All YSM TASS projected volumes include the following adjustments: default Operational Adjustment Factors OAF1 (15%) and OAF2 (5%), stem rust (DSG, DCS, & DSS) impacts modeled in GRIM & CRIME from samples measured in 2017 or later, plus all remaining forest health impacts applied as interim approximations (see previous section). Note that endemic losses from pests and disease are assumed to be part of OAF2, so there can be some double-counting with the inclusion of the stem rust modules plus additional interim forest health impacts. There may also be some double-counting of non-productive area and stocking gap losses already assumed to be a component of OAF1, as these are also captured through the unbiassed grid sample design of the YSM program.

The average of all YSM TASS projections (red lines) are compared against the average of all spatially matched TSR yield tables (blue line), together with 95% confidence intervals (dashed lines). If the TSR projection overlaps within the 95% confidence interval of the average YSM TASS projection, then it is reasonable to assume young stands may meet future timber supply expectations. If not, there may be a need to revisit TSR input assumptions or TSR growth expectations.



** Net merchantable volume includes all species (deciduous + conifer), but excludes the modeled residual component in YSM TASS projections.*

Test to compare YSM TASS projections against TSR Predicted Yield Tables

TSR MSYTs are evaluated against YSM TASS projections, using paired t-tests of the volume differences (TSR-YSM) projected from 60 & 100 years. Highlighted fields (table right) indicate significant differences at alpha = 0.05. Overall percent differences are computed as (TSR-YSM/YSM), and the age at maximum percent volume difference is identified (table right).

Projection age (yrs)	**60**	**70**	**80**	**90**	**100**
# YSM samples	14	14	14	14	14
TSR Mean Proj. Vol	139	196	247	292	330
YSM Mean Proj. Vol	167	202	230	257	280
Mean vol diff	-28	-6	17	36	51
P-value of vol diff	0.461	0.880	0.710	0.477	0.344
% vol diff	-17%	-3%	8%	14%	18%

Max % vol diff		18%
Age @max vol diff		100
Significant?	*(when n>=10)*	No
TSR bias?		No

Total number of YSM samples by:

Sample Type			**TSR Yield Table Assignment Current Regime**		**YSM Plot Occupancy of trees >=4cm DBH**		**Availability of stem mapped YSM Samples used in TASS Projections**		**TASS Version used for YSM Projections**	
Grid (km)		**Total**								
CMI	*20km X 20km*	*2*	*TSR VDYP*	*2*	*Treed*	*13*	*Stem mapped plots*	*13*	*TASS ver. 2*	*8*
YSM	*10km X 5km*	*12*	*TSR TIPSY Opening Specific*	*12*	*Empty*	*1*	*Not stem mapped*	*1*	*TASS ver. 3*	*6*
Total		*14*	*Total*	*14*	*Total*	*14*	*Total*	*14*	*Total*	*14*

Tree Species and Damage Agents Recorded from YSM Samples in the Boundary TSA

Tree Species Codes / Names	
AC	Black cottonwood
AT	Trembling aspen
BL	Subalpine fir
CW	Western redcedar
EP	Paper birch
FD	Douglas-fir
HW	Western hemlock
LW	Western larch
PL	Lodgepole pine
PW	Western white pine
SE	Engleman spruce
SW	White spruce
XC	Unknown conifer

Damage Agent Codes / Names	
A	Animal damage
AB	Bear
AD	Deer
AP	Porcupine
AS	Squirrel
DS	Stem Diseases (Cankers and Rusts)
DSA	Atropellis Canker (Lodgepole pine)
DSB	White pine Blister Rust
DSG	Western Gall Rust
ISP	Pitch Nodule Moths
IWS	White pine Weevil (on Spruce)
NB	Fire
NGK	Shoot/Bud Frost Kill
NW	Windthrow
NX	Wind scarring or rubbing
NY	Snow or Ice (includes snow press)
NYB	Snow or Ice Breakage
NYP	Snow Press
O	None
TL	Logging Wounds
U	Unknown Damage
UBT	Unknown Broken Top Damage
UCR	Unknown Crook Damage
UF	Unknown Fork Damage
VP	Vegetation Press

Damage Agent Codes / Names (cont.)

General Notes / Assumptions

* TSR existing MSYTs are based on FAIB ver. 2022MAR08 using TIPSY 4.4, with RESULTS opening age, species density, regen type and genetic worth, and based on spatially matched RESULTS opening ID where present, or based on aggregated RESULTS input data where Opening ID is unavailable. TSR existing NSYTs are generated by running VDYP7 batch console together with the published 2022 VRI, for YSM sample locations modeled as "existing unmanaged". Each YSM GPS location is intersected with the published 2022 VRI and linked to each TSR yield table by the FEATURE_ID attribute.

* YSM samples that collectively comprise at least 80% PL & SW combined use TASS 3 (ver 3.01.21) to project yields. YSM samples that include all other species combinations use TASS 2 (ver. 2.07.76) to project yield. The rationale is that Tipsy 4.4 base data consists of TASS3-derived yield tables for PL & SW, and TASS2-derived yield tables for all other species.

* TASS projections of each YSM ground sample plot use all available tree data collected at each measurement. This includes individual tree stem mapping, species, DBH and height from all tagged trees, site index by species from all available site trees (including site height and site age), forest health damage and severity (up to 5 per tree), plus specific stem rust damage agent data collected to permit running TASS GRIM/CRIME modules. The TASS-required height vigour coefficients are computed as a ratio of each individual tree height divided by the compiled site height of the same species. Separate tracking of both managed and residual cohorts from the YSM tree list is maintained throughout the entire TASS projection.

* For those YSM samples that are stem-mapped, TASS input tree lists are generated from each sample by first clipping hexagon shaped plots from the circular 0.04ha main plot (tagged trees >9cm DBH) and the 0.01ha subplot (tagged trees 4-9cm DBH), replicating each hexagon and randomly orienting and superimposing both main and subplots onto an expanded 1ha stem-mapped tree list comprising all tagged trees >=4cm DBH. For those YSM samples not yet stem-mapped, TASS assumes a random spatial pattern of the tagged trees.

* When comparing future yield expectations at rotation between spatially matched TSR-derived yield tables and YSM TASS projections, the same reference age is used, which is either based on the age of the intersecting RESULTS opening ID if present, otherwise from the intersecting VRI VEGCOMP poly rank1 projected age attribute (adjusted to year of ground sampling). To ensure consistency with assumptions in the TSR MSYTs, the future yield expectations at rotation of YSM TASS projections exclude the residual cohort.

* All YSM TASS projections include standard OAF1 (15%) and OAF2 (5%) adjustments, with OAF1 applied in a non-standard way by assigning no OAF1 at the YSM sample's current age and volume, and linearly increasing OAF1 so that 100% of its value is achieved by rotation age (assumed as 80yrs).

* TASS projections of YSM samples measured since 2017 include additional GRIM/CRIME modeled impacts (ie., height & %encirclement data are measured for each observed stem rust). The impact of all other recorded damage agents are approximated as having either immediate impact (@90%) or incremental impact (@2.5%/decade), and modeled as additional reduction factors. The subset of damage agents estimated as having immediate or incremental impact on future yields, were identified following discussions with provincial government forest health specialists.

* Potential site index (used to compare against YSM ground-based site index) originates from the Provincial Site Productivity Layer (PSPL) ver 7.0 intersected with each YSM GPS location. Note these potential site index estimates are used as inputs for the TSR-MSYTs.

* YSM leading species is compared to the VRI VEGCOMP leading species for an assessment of leading species agreement. YSM overall species composition is compared to the RESULTS species composition used in TSR MSYTs (which includes planted or natural cohorts).

* Stand table & species composition histograms are computed as pooled (weighted) averages of all YSM samples combined.

* Forest health incidence histograms are computed as pooled (weighted) averages, together with 95% confidence intervals computed using the "variance of a ratio estimator". Current incidence summaries for a given damage agent are based on all possible occurrences recorded for a given tree, which can be up to 5 damage agents per tree. Therefore, current incidence of all damage agents can together add up to more than 100%. Conversely, when summarizing change in forest health incidence over time, only the primary damage agent is included; therefore, the total change in average incidence will add up to 100%.

* Components of change are computed from individual tree changes (ie., survivor, ingrowth, mortality) between the last two measurements only. Trees initially tagged as subplot trees (4-9 cm DBH) and subsequently as main plot trees (>9 cm DBH) have their 'per-hectare-factors' (PHF) fixed relative to the first measurement.

*All reported net merchantable volumes are at 12.5cm close utilization for PL, 17.5cm for other species, and include all species (deciduous + conifer)

References

YSM Technical Handouts for all available TSAs, plus resource information on Provincial Monitoring Programs
https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-inventory/ground-sample-inventories/provincial-monitoring
Public access to Ground Sample Data approved as OpenData under BC Open Government Licence
https://catalogue.data.gov.bc.ca/dataset/824e684b-4114-4a05-a490-aa56332b57f4