Exploring the Establishment of TSR Reference Thresholds for use in the Riverside Results-Based Silviculture Assessment System

Review Draft 2

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Introduction

A results-based regeneration survey system has been proposed by Riverside Forest Products Ltd (the Riverside System) that evaluates licensee performance at the level of an entire management unit rather than for an individual stand (Martin et al. 2002, J.S. Thrower & Assoc. 2002). The system uses predictions of expected yield based on measured regeneration performance as compared to a compliance minimum standard. If the sum of the predicted yields for all stands of a given age is greater than the cumulative standards for those stands, the licensee is deemed to have met its reforestation obligations, even if the predicted yield of one or more stands alone falls below the stand level minimum. Integral to this system is the setting of meaningful compliance standards that are both reasonably achievable and meet the expectations of the Crown.

Also required are one or more interpretive thresholds, above the minimum compliance standard, against which licensees and the Crown can judge relative performance. It is expected ultimately that all licenses must perform to a level above the minimum standard, but to what extent? One possible benchmark that can be used in this regard is current average performance. Such a benchmark would be a target rather than a compliance minimum threshold[1].

Current silviculture practice is already expressed in terms of yield curves in the Ministry of Forests' Timber Supply Review (TSR) process, where this concept forms the basis of setting initial conditions for managed stand yield curves. Assuming that the inputs and processes for TSR and the Riverside System are sufficiently compatible, the TSR Forest Management Assumptions might provide the required information to set a "TSR Reference Level" that is meaningful in the context of the Riverside System. The purpose of this document, then, is to propose, describe and evaluate potential methods of making such linkages. The 2002 TSR for the Fort St. John Timber Supply Area (Anon. 2002a) will be used as a case study.

At its current stage of development, the Riverside System is relatively simplistic and only handles regenerated stands of white spruce and lodgepole pine. Comparable yield tables have not yet been developed for other species. While the Analysis Report for the Fort St. John TSA also describes Forest Management Assumptions for aspen, these will not be incorporated in this document.

Please note that this document is not intended to stand alone as an explanation of the Riverside System and its application. It is assumed that the reader is already familiar with the concepts of the system and its terminology. Readers unfamiliar with this material should first review the document by J.S.Thrower & Assoc. (2002) listed in the references section.

Threshold Levels for the Riverside System

The proposed system uses predicted yield based on achieved regeneration performance measured in the field compared to specified stratum-level thresholds. Because both predicted and threshold yields are derived from models based on sets of *initial conditions*[2] at a relatively early age (i.e. 10 years), the system is really comparing existing stand conditions at the measurement date relative to some idealized set of stand conditions that is assumed to produce the threshold yield.

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[1] Terminology used in this document regarding thresholds, compliance minimums and targets differs somewhat from that used in previous papers on the subject, and reflects that of an evolving set of philosophies and processes. Terminology in any final version of the system will likely vary from that presented here.

[2] *Initial conditions* are the stand descriptors used to initiate quantitative models. For forestry yield models these typically include factors such as site index, species, age and/or height, and stocking level.

The distinction between threshold yields and the initial conditions that are predicted to produce those yields is important. While silviculture performance in this system is quantified based on yields, these yields are derived values from models, and are not actually measured. The stratum-level thresholds are set based on perceptions of different sets of initial conditions, rather than vice versa.

In a trial of the system for TFL 49 (Anon. 2002b), for example, compliance minimum yields were defined as 90% of the maximum achievable with a very aggressive reforestation regime. In this case, maximum yield was defined as that predicted using the yield tables presented by J.S. Thrower & Assoc. (2002), assuming an MSQ of 4.0 (full stocking) 10 years after harvest, 2-year-old trees planted immediately after harvest (no "lost" growing seasons) and a standard height/age relationship by site index. The compliance standard, then, is defined as a major proportion (90%) of the expected yield from a stand with the initial conditions of virtually perfect stocking and 12-year-old top height trees 10 years after harvest on a site with a given site index with an associated standard height growth pattern.

There are many different methods that might be employed in setting different threshold yields for different purposes. The TSR Reference Level being developed in this document is a threshold which might, if found suitable, be used to set realistic targets for silvicultural achievement as opposed to the minimum standard. At the very least, it will be useful for licensees to evaluate their performance against those assumed in the latest TSR analysis.

TSR Forest Management Assumptions

Like yield curves used in the Riverside System, yield curves for TSR are implied based on a set of initial conditions, in this case as outlined in the Forest Management Assumptions. Such a set of Forest Management Assumptions from the 2002 TSR Analysis Report for the Fort St. John TSA are reproduced in Table 1. On close inspection, some important inconsistencies exist between how initial conditions are specified between the Forest Management Assumptions and Riverside System thresholds:

1. There are differences in land base stratification between TSR and the Riverside System. For TSR, the land base is stratified by *analysis unit*. These are collections of stands with similar enough characteristics that they can all be assigned the same yield curve. Most typically, analysis units are defined based on species composition (at a very coarse scale) and site index class. For the Riverside System, the land base is currently stratified by species group and stocking class and target stocking standard[3] (TSS). The major difference between the two is the lack in TSR of differentiation by target stocking standard. Stocking standards are typically assigned based on ecosystem class (site series), while analysis units for TSR may span many ecosystem classes. There may also be differences in how species classes are identified, but this is likely a minor issue.
2. Stocking levels for TSR are specified in terms of total trees/ha, while stocking in the Riverside System is specified in terms of mean stocked quadrants (MSQ). Note that the Riverside System could also potentially use well-spaced trees as a measure of stocking, but this is not the current plan.

[3] Target stocking standards are defined based on the desired number of well spaced trees achieved per hectare of reforested land. The concept of well spaced trees incorporates stocking (avoidance of unstocked gaps), species acceptability and tree condition (trees must be healthy and well formed to be counted).

3. There are different assumptions made regarding the use of Operational Adjustment Factors[4] (OAFs).

To a large extent, these issues are closely related and are difficult to discuss in isolation.

Table1. Regeneration assumptions by analysis unit for the Fort St. John TSA

(Reproduced from Table A-19 in the 2002 Fort St. John Timber Supply Analysis Report)

Analysis unit	Species composition	OAFs (%)		Regen delay	Regen Method		Species		Density (stems/hectare)	
		1	2	(years)	Type	(%)	Code	(%)	Initial	Thin
1001, 2011, 1012, 2013, 2014, 2514, 2551, 2511	S leading conifer	15	5	2	Art	100	Sx	90	1400	
							Pl	10		
1002, 2021, 2024, 2025, 2026, 2029	Pl leading conifer	15	5	2	Art	90	Pl	90	1600	
							Sx	10	1400	
				2	Nat	10	Pl	100	10000	1600
2031, 2034, 2035	Small pine conifer	15	5	2	Art	90	Pl	90	1600	
							Sx	10	1400	
				2	Nat	10	Pl	100	10000	1600
1009, 2081, 2084, 2085, 2093, 2097, 2552, 2561	Pl leading mixed-wood	15	5	2	Art	65	Sx	90	1400	
				2			Pl	10	1600	
				1	Nat	35	At	100	10000	1600
2064, 2061, 1056, 2076, 2073, 2521, 1556	S leading mixed-wood	15	5	2	Art	65	Sx	100	1400	
				1	Nat	35	At	100	10000	
1051, 1052, 1053, 1005	Aspen leading	15	5	1	Nat	65	At	90	10000	
				1			Ac	10	10000	
				2	Art	35	At	100	1400	
2101, 2102, 2103	Aspen leading mixed-wood	15	5	1	Nat	65	At	100	10000	
				2	Art	35	Sx	90	1400	
				2			Pl	10	1600	

Data source and comments:

- Class A seed has not been collected so tree improvement has not been factored into the regenerated growth and yield curves
- Advanced regeneration is present in stands in the ESSF BEC zone
- Brushing activities are expected in the mixed-wood deciduous-leading analysis units to release the conifer component
- Operational adjustment factors (OAFs) were used to adjust timber yield estimates to account for operational factors. OAF1 is a constant percentage reduction to account for small stocking gaps within stands. OAF2 accounts for losses that increase with stand age, for example decay due to disease. In this case OAF2 increases from 0 at stand establishment and passes through 5% at 100 years of age. Provincial average operational adjustment factors (OAFs) values were applied to the managed stand yield curves, as recommended by the Ministry of Forests, Research Branch, as no local OAFs are available.

[4] Operational Adjustment Factors are used to adjust *potential* yields as predicted by some yield models into more typically observed *operational* yields that are more typical of landscape level averages. Potential yields are more typical of the very best stands such as those observed on ideally stocked research plots that are relatively free of pests or other yield reducing agents.

Applying TSR Assumptions Regarding Seedling Age and Regen Delay

The Riverside System in its current form uses stand assessments at a fixed 10-year interval after harvest. The system must account for the actual and effective ages of seedlings at that date in order to make appropriate yield predictions. For planted seedlings, the Fort St. John TSR analysis assumed 1-year old seedlings planted after a 2-year regeneration delay. This would result in 9-year old trees at the 10-year assessment date. For setting thresholds, then, the effective age used to determine threshold yields for planted stands is 9 years. For naturally regenerated lodgepole pine, with a 2-year regeneration delay, the appropriate effective age would be 8 years.

Interpreting TSR Stocking Levels and OAFs

The common use of TIPSY-based stocking and spatial distribution assumptions between TSR and the Riverside System has greatly facilitated determination of stocking equivalents. The 1400 and 1600 planted trees/ha (spruce and pine respectively) assumed in TSR can be roughly translated into MSQ values using Table 2. For 1400 planted trees and no natural ingress, an MSQ value of 3.91 appears warranted. Extrapolating for a planting density of 1600 trees/ha suggests an MSQ value of 3.95[5]. A naturally established lodgepole pine stand at a density of 10,000 trees/ha would warrant an MSQ assignment of 4.0.

The base yield levels that would thus be derived using effective age and MSQ values as initial conditions are still not suitable for use in setting Riverside System thresholds, however. The TSR potential yields are adjusted using a set of OAF's, which assume reductions for factors that are explicitly measured and accounted for in the Riverside System. The OAF1 value of 15% used in TSR is generally broken down as follows (Nussbaum 2001):

- 4% for non-productive "holes" within the stand that are too small to type out in a conventional inventory
- 4% for "holes" in a stand caused by irregular stand establishment, competition from non-commercial brush and elements that cause trees to be more irregularly spaced than is assumed in TIPSY
- 4% for endemic disease and insect losses over the life of the stand
- 3% for other random risk factors such as windthrow, top damage and snow press.

The 4% reduction for irregular espacement and competition from non-commercial brush is a factor that is definitely accounted for in the Riverside system. These factors, if present in a stand, will result in lower achieved MSQ values, and thus lower predicted yields. If an average of 4% reduction in yield is expected for these factors across the land base, then comparable stratum-level thresholds for the Riverside System should be reduced by 4% from the potential yields suggested by the stated stocking values alone.

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[5] Note that the relationship between well spaced trees and MSQ values was developed using lodgepole pine simulations, but should be eqully appropriate for interior spruce.

Table 2. Mean number of stocked quadrants from 30 simulated surveys at age 10 using TASS with different combinations of planted and natural Pl. Table reproduced from J.S Thrower & Assoc. (2002).

Naturals		Planted Density					
Distribution	Density (no/ha)	0	400	800	1000	1200	1400
	0		1.89	3.39	3.71	3.86	3.91
	400	1.56	2.75	3.62	3.86	3.95	3.96
	800	2.48	3.20	3.79	3.92	3.96	3.98
	1,200	3.02	3.54	3.85	3.95	3.98	3.99
Random	1,600	3.43	3.71	3.92	3.97	3.99	3.99
	2,000	3.66	3.81	3.95	3.98	4.00	4.00
	5,000	3.99	4.00	4.00	4.00	4.00	4.00
	8,000	4.00	4.00	4.00	4.00	4.00	4.00
	400	0.95	2.42	3.57	3.83	3.94	3.95
	800	1.60	2.77	3.65	3.89	3.95	3.97
	1,200	2.26	3.06	3.74	3.91	3.98	3.98
Clumped	1,600	2.63	3.28	3.79	3.93	3.98	3.98
	2,000	2.96	3.41	3.85	3.95	3.98	3.99
	5,000	3.84	3.91	3.98	3.99	4.00	4.00
	8,000	3.98	3.99	3.99	4.00	4.00	4.00

A further reduction in the threshold yields *may* be warranted depending on how non-productive areas are dealt with in the Riverside System survey. If all NP patches are stratified out and not sampled, then no reduction for NP “holes” is appropriate. If only a portion of the NP holes is stratified out based on size (i.e. NP areas over 1 ha), then a corresponding portion of the NP reduction must be applied. Determining the applicable portion may be difficult, however, and it seems prudent to use an all-or-none strategy. The easiest method is likely to exclude all NP areas from the survey (including predominantly NP quadrants), and to not apply a reduction for NP areas. Note that, if desired, a tally of NP areas could still be maintained for long term comparisons to TSR OAF assumptions.

No reductions need to be made for endemic disease and random risk factors. These factors apply equally to the target and predicted stands and equivalent results will be achieved in the Riverside System whether they are applied to both or applied to neither. The only case where an adjustment should be made based on these factors is where it can be demonstrate that silvicultural practice is affecting these risk factors. We currently do not have sufficient information to justify such assessments.

Calculating Thresholds

The yield tables currently used for the Riverside System are reproduced in Appendix I. The initial conditions for the target stand using these tables are described in terms of effective age and Mean Stocked Quadrants (MSQ). The effective age for the target stand will be 9 years. The MSQ value is provided in Table 2 based on total trees/ha by origin(planted versus natural). Adjustments to the threshold yield for site index follow procedures outlined by J.S thrower & Assoc. (2002) using values in Table 3[6]. Thresholds should then be reduced by 4% to allow for the assumed average losses for irregular espacement and competition from non-commercial brush.

Table 3. Volume multipliers to adjust target and predicted merchantable volume for different site indices (adapted from J.S. Thrower & Assoc. 2002)

	Site Index (m)														
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Multiplier	0.35	0.44	0.52	0.60	0.68	0.76	0.85	0.93	1.00	1.07	1.12	1.18	1.24	1.28	1.32

Example: Dominant Species = lodgepole pine
Site Index = 17
TSR stocking assumption = 1400 trees/ha

The effective age is 9 years

From Table 2, the target stand MSQ is 3.91

From Table 5 in Appendix I, the target stand yield can be determined as 452 m^3/ha

From Table 3 the site index multiplier is 0.76.

TSR Reference Threshold = Predicted Target Stand Yield * SI factor * 0.96

= 452 m^3/ha * 0.76 * 0.96

= 330 m^3/ha

Reconciling TSR Stratification with Riverside System Thresholds

The coarse analysis unit-based stratification and lack of sensitivity to ecosystems has led to highly simplified stocking assumptions in the TSR analysis. Where in reality stocking levels will vary considerably by ecosystem unit (target stocking standards vary from 400 to 1200 well spaced trees/ha in the BWBSdk1 subzone, and there is often variability in regeneration performance that can be correlated to site series), the TSR analysis has assumed a single stocking level across the

[6] Values in this table serve the same purpose as those in Table 4 of J.S. Thrower & Assoc. (2002). Values for lower SI's were required than previously provided, and extending the previously published values for lower SI's resulted in unrealistic multipliers for SI's 12 through 15. The values provided here were re-calculated, and should serve in the interim until this issue has been re-visited in greater detail.

entire land base for planted stands of each species[7]. For use in the Riverside System, a greater sensitivity to ecosystem-based stocking levels is desirable but not currently available. All planted sites with a given leading species, then, must be lumped together regardless of stocking standard.

At the species level. TSR analysis units are based on pre-harvest species composition, while Riverside System strata are based on post-harvest composition. Simply to apply the Riverside system we must keep its stratification and methodology intact, therefore each reforestation unit sampled must be stratified based on the existing species composition (spruce leading versus pine leading versus mixed spruce and pine). Given that there is a distinction in the TSR analysis based on natural versus artificial regeneration, we can also sub-divide the pine thresholds for these separate stand origins. Thus, we would end up with four sets of TSR Reference Level Thresholds (one each for Pl leading of natural origin, Pl leading of artificial origin, Sx leading and Mixed Pl/Sx).

TSR Reference Level Thresholds

A set of TSR Reference Level thresholds that could be used in the Fort St. John TSA has been calculated and provided in Table 4.

Table 4. TSR Reference Threshold volumes*, using initial conditions based on the 2002 Fort St. John Timber Supply Area Analysis Report.

Site Index (m)	Sx leading	Pl Leading (planted)	Pl Leading (natural)	Mixed Sx/Pl
12	154	143	142	148
13	193	180	179	186
14	229	213	212	220
15	264	246	244	253
16	299	279	277	287
17	334	312	309	321
18	374	348	346	359
19	409	381	379	393
20	440	410	407	422
21	470	439	436	452
22	492	459	456	473
23	519	484	480	498
24	545	508	505	524
25	563	525	521	541
26	580	541	537	558

* Volumes may change based on updated SI multipliers

[7] To date it has not been feasible to maintain stratification to the site series level in TSR analyses primarily due to a lack of landscape scale ecosystem mapping but also due to a functional limit on the number of strata/analysis units which can be realistically modeled..

Discussion

In reviewing the Forest Management Assumptions from the 2002 Fort St. John TSA Analysis Report (Anon. 2002a) and adapting the initial conditions for determining TSR Reference Levels for use in the Riverside System, three major questions arose. The first relates to the broad brush approach of applying generalized TSA assumptions regarding average operating conditions to the operations of discrete licensees, any one of which may be experiencing operating conditions that differ considerably from the TSA averages (pers. Comm. A Nussbaum[8]). The second relates to the use of a single stocking level by species, and the third to the magnitude of yields that are assumed in the TSR and their interpretive value.

The risk of inequalities based on different levels of reasonably achievable performance in different portions of a TSA seems quite real. The Fort St. John TSA, for example, used the assumption that all spruce would regenerate to a density of 1400 trees/ha. Some licensees with operations predominantly in the most favorable climates or in areas with low levels of predominant brush competition may have little difficulty achieving that stocking level, while others in areas of high brush competition, in more climatically severe areas (i.e. high elevations), or areas with higher pest risks (i.e. spruce leader weevil) may have more difficulty. For one licensee, a typical plantation density at free growing may be 1800 total trees/ha with relatively uniform distribution, while for another on tougher ground it may be typical to achieve only 1100 trees/ha with patchy distribution. The licensee on the tougher ground will be perceived to be doing a poorer job based on the application of a TSA-based average threshold.

A TSA-based benchmark with no further geographic based stratification precludes the use of different management goals for different portions of the landbase. In the Fort St. John TSA, for example, it might be found that there are different reforestation expectations for the boreal plains versus the subalpine foothills. If these differences are recognized explicitly in the TSR analysis, there is no problem, but the more common current practice in TSR analyses is to apply a single standard by species to the entire TSA. Such issues may disappear in the future as TSR analyses become more spatially explicit.

A problem somewhat related to the landscape level variations but at a more localized scale is the lack of sensitivity of the TSR analyses to variations in site series and the resulting changes in stocking expectations. There is in most if not all subzones a certain number of site series, typically comprising a minor portion of the total area, on which the Target Stocking Standards (TSS) are lower than on the larger area of cirum-mesic sites.

To truly reflect practices, it would be necessary to deviate from the TSR assumptions on sites where the TSS drops below the most commonly applied 1200[9] well spaced trees/ha. In these cases one would need to use a lower total number of trees/ha. If we assume a total number of planted trees in excess of the well spaced stocking standard that is a constant percentage of the TSS(16.67% for spruce, 33.33% for pine), a total number of trees planted can be calculated for each stocking standard, and a corresponding MSQ value can be predicted from Table 2. The results for a range of stocking standards are shown in Table 4. Note that random rather than square (planted) spacing has

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[8] Timber Supply Branch, BC Ministry of Forests

[9] The value of 1200 well spaced tree/ha is the most common target stocking standard for sites in the interior of BC. Other values are prevalent for coastal sites.

been assumed for the stocking standards lower than 1200 trees/ha due to the likelihood that planting spot selection will be restricted on sites with lower than normal stocking standards.

Table 4. Derivation of MSQ values upon which to base target yields for Target Stocking Standards other than 1200 well spaced trees/ha. The MSQ values were calculated by fitting a third order polynomial equation to the first column of MSQ values for random distributions in Table 2.

TSS (well spaced trees/ha)	Total Planted (trees/ha)		Target Stand MSQ	
	Sx	Pl	Sx	Pl
400	467	533	1.75	1.93
600	700	800	2.30	2.48
800	933	1067	2.69	2.87
1000	1167	1333	2.99	3.16
1200	1400	1600	3.91	3.95

A methodology such as this has not currently been employed in setting the TSR reference level, as it is not employed in TSR analyses. Given that sites with TSS's below 1200 trees/ha are relatively uncommon and are usually small in area, the resulting bias may be quite small.

Overall, yield levels suggested by the TSR Reference Thresholds calculated here may be on the high side, and interpretations of licensee performance based on these thresholds must be applied with caution. The assumptions used in the Fort St. John TSR result in yield predictions that are very close to maximums. The stocking assumptions are such that predicted yields could not be increased significantly by changing them (they are close to optimum), although there is a 4% OAF applied to account for irregular stocking and competition from non-crop species. There is also a 2-year regeneration delay assumed, which potentially results in a 1 to 3% reduction in predicted yields at a given age (compared to planting immediately), depending on site. All told, yield thresholds set using the Fort St. John TSR Forest Management Assumptions would be within 5 to 7% of the maximum achievable using an aggressive silvicultural regime.

In the trial application of the Riverside System on TFL 49 (Anon. 2002b), by comparison, compliance minimum yields were set at 90% of those predicted using the initial conditions assumed to reflect an aggressive silviculture regime, based at least partially on inputs by the Chief Forester. While the difference between 90% and 93 to 95% may seem small, the higher yield levels suggested by the TSR Reference Level may be subject to the principle of diminishing returns. It is quite possible (likely?) that as one approaches the maximum, the increased investment required increases sharply for each additional percentage gain in yield. It may be critical, therefore, to assess whether or not the TSR Reference Level yields exceed what is reasonably achievable by the licensees (at least in this case).

While the Forest Management Assumptions may provide a convenient starting point for the establishment of pilot project thresholds, it is difficult to imagine them being used for long term operational application. The TSR Forest Management Assumptions were developed for a very specific purpose, and in their current form don't well satisfy the needs of applying the Riverside System. These management assumptions are relatively crude, and are readily acknowledged to be based on imperfect information. One of the long term benefits of applying the Riverside System may be the collection of defensible data which can be used to improved the formulation of TSR Forest Management Assumptions (the surveys will quantify "current practice").

Ultimately, methods other than the current TSR Forest Management Assumptions may be required to render sets of initial conditions that reflect the stratification and data requirements of the Riverside System. No system, however, can be deemed "appropriate" until it has been tested on the ground. The simple fact is that we haven't yet quantified in defensible terms the yield implications of current practice, nor have we defined whether current practice for any one test unit is the ideal for that unit.

Fortunately, there is no real onus on licensees at this time to achieve draft compliance minimum yields, TSR Reference Level yields or any other interim thresholds. Any pilot project using these (or other) thresholds in the short term would be testing the thresholds as much as they would be testing the system. In all test cases, the thresholds being used should be under at least as much if not more scrutiny that the silvicultural performance being measured. Where large differences between achieved performance and thresholds occur, both the level of performance and the thresholds should be considered suspect until investigated further. It may be only through repeated applications of this system to a number of different management units that appropriate thresholds can ultimately be defined.

References

Anon. 2002a. **Fort St. John timber supply area Analysis report.** BC Ministry of Forests, Timber Supply Branch, Victoria. 152 p.

Anon. 2002b. **Sample design for the 2002 pilot of Riverside's new approach to silviculture obligations**. BC ministry of Forests, Forest Practices Branch, Victoria. 21 p.

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Appendix I

Yield Tables

Table 5. Predicted merchantable volumes 80 years after harvest for pure Pl stands. Values for ages 5, 7, 10 and 13 were obtained from the fitted equations; all other values were linearly interpolated.
(reproduced from J.S. Thrower & Assoc. 2002)

	Effective Total Age								
MSQ	5	6	7	8	9	10	11	12	13
1.0	140	143	146	151	155	159	163	167	172
1.1	156	159	162	166	171	175	179	183	187
1.2	171	174	178	182	186	190	195	199	203
1.3	186	189	192	197	201	205	209	214	218
1.4	201	204	207	211	215	220	224	228	232
1.5	214	218	221	225	229	234	238	242	246
1.6	228	231	234	239	243	247	251	255	260
1.7	241	244	247	252	256	260	264	269	273
1.8	254	257	260	264	269	273	277	281	285
1.9	266	269	272	276	281	285	289	293	297
2.0	277	280	284	288	292	296	301	305	309
2.1	288	291	295	299	303	308	312	316	320
2.2	299	302	305	310	314	318	322	326	331
2.3	309	312	315	320	324	328	332	337	341
2.4	319	322	325	329	334	338	342	346	350
2.5	328	331	334	339	343	347	351	356	360
2.6	337	340	343	347	352	356	360	364	368
2.7	345	348	351	356	360	364	368	372	377
2.8	353	356	359	363	368	372	376	380	384
2.9	360	363	366	371	375	379	383	388	392
3.0	367	370	373	378	382	386	390	394	399
3.1	373	376	380	384	388	393	397	401	405
3.2	379	382	386	390	394	398	403	407	411
3.3	385	388	391	395	400	404	408	412	416
3.4	389	393	396	400	404	409	413	417	421
3.5	394	397	400	405	409	413	417	421	426
3.6	398	401	404	409	413	417	421	425	430
3.7	401	405	408	412	416	421	425	429	433
3.8	404	408	411	415	419	424	428	432	436
3.9	407	410	413	418	422	426	430	434	439
4.0	409	412	415	420	424	428	432	437	441

Table 6. Predicted merchantable volumes 80 years after harvest for pure Sx stands. Values for ages 5, 7, 10 and 13 were obtained from the fitted equations; all other values were linearly interpolated.
(reproduced from J.S. Thrower & Assoc. 2002)

	Effective Total Age								
MSQ	5	6	7	8	9	10	11	12	13
1.0	163	168	172	179	185	191	197	203	209
1.1	179	184	188	195	201	207	213	219	225
1.2	195	199	204	210	216	223	229	234	240
1.3	210	214	219	225	231	238	243	249	255
1.4	224	228	233	239	246	252	258	264	270
1.5	238	242	247	253	260	266	272	278	284
1.6	251	256	260	267	273	279	285	291	297
1.7	264	269	273	280	286	293	298	304	310
1.8	277	281	286	292	299	305	311	317	323
1.9	289	294	298	304	311	317	323	329	335
2.0	301	305	310	316	322	329	335	341	346
2.1	312	316	321	327	333	340	346	352	358
2.2	322	327	331	338	344	350	356	362	368
2.3	333	337	342	348	354	361	367	372	378
2.4	342	347	351	358	364	370	376	382	388
2.5	351	356	360	367	373	379	385	391	397
2.6	360	365	369	376	382	388	394	400	406
2.7	368	373	377	384	390	396	402	408	414
2.8	376	381	385	392	398	404	410	416	422
2.9	384	388	393	399	405	412	417	423	429
3.0	390	395	399	406	412	418	424	430	436
3.1	397	401	406	412	418	425	431	437	442
3.2	403	407	412	418	424	431	437	442	448
3.3	408	413	417	423	430	436	442	448	454
3.4	413	417	422	428	435	441	447	453	459
3.5	417	422	426	433	439	445	451	457	463
3.6	421	426	430	437	443	449	455	461	467
3.7	425	429	434	440	447	453	459	465	471
3.8	428	432	437	443	450	456	462	468	474
3.9	430	435	439	446	452	458	464	470	476
4.0	433	437	441	448	454	461	466	472	478

Table 7. Predicted merchantable volumes 80 years after harvest for mixed Pl/Sx stands. Values for ages 5, 7, 10 and 13 were obtained from the fitted equations; all other values were linearly interpolated.
(reproduced from J.S. Thrower & Assoc. 2002)

	Effective Total Age								
MSQ	5	6	7	8	9	10	11	12	13
1.0	146	151	156	162	167	172	177	182	187
1.1	161	167	172	178	183	188	193	198	203
1.2	177	182	188	193	198	203	208	213	218
1.3	192	197	203	208	213	218	223	228	233
1.4	206	212	217	222	228	233	238	243	248
1.5	220	226	231	236	242	247	252	257	261
1.6	234	239	244	250	255	260	265	270	275
1.7	247	252	257	263	268	273	278	283	288
1.8	259	265	270	275	281	286	291	296	301
1.9	271	277	282	287	293	298	303	308	313
2.0	283	288	294	299	304	309	314	319	324
2.1	294	299	305	310	315	321	325	330	335
2.2	305	310	315	321	326	331	336	341	346
2.3	315	320	326	331	336	341	346	351	356
2.4	325	330	335	341	346	351	356	361	366
2.5	334	339	344	350	355	360	365	370	375
2.6	342	348	353	358	364	369	374	379	384
2.7	351	356	361	367	372	377	382	387	392
2.8	358	364	369	375	380	385	390	395	400
2.9	366	371	377	382	387	392	397	402	407
3.0	373	378	383	389	394	399	404	409	414
3.1	379	384	390	395	400	406	410	415	420
3.2	385	390	396	401	406	411	416	421	426
3.3	390	396	401	406	412	417	422	427	432
3.4	395	401	406	411	417	422	427	432	436
3.5	400	405	410	416	421	426	431	436	441
3.6	404	409	414	420	425	430	435	440	445
3.7	407	412	418	423	428	434	439	443	448
3.8	410	416	421	426	431	437	442	447	451
3.9	413	418	423	429	434	439	444	449	454
4.0	415	420	426	431	436	441	446	451	456