Appendix 4: Reforestation Strategy: Stocking Estimators and Future Volume

Silviculture Note #??

Stocking estimators and future volume

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1. Introduction

Tree stocking, the degree to which growing space is occupied, is an important forestry concept. In a young stand, stocking is a main determinant of future stand volume/ha and the distribution of tree sizes at harvest (Clutter et al. 1983). A variety of estimators have been developed to quantify the stocking in regenerated stands (Stein 1978; Shreuder, Gregoire and Woods 1993, pg 291). Typically, these estimators are designed to take on greater values as density and uniformity of tree distribution increase, and many are capped at some maximum value. When stocking estimators are evaluated, the focus has been on ease of use, cost, and the extent to which they exhibit desired behaviour over a range of tree density and uniformity (Stein 1978). Historically, the ability of a stocking estimator to predict future volume has not been an important evaluation criterion.

Recently in B.C. interest has grown in the relationship between stocking estimators and future volume. Bergerud (2001) demonstrated the relationship between the stocking estimator "total well-spaced trees/ha" and TASS predicted merchantable volume/ha at age 67 years for lodgepole pine on site index 18 m. J.S. Thrower and Associates (2002) developed a new stocking estimator "MSQ" and demonstrated its relationship to TASS predicted merchantable volume/ha at age 80 years for lodgepole pine on site index 20 m.

Martin, Browne-Clayton, and McWilliams (2002) described a new system for managing reforestation that is based on the future volume predicted, in part, from the stocking observed in young stands. Though this new system uses the stocking estimator "MSQ," it could be re-formulated to use other stocking estimators. In future implementations of this new system, it is desirable to ensure that the stocking estimator used has high predictive power. In this paper, I report the results of a cursory assessment of the ability of four stocking estimators to predict merchantable volume/ha at age 80 years for lodgepole pine on site index 18 m.

2. Methods

The spatially explicit, individual tree growth model TASS (Mitchell 1975, Mitchell and Cameron 1985) was used to generate a variety of tree spatial patterns in a 100 m x 100 m plot. From bare ground the stand represented by each plot was grown to the silviculture survey date at which time surveys were simulated in the stand. The survey parameters were computed and the stand was grown for 100 years. Volumes

at ages 60, 80, and 100 years (site heights of 18.8, 21.9, and 24.0 m, respectively) were extracted from the TASS output, though only the volume at age 80 is reported here. Regression analysis was used to assess the strength of the relationship between the four stocking estimators and merchantable volume/ha at age 80.

2.1 Stocking estimators

Though a total of seven stocking estimators were evaluated, in this paper I report only the results for four (Table 1):

Table 1. Description of the four stocking estimators that were assessed.

Code	Name	Plot procedure	Compilation
TTPH	Total trees per hectare	In a 3.99 m radius plot, the surveyor counts all live trees.	Plot counts are averaged and expanded to a per hectare basis.
WSTPH	Well-spaced trees per hectare	In a 3.99 m radius plot, the surveyor maximizes the count of well-spaced trees. No "M" cap. 2.0 m MITD.	Plot counts are averaged and expanded to a per hectare basis.
MSQ	Mean stocked quadrants	In a 3.99 m plot divided into quarters along cardinal directions, the surveyor counts the number of quarters containing at least one live tree.	Plot counts are averaged.
PERSP	Percent stocked 1.4 m radius plots	The surveyor counts a 1.4 m plot as stocked if it contains at least one live tree.	Percent of all plots that were tallied as stocked is computed.

2.2 TASS simulations

Fifty different tree spatial distributions were taken from the many stem maps used to produce Land Management Handbook 50 (Bergerud 2002). From those distributions classified as clumped, maps with the following initial trees/ha were used: 300, 425, 550, 650, 750, 900, 950, 1020, 1150, 1240, 1400, 1500, 1750, 2000, 2250, 2500, 2750, 2900, 3100, 3265, 3906, 4500, 5200, 5917, 6944, 8000, 10000, and 20000. From those distributions classified as natural (random spatial pattern), maps with the following initial trees/ha were used: 300, 550, 750, 950, 1150, 1400, 1750, 2250, 2750, 3100, 3906, 5200, 6944, and 10000. From those distributions classified as planted (grid spatial pattern), maps with the following initial trees/ha were used: 425, 650, 950, 1240, 1750, 2500, 4500, and 8000.

The following run specifications were used for each TASS simulation:

TASS version: v2.07.14WS

Species: interior lodgepole pine

Site index: 18 m

Site index curve code: PI_THROWNIGH

Merchantable volume

Minimum dbh: 12.5 cm

Top dib: 10 cm

Stump height: 0.3 m

OAFs: No OAFs applied

Plot size: 100 m X 100 m

The TASS runs and the survey simulations were conducted by RamSOFT Systems Ltd.

2.3 Survey simulation

Each stem map was grown to a site height of 5 m, which occurred 16 years from run initialization. Surveys were simulated at this time. Ten plots were randomly located on the stem map, plot values taken, and the sample mean computed. This was repeated 1000 times. Last, the 1000 sample means were averaged. Thus, each survey value is a mean from 10,000 plots. In counting trees, no minimum height criteria were applied. To reduce costs by re-using data previously compiled, one set of plot centers was used for WSTPH and MSQ and a different set for the other estimators.

2.4 Data analysis

A single equation form was identified that could provide a good fit to each of the four volume-stocking estimator relationships. A function in the Weibull family was fit with nonlinear least squares using the SYSTAT statistical software (SPSS Inc. 1998):

$$V = b_0\left(1 - \exp\left(b_1\left(X/\phi\right)^{b_2}\right)\right)$$

Where V is merchantable volume/ha at age 80,

b_0, b_1, and b_2 are parameters, and

X is the stocking estimator (TPH, WSTPH, MSQ, and PERSP). ϕ is a constant assigned before fitting equal to the largest X value in the data set: $\phi = 16712$ for TPH, $\phi = 2182$ for WSTPH, $\phi = 4$ for MSQ, and $\phi = 100$ for PERSP.

The fit statistics and a visual examination of residuals indicated that excellent fits were obtained. Two fit statistics, the mean square error and the squared correlation between observed and predicted values, were taken to indicate the ability of a stocking estimator to predict future volume/ha (Table 2).

The complete data set is provided in Appendix A.

3. Results

The relationship between each stocking estimator and TASS-predicted volume at age 80, with the fitted curve, is displayed in Figures 1-4.

Though volume/ha at 80 years is approximately linearly related to MSQ, the relationship is curvilinear with TTPH, WSTPH, and PERSP. A visual assessment suggests that the stocking estimators TPH, WSTPH and PERSP produce values that are spread more widely, while many of the 50 stem maps assessed returned MSQ values very close to 4. However, an increased spread is not associated with an improved ability to predict future volume (Table 2).

MSQ predicts future volume/ha slightly better than WSTPH and PERSP do and much better than TTPH does (Table 2). The relationships between future volume and WSTPH, PERSQ, and MSQ are so strong that little improvement can be expected from adding additional explanatory variables or stratifying the data.

Table 2. Fit statistics from regressions relating stocking estimators to future volume.

Stocking estimator	Mean square error	R^2: Correlation of observed and predicted values (squared)
TTPH	703	0.84
WSTPH	142	0.97
MSQ	44	0.99
PERSP	152	0.97

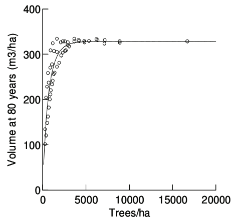

Figure 1. Relationship between merchantable volume/ha at age 80 and total trees/ha at survey. Solid line is fitted regression.

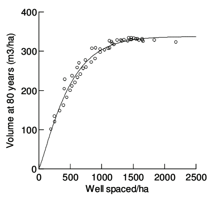

Figure 2. Relationship between merchantable volume/ha at age 80 and total well spaced trees/ha at survey. Solid line is fitted regression.

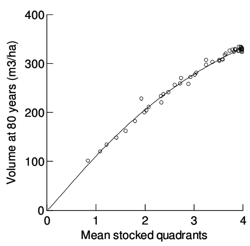

Figure 3. Relationship between merchantable volume/ha at age 80 and mean stocked quadrants at survey. Solid line is fitted regression.

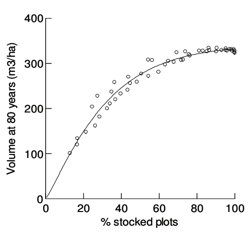

Figure 4. Relationship between merchantable volume/ha at age 80 and percent stocked plots at survey. Solid line is fitted regression.

4. Discussion

In terms of its ability to predict future volume, the stocking estimator MSQ is superior to the three others examined (TTPH, WSTPH, and PERSP). However, WSTPH and PERSP are almost as good so when other factors are considered, such as cost, ease of use, or familiarity of procedure – the use of MSQ, WSTPH, or PERSP could easily be justified. As expected, TTPH is a poor estimator of future volume and, for this purpose, its use is not recommended.

Bergerud (2001) found that the relationship between TASS-predicted future volume and well-spaced trees/ha varied with tree spatial pattern. Though this issue was not specifically examined in this analysis, the excellent fits suggest that little could be gained by stratifying by tree distribution type (random, clumped, or grid). Additional replicates of the planted and natural spatial pattern stem maps and subsequent analysis is recommended to further examine this issue.

The volumes used in this study are TASS-predicted volumes, not actual volumes observed in real stands that originated with the specified tree spatial patterns. Thus, the fit statistics grossly over-state the accuracy with which these stocking estimators will predict real stand future volumes. Moreover, if there is some systematic bias in TASS predictions, for example, if volumes are consistently over-estimated at low stockings, then the shape of the volume-stocking relationships displayed in Figure 1-4 will be incorrect.

These results indicate the correlation between future volume and a stocking estimator when sample size is enormous. Each data point is the mean of 10,000 sample plots. The correlation under operationally realistic sample sizes should be investigated. Furthermore, it would certainly cost less to take a single PERSP plot than to take a single WSTPH plot. In dense stands, TPH is also time consuming to tally. However, cost has not been considered in this analysis. Subsequent study should attempt to identify the stocking estimator that provides the most accurate prediction of future volume at a realistic fixed cost.

5. Literature cited

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Appendix A: Complete data set

Stem map #	TASS initialization density (#/ha)	Tree spatial distribution type	Trees per hectare at survey (#/ha)	Well-spaced trees per hectare (#/ha)	Mean stocked quadrants with unrotated 3.99 m plots	Percent stocked 1.4 m radius plots (percent)	Merch. volume at age 80 (m3/ha)
1	300	clumped	278	192	0.84	12.81	101
2	425	clumped	402	254	1.09	16.64	120
3	550	clumped	524	334	1.42	21.28	148
4	650	clumped	628	394	1.61	26.23	162
5	750	clumped	716	446	1.80	28.50	182
6	900	clumped	852	500	1.99	32.54	200
7	950	clumped	898	528	2.08	33.99	211
8	1020	clumped	948	576	2.34	36.91	220
9	1150	clumped	1086	616	2.33	39.68	233
10	1240	clumped	1170	662	2.48	43.32	241
11	1400	clumped	1290	706	2.61	44.67	256
12	1500	clumped	1400	752	2.72	48.21	259
13	1750	clumped	1658	836	2.93	54.34	272
14	2000	clumped	1908	896	3.05	59.73	281
15	2250	clumped	2156	978	3.25	63.15	297
16	2500	clumped	2314	1046	3.38	67.82	303
17	2750	clumped	2582	1104	3.52	71.72	307
18	2900	clumped	2670	1128	3.58	72.64	308
19	3100	clumped	2894	1168	3.65	75.81	320
20	3265	clumped	3064	1196	3.63	76.23	317
21	3906	clumped	3676	1306	3.79	83.15	328
22	4500	clumped	4234	1356	3.84	86.54	329
23	5200	clumped	4842	1416	3.92	90.25	326
24	5917	clumped	5350	1468	3.95	93.00	329
25	6944	clumped	6218	1512	3.96	95.21	333
26	8000	clumped	7184	1572	3.98	97.32	331
27	10000	clumped	8892	1648	3.98	98.58	328
28	20000	clumped	16712	1840	3.98	99.95	328
29	300	random	286	250	1.22	16.76	134
30	550	random	518	414	1.93	27.34	228
31	750	random	702	530	2.38	34.83	237
32	950	random	890	640	2.74	43.77	270
33	1150	random	1086	742	3.02	50.62	277
34	1400	random	1310	846	3.25	56.31	307
35	1750	random	1642	976	3.52	64.82	305
36	2250	random	2102	1124	3.73	73.93	326
37	2750	random	2578	1248	3.85	81.13	328
38	3100	random	2910	1322	3.90	85.30	326
39	3906	random	3662	1432	3.96	90.55	334
40	5200	random	4810	1474	3.97	95.25	329
41	6944	random	6332	1546	3.98	98.17	331
42	10000	random	8906	1660	3.98	99.79	325
43	425	planted	406	406	2.03	24.58	204
44	650	planted	612	612	2.89	36.40	258
45	950	planted	906	904	3.59	54.18	308
46	1240	planted	1170	1158	3.82	69.25	324
47	1750	planted	1646	1472	3.92	86.22	334
48	2500	planted	2336	1594	3.98	95.90	328
49	4500	planted	4150	1644	3.98	99.55	331
50	8000	planted	7138	2182	3.98	100.00	323