Estimating Inventory Attributes for the Lakes Timber Supply Area from Remeasured Vegetation Resources Inventory Ground Data

2013

BRITISH COLUMBIA

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ISBN 978-0-7726-6730-4 – Print version

ISBN 978-0-7726-6731-1 – Digital version

Citation
Nigh, Gordon D. 2013. Estimating inventory attributes for the Lakes Timber Supply Area from remeasured Vegetation Resources Inventory ground data. Prov. B.C., Victoria, B.C. Tech. Rep. 078.
www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr078.htm

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ABSTRACT

Ninety-three Vegetation Resources Inventory plots were remeasured and analyzed to assist in making decisions regarding future timber supply and lumber manufacturing in the Lakes Timber Supply Area, British Columbia. The live and dead volumes were analyzed at various utilization levels in two sets of domains: Immature, pine leading (Pl) < 80, Pl 80 +, and Mature; and South, Central, and North. Histograms of the diameter distributions, small-tree densities, log grades, and damage and loss factors were used to assess the quality of the timber. At the 12.5 + utilization level, the estimated live (dead) volumes for the Immature, Pl < 80, Pl 80 +, and Mature domains were 3.2 (0.4), 11.8 (19.2), 12.0 (25.4), and 43.8 (18.1) million m^3, respectively. The estimated live (dead) volumes at the 12.5+ utilization level were 10.3 (17.9), 25.8 (24.0), and 34.7 (21.1) million m^3 for the South, Central, and North areas, which included the Burns Lake and Cheslatta Community Forests. Most of the trees were in the smaller diameter classes; in the larger diameter classes, the number of trees decreased as diameter increased. As well, there was a large amount of advance regeneration in the stands. Log grade, damage, and loss factor histograms provided information on timber quality.

ACKNOWLEDGEMENTS

I thank Chris Mulvihill, Bill Kovacs, Bob Krahn, Will Smith, Sam Otukol, and Gary Johansen, all with the B.C. Ministry of Forests, Lands and Natural Resource Operations, Forest Analysis and Inventory Branch, for assembling the ground sample data and inventory data, and answering many questions about the data. Thanks also go to Doug Layden for doing the GIS work, including calculating the areas of each domain and the volume of timber in each domain from the inventory data, and to Peter Ott for helping with the data analysis. Peter and Doug are also with the Forest Analysis and Inventory Branch. Chris, Will, and particularly Peter and Doug, spent a lot of time on this project, and all were critical to its success. I thank Peter Ott, Albert Nussbaum, and Agathe Bernard (all with the B.C. Ministry of Forests, Lands and Natural Resource Operations) for comments on the manuscript.

CONTENTS

1 INTRODUCTION

On January 20, 2012, an explosion and subsequent fire destroyed the Babine Forest Products sawmill in Burns Lake, British Columbia. The mill was the largest employer in Burns Lake. The decision to rebuild the mill hinged largely on the timber supply in the Lakes Timber Supply Area (TSA) since this TSA supplies the mill with most of its timber. The composition of the timber supply in the TSA has recently been altered by the mountain pine beetle infestation, which swept through the area between 2000 and 2010, and peaked in 2005 (British Columbia Ministry of Forests, Lands and Natural Resource Operations 2012a). This made the availability of current information critical.

In the summer of 2012, the Forest Analysis and Inventory Branch of the B.C. Ministry of Forests, Lands and Natural Resource Operations remeasured 93 of the Vegetation Resources Inventory (VRI) permanent sample plots in the Lakes TSA. The data were collected to provide decision makers with updated information for the TSA. The information on live and dead volume was of particular interest, but other attributes, such as diameter distributions, small-tree counts, and quality of the timber, were also important.

Although the decision to rebuild the mill was made in December 2012, and work on its reconstruction began in 2012, the information from the VRI plots is still important for planning purposes. For example, the VRI data can be used to check the photo-interpreted volume in the inventory, which is used in timber supply analyses. This report describes the analysis of the VRI data and the results of the analysis.

2 DATA

The VRI plots were established in 2006 and 2007. The target population consisted of the vegetated treed land base, excluding private land, Indian Reserves, parks, and protected areas in the Lakes TSA (Figure 1). The designation of the population was based on the 2000 inventory (British Columbia Ministry of Forests and Range 2006, 2008). This area includes the Burns Lake Community Forest and the Cheslatta Community Forest. Originally, 115 plots were established with a stratified probability proportional to size with replacement sample design. By 2012, however, some destructive Net Volume Adjustment Factor sampling had been conducted on 17 plots (B.C. Ministry of Forests and Range 2006), and five plots had been harvested, which resulted in only 93 of the original 115 plots being remeasured. Details about the sample allocation are provided by the B.C. Ministry of Forests and Range (2006, 2008). The original samples were placed into one of four strata based on the inventory classification of polygon age and leading species: age ≤ 60 years/all species (Immature), age > 60 years/50–80% pine leading (Pl < 80), age > 60 years/80% pine leading (Pl 80 +), and age > 60 years / all none pine leading (Mature). The strata were further divided into three substrata (0, 1, and 2) based on volume, which yielded 12 mutually exclusive strata that completely covered the population. Table 1 shows the areas of the substrata and the original sample allocation.

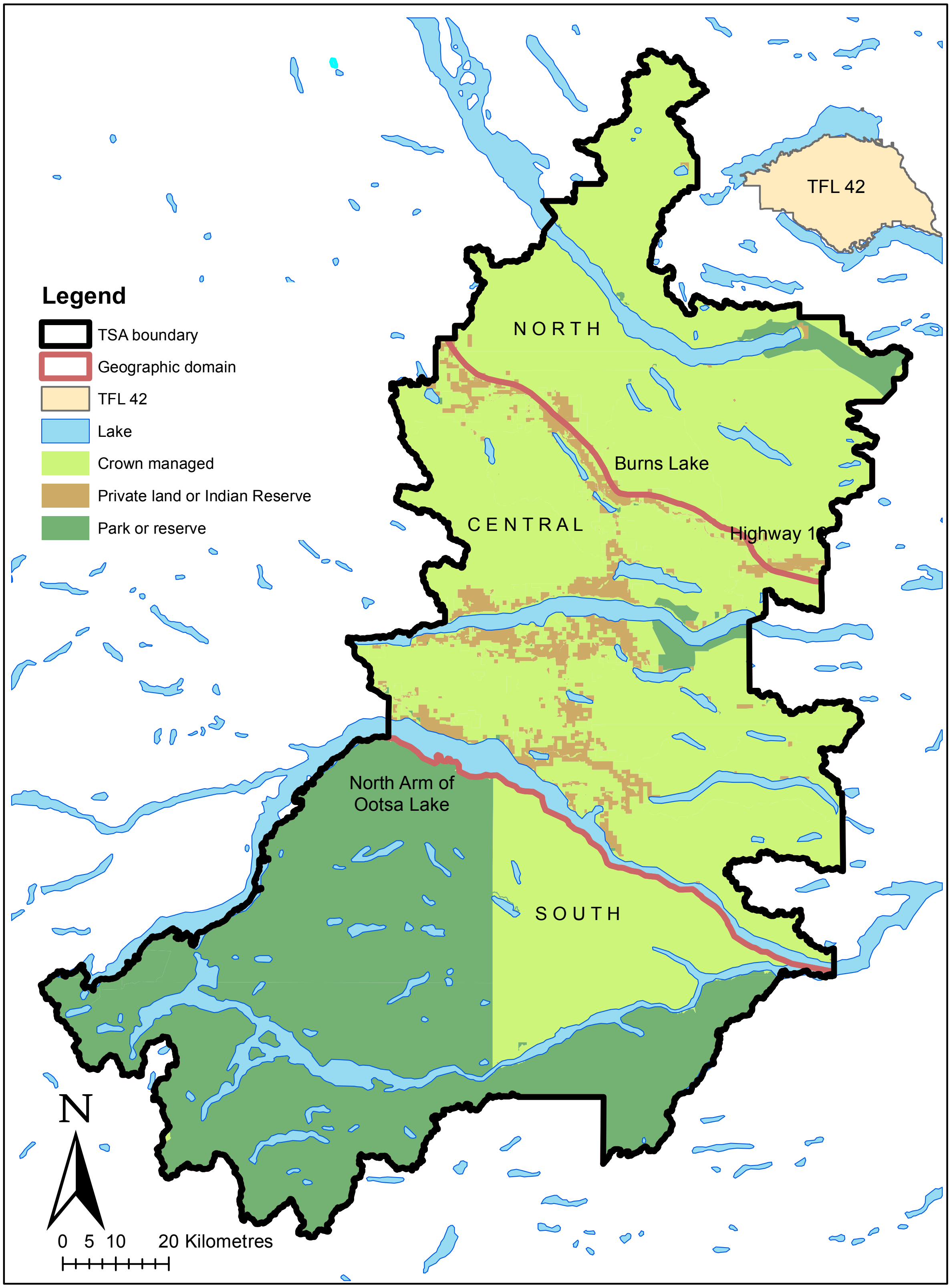

FIGURE 1 *Lakes Timber Supply Area (TSA) showing the South, Central, and North domains.*

TABLE 1 *Original sample allocation*

Strata	Substrata	Area (ha)	Number of samples (original)
Immature	0	36 712	5
	1	19 359	5
	2	16 659	5
Pl[a] < 80	0	50 493	8
	1	56 761	9
	2	67 459	8
Pl 80+	0	74 316	11
	1	78 689	12
	2	88 606	12
Mature	0	81 590	13
	1	95 295	14
	2	105 746	13

a Pl: pine leading

The plots consisted of a five-subplot cluster with one subplot at the centre (the Integrated Plot Centre [IPC]) and four auxiliary subplots in the cardinal directions. The subplots were either fixed area or variable radius. The fixed area plots were 0.01 ha, and the basal area factor for the variable radius plots ranged from 5 to 12. Fixed area (50 m^2) small-tree plots were established at all subplot locations (this was a deviation from the standards, which call for small-tree plots only at the IPC).

Many tree attributes and characteristics were collected (B.C. Ministry of Forests, Lands and Natural Resource Operations 2012b). These data were compiled into tree-, plot-, and per hectare-level attributes (B.C. Ministry of Forests and Range 2009). The variables that were analyzed are:

- whole stem volume of live and dead trees > 4.0 cm diameter at breast height (dbh) less cruiser-called decay, waste, and breakage × the net volume adjustment factor at different utilization levels and for different species and live/dead status groups;
- diameter distribution of the live and dead trees > 4.0 cm dbh;
- small-tree density (three height classes were used to tally small trees: 0.1–0.3 m, 0.3–1.3 m, > 1.3 m but < 4.0 cm dbh);
- log grades;
- damage agents; and
- loss factors.

The log grade data were collected using modified log grades for coastal British Columbia rather than interior log grades (B.C. Ministry of Forests, Lands and Natural Resource Operations 2012b). The grades are as follows: H, I, and J are sawlogs; P, Q, and R are small-tree grades and represent pretty good, questionable, and reject grades, respectively; and U, X, and Y are utility chipper grades. The IPC was the only subplot that had log grade, damage agent, and loss factor data for all trees greater than 4.0 cm dbh; hence, only the IPC subplot data were analyzed for these attributes.

3.1 Volume

To maintain fidelity with the original sampling design and to account for the movement of both population area and samples into different strata, the new strata were handled as domains (Lohr 1999). The 12 substrata within the main strata were considered to be unique strata in this analysis, as per the original design and analysis. The volume estimate calculations are described in Appendix 1.

Two separate domain analyses were performed. For the first analysis, species and age defined the domain of interest; for the second, coarse geographic location defined the domain. In both cases, the domain was delineated using information based on the inventory data, not the ground-based sample information.

3.1.1 Species and age domain In this analysis, four mutually exclusive domains were defined based on age and species: age ≤ 60 years/all species (Immature), age > 60 years / 50–80% pine leading (Pl < 80), age > 60 years/pine leading > 80% (Pl 80 +), and all other stands > 60 years (Mature). The definitions of these domains were identical to those of the original four strata.

The 2000 inventory, which was used to draw the 2006 sample, had not been updated with harvesting information since 2000. This created two issues in the analysis. First, in the original 2006 sample selection, 12 plots were assigned to harvested areas and consequently were moved/reselected to other unharvested locations in the same strata/substrata. This created an upward bias since the plots that should have had a volume of (or close to) 0 m^3/ha had a higher volume after being moved. The second issue occurred in determining the correct areas of the domains since they could not be calculated directly from the 2000 inventory. A third issue arose because, as mentioned previously, five plots were harvested after the samples were selected and were not remeasured in 2012. Similar to the 12 plots mentioned above, ignoring these low-volume plots in the volume estimates created a bias.

All 93 extant plots were used in the domain analysis. Additionally, the four plots harvested after 2007 and the one plot that was harvested after being selected in the sample but before being measured were included in the analysis. Also included in the analysis were the 12 plots that, in the initial plot selection and establishment process, were assigned to harvested areas and were moved/reselected to unharvested locations. These 17 plots were "moved back" into the population by creating new data records for the plots, assigning them to the Immature domain, and setting their volumes to 0 m^3/ha. However, these plots may have had some remaining volume after harvesting, or, less likely, they may have had enough growth to contain some trees above the 4.0 cm dbh measurement threshold. Consequently, setting their volumes to 0 may have slightly biased the volume estimates downwards. Adding these plots back into the sample accounted for the harvesting that occurred between 2000 and 2012. The weights for the plots were calculated by dividing the total area of the strata/substrata (Table 1) by the number of plots in the strata/substrata. All 93 extant and moved/reselected plots (i.e., the full complement of 110 plots) were considered in the weight calculations. The harvested plots went into the Immature domain, four plots that were originally in the Immature strata/substrata had matured into a non-immature domain and were assigned to their new domain, and all other plots remained in their corresponding domains.

The areas of these domains were needed so that the volume per hectare could be estimated. The areas of the Pl < 80, Pl 80 +, and Mature domains were calculated by taking the area in these strata as reported by the B.C. Ministry of Forests and Range (2008) (2000 inventory), subtracting the area depleted (sites denuded by harvesting) from 2000 to the end of 2011, and adding in the area that aged from the Immature strata into their new domain. The area of the Immature domain was calculated by taking the area in the Immature strata, adding the area depleted from the three mature strata, and subtracting the area that aged into the three mature domains. Although the recently denuded sites will not have 10% crown closure until a few years after they have been regenerated, they were still considered to be in the vegetated treed class, and hence, still in the population. The areas were obtained through a Geographic Information System (GIS) process (D. Layden, B.C. Ministry of Forests, Lands and Natural Resource Operations, pers. comm.).

3.1.2 Geographic domain In the other domain analysis, the TSA was divided into three geographic domains: North (area north of Highway 16), South (south of the north arm of Ootsa Lake), and Central (between the north arm of Ootsa Lake and Highway 16) (Figure 1). All 110 plots were used in this domain analysis. Since the geographic area did not depend on the vintage of the inventory or whether or not depleted areas were included in the inventory, some of the issues with the previous analysis did not exist. However, an issue did arise with determining the area in each geographic domain. The GIS analysis indicated that the total area in these three domains was 743 411 ha, which was 28 273 ha smaller than the area of the population in 2006 (771 684 ha). This difference could not be resolved; consequently, the "missing area" was allocated to the three domains proportional to the area of the domains as determined by the GIS analysis. This affected only the volume per hectare calculations.

3.2 Diameter Distribution, Small-tree Density, Log Grades, Damage Agents, and Loss Factors

The diameter distributions and small-tree density, log grade, damage agent, and loss factor data were analyzed with histograms. Only the 93 remeasured plots were analyzed; hence, the results apply only to the area represented by these plots (i.e., the area in the population that had not been harvested since 2000). Nevertheless, the area represented by the 93 plots is still referred to as the TSA in the text and figures for these analyses.

The statistical weights were calculated as:

$$w_{hij} = w_{hi} \times phf_{hij}$$

where w_{hij} is the weight of tree j in plot i in stratum h, phf_{hij} is the per hectare factor for tree j in plot i in stratum h (i.e., it is the number of trees per hectare that each sample tree represents; this was calculated by the VRI compiler, B.C. Ministry of Forests and Range [2009]), and w_{hi} is as described in Appendix 1. For fixed area plots, the per hectare factor is the inverse of the plot size. For variable radius plots, the per hectare factor is the basal area factor divided by the basal area of the sample tree.

The diameter distributions were determined by binning the individual trees into 2 cm diameter classes with the class midpoints being odd integers. The estimated number of trees in each diameter class was calculated by summing the weights (w_{hij}) of each tree in the diameter class. These sums were then converted into the percent of trees in the TSA. The small-tree densities are presented on a per hectare basis by domain. The plot weights (w_{hi}) were multiplied by the number of trees in each height class in the plot and then were summed by domain and height class to obtain an estimate of the total number of trees in each height class in each domain. The total number of trees was converted to stems per hectare by dividing by the area of the domain. The log grade data are presented as percent of live or dead log volume in the TSA by log grade. The tree weights (w_{hij}) were multiplied by the log volume and then summed across all plots for each grade to get volume per grade, which was then converted into a percent. The damage agent and loss factor data are presented as percent of trees in the TSA with the damage agent or loss factor class. The number of trees in the TSA with a damage agent or loss factor is the sum of the tree weights (w_{hij}) for trees with the target damage agent or loss factor. Some damage agents and loss factors are not mutually exclusive; that is, a tree can have more than one damage agent or loss factor; consequently, the percentages for damage agents and loss factors may not sum to 100.

4 RESULTS AND DISCUSSION

All results in Tables 2–5 are based on the full complement of 110 plots. The volumes of harvested plots that were reselected/moved were set to 0 m^3/ha in the analysis.

The total volume of all trees (live and dead) at a 12.5+ utilization level was estimated to be 133 802 900 m^3. The estimated volume per hectare (m^3/ha) of live timber at a 12.5+ utilization level was 25.83 (Immature), 75.13 (Pl < 80), 55.50 (Pl 80+), and 159.85 (Mature), for an average of 91.73 m^3/ha over the whole population.

The estimated total live volume based on the ground samples at 4.0+, 12.5+, and 17.5+ utilization levels was approximately 74.4, 70.8, and 57.1 million m^3, respectively (Table 2). The estimated total dead volumes at the same utilization levels were approximately 64.0, 63.0, and 56.8 million m^3, respectively (Table 2). The volume of dead timber was almost as much as the volume of live timber. The bulk of the dead timber was in lodgepole pine (*Pinus contorta*) leading stands, which is the result of the mountain pine beetle (*Dendroctonus ponderosae*) outbreak in the region (B.C. Ministry of Forests, Lands and Natural Resource Operations 2012a). In the Pl < 80 and Pl 80+ domains, the volume of dead timber was approximately twice the volume of live timber, particularly in the Pl 80+ domain.

The analysis of the volume data for the 12.5+ utilization level for lodgepole pine and 17.5+ for all other species (Table 2) is of particular interest since these are the assumed utilization levels in a timber supply analysis. For consistency, the timber volume at these utilization levels was calculated the same way as in the timber supply analysis for the Lakes TSA (Q. Su, B.C. Ministry of Forests, Lands and Natural Resource Operations, pers. comm.).

That is, the volume was calculated by applying the utilization level to the tree species within a plot (as opposed to applying it at the inventory level; i.e., to the Pl < 80 and Pl 80 + domains). The estimated live volume in the Immature, Pl < 80, Pl 80 +, and Mature domains was 2.9, 10.5, 11.0, and 38.5 million m^3 respectively, for a total volume of 62.8 million m^3 (Table 2). The estimated total dead volume was 62.2 million m^3 (Table 2), about the same as the live volume.

TABLE 2 *Results of the analysis of the Lakes Vegetation Resources Inventory data using domains based on species and age. The estimated total volume of the live and dead trees is shown (SE: standard error). The areas (ha) of the domains are Immature: 124 441; pine leading (Pl) < 80: 157 161; Pl 80+: 216 356; and Mature: 273 726.*

			Volume (m^3) in domain ± SE				
Species	**Utilization**	**Timber status**	**Immature**	**Pl < 80**	**Pl 80 +**	**Mature**	**All**
All	4.0 +	Live	3 820 357 ± 726 759	12 351 358 ± 2 147 330	12 981 969 ± 2 473 999	45 227 010 ± 4 957 381	74 380 694 ± 5 986 276
		Dead	391 490 ± 211 681	19 256 992 ± 2 083 540	25 996 523 ± 3 716 442	18 369 445 ± 2 471 249	64 014 450 ±4 930 006
All	12.5 +	Live	3 213 750 ± 671 265	11 807 823 ± 2 101 190	12 008 458 ± 2 346 669	43 756 463 ± 4 846 230	70 786 495 ± 5 818 797
		Dead	389 152 ± 210 396	19 186 192 ± 2 072 873	25 373 179 ± 3 689 138	18 067 882 ± 2 441 958	63 016 405 ± 4 890 191
All	17.5 +	Live	1 802 453 ± 522 552	9 773 263 ± 2 017 374	8 443 415 ± 1 792 545	37 064 756 ± 4 490 073	57 083 886 ± 5 264 677
		Dead	371 425 ± 209 010	17 712 998 ± 1 940 407	21 885 800 ± 3 350 462	16 792 180 ± 2 305 585	56 762 403 ± 4 511 118
All	12.5 + for	Live	2 855 690 ± 610 604	10 474 650 ± 1 988 942	10 961 670 ± 2 135 015	38 459 313 ± 4 511 264	62 751 323 ± 5 407 265
	17.5 + for	Dead	371 425 ± 209 010	19 126 572 ± 2 062 758	25 285 503 ± 3 661 209	17 400 363 ± 2 401 597	62 183 862 ± 4 844 664

Table 3 presents the results of the domain analysis for the geographic regions. This table is similar to Table 2 except that there are only three domains and the results for utilization level 4.0+ are not presented. This analysis shows that the North zone contained the most live volume and the Central zone contained the most dead volume. The South domain was substantially smaller than the Central and North domains (Figure 1).

TABLE 3 *Results of the analysis of the Lakes Vegetation Resources Inventory data using domains based on geographic zones. The estimated total volume of the live and dead trees is shown (SE: standard error). The areas (ha) of the domains are South: 124 106; Central: 360 579; and North: 286 999.*

			Volume (m^3) in domain ± SE			
Species	**Utilization**	**Timber status**	**South**	**Central**	**North**	**All**
All	12.5+	Live	10 315 019 ± 2 736 052	25 750 340 ± 4 499 847	34 721 136 ± 6 764 976	70 786 495 ± 8 573 185
		Dead	17 870 945 ± 4 958 548	24 032 692 ± 4 531 897	21 112 768 ± 3 846 265	63 016 405 ± 7 740 739
All	17.5+	Live	8 315 081 ± 2 315 746	20 110 424 ± 3 884 744	28 658 381 ± 6 068 190	57 083 886 ± 7 568 147
		Dead	16 250 792 ± 4 599 437	21 446 204 ± 4 161 837	19 065 407 ± 3 500 194	56 762 403 ± 7 122 294
All	12.5+ for pine	Live	9 077 197 ± 2 422 956	22 462 305 ± 4 024 288	31 211 821 ± 6 245 899	62 751 323 ± 7 815 168
	17.5+ for all others	Dead	17 820 438 ± 4 955 534	23 696 383 ± 4 473 856	20 667 041 ± 3 793 785	62 183 862 ± 7 678 900

Table 4 shows a comparison between the total live and dead volume on the inventory file and the estimated volumes from the ground sample plots for the 12.5+ and 17.5+ utilization levels for the species/age domains. The inventory data were compiled to be current to the end of 2011 (D. Layden, B.C. Ministry of Forests, Lands and Natural Resource Operations, pers. comm.). These are the same inventory data being used in an updated timber supply analysis of the Lakes TSA (Q. Su, B.C. Ministry of Forests, Lands and Natural Resource Operations, pers. comm.).

The comparisons in Table 4 reveal some discrepancies between the inventory and the ground sample–based estimates at the domain level. At both of the reported utilization levels, the inventory live volume in the Immature domain was significantly less than that of the sample estimate, but the inventory dead volume was significantly greater than the estimated dead volume from the sample. Also, at both utilization levels, the inventory was significantly less than the sample for the dead volume in the Mature domain. Although not significantly different, the inventory for the dead volume in the Pl 80+ domain was substantially less than the dead volume from the samples at both the 12.5+ and 17.5+ utilization levels. The inventory volume was also greater than the sample volume for the live volume in the Pl < 80 domain at both utilization levels, but the difference was statistically significant only at the 17.5+ utilization level.

TABLE 4 *Comparison of the estimated volume of live and dead trees from the ground sample plot data and the inventory data for 12.5 + and 17.5 + utilization levels by species/age domains. A 95% confidence interval is shown beneath the estimated sample data volume. Inventory volumes that are significantly different from the sample-based estimated volumes are shaded gray.*

		Live volume (m^3)		Dead volume (m^3)	
Utilization level	**Domain**	**Inventory**	**Sample**	**Inventory**	**Sample**
12.5 +	Immature	1 120 360	3 213 750 (1 871 220–4 556 281)	1 412 595	389 152 (-31 639–809 944)[a]
	Pl[b] < 80	15 952 537	11 807 823 (7 605 443–16 010 204)	22 538 980	19 186 192 (15 040 445–23 331 938)
	Pl 80 +	10 885 725	12 008 458 (7 315 120–16 701 796)	19 315 820	25 373 179 (17 994 903–32 751 455)
	Mature	37 812 835	43 756 463 (34 064 004–53 448 922)	12 515 637	18 067 882 (13 183 965–22 951 798)
	All	65 771 457	70 786 495 (59 148 902–82 424 088)	55 783 032	63 016 405 (53 236 022–72 796 787)
17.5 +	Immature	707 633	1 802 453 (757 349–2 847 556)	1 321 662	371 425 (-46 595–789 445)[a]
	Pl < 80	14 502 026	9 773 263 (5 738 515–13 808 011)	20 049 156	17 712 998 (13 832 183–21 593 812)
	Pl 80 +	9 398 418	8 443 415 (4 858 325–12 028 505)	16 974 879	21 885 800 (15 184 875–28 586 724)
	Mature	35 756 404	37 064 756 (28 084 610–46 044 901)	11 930 853	16 792 180 (12 181 010–21 403 351)
	All	60 364 481	57 083 886 (46 554 531–67 613 241)	50 276 550	56 762 403 (47 740 167–65 784 639)

a A negative lower confidence limit is, in this analysis, illogical, but is nevertheless presented for completeness. It can be assumed that realistically the lower limit is 0 m^3/ha.

b Pl: pine leading

Table 5 is a comparison of the estimated total live and dead volume with the same volumes from the inventory by geographic domain. The inventory data were compiled to be current to the end of 2011 (D. Layden, B.C. Ministry of Forests, Lands and Natural Resource Operations, pers. comm.). This comparison shows that there was a good correspondence between the inventory and the sample volume estimates; that is, there were no statistically significantly differences in volume between the inventory and the estimated volume from the samples.

TABLE 5 *Comparison of the estimated volume of live and dead trees from the inventory and ground sample plot data for 12.5+ and 17.5+ utilization levels by geographic domain. A 95% confidence interval is shown beneath the estimate for the sample data. None of the sample-based estimated volumes are significantly different from the inventory volumes.*

		Live volume (m^3)		Dead volume (m^3)	
Utilization level	**Domain**	**Inventory**	**Sample**	**Inventory**	**Sample**
12.5+	South	7 921 546	10 315 019 (4 842 914–15 787 123)	14 130 865	17 870 945 (7 953 849–27 788 041)
	Central	28 092 039	25 750 340 (16 750 646–34 750 034)	24 611 661	24 032 692 (14 968 897–33 096 487)
	North	29 757 872	34 721 136 (21 191 185–48 251 088)	17 040 506	21 112 768 (13 420 238–28 805 297)
	All	65 771 457	70 786 495 (53 640 125–87 932 865)	55 783 032	63 016 405 (47 534 926–78 497 883)
17.5+	South	6 961 357	8 315 081 (3 683 588–12 946 573)	12 185 730	16 250 792 (7 051 917–25 449 667)
	Central	25 536 785	20 110 424 (12 340 937–27 879 912)	22 032 044	21 446 204 (13 122 530–29 769 878)
	North	27 866 339	28 658 381 (16 522 000–40 794 762)	16 058 776	19 065 407 (12 065 019–26 065 794)
	All	60 364 481	57 083 886 (41 947 592–72 220 180)	50 276 550	56 762 403 (42 517 815–71 006 990)

Tree diameters followed a reverse-J distribution (Figure 2), which is usually associated with uneven-aged forests (Oliver and Larson 1996). The distribution of the dead trees was more uniform across the range of diameters. In any case, most of the trees were in the smaller diameter classes. The Immature domain had some very large-diameter trees (not shown). This could be the result of misclassification errors in the inventory since the domains were based on inventory information, not on the ground sampled information, or because the large trees could have been purposely left behind after harvesting. The number of dead trees was greater than the number of live trees in many of the larger diameter classes. This is a reflection of the mountain pine beetle infestation.

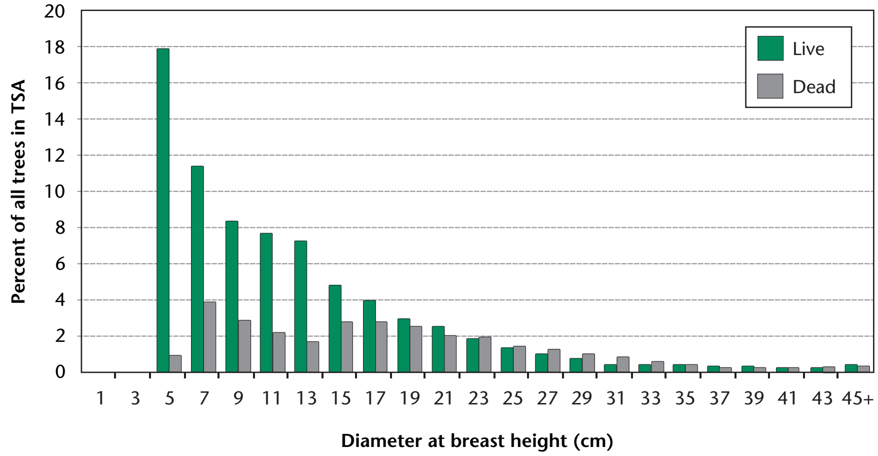

FIGURE 2 *Diameter distributions for live and dead trees in the Timber Supply Area (TSA).*

The analysis of small-tree densities (Figure 3) showed that there is a large amount of natural regeneration in the stands in all of the species/age domains and in the geographic domains. The large amount of regeneration in the South domain may indicate that the stands are recovering from the mountain pine beetle infestation. However, these data do not include recently harvested areas (i.e., post 2000). Presumably, these would be (or will be) well stocked as well.

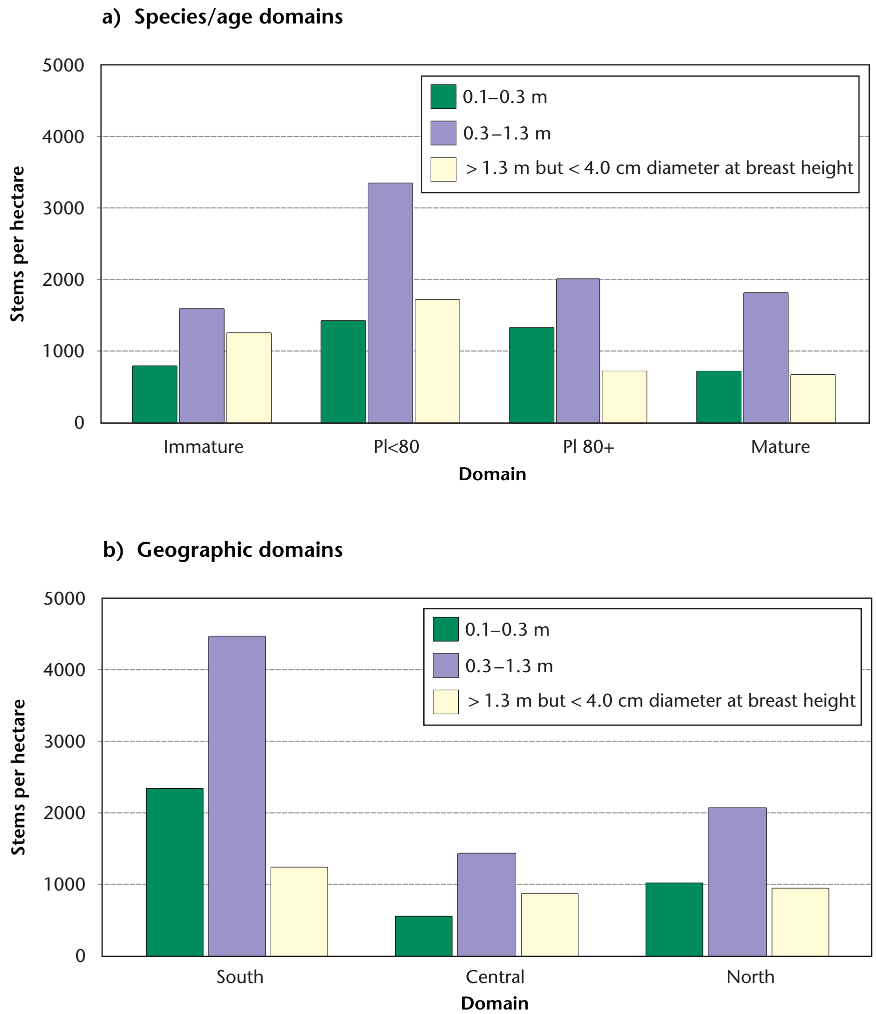

FIGURE 3 *Distribution of small-tree density among height classes for (a) the species/age-based domains and (b) the geographic-based domains. Pl: pine leading.*

Results of the analysis of the small-tree density prompt the question about how well the stands are stocked. To answer this question, two levels of stocking were defined and analyzed: very low stocking (basal area < 5 m^2 or small-tree density < 500 stems per hectare) or low stocking (basal area < 10 m^2 or small-tree density < 1000 stems per hectare). Based on these definitions, 4.5% of the area had very low stocking and 6.7% had low stocking. Information on stocking is available for only the 93 extant plots that were remeasured in 2012; therefore, these results apply only to the land base represented by these plots.

The log grade data (Figure 4) indicates that most live trees are either grade J or U, while dead trees are mostly grade Y. On a percentage basis, the South domain had very little sawlog-quality trees, whereas the Central and North domains had increasing sawlog percentages (not shown). This is probably a reflection of the diminishing pine component in the northern regions of the TSA.

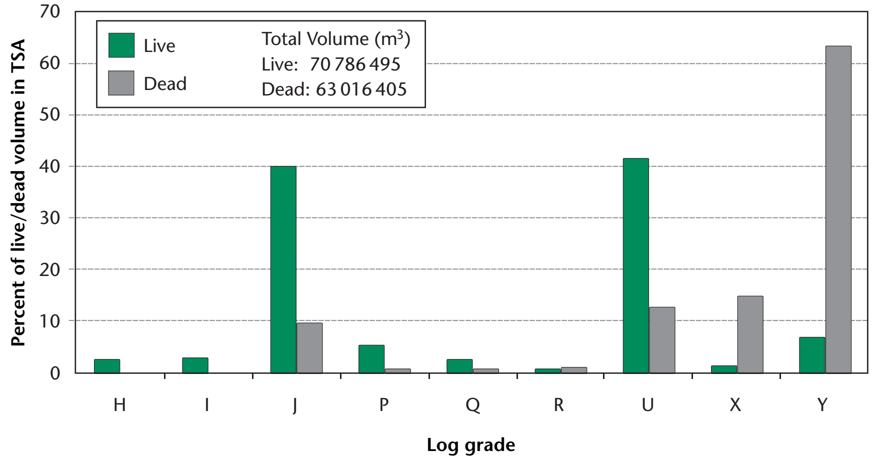

FIGURE 4 *Log grades for live and dead trees in the Timber Supply Area (TSA).*

A large percentage of the live trees did not have any damage (Figure 5) or loss factors (Figure 6). Most dead trees also did not have any loss factors (Figure 6), but many had some damage (Figure 5). Again, the effect of the mountain pine beetle outbreak was evident in the amount of insect damage, particularly in the dead trees. Insect and non-biological damage were the most common damage agents. The dead trees had a large amount of damage due to unknown factors. This may have been because deterioration of the dead trees made it difficult to identify damage agents. Broken or dead tops, forks, crooks, and scars comprised most of the loss factors.

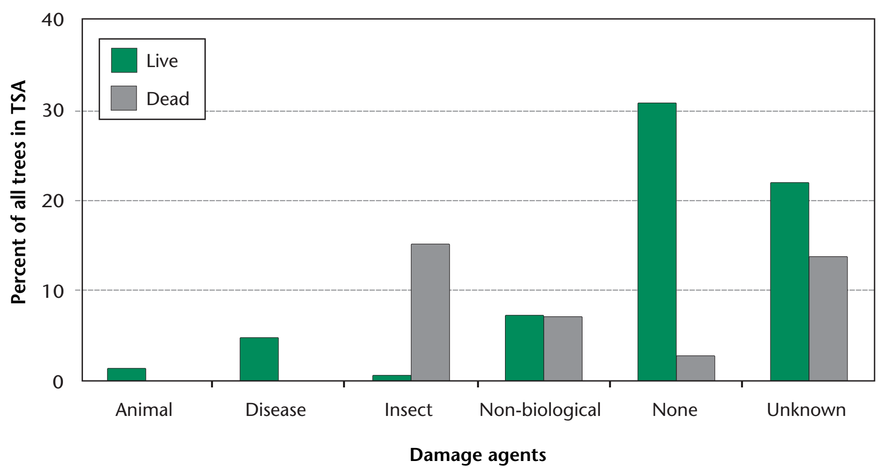

FIGURE 5 *Damage agents for live and dead trees in the Timber Supply Area (TSA).*

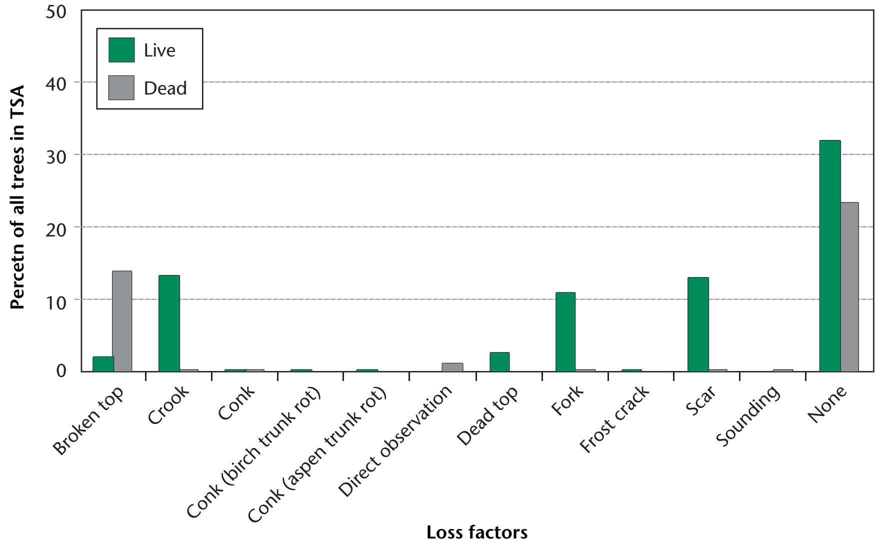

FIGURE 6 *Loss factors for live and dead trees in the Timber Supply Area (TSA).*

5 CONCLUSION

There is an estimated 74.4 million m^3 of live timber and 64.0 million m^3 of dead timber in the Lakes TSA. The large amount of dead timber is due to the recent mountain pine beetle infestation. The amount of live volume at 12.5+ and 17.5+ utilization levels is 70.8 million m^3 and 57.1 million m^3, respectively.

The diameter distributions are generally a reverse-J pattern; that is, large numbers of small trees that decrease as the diameter increases. Additionally, there is a large amount of natural regeneration in these stands. Less than half the live trees and very few dead trees are sawlog quality. The log grades and damage agent data reflect the effects of the mountain pine beetle outbreak. Nevertheless, more than half of the live and dead trees were free of loss factors.

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Volume estimators and their standard errors presented using live volume of all species as an example.

1.1 Variable Definitions and Notation

1.1.1 Indexes

h indexes strata (h = 1, 2, . . . 12)
i indexes sampled polygons within strata (i = 1, 2 . . . n_h, where n_h is the number of polygons sampled in stratum h), with repeats possible
d indexes domain of interest (d = 1, 2, . . . D, where D is the number of domains)

1.1.2 Volumes

v_{hi} = live volume (m^3) per hectare of all species for polygon i in stratum h
v_d = live volume (m^3) per hectare of all species for domain d
v = live volume (m^3) per hectare of all species in the population
V_{hi} = total live volume (m^3) of all species for polygon i in stratum h
V_d = total live volume (m^3) of all species in domain d
V = total live volume (m^3) of all species in the population
$V_{d(h)}$ = total live volume (m^3) of all species in stratum h that are also in domain d

1.1.3 Areas

z_{hi} = area (ha) of polygon i in stratum h
z_h = area (ha) of stratum h
z_d = area (ha) of domain d
z = total area (ha) of population $= \sum_{h=1}^{12} z_h = \sum_{d=1}^{D} z_d$

1.1.4 Indicator Variable

$$I_{d(hi)} = \begin{cases} 0 \text{ if observation (hi) is not in domain d} \\ 1 \text{ if observation (hi) is in domain d} \end{cases}$$

1.1.5 Weights

w_{hi} = original weight for plot i in stratum h
x_{hi} = weight for plot i in stratum h for the domain analysis

1.1.6 Notation

^ indicates an estimate of a variable
¯ indicates the mean of a variable

1.2 Calculation of the Weights for Each Observation

The selection probability of a polygon in stratum h is $n_h \times z_{hi} / z_h$. Since the (estimated) total volume per polygon V_{hi} is $v_{hi} \times z_{hi}$, the weight (reciprocal of the selection probability) for polygon i in stratum h when working with v_{hi} is $w_{hi} = z_h / n_h$.

For the domain analysis, the weights (x_{hi}) for plot i in stratum h are:

$$x_{hi} = w_{hi} \times I_{d(hi)} = \begin{cases} 0 \text{ if observation (hi) is not in domain d} \\ w_{hi} \text{ if observation (hi) is in domain d} \end{cases}$$

1.3 Estimation of Total Volume

The estimated total volume in domain d is:

$$\hat{V}_d = \sum_{h=1}^{12} V_{d(h)} = \sum_{h=1}^{12} \sum_{i=1}^{n_h} x_{hi} \times v_{hi}$$

If polygon i in stratum h also belongs to domain d, then $x_{hi} \times v_{hi}$ represents the total volume estimated by polygon i in stratum h that is also in domain d. The estimated total volume in the population is:

$$\hat{V} = \sum_{d=1}^{D} \hat{V}_d$$

1.4 Estimation of the Variance of the Total Volume

The estimated variance of the total volume in domain d is:

$$\text{var}(\hat{V}_d) = \sum_{h=1}^{12} \text{var}(\hat{V}_{d(h)}) = \sum_{h=1}^{12} \sum_{i=1}^{n_h} \text{var}(x_{hi} \times v_{hi})$$

Here $\text{var}(\hat{V}_{d(h)})$ represents the variance of the estimated total volume for those areas in stratum h that belong to domain d. $\text{Var}(x_{hi} \times v_{hi})$ is estimated from the n_h observations in stratum h. Using the properties of the probability proportional to size with replacement variance estimator, it can be shown that:

$$\text{var}(\hat{V}_{d(h)}) = \frac{n_h}{n_h - 1} \times \sum_{i=1}^{n_h} (x_{hi} \times v_{hi} - \overline{vx}_h)^2$$

where

$$\overline{vx}_h = \frac{1}{n_h} \times \sum_{i=1}^{n_h} (x_{hi} \times v_{hi})$$

The estimated variance of the estimated total volume is:

$$\text{var}(\hat{V}) = \sum_{d=1}^{D} \text{Var}(\hat{V}_d)$$

1.5 Estimation of Volume per Hectare

The estimated volume per hectare in domain d is the estimated total volume in domain d divided by the area of domain d:

$$\hat{v}_d = \frac{\hat{V}_d}{z_d}$$

The estimated volume per hectare for the population is the estimated total volume of the population divided by the total area of the population:

$$\hat{v} = \frac{\hat{V}}{z}$$

1.6 Estimation of Variances of the Estimated Volumes per Hectare

The estimated variances of the estimated volumes per hectare are calculated using straightforward formulae for variances:

$$\mathrm{var}(\hat{v}_d) = \frac{\mathrm{var}(\hat{V}_d)}{z_d^2}$$

$$\mathrm{var}(\hat{v}) = \frac{\mathrm{var}(\hat{V})}{z^2}$$