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VALIDATION OF FPINNOVATIONS BIOS APP IN TOPLEY, BC: METHODOLOGY AND RESULTS

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ABSTRACT:

FPInnovations completed the third validation of the FPBiOS app in the summer of 2020. A cutblock located in the transition area between the SBS mc2 and the ESSF mc2 near Topley, BC was chosen. This validation required researchers to measure available biomass in the field, including dispersed volume, residual pile volume and leftover residual pile volume on site after the secondary harvest. After measurements were completed, the values collected were compared with the outputs calculated by BiOS. The BiOS app recovered biomass estimate came within 4% of the actual biomass recovered in the field.

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INTRODUCTION

Background

The BiOS mobile application project is a key part of a larger initiative within the Ministry of Forests, Lands and Natural Resource Operations and Rural Development (FLNRORD) aiming to develop a Forest Residual Biomass Geographic Information System for the development of the British Columbia (BC) forest bioeconomy (Forest BioGIS). The interactive map developed by FLNRORD will show location, type and amount of residual fibre generated by harvest activities, and economic feasibility to utilize them to produce advanced bio-materials. Forest BioGIS will improve area planning and support decision makers by having a better understanding of the fibre potential located in each Timber Supply Area (TSA). As a key feature of the BC Forest BioGIS interactive map, the BiOS app will help to serve the purpose of developing the forest bioeconomy cluster(s) for advanced biomaterial manufacturing in BC and may support other related government key priorities like GHG targets.

The need for such an interactive tool comes from the BC commitment to reducing greenhouse gas emissions to 80% below 2007 levels by 2050. The forest harvest levels in BC averaged 67 M m3 harvest from 2005 to 2015 (42% of Canada harvest). The harvest of this merchantable roundwood generates logging residues to the amount of about 10 million oven-dry tonnes (odt) per year (assuming 0.15 odt/m3). The BC Wildfire Act and Wildfire Regulation stipulate that the forest industry dispose of leftover slash and wood residues to abate fire hazards. The most common practice for reduction of fuel loading by forest tenure holders is to pile and burn. In 2015, it is estimated that 2.5 M odt of forest fibre was piled and burned in BC. The emissions generated by this practice are equivalent to those from 1 M cars (1/3 of all BC cars).

The BiOS app was introduced to both iOS and Android platforms in February 2018. This first version of the app utilized the core of the BiOS and Carbon modules of FPInterface to present a full biomass flow and carbon accounting of supply chain operations. The BiOS app serves foresters better assess the amount of logging residues generated following logging operations and measure the supply chain cost and carbon footprint. Data collected by the app to update Forest BioGIS will mainly come from users such as logging contractors, secondary users of harvest residual fibre and FLNRORD field technicians. The BiOS mobile app will be utilized in a larger information system (Forest BioGIS) to provide data to industry which will help to improve biomass utilization and support the bio-economy and mitigate GHG emissions from existing slash burning operations.

BiOS application validation – Topley, BC

A series of development activities are required to bring the app from a base tool to a completer and more validated asset. For this reason, in-field validation trials to assess roadside pile volume and density are required. These field trials should be done in cooperation with industry leaders that show an interest in the Forest BioGIS platform.

FPInterface is a validated tool with multiple productivity studies performed across Canada for the last 40 years used to calculate machine productivities for various stand types and operating conditions. BiOS has also been validated in the Boreal forest across Canada and is well calibrated to perform TSA-level estimates. Given the variability of ecosystems in BC, FPI suggests completing at least one validation trial per forested Biogeoclimatic (or ecological) zone according to the Biogeoclimatic Ecosystem Classification (BEC) program. There are 14 recognized forested zones in BC. Some zones (e.g. Coastal Western Hemlock) may need more than one validation trial to capture the variance. Therefore, at least 20 trials are recommended to fully validate the BiOS app for BC conditions. Two less comprehensive trials were completed in Powell River (2011) and Williams Lake (2011). Fully comprehensive trials were recently completed in Mackenzie (2019) and Powell River (2020). A fifth trial is scheduled for completion in Williams Lake (2020).

This document will outline the methodology utilized in the 2020 Topley trial and present the field results compared to the BiOS App results.

METHODOLOGY

Note: Many parts of the Methodology section will reference the BiOS App in terms of the data entry tabs and the data fields required to create the app's report in order to compare the App's results and the field trial results. For a full list of values entered in the BiOS App for this trial, please see Appendix I.

Site and operation description

Site characteristics

<u>Location</u>

The 31.1-hectare cutblock (TOPL0176) chosen for the trial is located near Baboon Lake and is approximately 100 km from the Pinnacle Pellet plant in Burns Lake, BC (Figure 1). This site was far enough from any airport (>7km) that a UAV could be utilized to measure the residue piles.

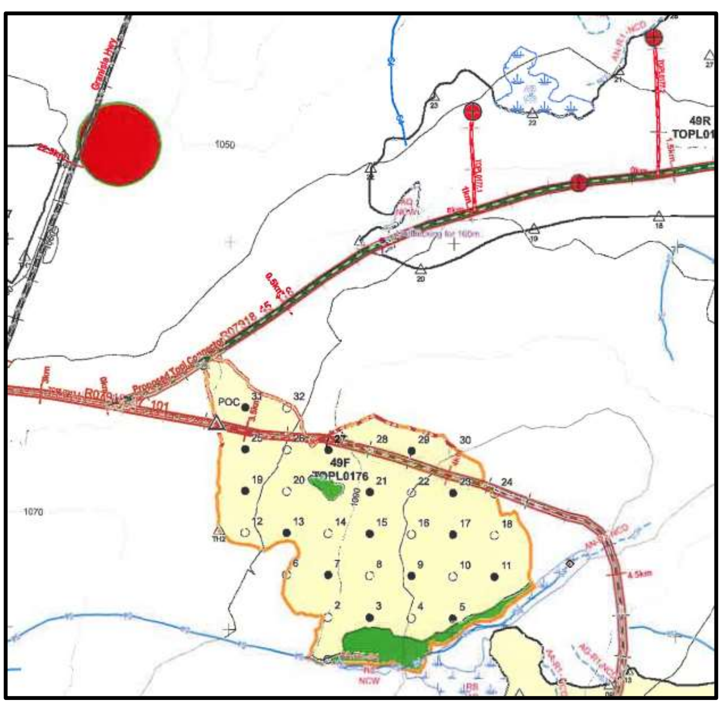

Figure 1. Map for cutblock TOPL0176.

Biogeoclimatic zone

Cutblock TOPL0176 is located in the transition zone between the Sub-Boreal Spruce (SBS), mc2 variant biogeoclimatic zone and the Engelmann Spruce Sub-Alpine Fir, mc variant biogeoclimatic zone (Figure 2). According to the government of BC ‘s BCWEB website, the SBS mc2 occurs “in the western portion of the guide area, generally at elevations between 900 and 1200 m. Over most of the guide area it is bordered at lower elevations by the SBSdk and at its upper limits by the ESSFmv1. In the southwestern portion of the guide area it occurs as a thin band on warm aspects above the SBSmc3 and below the ESSFmv1.”. The ESSFmc2 occurs adjacent to the SBSmc and shares many of its attributes.

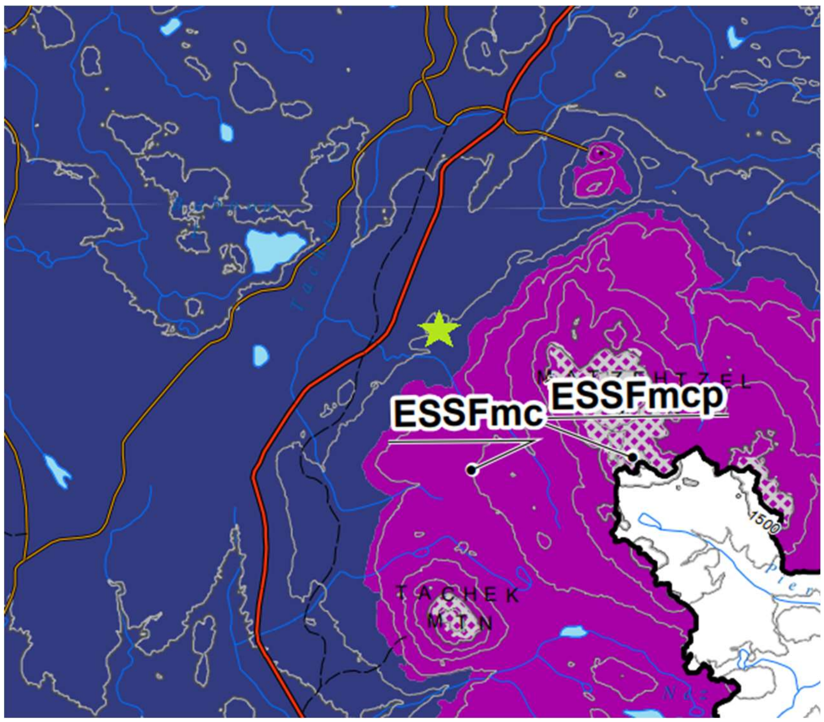

Figure 2. Biogeoclimatic zone map. Block location is denoted by the green star.

Stand description

The cutblock was timber cruised to FLNRORD standards (1.0 plots/ha, 6 BAF prism) in mid 2016 and was harvested in 2018. The stand was mainly composed of lodgepole pine and hybrid spruce with a minor component of subalpine fir, black cottonwood and trembling aspen (Table 1). Significant portions of the lodgepole pine were killed by the mountain pine beetle before harvest. The cruise compilation summary can be found in Appendix II.

Table 1. Stand description from timber cruise results

Species	Gross merchantable volume (m^3/ha)	Stems per hectare	Gross merchantable volume per tree (m^3)	% of stand (by volume)
Lodgepole pine	232.2	583.2	0.40	84%
Hybrid spruce	23.4	66.8	0.35	8%

Subalpine fir	5.9	16.5	0.36	2%
Trembling aspen	13.2	61.2	0.62	5%
Black cottonwood	2.9	4.7	0.22	1%

Operational characteristics

Primary harvest

The cutblock was harvested in 2018 with a feller-buncher, skidder and processor combination, where processing occurred at roadside. All merchantable sized (diameter at breast height > 10 cm) coniferous trees were felled. The majority of the deciduous trees were left standing. The residues at roadside were piled for burning and left as windrow shaped piles (Figure 3).

Figure 3. Residue pile located in trial cutblock.

Secondary harvest

The secondary harvest occurred in July 2020. Machinery utilized included a Peterson 5710 horizontal grinder (Figure 4), a Volvo EC220 excavator (see Figure 5) and an Eltec LL317L log loader (Figure 6). The excavator and log loader were both equipped with grapple attachments.

Figure 4. Peterson 5710 horizontal grinder.

Figure 5. Volvo EC220 excavator

Figure 6. Eltec LL317 log loader.

The excavator was used to prepare grinder pads beside the road and to prepare piles for grinding. The log loader was used to feed residue into the grinder.

Six truck and trailers in 3 configurations were used to transport hog fuel to the pellet mill:

- Tandem drive truck with 53ft walking floor trailer (3)
- Tri-drive truck with 53ft walking floor trailer (1)
- Tandem drive truck with 52ft chain drive trailer (2) (Figure 7)

Residue was ground directly into the chip trailers.

Figure 7. Tandem drive with truck with 53ft chain drive trailer.

Stand and residue measurements

In order to compare and validate the theoretical results from the BiOS App to the trial results, all portions of stand fibre needed to be measured in the field including volume located in the dispersed area of the cutblock, residue pile volume, secondary harvest volume and volume left after the secondary harvest. Standing residual trees (deciduous) were not measured as very few were harvested (<1%).

Standing residual trees

BiOS entry

The BiOS App calculates the volumes of trees left standing after the primary harvest based on initial inputs by the user. In this trial all volumes for coniferous species were set to 100% harvest removal and 0% harvest removal for deciduous stems (Figure 8).

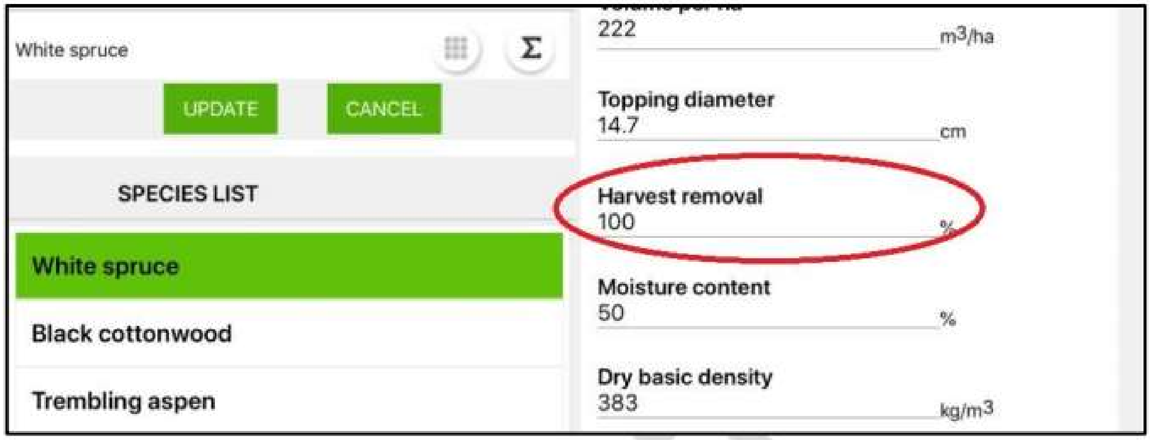

Figure 8. Species Operations data entry page; specifically harvest removal entry field.

<u>Field measure</u>

Lodgepole pine, hybrid spruce and subalpine fir trees were 100% harvested, with only deciduous trees left standing. The volume for the deciduous trees was captured in the timber cruise and was not measured by researchers during the validation due to the rigor of provincial timber cruising.

Dispersed volume

<u>BiOS</u>

The BiOS app estimates dispersed residues using a default, at the stump, recovery factor which is applied to the total amount of residues generated by the logging operation based on the data entered into the app in the Biomass Operations tab. Most of the time, dispersed volume is not targeted by secondary users due to the prohibitive cost associated with harvesting it.

<u>Field measure</u>

The line transect method was used to collect dispersed volume data in the field (see Appendix III for full method).

Total dispersed volume for the cutblock is calculated by multiplying the average volume of the dispersed plots by the area of the cutblock (31.1 ha).

Roadside pile measurement

Four different methods of residue pile volume calculation were used and then compared to derive the best method of pile data collection. The following sections describe how each method works.

I. <u>Manual Measurement Method (3M)</u>

The manual measurement method, or 3M, requires the following steps:

1. Measure width of pile in metres
2. Measure length of pile in metres

3. Measure height of pile in metres. If height is irregular, determine average of multiple heights.
4. Determine a shape of the pile from the following list (Note: all piles for this trial were windrows):
    a. Cone (haystack),
    b. Windrow,
    c. Oriented pile
5. Determine a factor for each pile based on pile shape. Pile shape factors are as follows:
    a. Cone (haystack) – 0.4
    b. Windrow – 0.6
    c. Oriented pile - 0.5

Note: These are the factors that have consistently been used in past FPI reports and projects.

6. To determine apparent volume of the pile (Note: this is not fibre volume), multiply the length, width, height and pile shape factor.

The calculated apparent volume will then be used to determine pile density once harvested volume and the volume remaining after secondary harvest has been derived (discussed below in the Pile density section of the Methodology).

II. GPS Measure Method (GMM)

The GPS Measure Method, or GMM, is similar to the 3M except that a GPS is used to determine the area or footprint of the pile. The GMM requires the following steps:

1. Set GPS track feature to one point per second.
2. Walk around the pile, holding the GPS above the pile edge.
3. When the pile has been circumnavigated, create a waypoint with a pile name.
4. Measure height of pile in metres. If height is irregular, determine average of multiple heights.
5. Determine a shape of the pile from the following list (Note: all piles for this trial were windrows):
    a. Cone (haystack),
    b. Windrow,
    c. Oriented pile
6. Determine a factor for each pile based on pile shape. Pile shape factors are as follows:
    a. Cone (haystack) – 0.4
    b. Windrow – 0.6
    c. Oriented pile - 0.5
7. To determine apparent volume of the pile (Note: this is not fibre volume), multiply the area of the pile derived by GPS, height and pile shape factor.

The calculated apparent volume will then be used to determine pile density once harvested volume and the volume remaining after secondary harvest has been derived (discussed below in the Pile density section of the Methodology).

III. UAV Point Cloud Method (PCM)

The UAV point cloud method, or PCM, used a DJI Inspire 2 UAV, fitted with a Zenmuse X4S gimble camera, to acquire RGB images at 60m of altitude looking nadir with 75% of side and front overlap. Prior to image acquisition, reference points at known and measured heights of 2 metres and 4 metres height were marked with yellow placards on two of the selected piles. These piles were used as scaling points and for validation of height estimation. The images were assessed for quality, and standard photogrammetric methods were used to process the data in Agisoft Photoscan software v1.4. High accuracy, ultra high-quality point cloud with aggressive filtering options was used to create the point clouds. A mesh representing the pile was generated and everything that was not in the pile (noise) or faces that were spuriously generated were eliminated (see Figure 9). Volume and surface area occupied by the piles was directly estimated.

Figure 9. Point cloud diagram of residue pile.

IV. BiOS Pile Volume Visual Estimator Method (VEM)

The BiOS Pile Volume Estimate Method, or VEM, is an automated derivative of the 3M method, located in the BiOS app. To use the VEM method, users need to follow these steps:

1. In the Visual Estimator function, click ‘Add Pile’ (Figure 10).

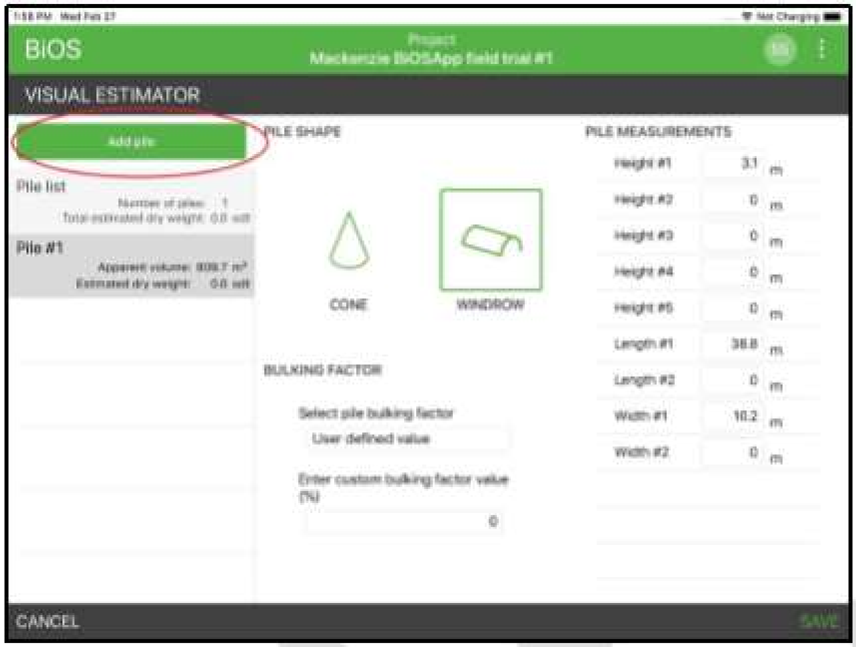

Figure 10. Add pile button in BiOS visual estimator.

2. Select a pile shape. Note: currently there are only two shapes (conical and windrow) available (Figure 11). More shapes are planned for future versions.

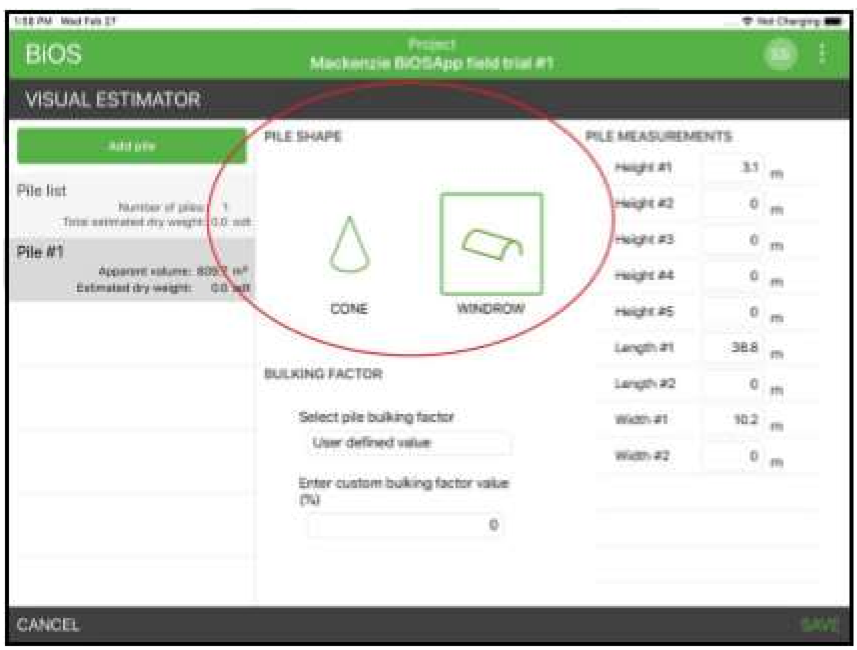

Figure 11. Pile shape buttons in BiOS visual estimator.

3. Enter the height, length and width values collected in the field. The cone shape requires a height and diameter (Figure 12).

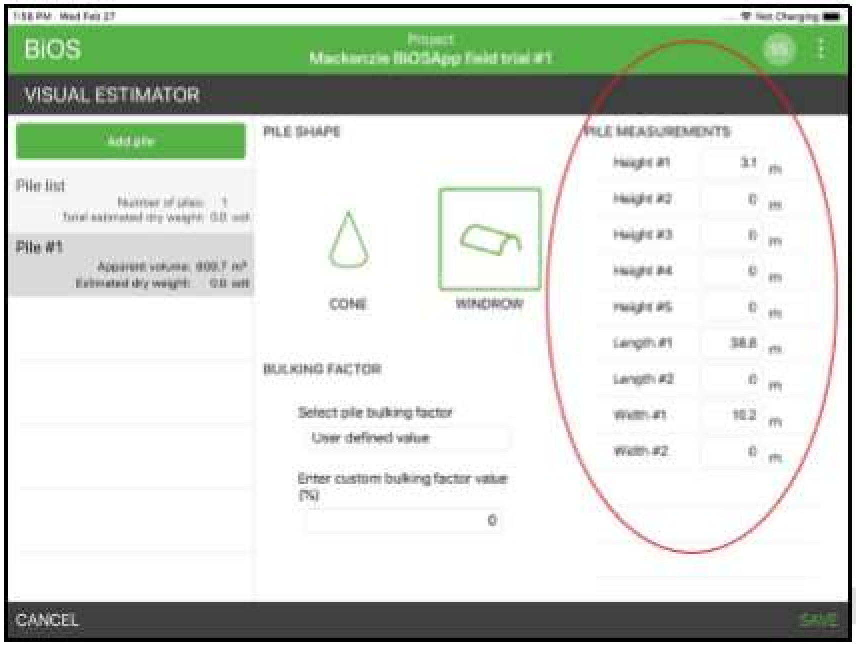

Figure 12. Pile measurement entry fields in BIOS visual estimator.

4. Choose a pile bulking factor from the list or enter a value manually (Figure 13).

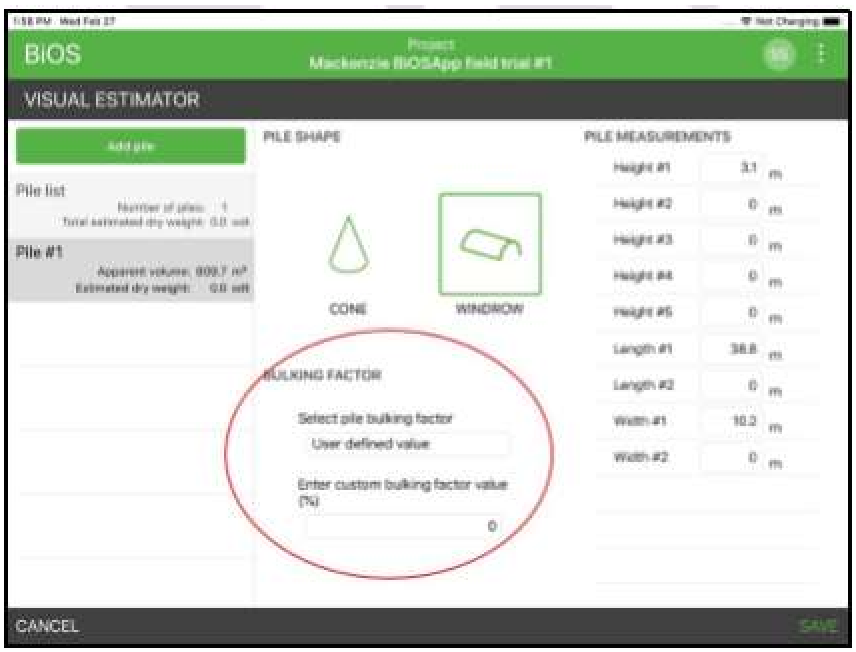

Figure 13. Bulking factor choice via drop-down in BiOS visual estimator.

For each pile, the visual estimator will calculate the apparent volume and estimate an oven dry weight of the fibre in the pile. A summary with the number of piles and the total estimated oven dry weight of the piles is calculated and located in the upper left corner of the screen (Figure 14).

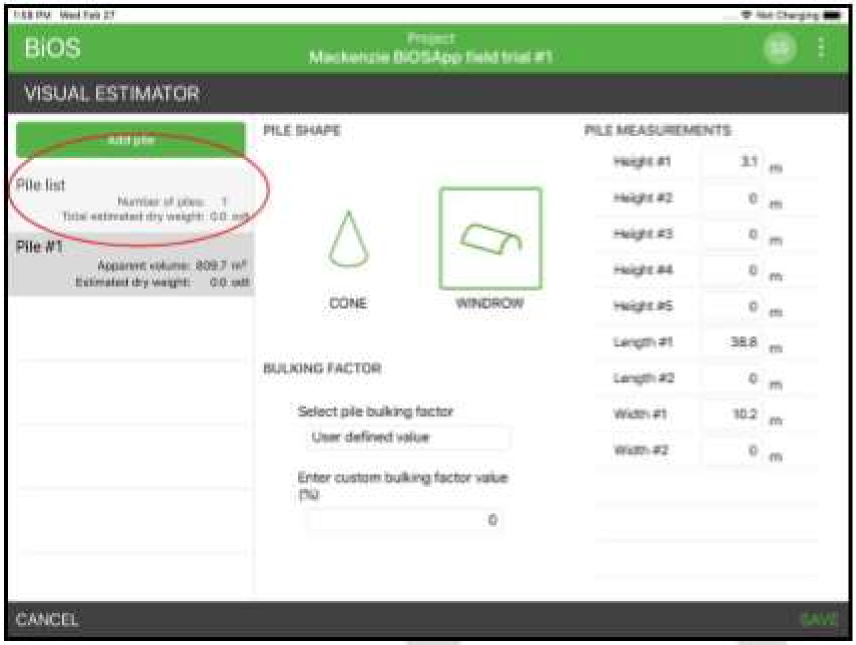

Figure 14. Pile counter and dry weight calculation.

Comminution

The volume harvested from each pile was monitored by a researcher in the field. Load slips containing the green weight of each load were provided by Pinnacle Pellet and were cross referenced with individual residue piles. Moisture content data was provided by Pinnacle Pellet.

Post-harvest measurement

After each pile was harvested, leftover volume within the pile footprint was quantified using a line transect survey. For description of line transect survey methodology, please see Appendix III.

Pile density

A summary of oven dry weight for each pile was calculated to derive pile density. Pile density can be defined as the measured volume of the pile divided by the oven dry weight of the pile.

BiOS comparison

The BiOS reporting phase tabulates the results generated from the inputs entered by the user. These results are displayed in five sections including:

- Biomass recovery
    - Area
    - Recovered biomass (odt)
    - Average moisture content (%)
    - Biomass yield (odt/ha)
    - Biomass / merchantable (odt/m^3)
    - Low heating value (MJ/kg)

    - Fuel consumption (L/odt)
    - GHG emissions (tonnes)
- Biomass transport
    - Distance to end use (km)
    - Operational road length (km)
    - Primary road length (km)
    - Public or paved road length (km)
    - Fuel consumption (L/odt)
    - GHG emissions (tonnes)
- Biomass supply cost
    - Recovery – stump to roadside ($/odt)
    - Transport – roadside to mill ($/odt)
- Species breakdown chart
    - Carbon delivered (tonnes)
    - Avoided GHG (tonnes CO2eq)
    - Odt of biomass
    - Odt/m^3
    - Odt/ha
- Biomass flow diagram
    - Total fibre (odt)
    - Merchantable volume harvested (odt)
    - Available biomass (odt)
    - Natural losses (odt)
    - Uncut trees (odt)
    - Cutover residues (odt)
    - Roadside volume (odt)
    - Roadside volume not recovered (odt)
    - Net roadside volume (odt)
    - Visual estimator volume (odt)
    - Recovered (%)
    - Biomass ratio (%)

The comparison in this report will focus only on the results displayed in the Biomass Flow Diagram of the report created by BiOS as these were the measurable outputs.

BiOS calculates greenhouse gas, or GHG, emissions for the biomass recovery and transport phase of an operation. It also calculates the volume of carbon delivered and the volume of avoided GHG by not burning the hauled residue at roadside. As there was not a viable way to measure greenhouse gas during the trial, the BiOS results for GHG's were not validated.

RESULTS AND DISCUSSION

Standing residual trees

Cruise data was provided by Pinnacle and a summary can be viewed in Table 1. A more comprehensive version can be found in Appendix II. In the primary harvest, 100% of the coniferous stems were harvested and 0% of the deciduous stems were harvested.

Conversion from cubic metres to oven dry tonnes was completed using the dry basic density for each species (Table 2).

Table 2. Volume of standing trees pre-secondary harvest

Species	Gross merchantable volume (m^3)	Dry basic density (oven dry kg/m^3)	Gross merchantable volume (oven dry tonnes/ha)
Lodgepole pine	[redacted]	[redacted]	0
Hybrid spruce	[redacted]	[redacted]	0
Subalpine fir	[redacted]	[redacted]	0
Trembling aspen	13.2	387	5.1
Black cottonwood	2.9	338	1.0
Total			**6.1**

Dispersed volume

Nine plots were completed in the dispersed area of the cutblock. Dispersed volume results for each plot can be found in Table 3. The total volume in the dispersed area of the cutblock was 292.3 oven dry tonnes (9.4 oven dry tonnes per hectare multiplied by 31.1 hectares).

Table 3. Dispersed volume

Plot	m^3/ha	odt/ha
1	29.5	11.8
2	63.7	25.5
3	27.2	10.9
4	51.5	20.6
5	12.0	4.8
6	6.0	2.4
7	4.4	1.8
8	10.1	4.0
9	7.0	2.8
Average		9.4

Pile measurements

As described in the Methodology section of this report, there were four methods of pile measurement used to determine geometric volume of residual piles.

I. Manual Measurement Method (3M)

Total apparent volume for the 3M method was 17,025.7 m^3 (Table 4).

Table 4. Pile dimensions using the Manual Measurement Method

Pile dimensions using the Manual Measurement Method							
Pile name	**Length (m)**	**Width (m)**	**Height (m)**	**Shape**	**Shape factor**	**Pile area (m^2)**	**Apparent volume (m^3)**
1	39.9	12.5	3.6	Windrow	0.6	498.8	1077.3
2	48.5	9.4	3.7	Windrow	0.6	455.9	1012.1
3	51.1	10.0	3.5	Windrow	0.6	511.0	1073.1
4	58.2	11.1	3.7	Windrow	0.6	646.0	1434.2
5	65.9	9.6	3.5	Windrow	0.6	632.6	1328.5
6	57.8	13.5	3.6	Windrow	0.6	780.3	1685.4
7	62.4	10.2	3.2	Windrow	0.6	636.5	1222.0
8	80.5	10.0	3.7	Windrow	0.6	805.0	1787.1
9	63.9	14.3	3.2	Windrow	0.6	913.8	1754.4
10	27.9	10.9	3.2	Windrow	0.6	304.1	583.9
11	49.9	12.6	3.6	Windrow	0.6	628.7	1358.1
12	28.9	13.1	2.3	Windrow	0.6	378.6	522.5
13	19.9	8.6	2.8	Windrow	0.6	171.1	287.5
14	68.9	10.2	3.1	Windrow	0.6	702.8	1307.2
15	35.5	10.3	2.7	Windrow	0.6	365.7	592.4
Total							**17025.7**

II. GPS Measure Method (GMM)

Total apparent volume for the GMM method was 18,449.1 m^3 (Table 5).

Table 5. Pile dimensions using the GPS Measure Method

Pile dimensions using the GPS Measure Method					
Pile name	**Height (m)**	**Shape**	**Shape factor**	**Pile area (m^2)**	**Apparent volume (m^3)**
1	3.6	Windrow	0.6	483.2	1043.7
2	3.7	Windrow	0.6	584.3	1297.1
3	3.5	Windrow	0.6	554.0	1163.4
4	3.7	Windrow	0.6	748.6	1661.9
5	3.5	Windrow	0.6	789.0	1656.9
6	3.6	Windrow	0.6	715.2	1544.8
7	3.2	Windrow	0.6	732.7	1406.8
8	3.7	Windrow	0.6	886.4	1967.8
9	3.2	Windrow	0.6	884.5	1698.2
10	3.2	Windrow	0.6	287.1	551.2
11	3.6	Windrow	0.6	706.5	1526.0
12	2.3	Windrow	0.6	356.9	492.5

13	2.8	Windrow	0.6	128.9	216.6
14	3.1	Windrow	0.6	850.9	1582.7
15	2.7	Windrow	0.6	394.7	639.4
Total					**18449.1**

III. UAV Point Cloud Method (PCM)

Total apparent volume for the PCM method was 16,162 m^3 (Table 6).

Table 6. Pile dimensions using the UAV Point Cloud Method

Pile dimensions using the UAV Point Cloud Method	
Pile name	**Apparent volume (m^3)**
1	926.5
2	895.8
3	705.5
4	1394.4
5	1340.4
6	1063.7
7	1065.4
8	2648.5
9	2478.6
10	341.3
11	1142.8
12	436.5
13	114.9
14	1073.4
15	534.6
Total	**16162.3**

IV. BiOS Pile Volume Estimate Method (VEM)

Total apparent volume for the VEM method was 18,819 m^3 (see Table 7) and because the visual estimator uses a bulking factor in its calculations, it provided an estimated dry weight of 1,522 oven dry tonnes.

Table 7. Pile dimensions using the BiOS Pile Volume Estimate Method

Pile dimensions using the BiOS Pile Volume Estimate Method							
Pile name	**Length (m)**	**Width (m)**	**Height (m)**	**Shape**	**Apparent volume (m^3)**	**Bulking factor (%)**	**Estimated dry weight (oven dry tonnes)**
1	39.9	12.5	3.6	Windrow	1185.0	20.0	96.0
2	48.5	9.4	3.7	Windrow	1133.3	20.0	90.1
3	51.1	10.0	3.5	Windrow	1251.2	20.0	101.3
4	58.2	11.1	3.7	Windrow	1577.6	20.0	127.7
5	65.9	9.6	3.5	Windrow	1461.4	20.0	118.3
6	57.8	13.5	3.6	Windrow	1854.0	20.0	150.1

7	62.4	10.2	3.2	Windrow	1344.2	20.0	108.8
8	80.5	10.0	3.7	Windrow	1965.8	20.0	159.2
9	63.9	14.3	3.2	Windrow	1929.9	20.0	156.3
10	27.9	10.9	3.2	Windrow	642.3	20.0	52.0
11	49.9	12.6	3.6	Windrow	1493.9	20.0	121.0
12	28.9	13.1	2.3	Windrow	574.7	20.0	46.5
13	19.9	8.6	2.8	Windrow	316.3	20.0	25.6
14	68.9	10.2	3.1	Windrow	1437.9	20.0	116.4
15	35.5	10.3	2.7	Windrow	651.6	20.0	52.8
Total					**18819.1**		**1522.1**

Pile volume method comparison

The apparent volumes derived from each pile measurement method can be found in Table 8.

The total apparent volume of the piles measured using the PCM was the lowest. This is not unexpected at the PCM method removes most of the air space included by other methods. Of the three remaining methods, the 3M method apparent volume was lowest. This is likely because it is difficult (and unsafe) to measure the width of the piles on long windrows with a string box. If the width measured at the end of the pile was narrower than other portion further along the windrow, the apparent volume would be lower than that of the GPS method, which calculates using the actual footprint area.

Table 8. Apparent volumes of residue pile measurement methods

Apparent volumes of residue pile measurement methods				
Pile name	**3M**	**GMM**	**PCM**	**VEM**
1	1077.3	1043.7	926.5	1185.0
2	1012.1	1297.1	895.8	1133.3
3	1073.1	1163.4	705.5	1251.2
4	1434.2	1661.9	1394.4	1577.6
5	1328.5	1656.9	1340.4	1461.4
6	1685.4	1544.8	1063.7	1854.0
7	1222.0	1406.8	1065.4	1344.2
8	1787.1	1967.8	2648.5	1965.8
9	1754.4	1698.2	2478.6	1929.9
10	583.9	551.2	341.3	642.3
11	1358.1	1526.0	1142.8	1493.9
12	522.5	492.5	436.5	574.7
13	287.5	216.6	114.9	316.3
14	1307.2	1582.7	1073.4	1437.9
15	592.4	639.4	534.6	651.6
Total	**17025.7**	**18449.1**	**16162.3**	**18819.1**

As stated in the Mackenzie validation trial report, when piles are measured, care should be taken to describe the method used as there is significant variance between the measurement methods.

Comminution

Load volume and moisture content

Over the course of the trial, 106 loads of hog fuel were comminuted in cutblock TOPL176 and hauled to the local pellet mill. The average load size was 21.5 green tonnes or 16.5 oven dry tonnes. Average moisture content was 34.9%. A total of 2279.6 green tonnes or 1707.1 oven dry tonnes (54.9 odt/ha) were hauled from the cutblock.

Pile volume

Volume for each pile was calculated from the volume hauled during comminution (Table 9) and the volume left in each pile footprint. The volume for piles 1-4, 14 and 15 were an average of the total volume harvested during the latter portion of the trial, when the researchers were not present.

Table 9. Pile volume in oven dry tonnes

Pile	Volume (odt)
1	100.8
2	125.3
3	112.4
4	160.5
5	142.3
6	135.4
7	156.4
8	217.4
9	186.7
10	29.4
11	109.5
12	36.0
13	12.9
14	153.3
15	62.1
Total	**1740.4**

Post-harvest measurement

After piles were comminuted, line transect surveys were performed within the pile footprint. A total of 33.3 oven dry tonnes were left in the pile footprint after harvest (Table 10).

Table 10. Volume found within pile footprint after comminution

Pile	Volume in footprint (odt)	Volume in footprint (odt/ha)
1	1.7	36.0
2	2.1	35.9
3	2.0	35.9

4	2.7	35.9
5	3.7	46.9
6	4.3	60.1
7	1.9	25.9
8	2.4	27.1
9	3.1	34.5
10	1.3	45.3
11	2.5	35.4
12	0.9	25.2
13	0.3	23.3
14	3.1	36.0
15	1.4	35.5
Total	**33.3**	

Pile density

Pile density was calculated by dividing the fibre volume (harvested and leftover), in oven dry kg, for the pile, by the **apparent volume**, in cubic metres, for the pile. This was done for each pile and for each method of pile measurement (Table 11). Average pile densities varied from 95.3 oven dry kg per cubic metre for the VEM method (BiOS calculator) to 116.2 oven dry kg per cubic metre for the PCM method (UAV measure). The higher average densities of the PCM method are likely a result of the reduced apparent volume that occur when the airspace outside of the piles are eliminated. The lower average densities are a result of the 'smooth' shape generated with the other methods.

Table 11. Pile density for four residue pile measurement methods

Pile density for four residue pile measurement methods					
Pile name	**Volume (oven dry tonnes)**	**3M**	**GMM**	**PCM**	**VEM**
1	100.8	93.6	96.6	108.8	85.1
2	125.3	123.8	96.6	139.8	110.5
3	112.4	104.8	96.7	159.4	89.9
4	160.5	111.9	96.6	115.1	101.7
5	142.3	107.1	85.9	106.1	97.3
6	135.4	80.4	87.7	127.3	73.0
7	156.4	128.0	111.2	146.8	116.4
8	217.8	121.9	110.7	82.2	110.8
9	186.7	106.4	109.9	75.3	96.7
10	29.4	50.4	53.4	86.2	45.8
11	109.5	80.6	71.7	95.8	73.3
12	36.0	68.9	73.1	82.5	62.6
13	12.9	45.0	59.8	112.7	40.9
14	153.3	117.3	96.9	142.8	106.6
15	62.1	104.9	97.1	116.2	95.3
Average		**96.3**	**89.6**	**113.1**	**87.1**

Of the four pile measurement methods that were attempted, the GPS measure method was considered to have the most accurate shape and apparent volume methodology for the ground-based measurement methods, although all three methods were very close (<10% difference). It is recommended that the Visual Estimator in BiOS adopt the ability to track the pile outline with GPS to improve on its current methodology. The UAV method gave an absolute apparent volume. The time required to fly the cutblock was similar to that of the ground-based measurement methods.

Average density between the different methods varies, therefore, it is recommended that the method of pile measurement be identified when reporting residue pile density.

BiOS comparisons

The BiOS App creates a report which is summarized in a flowchart format (see Figure 15). The information in the flowchart was the focus of the Topley BiOS validation. The entire list of BIOS inputs, in the order they were entered into the app, can be found in Appendix I.

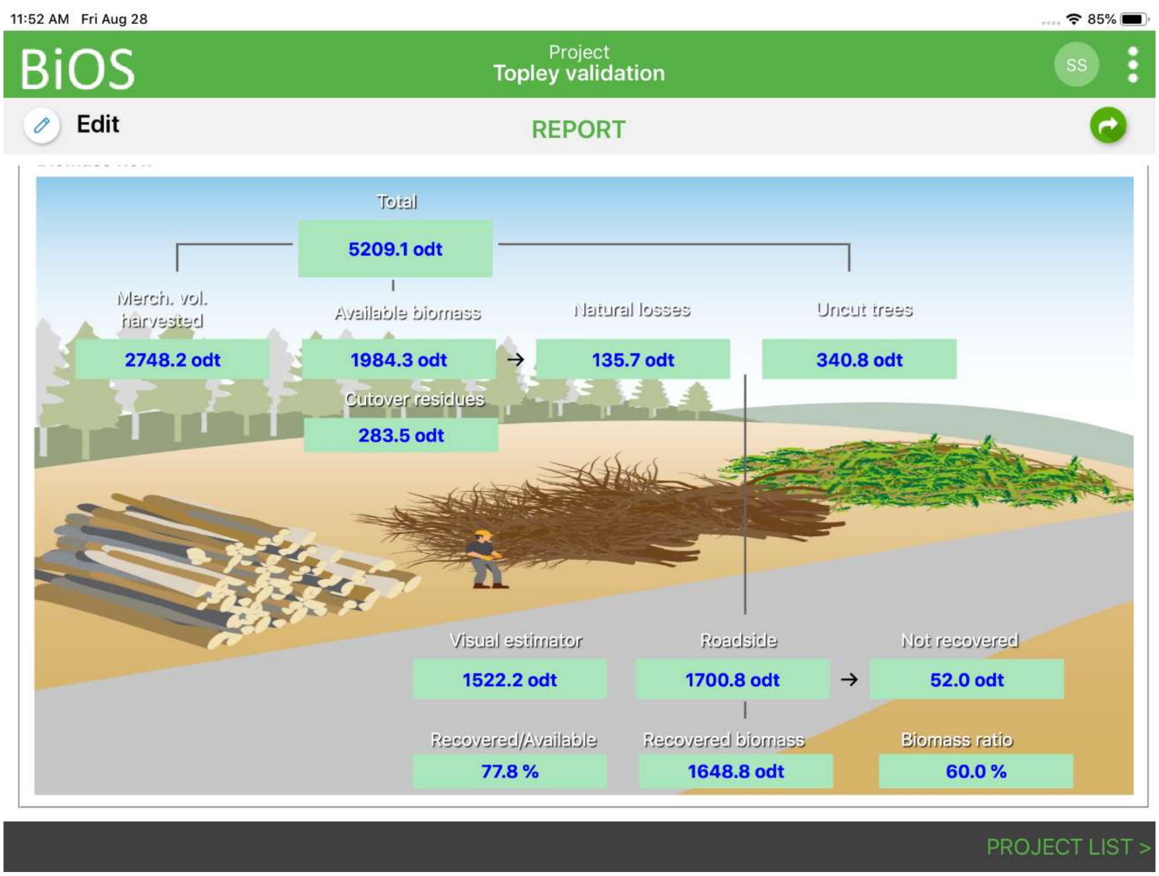

Figure 15. Biomass flowchart produced by the BiOS app for Topley cutblock.

In order to compare the data in the flowchart with the actual results found in the field, Table 12 was created to ease analysis. Each line in the table describes one aspect of the flowchart except for Line 1, which depicts topping diameter (arguably one of the biggest influences on BiOS calculations).

Table 12. Comparison of BiOS calculated results and field trial results

Reference line	BiOS flowchart field	BiOS calculated results	Field trial results	Difference between BiOS and field trial results
1	Topping diameter (cm)	(Pl 12.6, Sx 12.5, Bl 13.0)	(Pl 12.6, Sx 12.5, Bl 13.0)	n/a
2	Total fibre (odt)[a]	5209.1	5802.0	-10.2%
3	Merchantable volume harvested (odt)	2748.2	3292.7	-16.5%
4	Available biomass (odt)	1984.3	2032.8	-2.4%
5	Natural losses (odt)	135.7	135.7	n/a
6	Uncut trees (odt)	340.8	340.8	n/a
7	Cutover residues (odt)	283.5	292.4	-3.0%
8	Visual estimator (odt)	1522.2	1740.4	-12.5%
9	Roadside (odt)	1700.8	1740.4	-2.3%
10	Recovered biomass (odt)	1648.8	1707.1	-3.4%
11	Not recovered (odt)	52.0	33.3	56.2%

[a]Standing trees (merchantable stem + tops, branches and leaves)

Line 1 – Topping diameter

Line 1 displays the topping diameter used by BiOS and the measured results in the field analysis. Topping diameter is used in BiOS to determine the proportion of the volume of total fibre in the cutblock that is considered merchantable or within merchantable size specifications. Topping diameter was entered as 12.6 cm for lodgepole pine, 12.5 cm for hybrid spruce and 13.0 cm for subalpine fir in BiOS to match the average butt diameter of 'top' pieces measured in the residue piles.

Line 2 – Total fibre

'Total fibre' in Line 2 is the total volume of woody fibre in the cutblock. This includes merchantable fibre, available biomass, natural losses (needles and leaves) and uncut trees. The BiOS predicted volume of 5209.1 oven dry tonnes is within 10.2% of the actual total volume 5802.0 oven dry tonnes derived from the field results. The difference between these two values is a result of the variance found in the merchantable volume values found in Line 3. If the absolute volumes in Line 3 were more similar this would have reduced the difference in Line 2. See the section below 'Line 3 – Merchantable volume harvested' for possible causes of the variance found there.

Line 3 – Merchantable volume harvested

'Merchantable volume harvested' in Line 3 of Table 12 describes the proportion of total fibre considered merchantable by the BiOS app after entering the inputs from the Species Operations Tab. BiOS estimated merchantable volume for the trial cutblock to be 2748.2 oven dry tonnes. The merchantable volume harvested value of 3292.7 oven dry tonnes was provided by Canfor and represents the actual volume hauled during the primary harvest. Merchantable volume harvested results between the BiOS result and the actual merchantable volume harvested were somewhat varied at a difference of 16.5%. It is unknown exactly why this difference occurred, although there are a number of possible sources including:

- Variance of basic wood density and conversion factors for the species found within the block from the actual density
- Variance in topping diameters used in BiOS from those sampled in the field
- Unreported volume (possibly attributed to a different cutblock if errors in load slips occurred)

It should be noted that although the merchantable volume for the cutblock varied, the roadside biomass reporting fell within acceptable parameters.

Line 4 – Available biomass

BiOS calculates the 'Available biomass' located in Line 4 of Table 12 by subtracting the merchantable volume, natural losses and uncut trees from total fibre. To determine available biomass in the actual results column, the leftover (not recovered in the flowchart), recovered and cutover residues were added together. The BiOS result, 1984.3 oven dry tonnes and the actual result, 2032.8 oven dry tonnes, were 2.4% different. The difference between these two values is within acceptable parameters.

Line 5 – Natural losses

'Natural losses' from Line 5 in Table 12 describes the volume of leaves or needles in the cutblock that have fallen off due to season of harvest (no leaves in winter), or time from initial harvest (after one year, 70% of needles and 100% of leaves fall off). As the secondary harvest was two years after the primary harvest and the majority of lodgepole pine was standing dead from mountain pine beetle natural losses for this validation were total at 135.7 odt. Data collection for natural losses is virtually impossible even when needles and leaves are attached to branches, so the BiOS value was utilized for both the BiOS and field trial results.

Line 6 – Uncut trees

In BiOS, 'Uncut trees' is the volume attributed to trees left standing after the primary harvest. All coniferous trees were harvested in the primary harvest and all deciduous trees were left standing. Because the harvesters did not deviate from this prescription, no standing trees were measured, and the BiOS value was utilized for the BiOS and field trial results. Total volume of standing trees was 340.8 odt.

Line 7 – Cutover residues

'Cutover residue' described in Line 7 of Table 12 describes the volume of fibre that is left in the dispersed area of the cutblock and will not be harvested. This volume is calculated based on the 'Technical losses at the stump' value found on the Biomass Operations data entry tab. The default for this value is set at 30%. The BiOS predicted value of 283.5 odt was 3.0% lower than the measured field results of 292.4 odt. The difference between these two values is within acceptable parameters.

Line 8 – Visual estimator

The calculated volume from the visual estimator is independent of the rest of the BiOS flow calculations. This indicator is useful to assess the volume per pile and was compared with total pile volume from the field results. The visual estimator predicted 1522.2 oven dry tonnes of volume within the residue piles at roadside. This was a 12.5% lower than the 1740.4 oven dry tonnes of roadside volume found in the piles (both harvested and left in the pile footprints). This difference between these two values is likely a result of the difference between the actual packing value of the piles versus the 20% default value available in BiOS. If the value were consistently found to be higher in future cutblocks of similar profiles, the user could manually increase the packing ratio to better reflect the actual conditions.

Line 9 - Roadside

The BiOS calculation for roadside volume in Line 9 of Table 12 consists of all the volume that is hauled to roadside. To determine roadside volume for the actual field results, total hauled volume, minus the logs ground from the dispersed area, was added to the leftover pile volume to get 1740.4 oven dry tonnes. This is different from the BiOS calculation of 1700.8 oven dry tonnes by 2.3%. The difference between these two values is within acceptable parameters.

Line 10 – Recovered biomass

The BiOS calculation for recovered biomass in line 10 of Table 12 consists of the roadside biomass volume that was comminuted and transported in the secondary harvest. The BiOS calculation for recoverable biomass of 1648.8 oven dry tonnes was 3.4% different than the calculated field result of 1707.1 oven dry tonnes.

Line 11 – Not recovered

The 'not recovered' value in Line 11 of Table 12 consists of the volume left at roadside after the secondary harvest. BiOS calculates this using the Recovered Technical Efficiency Value found in the pre-piling and comminution functions of the Biomass Operations Tab. In the field, line transect surveys were completed to determine volume. The BiOS volume for 'not recovered' was 52.0 oven dry tonnes (assuming an average roadside recovery technical efficiency of 90%) and was 56.2% different than the value of 33.3 oven dry tonnes calculated in the field. Although there was some difference between the BiOS calculated value and the results from the field trial, the underestimation of the recovered biomass value likely means that the operators collected more biomass from the piles than anticipated. If the overestimation of 'not recovered' biomass was to continue, it is recommended that the roadside recovery technical efficiency be increased slightly to reflect the circumstances.

Overall analysis of comparison

In most of the categories found in Table 12, especially those which calculate biomass volume, the BiOS values and the actual field results were remarkably close. This supports the allometric equations utilized by BiOS for the species present in the cutblock (Lambert et al. 2005, Ung et al. 2008, Standish et al. 1985).

There was a notable discrepancy (16.5%) between the merchantable volume values which is unexplained at this time (see possible explanations for variation in merchantable volume harvested in previous section). Fortunately, this discrepancy did not affect the predicted biomass volumes.

The overall positive results of this validation trial under less than perfect conditions (extensive mountain pine beetle killed lodgepole pine) confirms the robustness of the model and its predictive capabilities.

Although the visual estimator results were close, a technique may be needed to better estimate the appropriate bulking factor for different residue profiles. This may be accomplished by offering more options than those currently provided, to fill gaps between the choices (ie, partially aligned tops, or densely piled slash).

Greenhouse gas results

BiOS calculates greenhouse gas emissions in the Biomass Recover, Biomass Transport and Species Breakdown portion of the overall report.

For this validation, biomass recovery emissions were calculated by BiOS at 17.2 tonnes (CO_2eq) and biomass transport emissions were calculated at 28.2 tonnes (CO_2eq) for a total of 5.6 tonnes (CO_2eq).

In the Species breakdown portion of the report it states that 824.4 tonnes of carbon were delivered, which constitutes a 18:1 ratio of delivered to emitted carbon (delivery distance 99km). The report also states that 2687.5 tonnes of greenhouse gas were avoided in roadside burning. Validation of greenhouse gas reductions were outside the scope of this project, however, given the increasing interest in this topic there are opportunities to expand the validation of BiOS to quantify this metric.

CONCLUSION

FPInnovations completed a field validation of the FPBiOS App in July 2020. A cutblock located in the SBSmc2 biogeoclimatic zone near Topley, BC was chosen. This validation required researchers to measure available biomass in the field, including dispersed volume, residual pile volume and volume left over on site after the secondary harvest. After measurements in the field were completed, the values collected were compared with the outputs calculated by BiOS.

Of the four pile measurement methods that were attempted, the GPS measure method was considered to have the most accurate shape and apparent volume methodology for the ground-based measurement methods. It is recommended that the Visual Estimator in BiOS adopt the ability to track the pile outline with GPS to improve on its current methodology. Discussions should occur regarding the addition of more pile bulking factor options to better improve estimator volume predictions.

Although there was an unexplained discrepancy between the calculated merchantable volume and the actual merchantable volume harvested, the field result for recovered biomass was within

4% of the BiOS predicted outputs. Overall, this validation displays a very favourable outcome for predicting recovered biomass in this biogeoclimatic zone and species profile.

REFERENCES

Lambert, M.-C., Ung, C.-H., and F. Raulier, 2005. Canadian national tree aboveground biomass equations. Can. J. For. Res. 35: 1996-2008.

Ung, C.-H., Bernier, P. and Guo, X.J. 2008. Canadian national biomass equations: new parameter estimates that include British Columbia data. Can. J. For. Res. 38: 1123-1132.

Standish, J.T., Manning, G.H. and Demaerschalk, J.P. 1985. Developement of biomass equations for British Columbia tree species. Information report BC-X-264. Pacific Forest Research Center. 48 p.

APPENDIX I – BIOS APP DATA ENTRY

Run	Tab	Area
1	Project Information	31.1

Run	Tab	Data source	Species	Volume/ha	Top dia	Harvest removal	Decay waste breakage	MC	Dry basic density	Green density	Volume /stem
1	Species Operations	Cruise + Field	Pl	232.2	12.6	100	30	34.9	409	629	0.40
			Sx	23.4	12.5	100	3	34.9	383	589	0.35
			Bl	5.9	13	100	5	34.9	329	506	0.36
			At	13.2	12.5	0	50	55	387	860	0.22
			Ac	2.9	12.5	0	68	55	338	751	0.62

Run	Tab	Average Skid Distance	Harvest Data	Harvest Method
1	Logging Operations	250	06/30/2019	Full tree with roadside processing

Run	Tab	Technical Losses at the Stump	Recovery Date	Pre-piling	Comminution
1	Biomass Operations	30%	29/07/2020	on (30%)	Grinder (90%)

Run	Tab	Truck Configuration	Destination	Distance
1	Transport	Semi trailer with 3 axles	Pinnacle Pellet, Burns Lake	User defined (1km operational, 3km primary, 95km public)

Run	Tab	Piles	Pile Type	Ht1	L1 (or diameter)	W1	Bulking Factor
1	Visual Estimator	1	WR	3.6	39.9	12.5	20
		2	WR	3.7	48.5	9.4	20
Number of Piles: 15		3	WR	3.5	51.1	10.6	20
		4	WR	3.7	58.2	11.1	20
		5	WR	3.5	65.9	9.6	20
		6	WR	3.6	57.8	13.5	20
Total estimated dry weight: 1516.8 odt		7	WR	3.2	62.4	10.2	20
		8	WR	3.7	80.5	10	20
		9	WR	3.2	63.9	14.3	20
		10	WR	3.2	27.9	10.9	20
		11	WR	3.6	49.9	12.6	20
		12	WR	2.3	28.9	13.1	20
		13	WR	2.8	19.9	8.6	20
		14	WR	3.1	68.9	10.2	20
		15	WR	2.7	35.5	10.3	20

APPENDIX II – CRUISE COMPILATION

*** FOR APPRAISAL PURPOSES ***

Block Summary

Average Line Method	Grades: MOF Computerized	FIZ: I	22-Jul-2016 10:39:07
CANFOR	Computerized Decay	PSYU: Babine	Filename: cp49f_final
Licence Number: A16828 CP: 49F	Computerized Waste	Region: 8 - Skeena	Compiled by: Canadiar
Project: CP 49F	Computerized Breakage	District: 08 - Nadina	Cruised by: AVISON MA
			Version: 2016.00 IF

Net Area: Block : (M) - 176:TOPL0176, Plots in Block: 31, TUs: [A : 31.1]

		Total	Conifer	Decid	B	S	PL	AC	AT
Utilization Limits									
Min DBH	cm (M)				17.5	17.5	12.5	17.5	17.5
Stump Ht	cm (M)				30.0	30.0	30.0	30.0	30.0
Top Dia	cm (M)				10.0	10.0	10.0	10.0	10.0
Log Len	m				5.0	5.0	5.0	5.0	5.0
Volume and Size Data									
Gross Merchantable	m3	8634	8133	500	184	729	7220	90	410
Net Merchantable	m3	6191	5975	216	175	710	5090	25	191
Net Merch - All	m3/ha	199	192	7	6	23	164	1	6
Distribution	%	100	97	3	3	11	82	0	3
Decay	%	10	9	40	3	1	10	50	38
Waste	%	1	0	13			0	18	12
Waste(billing)	%	1	0	29			0	63	25
Breakage	%	17	18	4	2	2	20	4	4
Total Cull (DWB)	%	28	27	57	5	3	30	72	54
Stems/Ha (Live & DP)		732.4	666.5	65.9	16.5	66.8	583.2	4.7	61.2
Avg DBH (Live & DP)	cm	24.5	24.8	21.2	24.4	25.8	24.7	32.4	20.1
Snags/Ha									
Avg Snag DBH	cm								
Gross Merch Vol/Tree	m3	0.38	0.39	0.24	0.36	0.35	0.40	0.62	0.22
Net Merch Vol/Tree	m3	0.27	0.29	0.11	0.34	0.34	0.28	0.17	0.10
Avg Weight Total Ht	m	20.4	20.4	19.5	19.9	18.2	20.6	22.0	19.0
Avg Weight Merch Ht	m	15.3	15.4	12.8	14.2	13.1	15.7	16.1	12.3
Avg 5.0 m Log Net	m3	0.12	0.13	0.05	0.15	0.14	0.13	0.07	0.05
Avg 5.0 m Log Gross	m3	0.14	0.14	0.11	0.15	0.14	0.14	0.21	0.10
Avg # of 5.0 m Logs/Tree		2.71	2.75	2.30	2.33	2.50	2.79	3.00	2.25
Net Immature	%	96.5	100.0		100.0	100.0	100.0		
Average Slope	%	7							
LRF and Log Summary									
Net Merch - Stud	%	60.0	62.1		74.0	66.1	61.2		
Net Merch - Small Log	%	99.5	99.5	100.0	100.0	100.0	99.4	100.0	100.0
Net Merch - Large Log	%	0.5	0.5				0.6		
Avg LRF All	bdft/m3	123.1	122.6	136.7	178.9	182.3	112.3	141.3	136.1
Statistical Summary									
Coeff. of Variation	%	27.4	30.4	167.8	191.5	100.9	35.4	278.4	165.3
Two Standard Error	%	14.4	16.0	88.5	101.0	53.2	18.7	146.8	87.2
Number and Type of Plots		MP - 15	CP - 16						
Number of Potential Trees		97							
Plots/Ha		1.0							
Cruised Trees/Plot		5.7							

FLAGS: Full Volumes, Normal Cruise, All Trees Compiled, Double Sampling Factor Applied, Damage, , Net Belt Fir

APPENDIX III – LINE TRANSECT SURVEY METHODOLOGY

- Volume leftover after the secondary harvest was assessed using line transect methodology
- Starting location within the pile footprint should be chosen randomly. Number of plots within the footprint should be determined in the field to adequately represent the size of the footprint.
    - At least two 10 m transects per plot.
    - The transect bearing selection should be done by spinning the compass wheel and randomly stopping on a given bearing.
    - The minimum length of pieces that cross the transect to be measure is 30 cm.
- Tallied pieces over 5 cm in diameter can be identified by species or group (softwood & hardwood) depending on site conditions and relevance to study (species was not collected for this trial). Pieces with a diameter less than 5 cm (down to 1 cm) are only to be tallied (counted) regardless of species or group.
- Not to be tallied:
    - Non-commercial species or brush species that won't become a full grown tree.
    - Roots
    - Stumps
    - Trees with root ball (roots in the ground) attached counts as standing and not as slash on the ground
    - Slash height (site assessment factor)
    - Pieces with more than 50% rot (it breaks apart easily)

[1]**Van Wagner. 1968.** The Line Intersect Method in Forest Sampling. Forest Science.

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