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VALIDATION OF FPINNOVATIONS BIOS APP IN POWELL RIVER, BC:

METHODOLOGY AND RESULTS

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ABSTRACT:

FPInnovations completed the second validation of the FPBiOS app in the winter of 2020. A cutblock located in the CWH dry maritime biogeoclimatic zone near Powell River, 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 – Powell River, 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 build machine productivity equations 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). A fully comprehensive third trial was recently completed in Mackenzie (2019).

This document will outline the methodology utilized in the 2020 Powell River 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

Location

The 10.2-hectare cutblock (H232) chosen for the trial is located near Haslam Lake and is approximately 17.3 km from the Paper Excellence Pulp Mill in Power River, BC (Figure 1). This site was chosen due to its proximity to the pulp mill, yet far enough from the airport (>7km) that a UAV could be utilized to measure the residue piles.

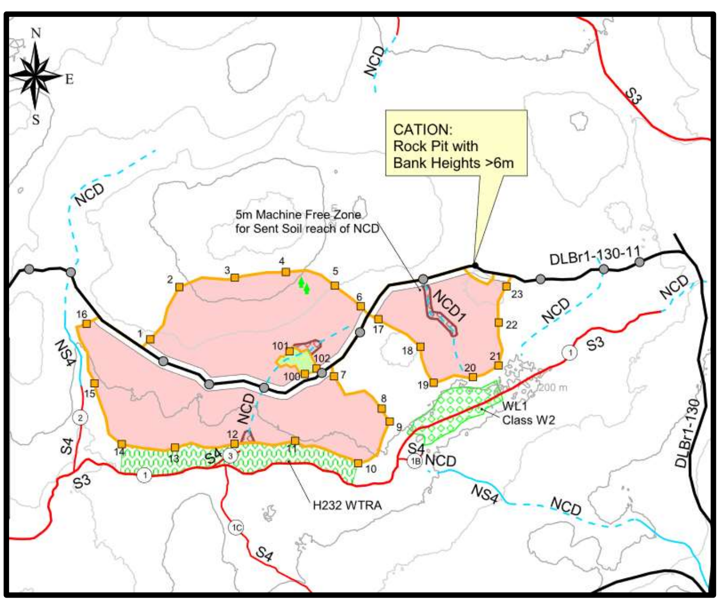

Figure 1. Map for cutblock H232.

BGCZ

Cutblock H232 is located in the Coastal Western Hemlock biogeoclimatic zone, dry maritime variant (Figure 2). According to the government of BC 's BCWEB website, the CWHdm occurs "at low elevations on the mainland and immediately adjacent islands. It extends from Hardwicke Island in the north to the Chilliwack River in the southeast. Along the Sunshine Coast and lower Fraser Valley it occurs above and adjacent to the CWH very dry maritime, respectively. Elevational limits range from sea level (or above CWHxm if present) to approximately 650 m (lower in wetter valleys)."

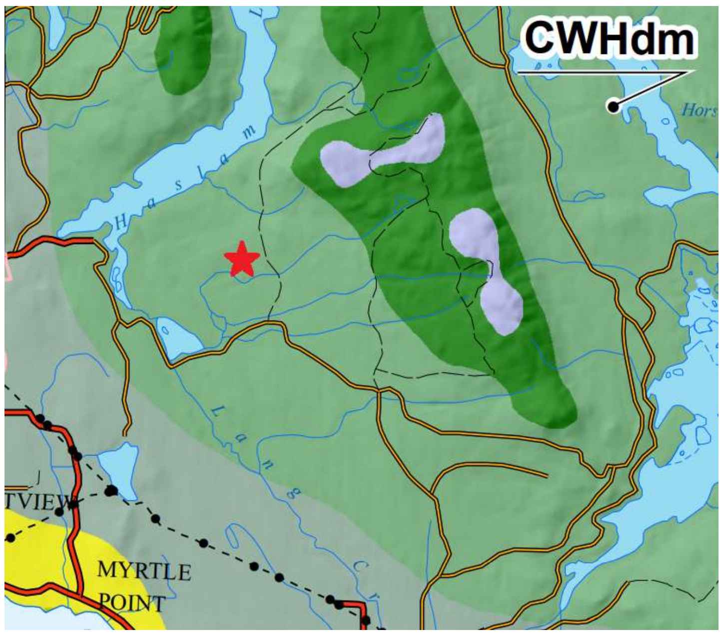

Figure 2. Biogeoclimatic zone map. Block location is denoted by the red star.

Stand description

Community Forests tenures are not required to timber cruise cutblocks before harvest so FPInnovations researchers placed simple cruise plots in adjacent stands to simulate normal timber cruise data. Eight cruise plots (0.8 plots/ha) were established using a 12 BAF prism (Table 1).

The stand was composed of mostly Douglas-fir and western hemlock with minor components of red alder, western red cedar and western white pine. No alder or pine were sampled in the cruise.

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)
Coastal Douglas-fir	526	367	1.43	77%
Western hemlock	138	72	1.92	20%

Western red cedar	23	182	0.13	3%

Operational characteristics

Primary harvest

The cutblock was felled with a feller buncher, processed with a harvester and stems (diameter at breast height > 10 cm) were hoe-chucked (loader forwarder) to roadside in January of 2020. All trees were felled except for a few western white pine trees (<10). Residue was piled for burning in the dispersed area of the block and then moved to roadside to facilitate grinding into trucks. Residue piles were clustered in groups of two to five haystack shaped piles and situated around the pads built for the grinder (Figure 3).

Figure 3. Residue pile located in trial cutblock.

Secondary harvest

The secondary harvest occurred in February 2020. Machinery included a Peterson 5410 horizontal grinder (Figure 4), and a Volvo EC220 27 tonne excavator with a grapple attachment (Figure 5).

Figure 4. Peterson 5410 horizontal grinder.

Figure 5. Volvo EC220 excavator

The excavator was used to build grinder pads beside the road to facilitate grinding. It was also used to feed the residue into the grinder.

Three truck and trailer configurations were used to transport hog fuel to the pulp mill:

- A tri drive truck with dual bins (Figure 6)
- A tandem drive truck with 52ft chain drive trailer (Figure 7)
- A tandem drive truck with 48ft chain drive trailer (Figure 8)

Residue was ground directly into the chip bins and trailers.

Figure 6. Tri-drive truck with dual bins.

Figure 7. Tandem drive truck with 52ft chain drive trailer.

Figure 8. Tandem drive truck with 48ft 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

<u>BiOS entry</u>

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 were set to 100% harvest removal (Figure 9).

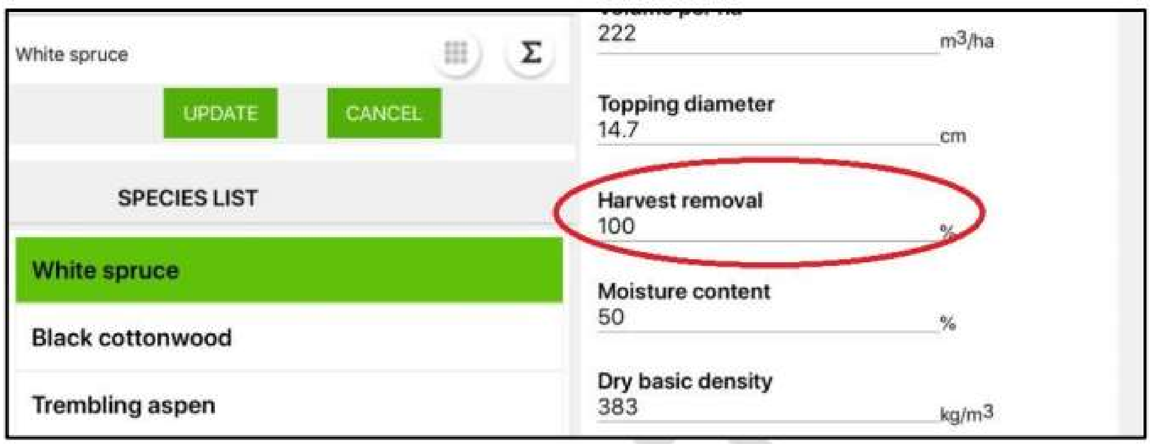

Figure 9. Species Operations data entry page; specifically harvest removal entry field.

<u>Field measure</u>

Douglas-fir, western hemlock and western red cedar trees were 100% harvested. Only western white pine trees were left standing and these numbered less than ten trees total. Because they likely would not have been captured in a cruise, and were left standing for retention, the pine was not included as a present species in the biomass flow analysis.

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 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 is 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 (10.2ha).

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. Manual Measurement Method (3M)

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 pile shapes for this trial were cones):
   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 pile shapes for this trial were cones):
   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 red ribbons on three 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 10). Volume and surface area occupied by the piles was directly estimated.

Figure 10. 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 11).

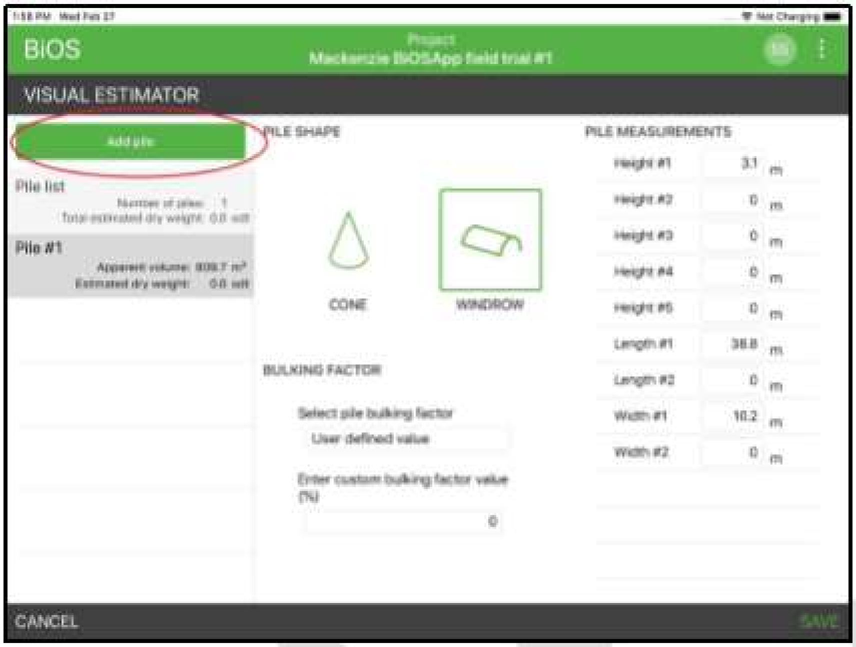

Figure 11. Add pile button in BiOS visual estimator.

Select a pile shape. Note: currently there are only two shapes (conical and windrow) available (Figure 12). More shapes are planned for future versions.

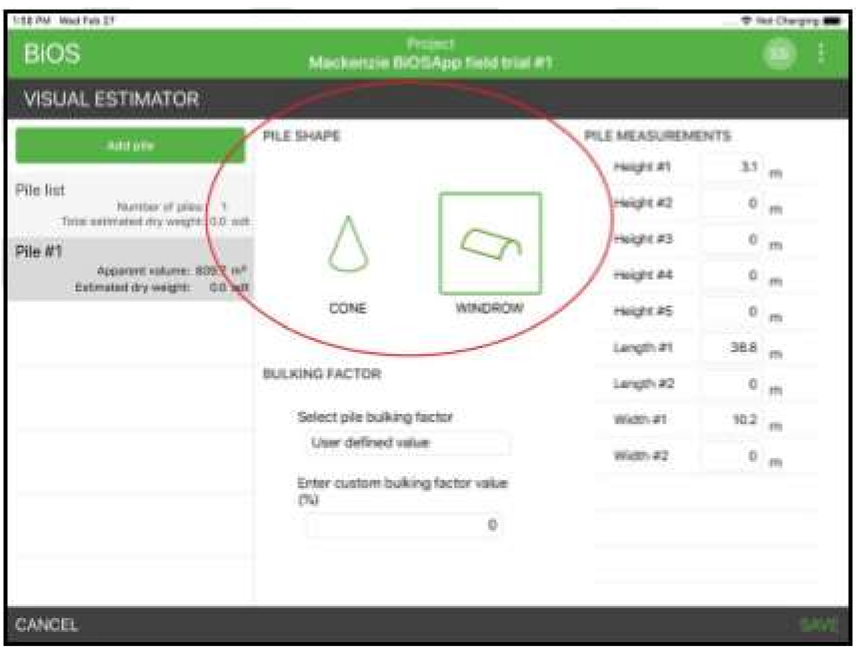

Figure 12. Pile shape buttons in BiOS visual estimator.

2. Enter the height, length and width values collected in the field. The cone shape requires a height and diameter (Figure 13).

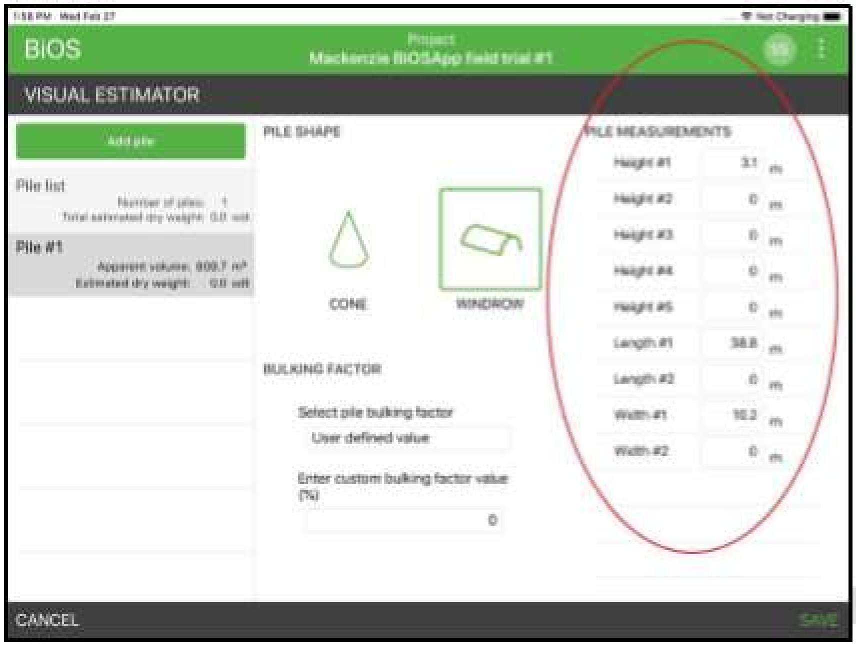

Figure 13. Pile measurement entry fields in BIOS visual estimator.

3. Choose a pile bulking factor from the list or enter a value manually (Figure 14).

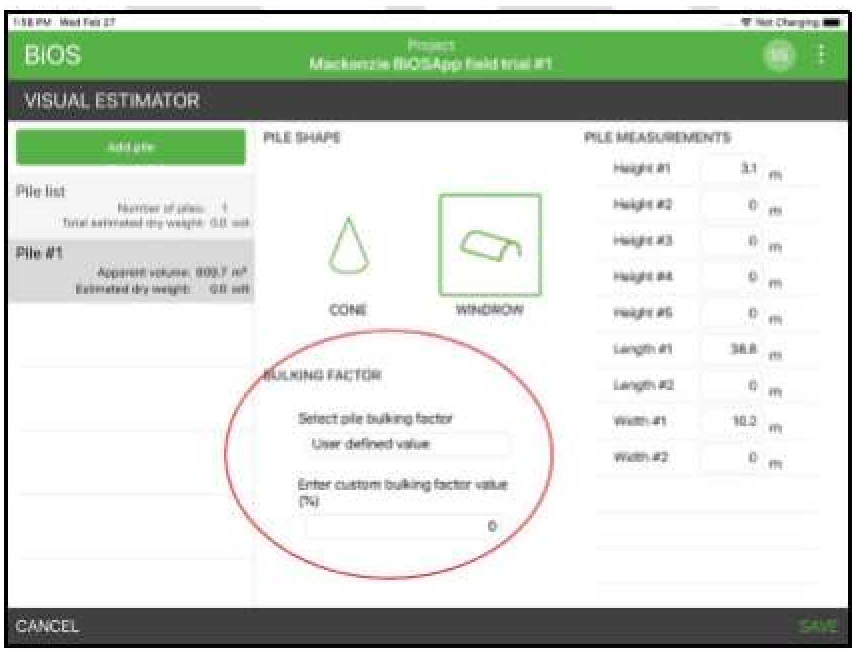

Figure 14. Bulking factor choice via drop-down in BiOS visual estimator.

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 15).

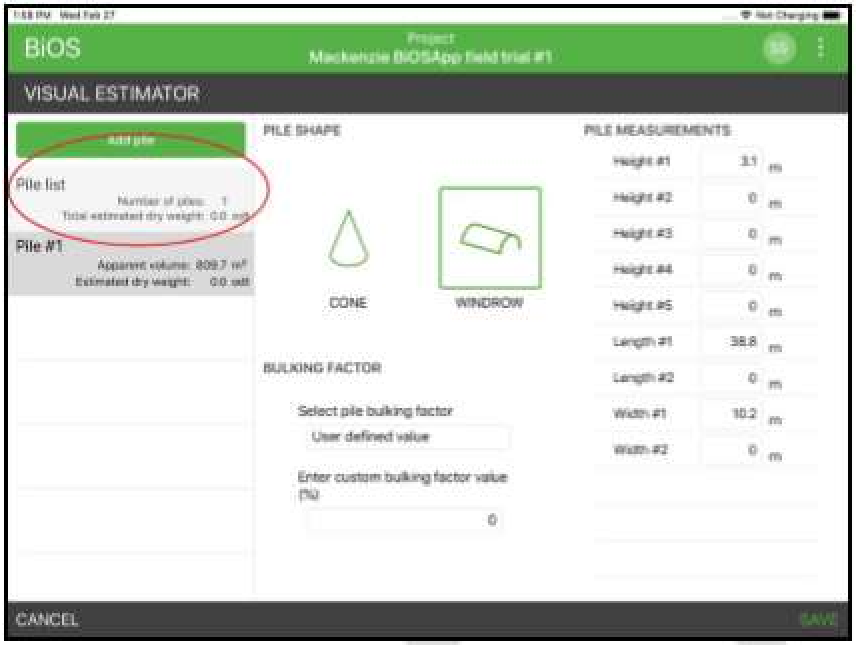

Figure 15. Pile counter and dry weight calculation.

Comminution

The volume harvested from each pile was monitored by a researcher in the field. The tare and total weight (green) for each load was measured using a set of Massload portable scales located on the cutblock roadbed. A hog fuel sample (1 litre) was taken from each load and moisture content analysis was performed in the FPInnovations Vancouver lab. For a detailed explanation of moisture content analysis methodology, please see Appendix II.

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 apparent 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 compared.

RESULTS AND DISCUSSION

Standing residual trees

As stated in the methodology, no standing trees were recognized in this trial.

Dispersed volume

Ten plots were completed in the dispersed area of the cutblock. Dispersed volume results for each plot can be found in Table 2. The total volume in the dispersed area of the cutblock was 242.9 oven dry tonnes (23.8 oven dry tonnes per hectare multiplied by 10.2 hectares).

Table 2. Dispersed volume

Plot	m^3/ha	odt/ha
1	31.4	13.8
2	8.5	3.8
3	89.4	39.3
4	63.6	28.0
5	40.5	17.8
6	26.4	11.6
7	26.6	11.7
8	167.8	73.8
9	52.7	23.2
10	34.3	15.1
Average		**23.8**

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.

Note: At the time of the UAV flight to perform the PCM method, not all piles were built. Only those piles built at the time of the flight are included in the four-method analysis.

I. Manual Measurement Method (3M)

Total apparent volume for the 3M method was 2,264.4 m^3 (Table 3).

Table 3. Pile dimensions using the Manual Measurement Method

Pile dimensions using the Manual Measurement Method						
Pile name	Height (m)	Radius (m)	Shape	Shape factor	Pile area (m^2)	Apparent volume (m^3)
1.1	3.7	5.4	Cone	0.4	90.8	134.3
1.2	4.1	4.4	Cone	0.4	60.1	97.4

1.3	4.9	4.1	Cone	0.4	52.2	102.2
1.4	3.4	4.2	Cone	0.4	55.4	75.4
1.5	3.2	4.4	Cone	0.4	59.4	76.1
2.1	1.0	2.8	Cone	0.4	24.2	9.7
2.2	4.2	4.1	Cone	0.4	53.5	89.8
2.3	4.1	5.6	Cone	0.4	96.8	158.7
2.4	3.9	6.1	Cone	0.4	115.9	180.9
3.1	4.5	3.7	Cone	0.4	43.0	76.6
3.2	3.7	2.9	Cone	0.4	26.0	38.4
3.3	4.2	2.9	Cone	0.4	26.4	44.4
3.4	3.8	4.0	Cone	0.4	50.3	76.4
3.5	3.7	5.3	Cone	0.4	89.1	131.8
4.1	4.3	4.9	Cone	0.4	73.9	127.1
4.2	5.2	4.6	Cone	0.4	65.0	135.3
4.3	4.9	4.7	Cone	0.4	70.1	137.5
4.4	5.1	5.8	Cone	0.4	105.7	215.6
5.1	3.6	4.9	Cone	0.4	73.9	106.4
5.2	4.1	5.2	Cone	0.4	84.1	138.0
5.3	6.2	3.8	Cone	0.4	45.4	112.5
Total						**2264.4**

II. GPS Measure Method (GMM)

Total apparent volume for the GMM method was 2,902 m^3 (Table 4).

Table 4. 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)**
1.1	3.7	Cone	0.4	63.5	94.0
1.2	4.1	Cone	0.4	74.7	121.1
1.3	4.9	Cone	0.4	79.9	156.6
1.4	3.4	Cone	0.4	60.4	82.1
1.5	3.2	Cone	0.4	52.6	67.3
2.1	1.0	Cone	0.4	19.5	7.8
2.2	4.2	Cone	0.4	42.7	71.8
2.3	4.1	Cone	0.4	71.9	118.0
2.4	3.9	Cone	0.4	100.6	156.9
3.1	4.5	Cone	0.4	73.5	130.7
3.2	3.7	Cone	0.4	60.2	89.1
3.3	4.2	Cone	0.4	69.2	116.2
3.4	3.8	Cone	0.4	55.2	83.8

3.5	3.7	Cone	0.4	71.2	105.4
4.1	4.3	Cone	0.4	143.5	246.8
4.2	5.2	Cone	0.4	105.3	219.0
4.3	4.9	Cone	0.4	115.7	226.7
4.4	5.1	Cone	0.4	164.6	335.8
5.1	3.6	Cone	0.4	79.2	114.0
5.2	4.1	Cone	0.4	86.1	141.3
5.3	6.2	Cone	0.4	87.5	217.1
Total					**2901.6**

III. UAV Point Cloud Method (PCM)

Total apparent volume for the PCM method was 3,064 m^3 (Table 5).

Table 5. Pile dimensions using the UAV Pile Count Method

Pile dimensions using the UAV Point Cloud Method	
Pile name	**Apparent volume (m3)**
1.1	119.0
1.2	125.3
1.3	130.6
1.4	128.1
1.5	118.7
2.1	12.3
2.2	80.8
2.3	150.4
2.4	189.4
3.1	162.2
3.2	96.1
3.3	117.8
3.4	83.7
3.5	151.1
4.1	172.6
4.2	210.4
4.3	257.2
4.4	317.0
5.1	129.9
5.2	132.8
5.3	178.7
Total	**3064.1**

IV. BiOS Pile Volume Estimate Method (VEM)

Total apparent volume for the VEM method was 1,898 m^3 (see Table 6) and because the visual estimator uses a bulking factor in its calculations, it provided an estimated dry weight of 417.5 oven dry tonnes.

Table 6. Pile dimensions using the BiOS Pile Volume Estimate Method

Pile dimensions using the BiOS Pile Volume Estimate Method						
Pile name	**Height (m)**	**Diameter (m)**	**Shape**	**Apparent volume (m^3)**	**Bulking factor (%)**	**Estimated dry weight (oven dry tonnes)**
1.1	3.7	10.8	Cone	113.0	50	24.9
1.2	4.1	8.8	Cone	83.1	50	18.3
1.3	4.9	8.2	Cone	86.3	50	19.0
1.4	3.4	8.4	Cone	62.8	50	13.8
1.5	3.2	8.7	Cone	63.4	50	13.9
2.1	1.0	5.6	Cone	8.2	50	1.8
2.2	4.2	8.3	Cone	75.7	50	16.7
2.3	4.1	11.1	Cone	132.3	50	29.1
2.4	3.9	12.2	Cone	152.0	50	33.4
3.1	4.5	7.4	Cone	64.5	50	14.2
3.2	3.7	5.8	Cone	32.6	50	7.2
3.3	4.2	5.8	Cone	37.0	50	8.1
3.4	3.8	8.0	Cone	63.7	50	14
3.5	3.7	10.7	Cone	110.9	50	24.4
4.1	4.3	9.7	Cone	105.9	50	23.3
4.2	5.2	9.1	Cone	112.7	50	24.8
4.3	4.9	9.5	Cone	115.8	50	25.5
4.4	5.1	11.6	Cone	179.7	50	39.5
5.1	3.6	9.7	Cone	88.7	50	19.5
5.2	4.1	10.4	Cone	116.1	50	25.5
5.3	6.2	7.6	Cone	93.8	50	20.6
Total				**1898.2**		**417.5**

Pile volume method comparison

The apparent volumes derived from each pile measurement method can be found in Table 7.

The total apparent volume of the piles was similar for the 3M and VEM methods. This is not surprising as they essentially use the same method of measure. However, the 3M and VEM, using a radius or diameter measure, assume a circular pile footprint and the footprint shapes derived using the GEM method demonstrate most of the piles were only roughly circular (Figure 16).

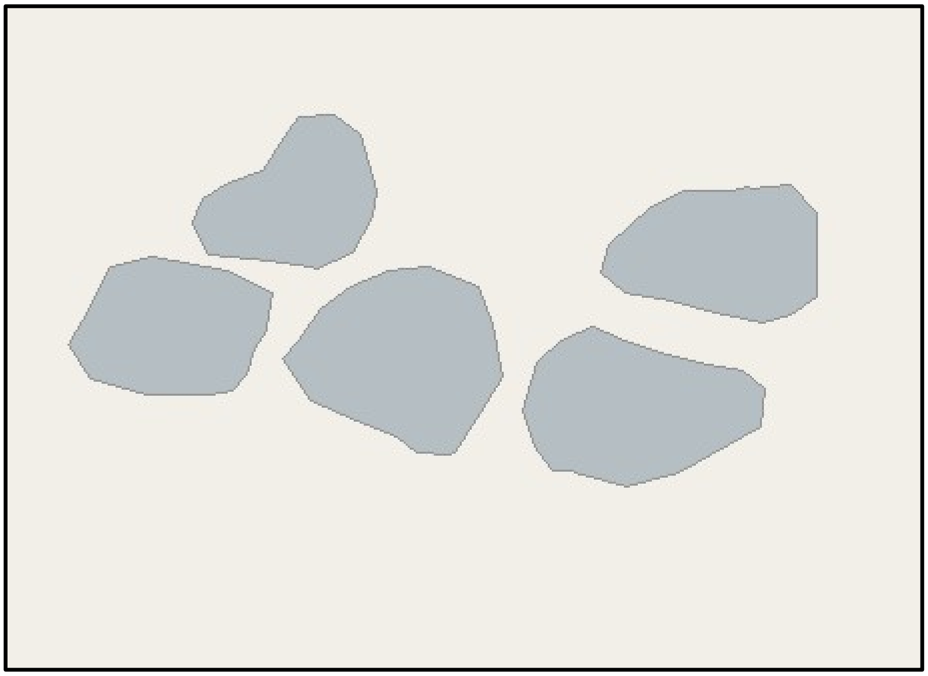

Figure 16. The non-circular footprints of the trial piles.

The total apparent volumes of the GEM and PCM methods were roughly similar. This also is not surprising as the piles would have used a similar footprint and surface area would have been similar because of the smooth sided nature of the piles (Figure 17).

Figure 17. Smooth nature of the outside of the residue pile shapes.

Table 7. Apparent volumes of residue measurement methods

Apparent volumes of residue measurement methods				
Pile name	**3M**	**GMM**	**PCM**	**VEM**
1.1	134.3	94.0	119.0	113.0
1.2	97.4	121.1	125.3	83.1
1.3	102.2	156.6	130.6	86.3
1.4	75.4	82.1	128.1	62.8
1.5	76.1	67.3	118.7	63.4
2.1	9.7	7.8	12.3	8.2
2.2	89.8	71.8	80.8	75.7
2.3	158.7	118.0	150.4	132.3
2.4	180.9	156.9	189.4	152.0
3.1	76.6	130.7	162.2	64.5
3.2	38.4	89.1	96.1	32.6
3.3	44.4	116.2	117.8	37.0
3.4	76.4	83.8	83.7	63.7
3.5	131.8	105.4	151.1	110.9
4.1	127.1	246.8	172.6	105.9
4.2	135.3	219.0	210.4	112.7
4.3	137.5	226.7	257.2	115.8
4.4	215.6	335.8	317.0	179.7
5.1	106.4	114.0	129.9	88.7
5.2	138.0	141.3	132.8	116.1
5.3	112.5	217.1	178.7	93.8
Total	**2264.4**	**2901.6**	**3064.1**	**1898.2**

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, 68 loads of hog fuel were comminuted in cutblock H232 and hauled to the local pulp mill. The average load size for the three truck configurations were 8.64 odt, 10.81 odt and 11.27 odt respectively. Average moisture content was 55%. A total of 1581.0 green tonnes or 710.9 oven dry tonnes (69.7 odt/ha) were hauled from the cutblock.

18 loads of firewood were hauled from the cutblock for a total of 610 cubic metres or 274.5 odt. This volume was included with the recovered biomass.

Pile volume

Volume for each pile was calculated from the volume hauled during comminution (Table 8) and the volume left in each footprint. The small pile clusters were grouped into single pile designations because volume was extracted from all of the small piles at the same time during comminution and differentiation was not possible. The volume for piles 8, 10, 11 and 13 are an average of the total volume harvested during the latter portion of the trial, when the researchers were not present.

Table 8. Pile volumes in oven dry tonnes

Pile	Volume (odt)
1	70.5
2	46.6
3	76.5
4	134.1
5	38.4
6	7.6
7	55.1
8	58.7
9	54.5
10	58.8
11	58.5
13	59.0
Total	**710.9**

Post-harvest measurement

After piles were comminuted, line transect surveys were performed within the pile footprint. A total of 7.38 oven dry tonnes were left in the pile footprints after harvest (Table 9).

Table 9. Volume found within pile footprint after comminution

Pile	Volume within footprint (odt/ha)	Total volume within footprint (odt)
1	5.3	0.18
2	33.8	0.79
3	32.5	1.07
4	16.2	0.86
5	38.6	0.98
6	11.3	0.04
7	10.1	0.33
8	21.1	0.53
9	21.1	0.61
10	21.1	0.68

11	21.1	0.42
13	21.1	0.90
Total		**7.38**

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 10). Average pile densities varied from 114.7 oven dry kg per cubic metre for the PCM method (UAV measure) to 175.6 oven dry kg per cubic metre for the VEM method (BiOS calculator). The higher average densities are likely a result of the simplified shape calculation versus the more exact shapes derived when using the GMM and PCM methods. Note: Piles 6 through 13 were not completed at the time of the UAV flight.

Table 10. Pile density for four residue pile measurement methods

Pile density for four residue pile measurement methods					
Pile name	**Volume (oven dry tonnes)**	**3M (od kg/m^3)**	**GMM (od kg/m^3)**	**PCM (od kg/m^3)**	**VEM (od kg/m^3)**
1	70.5	96.1	89.5	113.4	114.1
2	46.6	106.2	131.5	107.7	126.6
3	76.5	208.2	145.7	125.3	247.9
4	134.1	217.8	130.4	140.1	260.8
5	38.4	107.5	81.2	86.9	128.5
6	7.6	105.2	105.1	n/a	126.2
7	55.1	140.3	105.4	n/a	168.3
8	58.7	187.3	150.3	n/a	223.9
9	54.5	144.7	116.7	n/a	173.1
10	58.8	134.8	108.7	n/a	160.7
11	58.5	203.2	196.1	n/a	241.2
13	59.0	110.3	83.3	n/a	131.6
Average		146.8	120.3	114.7	175.6

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.

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, the summary of which is displayed in a flowchart format (Figure 18). The information in the flowchart was the focus of the Powell River BiOS validation. The entire list of BIOS inputs, in the order they were entered into the app, can be found in Appendix I.

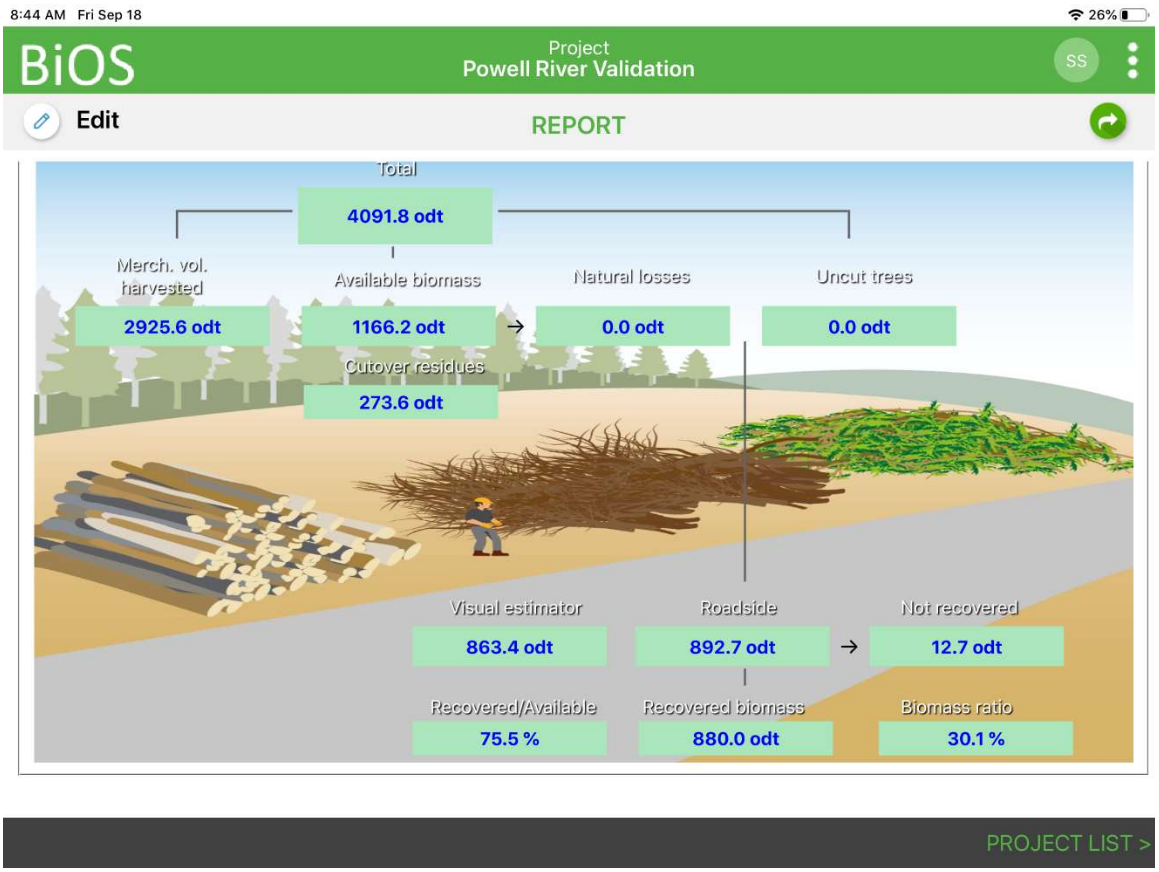

Figure 18. Biomass flowchart produced by the BiOS app for Powell River cutblock.

In order to compare the data in the flowchart with the actual results found in the field, Table 11 was created to ease analysis. Each line in the table describes one aspect of the flowchart except for Line 1, which depicts topping diameter.

Table 11. 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)	16.0	16.0	n/a
2	Total fibre (odt)[a]	4091.8	4164.6	-1.7%
3	Merchantable volume harvested (odt)	2925.6	2928.9	-0.1%
4	Available biomass (odt)	1166.2	1235.7	-5.6%
5	Natural losses (odt)	0	0	n/a
6	Uncut trees (odt)	0	0	n/a

7	Cutover residues (odt)	273.6	242.9	12.6%
8	Visual estimator (odt)	863.4	992.8	-13.0%
9	Roadside (odt)	892.7	992.8	-10.1%
10	Recovered biomass (odt)	880.0	985.4	-10.7%
11	Not recovered (odt)	12.7	7.4	71.6%

[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 16.0 cm 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 4091.8 oven dry tonnes is within 1.7% of the actual total volume 4164.6 oven dry tonnes derived from the field results. The difference between these two values is within acceptable parameters.

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 2925.6 oven dry tonnes. The merchantable volume harvested value of 2928.9 oven dry tonnes was provided by the Powell River Community Forest and represents the actual volume hauled during the primary harvest. Merchantable volume harvested results between the BiOS result and the cruise estimate were almost identical with a difference of 0.1%.

Line 4 – Available biomass

BiOS calculates the 'Available biomass' located in Line 4 of Table 11 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, 1166.2 oven dry tonnes and the actual result, 1235.7 oven dry tonnes, were 5.6% different. The difference between these two values is within acceptable parameters.

Line 5 – Natural losses

'Natural losses' from Line 5 in Table 11 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 less than two months after the primary harvest, there were no natural losses for this validation.

Line 6 – Uncut trees

In BiOS, ‘Uncut trees’ is the volume attributed to trees left standing after the primary harvest. No trees were left standing in this validation.

Line 7 – Cutover residues

‘Cutover residue’ described in Line 7 of Table 11 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 273.6 odt was 12.6% higher than the measured field results of 242.9 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 863.4 oven dry tonnes of volume within the residue piles at roadside. This was a 13% lower than the 992.8 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 50% packing ratio the researcher chose due to the dense nature of the piles. If the value were consistently found to be lower 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 11 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 992.8 oven dry tonnes. This different from the BiOS calculation of 892.7 oven dry tonnes by 10.1%. 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 11 consists of the roadside biomass volume that was comminuted and transported in the secondary harvest. The BiOS calculation for recoverable biomass of 880.0 oven dry tonnes was 10.7% different than the calculated field result of 985.4 oven dry tonnes.

Line 11 – Not recovered

The ‘not recovered value’ in Line 11 of Table 11 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 12.7 oven dry tonnes (assuming an average roadside recovery technical efficiency of 90%) and was 71.6%

different than the value of 7.4 oven dry tonnes calculated in the field. Because the absolute value of the difference was only 5.3 oven dry tonnes (or .5% of the total recovered biomass value), the difference between the two values is within acceptable parameters.

Overall analysis of comparison

In most of the categories found in Table 11, the BiOS values and the actual field results were close. The roadside biomass and recovered biomass values were a little further apart than those found in the interior trials (Mackenzie, Williams Lake, Topley) but are likely still acceptable for planning purposes. Some of the difference for these values may be from the trial methods, where cruising did not occur within the cutblock, but along the edge of it (community forest tenures are not required to cruise) and the need to use portable scales because the pulp mill did have a stationary scale on site.

The positive results of this validation trial under less than perfect conditions (adjacent cruising and portable scales) speak well to the robustness of the model and the allometric equations embedded within it (Lambert et al. 2005, Ung et al. 2008, Standish et al. 1985).

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, that 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 9.3 tonnes (CO2eq) and biomass transport emissions were calculated at 11.8 tonnes (CO2eq) for a total of 21.0 tonnes (CO2eq).

In the Species breakdown portion of the report it states that 449.1 tonnes of carbon were delivered, which constitutes a 21:1 ratio of delivered to emitted carbon (delivery distance 53 km). The report also states that 1464.1 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 February 2020. A cutblock located in the CWH dry maritime biogeoclimatic zone near Powell River, 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.

The field result for recovered biomass was within 10.1% of the BiOS predicted outputs. This may have occurred due to the need to cruise the adjacent stand and the use of portable scales on site. Overall, this validation displays a favourable outcome for predicting recovered biomass in this biogeoclimatic zone and species profile, although further validation may be necessary.

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	10.2

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	Cw	23	15.5	100	8	55	329	731	0.126
			Fdc	526	15.5	100	8	55	450	1000	1.43
			Hw	138	15.5	100	8	55	423	940	1.92

Run	Tab	Average Skid Distance	Harvest Data	Harvest Method
1	Logging Operations	150	12/15/2019	Full tree with loader forwarder

Run	Tab	Technical Losses at the Stump	Recovery Date	Pre-piling	Comminution
1	Biomass Operations	30%	02/18/2020	On (30%)	Grinder (90%)

Run	Tab	Truck Configuration	Destination	Distance
1	Transport	Semi with 3 axles	Catalyst, Powell River	User defined (3km operational, 15km primary, 35km public)

Run	Tab	Piles	Pile Type	Ht1	L1 (or diameter)	W1	Bulking Factor	Apparent Volume	Est Dry Weight
1	Visual Estimator	1	Cone	3.7	10.8	NA	50	113.0	24.9
Number of piles - 40		2	Cone	4.1	8.8	NA	50	83.1	18.3
		3	Cone	4.9	8.2	NA	50	86.3	19.0
		4	Cone	3.4	8.4	NA	50	62.8	13.8
		5	Cone	3.2	8.7	NA	50	63.4	14.0
		6	Cone	1.0	5.6	NA	50	8.2	1.8
Total estimated dry weight: 863.4		7	Cone	4.2	8.3	NA	50	75.7	16.7
		8	Cone	4.1	11.1	NA	50	132.3	29.1
		9	Cone	3.9	12.2	NA	50	152.0	33.5
		10	Cone	4.5	7.4	NA	50	64.5	14.2
		11	Cone	3.7	5.8	NA	50	32.6	7.2
		12	Cone	4.2	5.8	NA	50	37.0	8.1
		13	Cone	3.8	8.0	NA	50	63.7	14.0
		14	Cone	3.7	10.7	NA	50	110.9	24.4
		15	Cone	4.3	9.7	NA	50	105.9	23.3
		16	Cone	5.2	9.1	NA	50	112.7	24.8
		17	Cone	4.9	9.5	NA	50	115.8	25.5
		18	Cone	5.1	11.6	NA	50	179.7	39.6
		19	Cone	3.6	9.7	NA	50	88.7	19.5
		20	Cone	4.1	10.4	NA	50	116.1	25.6
		21	Cone	6.2	7.6	NA	50	93.8	20.7
		22	Cone	4.7	7.0	NA	50	60.3	13.3
		23	Cone	3.8	12.2	NA	50	148.1	32.6
		24	Cone	4.3	9.6	NA	50	103.7	22.9
		25	Cone	4.0	8.5	NA	50	75.7	16.7
		26	Cone	4.0	9.0	NA	50	84.8	18.7
		27	Cone	4.0	7.9	NA	50	65.4	14.4
		28	Cone	3.8	10.6	NA	50	111.8	24.6
		29	Cone	4.2	10.7	NA	50	125.9	27.7
		30	Cone	4.0	9.0	NA	50	84.8	18.7
		31	Cone	3.9	10.1	NA	50	104.2	22.9
		32	Cone	4.0	10.7	NA	50	119.9	26.4
		33	Cone	4.3	10.2	NA	50	117.1	25.8
		34	Cone	4.3	10.7	NA	50	128.9	28.4
		35	Cone	3.6	8.7	NA	50	71.3	15.7
		36	Cone	3.9	9.7	NA	50	96.1	21.2
		37	Cone	3.8	8.7	NA	50	75.3	16.6
		38	Cone	3.9	11.1	NA	50	125.8	27.7
		39	Cone	4.3	13.3	NA	50	199.1	43.9
		40	Cone	4.2	10.6	NA	50	123.5	27.2

Deviation from defaults highlighted in yellow.

APPENDIX II – MOISTURE CONTENT ANALYIS

Analyzing the Moisture Content of Biomass Samples

Objective: to find the moisture content percentage *mc* (%) (% by weight, wet basis) of a biomass sample.

Work space: This procedure should be performed in laboratory conditions.

Materials and equipment:

- Digital scale with a capacity of at least 2000 g and accuracy of 0.1g
- Drying oven
- Clean sample weighing tray, able to hold at least 300 g of biomass
- 6 L (>1 kg) of biomass sample (3 replicates of at least 300 g each)

Procedures:

Step 1
Follow the procedures for *Separating Biomass Samples* to separate 3 replicates of at least 300 g each from one sample of at least 1 kg of biomass

Step 2
Weigh the empty sample tray and record its weight (tare) m_t

Step 3
Load the material of a replicate into a weighing tray. Weigh the loaded tray and record the weight m_{we}

Step 4
Load the tray into the oven and set to 105ºC.
Keep the tray in the oven until constant mass is obtained[2].

Step 5
Weigh the loaded tray and record the weight of the dry material m_{dry}

Step 6
Calculate moisture content *mc* (%) according to the following formula:
$mc\ (\%) = [(m_{we} - m_{dry}) / (m_{we} - m_t)] \times 100$

Step 7
Analyze the 3 replicates and report the average.

[2] Mass constancy is obtained when the mass lost between two weights taken 60 minutes apart is not exceeding 0.2% of the total lost in mass (EN-TS 14774-1:2009). The drying time will depend on the particle size and the thickness of the sample in the tray, and may vary between 5 and 24 hours (overnight).

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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