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

DRAFT VERSION

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ABSTRACT:

FPInnovations completed a field validation of the FPBiOS app in the fall of 2018 and winter of 2019. A cutblock located in the SBS biogeoclimatic zone near Mackenzie, BC was chosen. This validation required researchers to measure available biomass in the field, including standing trees, dispersed volume, residual pile volume and volume leftover on site after the secondary harvest. After measurements in the field were completed the values collected were compared with the outputs calculated by BiOS. BiOS app estimates came within 5% of the cutblock total fibre outputs.

301012918: BIOS APPLICATION

TECHNICAL REPORT

ACKNOWLEDGEMENTS

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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 are massive, with an average annual harvest from 2005 to 2015 of 67 M m^3 (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/m^3). 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, which could have been put to good use. 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 – Mackenzie, BC

A series of development activities are required to bring the app from a base tool to a more complete and 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. In BC, there have only been two BiOS validation trials (Figure 1). In order for the BiOS app to provide accurate information at the cutblock level, multiple validation trials are required in various biogeoclimatic zones and harvesting systems. 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. Given that there are 14 recognized forested zones, FPI suggests a total validation dataset of 20 trials (some zones, such as the Coastal Western Hemlock, may need more than one to capture variance within the zone) that should be done in order to consider the BiOS app fully validated for BC conditions. Already two less comprehensive trials have been 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 Mackenzie trial and present the field results compared to the BiOS App results.

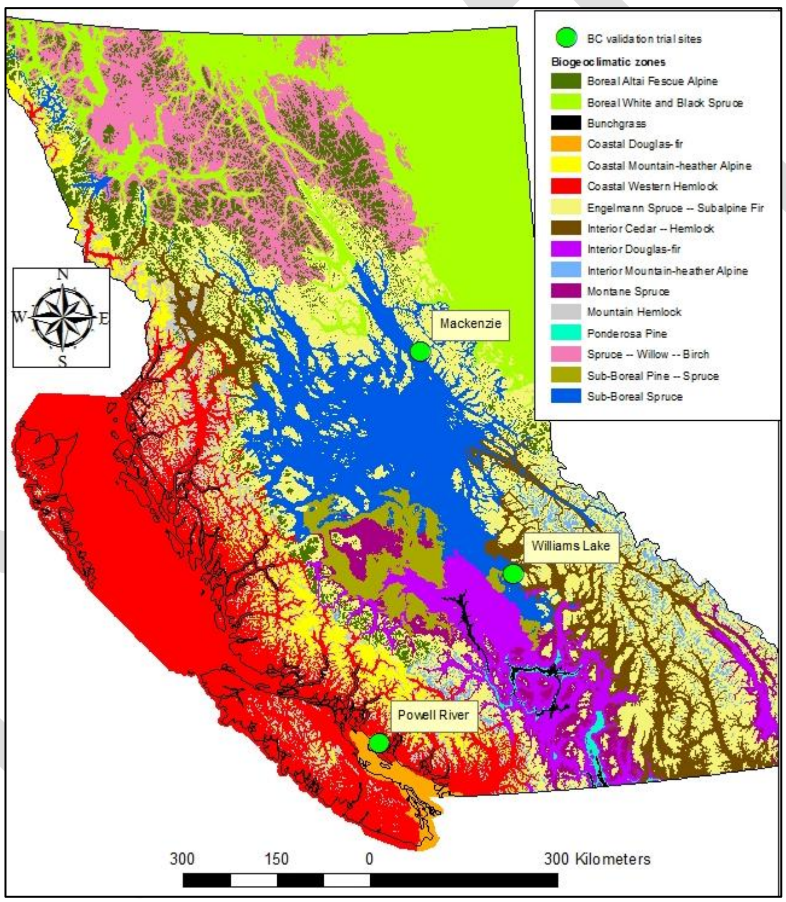

Figure 1. BiOS validation trial sites and Biogeoclimatic zones.

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 into the BiOS App for this trial, please see Appendix I.

Site and Operation Description

Site Characteristics

<u>Location</u>

The 11.4 hectare cutblock (A25-7120) chosen for the trial is located at 12.5km on the Parsnip East FSR (Figure 2) and is approximately 18km from the Conifex power plant on FFI Road in Mackenzie, BC. This site was chosen due to its proximity to the power plant, yet far enough from the airport (> 10km) that a UAV could be utilized to measure the residue piles.

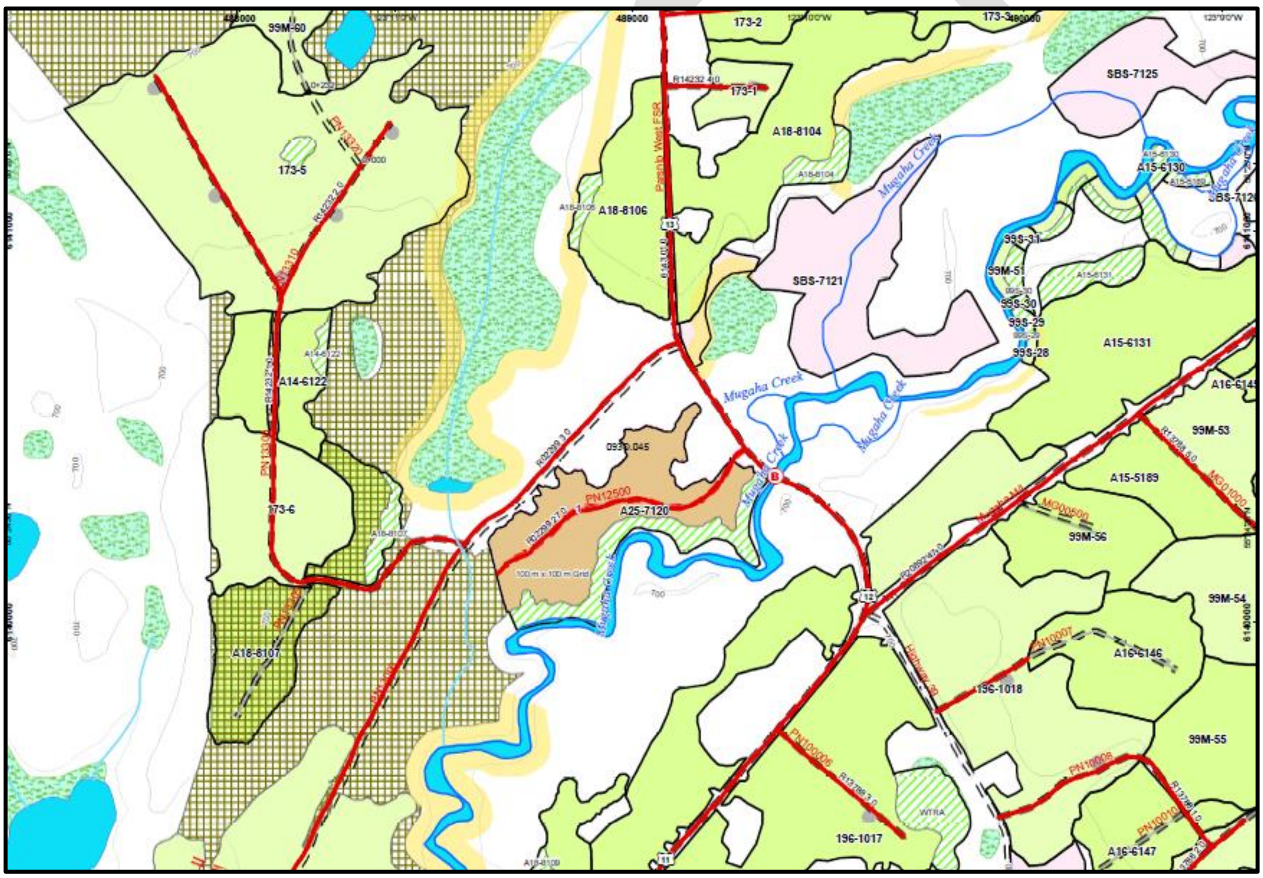

Figure 2. Trial cutblock site map – Blk 7120

<u>BGCZ</u>

Cutblock 7120 is located in the Sub-Boreal Spruce biogeoclimatic zone, moist cool (mk2) variant. According to the government of BC's BECWEB website, the SBSmk2 occurs at lower elevations along Williston Lake and along some of the major drainages feeding into Williston Lake[1].

[1]https://www.for.gov.bc.ca/hre/becweb/Downloads/Downloads_SubzoneReports/SBSmk2.pdf

Stand Description

The cutblock was timber cruised to FLNRORD standards (0.7 plots/ha, 8 BAF prism) in late 2016 and was harvested in the winter of early 2018. The stand was mainly composed of hybrid spruce and trembling aspen with a minor component of black cottonwood and birch. The cruise compilation summary can be found in Appendix IV.

Table 1. Stand description from timber cruise results

Timber cruise compilation summary				
Species	**Gross Merchantable Volume (m^3)**	**Stems per hectare**	**Gross Merchantable Volume per Tree (m^3)**	**% of Stand (by volume)**
Hybrid spruce	2950	364.8	0.71	60.4%
Trembling aspen	1397	79.9	1.53	28.6%
Black cottonwood	463	9.2	4.41	9.5%
Birch	71	3.6	1.74	1.5%

Operational Characteristics

Primary Harvest

The cutblock was harvested with a feller-buncher, skidder and processor operation where processing occurred at roadside. Many of the deciduous trees were left standing although some were felled and placed on the ground in the dispersed area. Some of the residues at roadside were piled for burning and left in a variety of forms including cone or haystack (see Figure 2a), windrow (see Figure 2b) or oriented (see Figure 2c).

Figure 2a. Cone (haystack) residue shape. Front view left. Top view right.

Figure 2b. Windrow residue shape. Front view left. Top view right.

Figure 2c. Oriented residue shape. Front view left. Top view right.

Secondary Harvest

The secondary harvest occurred in February 2019. Machinery utilized included a Diamond Z 4000 tracked horizontal grinder (see Figure 3a, left), a Komatsu 300 excavator with a bucket and thumb attachment (see Figure 3b, bottom) and a John Deere 2054 butt'n'top log loader with a grapple attachment (see Figure 3c, right).


Figure 3a, left. Diamond Z 4000 horizontal grinder. Figure 3c, bottom. Komatsu 300 excavator. Figure 3, right. John Deere butt'n'top loader

The excavator was used to clear snow from the road and create spaces for the grinder to sit in front of the piles. It was also used to feed the grinder when the log loader experienced mechanical difficulties. The log loader was used exclusively to feed the grinder, although for much of the trial it was unavailable due to mechanical breakdown.

Three 53ft walking floor chip cans were used to transport hog fuel to the powerplant (see Figure 4). Hog fuel was ground directly into the chip vans.

Figure 4. 53ft walking floor chip van.

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 standing volume, volume located in the dispersed area of the cutblock, residue pile volume, secondary harvest volume and volume left after the secondary harvest.

Some of the areas in which volumes needed to be measured were difficult or impossible to access due to mid-winter snow. In these cases, cruise volumes were used, alternative estimation methods established or assumptions from the BiOS app were made to replace field measurements.

Standing Residual Trees

BiOS Entry

The BiOS App calculates the volume of trees left standing after the primary harvest based on initial inputs by the user (see Figure 5).

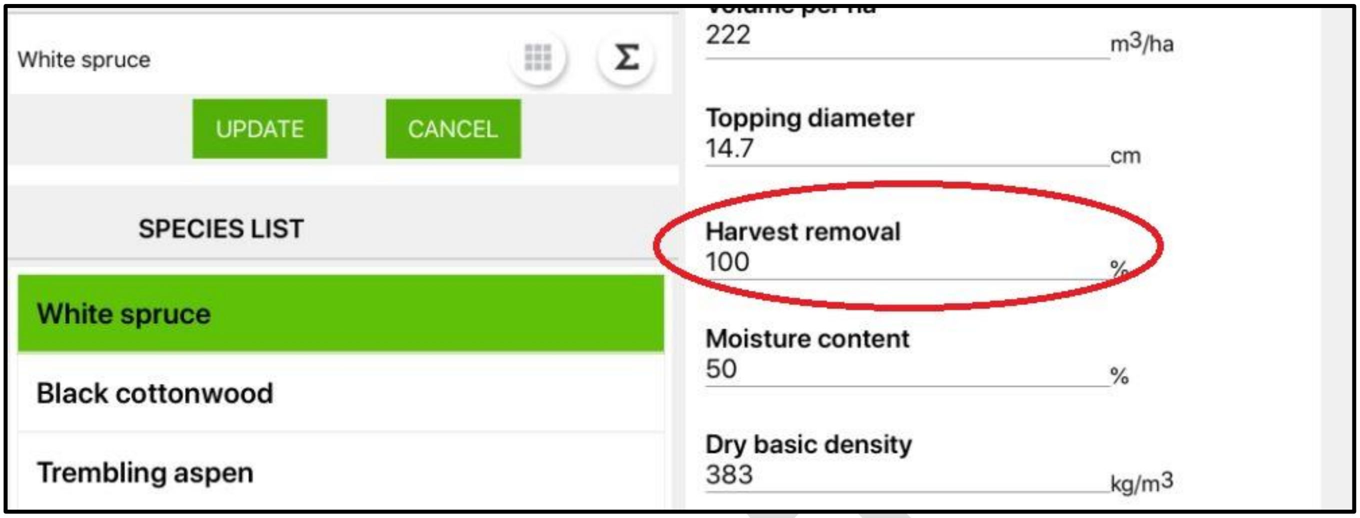

Figure 5. Harvest removal entry field in BiOS.

Field Measure

Ideally, standing trees would be measured in a second timber cruise completed after the primary harvest. However, due to time and weather constraints (>3 feet of snow), volume for standing trees was derived by counting the standing trees from roadside and attributing the gross merchantable volume per tree to each tree counted. Standing residual trees may be further assessed (cruised) in the spring as a part of other projects aimed at supporting further BiOS validation field trials.

Dispersed Volume

BiOS

The BiOS app calculates how much volume will be left in the dispersed area 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 collecting it.

Field Measure

Usually the line transect method is used to collect dispersed volume data in the field (see Appendix III for method). However, snow inhibited collection of dispersed residual volume data during the trial period so the BiOS result was used in further field trial calculations.

During the primary harvest, a portion of the standing deciduous trees were cut and laid on the ground, but not transported to roadside. The volume of these 'fallen' stems will be combined with the standing volume for the comparison between the field results and the BiOS results. As with standing trees, the fallen trees from the dispersed area were counted and the gross merchantable volume per tree was attributed to each counted tree. The compilation was done in this manner because if the data entered into the 'harvest removal' field (Figure 5) is entered with a value more than 0%, the program assumes that merchantable volume was collected from that species in the primary harvest, displaying a false merchantable volume value in the BiOS report.

Pile Measurements

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

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 (see Figure 2 for pictures of each pile shape):
    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 consistently 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 apparent volume calculated will then be used to determine pile density once harvested volume and the volume remaining after secondary harvest has been derived (discussed in the Pile Density section of the Methodology).

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 (see Figure 2 for pictures of each pile shape):
    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 :
    d. Cone (haystack) – 0.4
    e. Windrow – 0.6
    f. 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 apparent volume calculate will then be used to determine pile density once harvested volume and the volume remaining after secondary harvest has been derived (discussed in the Pile Density section of the Methodology).

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 2m and 4m height were marked with red ribbons on two of the selected piles. These piles were used as scaling points and validations 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 6). Volume and surface area occupied by the piles was directly estimated.

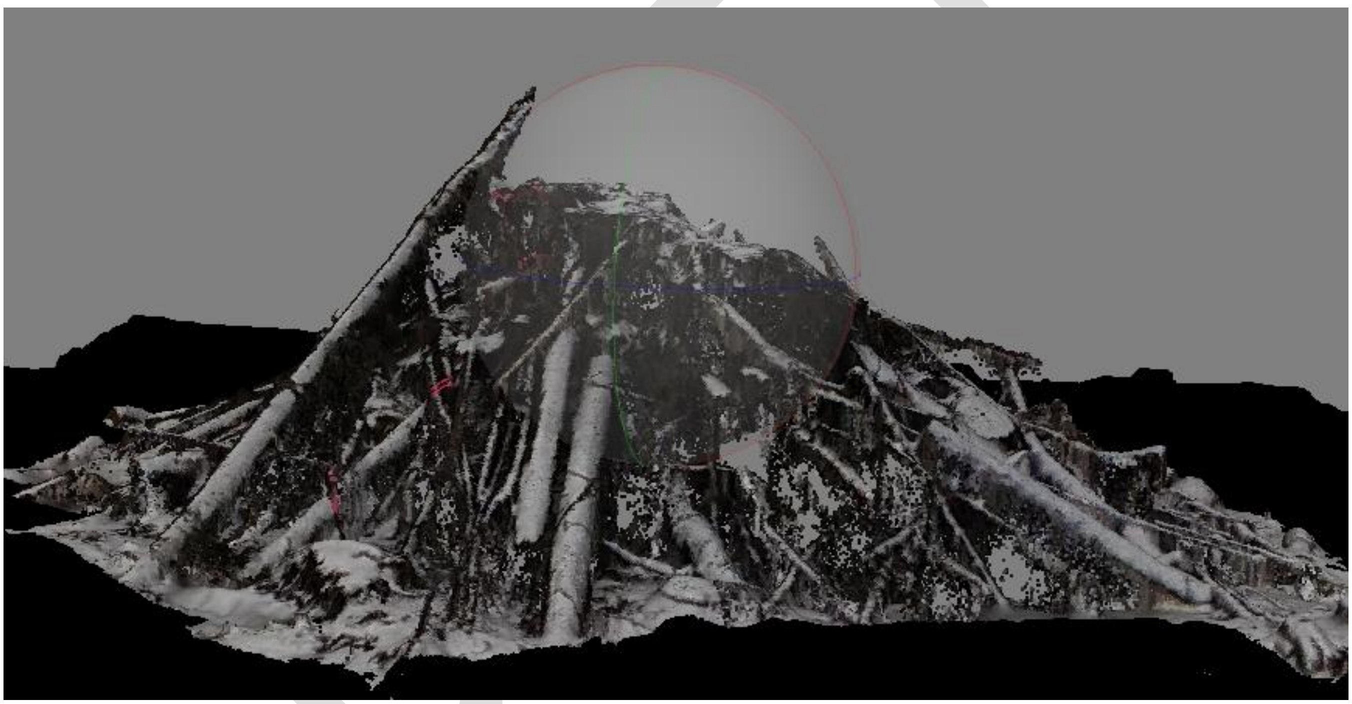

Figure 6. Point cloud diagram of pile 4.

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 7).

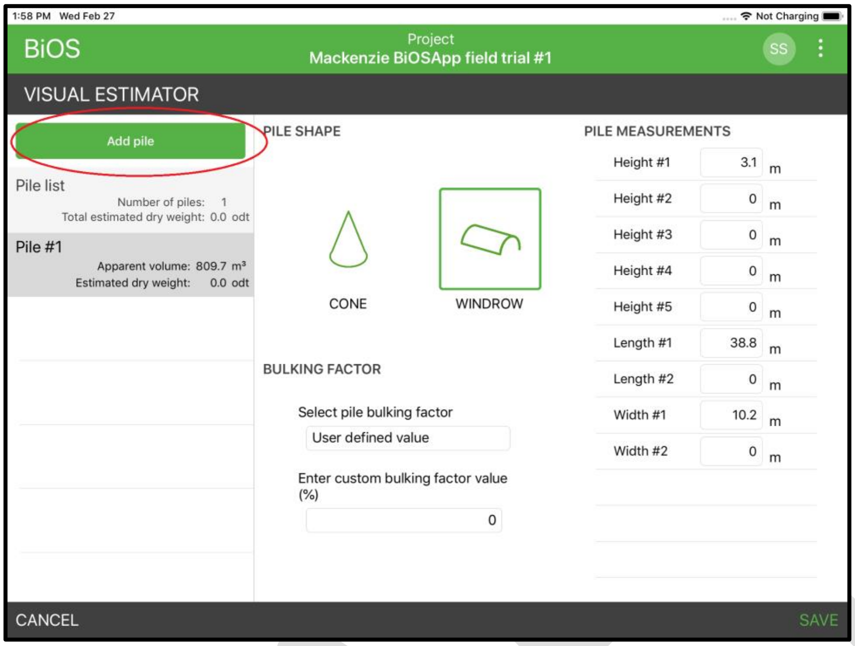

Figure 7. Add pile button in BiOS visual estimator.

2. Select a pile shape. Note: currently there is only two shapes (conical and windrow) available (Figure 8). More shapes are planned for future versions.

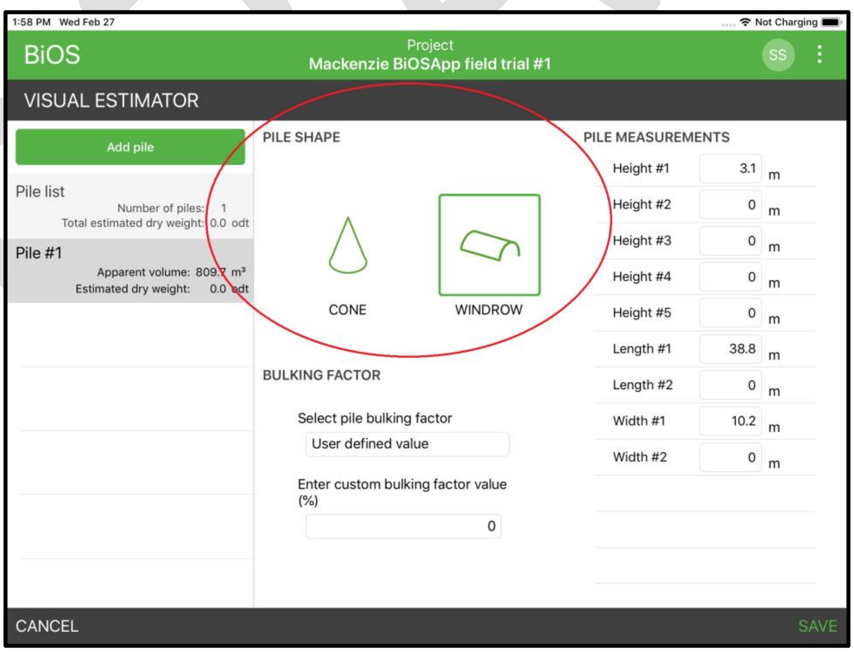

Figure 8. Pile shape buttons in BiOS visual estimator.

3. Enter the height, length and width values collected in the field. The cone shape requires a height and diameter (Figure 9).

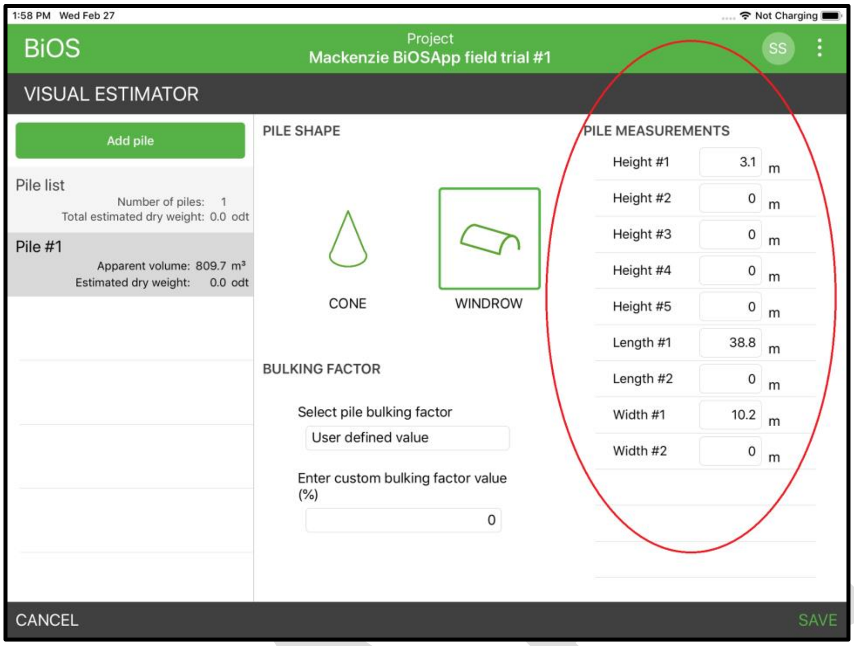

Figure 9. Pile measurement entry fields in BiOS visual estimator.

4. Choose a pile bulking factor from the list or enter a value manually (Figure 10).

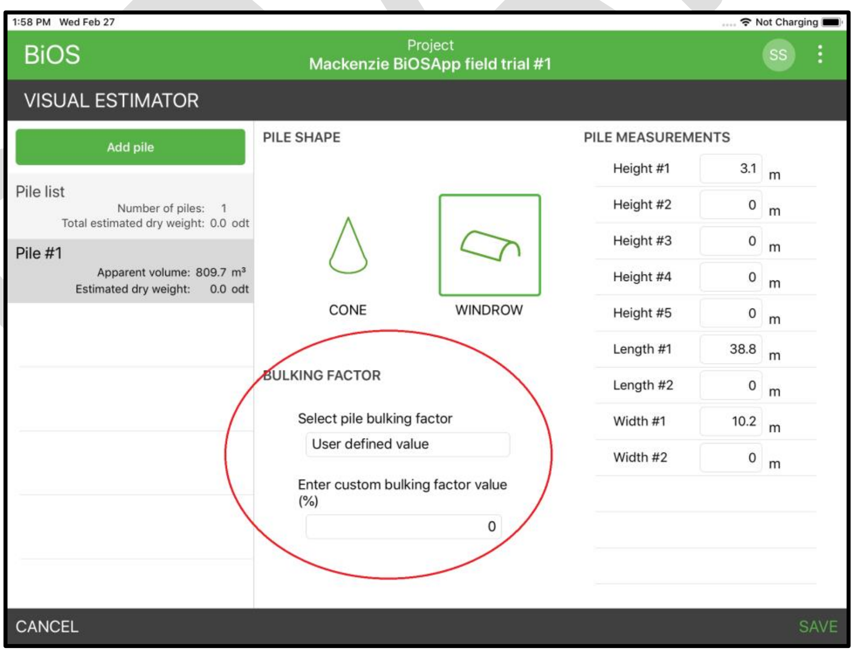

Figure 10. Bulking factor choice wheel in BiOS visual estimator.

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 right corner of the screen (Figure 11).

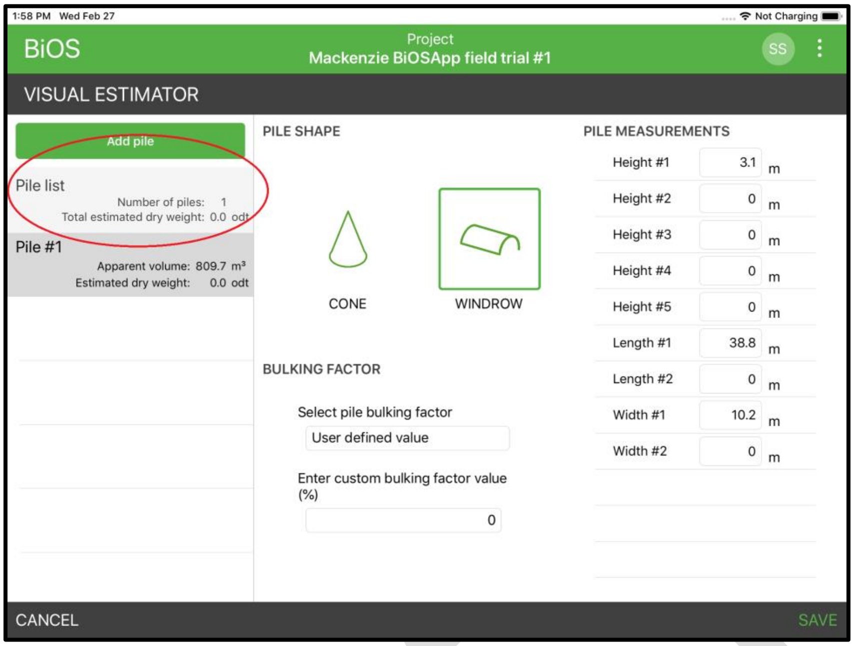

Figure 11. Pile counter and dry weight calculation.

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 Conifex and were cross referenced with individual residue piles. A hog fuel sample 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 a 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 for the pile.

BiOS Comparisons

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/m3)
    - 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/m3
    - 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 the 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 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

Stand and Residual Measurements

Standing Residual Trees

Cruise data was provided by Conifex and a summary can be viewed in Table 1 and more comprehensively in Appendix IV. In the primary harvest, 100% of the coniferous stems were harvested. No deciduous stems were hauled from the cutblock, although some were cut and placed onto the ground. No stems were cut in the secondary harvest, although some of the previously cut deciduous stems were harvested by the grinding operation.

Due to site conditions it was difficult at the time of the trial to determine the volume of trees left standing and the volume cut and laid onto the ground (Figure 12).

Figure 12. Deciduous stems cut and laid on the ground during the primary harvest.

As described in the methodology a piece count was performed to determine standing volume. Table 2 shows the results of the tree count to determine total volume of standing trees left after the primary harvest. Conversion from cubic metres to oven dry tonnes was completed using the dry basic density for each species.

Table 2. Volume of standing trees pre-secondary harvest

Volume of standing trees pre-secondary harvest				
	Aspen	**Cottonwood**	**Birch**	**Total**
No. of trees	134	143	8	285
Gross Merchantable Volume (m^3/tree)	1.5	4.4	1.7	
Total Gross Merchantable Volume (m^3)	205.0	630.6	13.9	
Dry Basic Density (oven dry kg/m^3)	387	338	539	
Total Gross Merchantable Volume (oven dry tonnes)	79.3	213.2	7.5	**300.0**

a Table note

Table 3 shows the total volume of the ‘fallen’ trees after the primary harvest.

Table 3. Volume of ‘fallen’ trees pre-secondary harvest

Volume of ‘fallen’ trees pre-secondary harvest				
	Aspen	**Cottonwood**	**Birch**	**Total**
No. of trees	291	111	15	417
Gross Merchantable Volume (m^3/tree)	1.5	4.4	1.7	
Total Gross Merchantable Volume (m^3)	445.2	489.5	26.1	
Dry Basic Density (oven dry kg/m^3)	387	338	539	
Total Gross Merchantable Volume (oven dry tonnes)	172.3	165.5	14.1	**351.8**

For the purpose of matching the actual results with the BiOS values, the total volume from Table 2 was added to the total volume from Table 3 to get 651.8 oven dry tonnes of ‘Uncut’ volume.

Dispersed Volume

As described in the methodology section, because no volume other than a portion of the ‘cut and dropped’ deciduous trees were collected by the secondary harvester (and cut and dropped trees were apportioned into the uncut trees category), and because there was already a layer of snow upon the ground, researchers did not measure the volume left in the dispersed area. Instead, the cutover residue volume calculated by BiOS, 115.3 oven dry tonnes, was used in both overall volume calculations (BiOS and trial results).

Pile Measurements

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

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

Total apparent volume for the 3M method was 5018 m^3 (Table 4).

Table 4. Pile dimensions using the Manual Measurement Method

Pile dimensions using the Manual Measurement Method							
Pile name	**Height (m)**	**Length (m)**	**Width (m)**	**Shape**	**Shape factor**	**Pile area (m^2)**	**Apparent volume (m^3)**
1	3.1	38.8	10.2	Windrow	0.6	396	736
2	1.9	47.5	14.3	Oriented	0.5	679	645
3	1.5	37.0	12.8	Oriented	0.5	474	355
4	4.0	Diameter - 10.6		Cone	0.4	88	141
5	2.4	47.9	15.3	Oriented	0.5	733	879
6	1.7	35.3	14.5	Oriented	0.5	512	435
7	1.6	70.3	14.9	Oriented	0.5	1047	838
8	1	11.8	7.2	Oriented	0.5	85	42
9	1.5	11.0	17.4	Oriented	0.5	191	144
10	3.1	37.5	11.5	Windrow	0.6	431	802
Total							**5018**

GPS Measure Method (GMM)

Total apparent volume for the GMM method was 5216 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	3.1	Windrow	.6	446	829
2	1.9	Oriented	.5	766	727
3	1.5	Oriented	.5	491	368
4	4.0	Cone	.4	138	220
5	2.4	Oriented	.5	669	803
6	1.7	Oriented	.5	524	445
7	1.6	Oriented	.5	959	767
8	1.0	Oriented	.5	118	59
9	1.5	Oriented	.5	186	139
10	3.1	Windrow	.6	461	857
Total					**5216**

UAV Point Cloud Method (PCM)

Total apparent volume for the PCM method was 3657 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	427
2	538
3	216
4	157
5	714
6	375
7	516
8	65
9	125
10	524
Total	**3657**

BiOS Pile Volume Estimate Method (VEM)

Total apparent volume for the VEM method was 6184 m^3 (Table 7) and because the Visual Estimator uses a bulking factor in its calculations it provided an estimated dry weight of 389.9 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	**Height (m)**	**Length (m)**	**Width (m)**	**Shape**	**Apparent volume (m3)**	**Bulking factor (%)**	**Estimated dry weight (oven dry tonnes**
1	3.1	38.8	10.2	Windrow	810	20	62
2	1.9	47.5	14.3	Windrow	852	15[a]	49
3	1.5	37.0	12.8	Windrow	469	15	27
4	4.0	Diameter – 10.6		Cone	118	20	9
5	2.4	47.9	15.3	Windrow	1161	15	67
6	1.7	35.3	14.5	Windrow	541	15	31
7	1.6	70.3	14.9	Windrow	1106	15	64
8	1.0	11.8	7.2	Windrow	56	15	3.2
9	1.5	11.0	17.4	Windrow	190	15	11
10	3.1	37.5	11.5	Windrow	882	20	68
Total					**6184**		**390**

a The windrow shape used for oriented piles in VEM makes the apparent volume of the oriented pile bigger than it would be if an oriented pile shape was used. Therefore because there is the same fibre volume in a larger apparent volume the packing ratio was slightly reduced for oriented piles in the VEM inputs.

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 using the 3M and GMM methods were very similar at 5018 m3 and 5216 m3. The apparent volume derived using the VMM method was approximately 20% higher than the 3M and GMM methods. This is believed to have occurred because the 3M and GMM methods include an oriented pile shape designation, which derive a smaller (and more accurate for oriented piles) apparent volume than the windrow shape.

The apparent volume derived from the point cloud method was significantly less than the apparent volumes derived using the other methods. This is simply because when using the 3M, GMM or VEM method the sides of the pile are 'smoothed' out and airspace is include in the apparent shape. The point cloud method eliminates these airspaces.

Table 8. Comparison of calculated apparent volumes using four residue pile measurement methods

Apparent volumes of residue pile measurement methods				
	Apparent volume (m^3)			
Pile name	**3M**	**GMM**	**PCM**	**VEM**
1	736	829	427	810
2	645	727	538	852
3	355	368	216	469
4	141	220	157	118
5	879	803	714	1161
6	435	445	375	541
7	838	767	516	1106
8	42	59	65	56
9	144	139	125	190
10	802	857	524	882
Total	**5018**	**5216**	**3657**	**6184**

a Table note

Comminution

Load Volume and Moisture Content

Over four days, 22 loads of hog fuel were comminuted in cutblock 7120 and hauled to the power plant. The average full load size was 26.3 green tonnes with average moisture content of 38.5%, or 16.3 oven dry tonnes (Table 9). Two partial loads were removed from the average calculation of load size because they were not full (this was due to trial protocol for measuring pile volumes) and therefore were not representative of the sample. A total of 560.2 green tonnes or 345.1 oven dry tonnes were hauled from the cutblock. Total volume hauled included volume from 34 deciduous trees pulled from the dispersed area but did not include volume from pile 5, which was not harvested.

Table 9. List of load weights in green tonnes and oven dry tonnes

List of load weights in green tonnes and oven dry tonnes			
Load	Weight (green tonnes)	Moisture content (%)	Weight (oven dry tonnes)
1	24.4	40.9	14.4
2	25.0	39.8	15.0
3[a]	14.8	39.6	9.0
4	30.2	31.6	20.7
5	24.2	42.6	13.9
6	26.4	40.2	15.8
7	24.6	35	16.0
8	24.2	39.5	14.6
9[a]	19.8	46.2	10.7
10	24.7	34.9	16.1
11	25.0	34.6	16.3
12	26.2	50.5	13.0
13	26.6	42.8	15.2
14	25.2	42.7	14.4
15	26.1	38.6	16.0
16	23.6	30.9	16.3

17	26.9	41.5	15.8
18	26.9	29.6	18.9
19	29.2	36.8	18.5
20	28.9	43.7	16.3
21	27.0	28.0	19.4
22	30.5	37.6	19.0
Average	26.3	38.5	16.3
Total	**560.2**		**345.1**

a Loads 3 and 9 were not included in the average load size because they were partial loads created by trial protocols

Pile Volume

Volume for each pile was calculated from the volume hauled during comminution and from the leftover volume found after the secondary harvest (Table 10). Deciduous trees pulled from the dispersed areas and included in the loads were not included in the pile volume. In some cases, load volumes were split between piles after consultation had occurred about load proportions with the grinder operator and truck driver.

Table 10. Volume per residue pile

Volume per residue pile		
Pile name	**Volume (oven dry tonnes)**	**Loads contributing to pile volume**
1	65.4	16,17,18,19(45%)
2	57.6	10,11,12,13(50%)
3	26.2	8,9 (85%)
4	16.9	7
5	53.7	Not harvested
6	25.1	2,3(50%)
7	67.1	1,4,5,6
8	12.9	13(50%),14
9	17.0	15
10	61.5	19,20,21,22

a Pile volume includes hauled volume and leftover volume within the pile footprint after harvest

The volume for pile 5 was determined by multiplying the apparent volume for the pile with the average pile density for that pile shape (oriented pile).

Post-Harvest Measurement

After piles were comminuted line transect surveys were performed within the pile footprint. Some leftover pieces were likely not measured due to snow depth, although a factor was applied by the researcher to describe how much volume was missed, usually between 10% and 30%. Pile 2 was not measured as an overnight snowfall buried the pile footprint before the researcher could measure it. No volume was calculated to Pile 5 as it was not harvested. A total of 26.3 oven dry tonnes left in the pile footprint after harvest was calculated (Table 11).

Table 11. Leftover volume per pile after secondary harvest

Leftover volume per pile after secondary harvest	
Pile number	**Leftover volume (oven dry tonnes)**
1	6.2
2	4.5
3	3.5
4	0.9
5	0.0 (not harvested)
6	3.1
7	2.4
8	0.6
9	2.2
10	2.9
Total	**26.3**

a Table note

The leftover volume for pile 2 was estimated using an average volume from nearby piles 1 and 10 which were similar in size and composition.

Pile Density

Pile density was calculated by dividing the fibre volume (harvested and leftover) from each pile by the apparent volume of the pile. This was done for each pile and for each method of pile measurement (Table 12). Density was not derived for pile 5 as it was not harvested. Average pile densities for the 3M and GMM methods were similar. The VEM density was lower than that found in the 3M and GMM methods. This is likely a factor of the pile shapes used in the different residue pile methods (3 in 3M and GMM, 2 in VEM), as explained in the Pile Volume Method Comparison section. The average density using the PCM method was significantly higher than found using the other methods. This is a result of the smaller apparent volume derived using this method.

Table 22. Pile density for four residue pile measurement methods

Pile density for four residue pile measurement methods					
		Density (oven dry kg/m^3)			
Pile name	**Volume (oven dry tonnes)**	**3M**	**GMM**	**PCM**	**VEM**
1	65.4	88.9	78.9	153.1	80.8
2	57.6	89.2	79.1	107.0	67.6
3	26.2	73.6	71.0	121.0	55.8
4	16.9	119.8	76.8	107.7	143.6
6	25.1	57.6	56.3	66.8	46.4
7	67.1	80.1	87.5	130.0	60.7
8	12.9	303.3	217.7	198.2	229.7
9	17.0	118.7	122.3	136.3	89.9
10	61.5	76.6	71.7	117.3	69.7
Average		**69.7**	**67.0**	**95.6**	**56.5**

a Pile 5 was not harvested and was removed from this table

The variance in average density between the different methods likely means that in future endeavours, researchers and authors will need to state the method of pile measurement when they describe density in residue piles.

Average density was also calculated by pile type in each method (Table 13). However, with only one 'cone' shaped sample, it is debateable how much emphasis can be placed on this comparison at this time. As more validations are completed, a more accurate picture of how shape affects pile density may be determined.

With the 3M and VEM methods, the cone density was significantly higher than that found in the GMM method. This is likely a function of the equation used in these methods where a diameter is used to determine a circular pile footprint area. The GMM method, using the GPS, shows that the footprint was not actually circular, as it appeared on the ground, but actually an oval of larger overall area. This makes the footprint area derived from the GMM method more credible. This is likely true of the other shape measures in the 3M and VEM which create a 'squared off footprint', rather than the actual rounded off footprint of the GPS method (add graphic). Also, the 3M and GMM method use a factor of 0.4 to describe the cone shape, whereas the VEM method uses a classic cone shape where the factor would be 0.33.

Table 33. Average density for three pile shapes for four residue pile measurement methods

Average density for three pile shapes for four residue pile measurement methods				
	Density (oven dry kg/m^3)			
Pile shape	**3M**	**GMM**	**PCM**	**VEM**
Windrow	82.7	75.3	135.2	75.2
Cone[a]	119.8	76.8	107.7	143.6
Oriented	83.8	83.2	112.2	64.1

a One cone sample only

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. The UAV method gave an absolute apparent volume. However, the time taken to fly the cutblock was over twice that of the ground based methods.

BiOS Comparisons

The BiOS App creates a report, the summary of which is displayed in a flowchart format (Figure 13). The information in the flowchart was the focus of the Mackenzie BiOS validation. The entire list of BiOS inputs, in the order they were entered into the app, can be found in Appendix I.

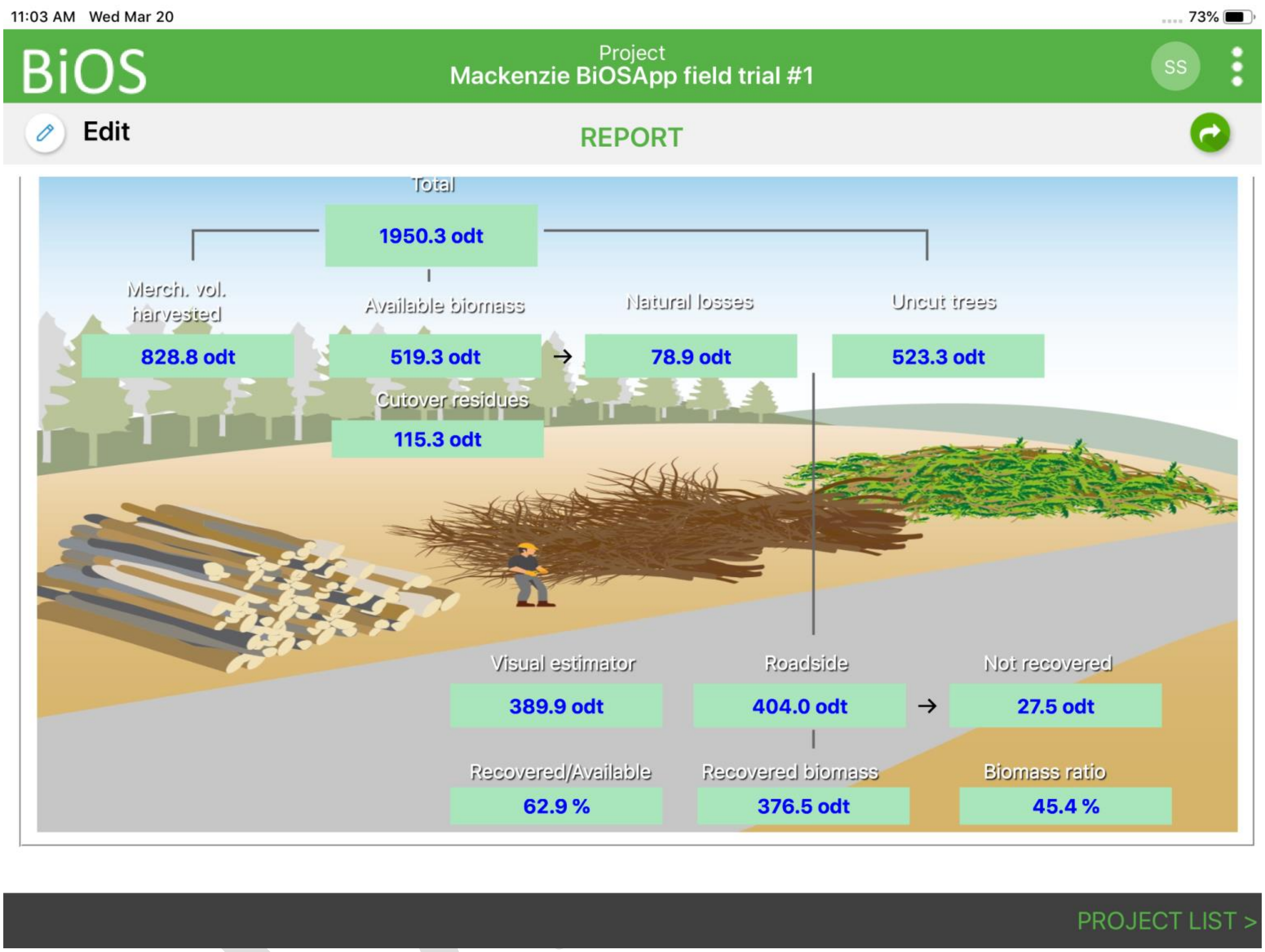

Figure 13.Biomass flowchart produced by the BiOS app for cutblock 7120.

In order to compare the data in the flowchart with the actual results found in the field, Table 14 was created to ease analysis. Each line in the table describes one aspect of the flowchart except for Line 1 which depicts topping diameter (arguable one of the biggest influences in BiOS calculations).

Table 44. Comparison of BiOS calculated results and field trial results

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)	14.7	14.7	n/a
2	Total Fibre (odt)	1951.7	2030.1	-4%
3	Merchantable Volume Harvested (odt)	828.8	780.9	6%
4	Available Biomass (odt)	519.3	518.5	0%
5	Natural Losses (odt)	78.9	78.9	Not assessed
6	Uncut Trees (odt)	524.6	651.8	-24%
7	Cutover Residues (odt)	115.3	115.3	Not assessed
8	Visual Estimator (odt)	389.9	403.2	-3%
9	Roadside (odt)	404.0	403.2	0%
10	Recovered Biomass (odt)	376.5	377.0	0%
11	Not recovered (odt)	27.5	26.3	4%

a Table note

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 14.7 cm in BiOS to match the average butt diameter of 'top' pieces found 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 1951.7 oven dry tonnes is within 5% of the actual total volume 2030.1 oven dry tonnes derived from the field results. This difference is likely caused by volume missing in the 'uncut trees' (Line 6) portion of the results and will be discussed in that section below.

Line 3 – Merchantable Volume Harvested

'Merchantable volume harvested' in Line 3 describes the proportion of total fibre considered merchantable by the BiOS app after entering the inputs from the Species Operations Tab (see Figure 14). BiOS estimated merchantable volume for the trial cutblock to be 828.8 oven dry tonnes. The merchantable volume harvested value for the actual results column in Table 14, 780.9 oven dry tonnes, was provided by Conifex and represents the actual volume hauled during the primary harvest. Merchantable volume harvested results between the BiOS result and the cruise estimate were similar at a difference of 6%.

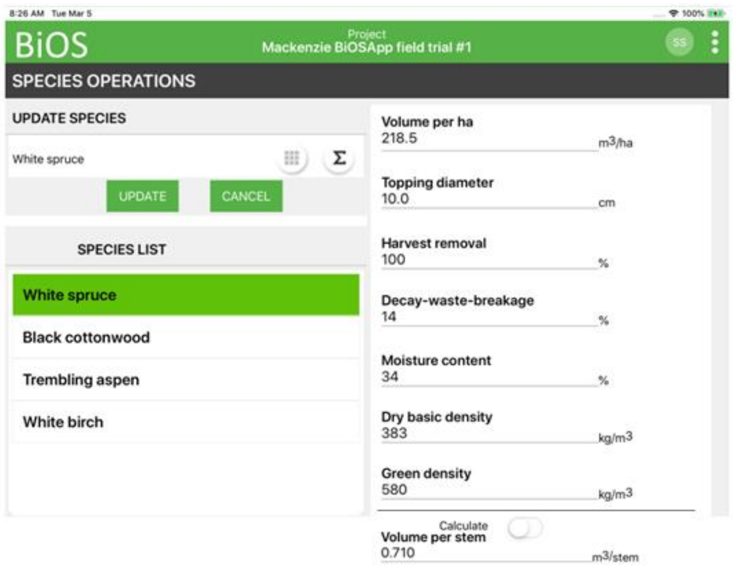

Figure 14 BiOS app Species Operations data entry tab.

Line 4 – Available Biomass

BiOS calculates the 'Available biomass' located in Line 4 of Table 14 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. For this analysis, the same cutover residue as BiOS was used. The BiOS result, 519.3 oven dry tonnes and the actual result, 518.5 oven dry tonnes, were 0% different.

Line 5 – Natural Losses

'Natural losses' from Line 5 in Table 14 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 have fallen off). As the secondary harvest was completed one year after the primary harvest, needles and leaves were not present at the time of the secondary harvest. The natural losses value calculated by BiOS was 78.9 oven dry tonnes. It would be physically impossible to measure fallen needles and leaves in the field so the same value of 78.9 oven dry tonnes was used for the actual results calculation.

Line 6 – Uncut trees

In BiOS, 'Uncut trees' is the volume attributed to trees left standing after the primary harvest and is calculated at 524.6 oven dry tonnes for this analysis. In the current trial, a proportion of deciduous trees were left standing, and a proportion was cut and left in the dispersed area. The volume of these two sources, standing trees and fallen trees, totaled 651.8 oven dry tonnes and was 24% different from the BiOS value.

The difference between values for standing trees is likely caused by one or two factors, or a combination of both. The first factor is the method in which the uncut trees were measured in the field. Simply counting the standing and 'fallen' trees and using the cruise gross merchantable volume per tree value from the cruise may have not addressed the variability that likely exists within the deciduous sample. To correct for this variability, a timber cruise should be completed in the spring. The second factor may be within BiOS itself and how volumes are allocated to different categories. To determine if this is the case, further validations are needed to see if the problem can be replicated.

Line 7 – Cutover residue

Cutover residue described in Line 7 of Table 14 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 'Natural losses at the stump' value found on the Biomass Operations data entry tab. No assessment of cutover residue was completed due to the amount of snow found in the dispersed area at the time of the trial. Therefore, the BiOS value of 115.3 oven dry tonnes was used in both the BiOS calculations and the actual results assessment. A line transect survey may be completed in the spring (after the snow is melted) to validate the BiOS at-the-stump technical recovery efficiency of 71%.

Line 8 – Visual Estimator

The visual estimator calculated volume is independent of the rest of the BiOS flow calculations and was compared with the field results total pile volume. The visual estimator predicted 389.9 oven dry tonnes of volume within the residue piles at roadside. This was 3% different than the 403.2 oven dry tonnes of roadside volume determined in the BiOS flow roadside field (explained below).

Line 9 – Roadside

The BiOS calculation for roadside volume in Line 9 of Table 14 consists of all of 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 403.2 oven dry tonnes. This differed from the BiOS calculation of 404.0 oven dry tonnes by 0%.

Line 10 – Recovered Biomass

The BiOS calculation for recovered biomass in Line 10 of Table 14 consists of the roadside biomass volume that was comminuted and transported in the secondary harvest. To determine recovered biomass volume for the field results, the volume for the logs ground from the dispersed area were subtracted from the volume hauled in the secondary harvest. The BiOS calculation for recoverable biomass of 376.1 oven dry tonnes was 0% different than the calculated field result of 377.0 oven dry tonnes.

Note: The value of 377.0 differs from the hauled volume of 345.1 listed in Table 9 because the estimated volume from pile 5 (53.7 odt) was added to the hauled volume and the volume of the fallen deciduous trees included into the load volume (21.8 odt) was subtracted.

Line 11 – Not recovered

The not recovered value in Line 11 of Table 14 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 (Figure 15). In the field, line transect surveys were completed to determine volume. The BiOS volume for 'not recovered' was 27.5 oven dry tonnes (assuming an average roadside technical recovery efficiency of 71%) and was 4% different than the value of 26.3 oven dry tonnes calculated in the field.

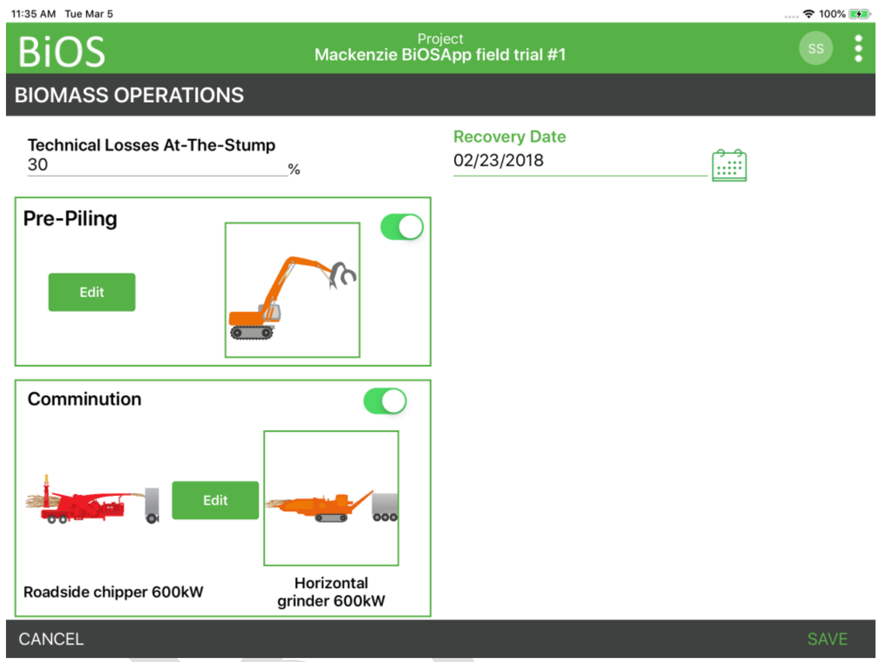

Figure 15. BiOS app Biomass Operations data entry tab.

Overall Analysis of Comparison

In most of the categories found in Table 14, especially those which calculate biomass volume and those from the visual estimator, the BiOS values and the actual field results were very close. This can likely be attributed to the Mackenzie validation occurring in the boreal region of British Columbia, which is similar to other boreal regions in Canada, where many validations were completed for the allometric equations utilized by BiOS to calculate volume (Lambert et al. 2005, Ung et al. 2008). However, until other validations are performed, it is unknown how close the BiOS equations will be in other regions or biogeoclimatic zones in BC where the equations are built from less comprehensive data (i.e.: only 19 Black cottonwood and 11 Douglas-fir Interior).

The 24% difference between the uncut value in BiOS and the volume calculated from the field results is concerning. However, because the total volume calculation for the BiOS and actual results were within 5%, the difference between values for standing trees is likely caused by one or two factors, or a combination of both. The first factor is the method in which the uncut trees were measured in the field. Simply counting the standing and 'fallen' trees and using the cruise gross merchantable volume per tree value from the cruise may have not addressed the variability that likely exists within the deciduous sample. To correct for this variability, a timber cruise should be completed in the spring. The second factor may be within BiOS itself and how volumes are allocated to different categories. To determine if this is the case, further validations are needed to see if the problem can be replicated.

Greenhouse Gas Results

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

For this validation, biomass recovery emissions were calculated by BiOS at 3.9 tonnes (CO2eq) and biomass transport emissions were calculated at 1.7 tonnes (CO2eq) for a total of 5.6 tonnes (CO2eq).

In the Species Breakdown portion of the report it states that 188.3 tonnes of carbon were delivered, which constitutes a 34:1 ratio of delivered to emitted carbon. The report also states that 613.7 tonnes of greenhouse gas were avoided in roadside burning.

CONCLUSION

FPInnovations completed a field validation of the FPBiOS app in the fall of 2018 and winter of 2019. A cutblock located in the SBS biogeoclimatic zone near Mackenzie, BC was chosen. This validation required researchers to measure available biomass in the field, including standing trees, dispersed volume, residual pile volume and volume leftover 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.

In most cases, one notable exception notwithstanding, the field results were within 5% of the BiOS outputs. While this can be viewed favourably, the tree species found in the validation were those whose quality of allometric equation were considered superior due to their distribution and frequency across Canada. Other tree species found in British Columbia have limited distribution and therefore the allometric equations developed for them are likely not as comprehensive. It is felt that validations for BiOS should be completed in a variety of other biogeoclimatic zones and with as many tree species as possible to ensure that the accuracy found during the Mackenzie validation remains consistent and/or proper calibration is developed for the app when used in specific circumstances.

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.

APPENDIX I – BIOS APP DATA ENTRY

Run	Tab	Area
1	Project Information	11.4

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	Sw	222.0	14.7	100	14	38.5	383	628	0.71
			At	71.0	14.7	0	42	38.5	387	634	1.53
			Ac	4.0	14.7	0	91	38.5	338	554	4.41
			Ep	2.0	14.7	0	62	38.5	539	884	1.74

Run	Tab	Average Skid Distance	Harvest Data	Harvest Method
1	Logging Operations	100	23-Feb-18	Full-tree with roadside

Run	Tab	Technical Losses at the Stump	Recovery Date	Pre-piling	Comminution
1	Biomass Operations	30%	23-Feb-19	On (30%)	Grinder (71%)

Run	Tab	Truck Configuration	Destination	Distance
1	Transport	Semi with 3 axles	Conifex, Mackenzie	User-defined (.5km operational, 18km primary)

Run	Tab	Piles	Pile Type	Ht 1	L 1 (or diameter)	W1	Bulking Factor	Apparent Volume	Est Dry Weight
1	Visual Estimator	1	W	3.1	38.8	10.2	20	810	62
Total # of piles - 10		2	W	1.9	47.5	14.3	15	852	49
		3	O (W)	1.5	37	12.8	15	469	27
		4	C	4	10.6		20	118	9
Total est dry weight - 389.9 odt		5	O (W)	2.4	47.9	15.3	15	1161	67
		6	O (W)	1.7	35.3	14.5	15	541	31
		7	O (W)	1.6	70.3	14.9	15	1106	64
		8	W	1	11.8	7.2	15	56	3
		9	O (W)	1.5	11	17.4	15	190	11
		10	W	3.1	37.5	11.5	20	882	68

APPENDIX II – MOISTURE CONTENT ANALYSIS

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_{wet}.

Step 4
Load the tray into the oven and set to 105°C.
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:
$mc\ (\%) = [(m_{wet} - m_{dry}) / (m_{wet} - m_t)] \times 100$

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[1]
- 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.

APPENDIX IV – CRUISE COMPILATION SUMMARY

Net Area: Block : (M) - 120:7120, Plots in Block: 12, TUs: [A : 11.4]
Gross Area: [R/W Removed : 2.1][Grand Total : 13.5]

		Total	Conifer	Decid	B	S	PL	AC	E	AT
Utilization Limits										
Min DBH	cm (M)				17.5	17.5	12.5	17.5	17.5	17.5
Stump Ht	cm (M)				30.0	30.0	30.0	30.0	30.0	30.0
Top Dia	cm (M)				10.0	10.0	10.0	10.0	10.0	10.0
Log Len	m				5.0	5.0	5.0	5.0	5.0	5.0
Volume and Size Data										
Gross Merchantable	m3	4881	2950	1931		2950		463	71	1397
Net Merchantable	m3	3399	2527	872		2527		41	27	804
Net Merch - All	m3/ha	298	222	77		222		4	2	71
Distribution	%	100	74	26		74		1	1	24
Decay	%	20	9	36		9		62	34	28
Waste	%	8	3	14		3		25	24	10
Waste(billing)	%	11	4	32		4		100	63	18
Breakage	%	3	2	4		2		4	4	4
Total Cull (DWB)	%	30	14	55		14		91	62	42
Stems/Ha (Live & DP)		457.4	364.8	92.6		364.8		9.2	3.6	79.9
Avg DBH (Live & DP)	cm	33.6	30.5	43.9		30.5		74.3	48.8	38.6
Snags/Ha		11.9	11.9			11.9				
Avg Snag DBH	cm	26.7	26.7			26.7				
Gross Merch Vol/Tree	m3	0.94	0.71	1.83		0.71		4.41	1.74	1.53
Net Merch Vol/Tree	m3	0.65	0.61	0.83		0.61		0.39	0.66	0.88
Avg Weight Total Ht	m	29.7	26.8	34.1		26.8		33.2	31.0	34.6
Avg Weight Merch Ht	m	23.5	21.3	28.3		21.3		27.9	23.8	28.6
Avg 5.0 m Log Net	m3	0.18	0.19	0.17		0.19		0.11	0.15	0.18
Avg 5.0 m Log Gross	m3	0.25	0.22	0.34		0.22		0.83	0.35	0.29
Avg # of 5.0 m Logs/Tree		3.67	3.26	5.32		3.26		5.28	5.00	5.34
Net Immature	%	51.7	69.5			69.5				
Average Slope	%	3								
LRF and Log Summary										
Net Merch - Stud	%	25.5	34.3			34.3				
Net Merch - Small Log	%	68.2	75.9	45.7		75.9		18.2	31.5	47.5
Net Merch - Large Log	%	31.8	24.1	54.3		24.1		81.8	68.5	52.5
Avg LRF All	bdft/m3	192.8	194.1	189.2		194.1		166.0	181.3	190.6
Statistical Summary										
Coeff. of Variation	%	62.2	60.9	233.9		60.9		180.2	346.4	256.2
Two Standard Error	%	39.5	38.7	148.6		38.7		114.5	220.1	162.8
Number and Type of Plots		MP = 12								
Number of Potential Trees		61								
Plots/Ha		1.1								
Cruised Trees/Plot		5.1								

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