

INTEGRATED BIOMASS HARVESTING

INCREMENTAL COST OF HARVESTING AND FORWARDING FOREST BIOMASS TO ROADSIDE IN NORTHERN NEW BRUNSWICK

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This report describes the methodology and the results of a biomass recovery trial performed in Northern New Brunswick in blocks harvested by two different cut-to-length systems (2-machine and 3-machine systems). A pre-harvest inventory was carried out in the test cut blocks and detailed productivity studies were conducted on the harvesting operations and on the grinding of the roadside harvest residues in the fall of 2022.

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1. INTRODUCTION

This study is a follow-up to an earlier FPInnovations (FPI) biomass logistics study in Northern New Brunswick (Volpé & Desrochers, 2019). A spatially explicit estimate of the fibre availability surrounding the Port of Belledune was created, providing a good understanding of the biomass supply. The study looked at how to create a biomass supply chain for the Belledune Port Authority, identifying supply chain elements to put in place and de-risking solutions. It provided the basis for assessing fibre resource supply and explored the feasibility and sustainability of various supply scenarios. Delivered cost of biomass products were estimated using FPI standard productivity and recovery equations. Availability was estimated for biomass from crown land operations, industrial freehold and private woodlots within a 150 km radius (straight line) from the Port of Belledune. The data provided a wood supply assessment based on AAC and historical harvesting levels. A high-level strategic view of availability using existing and potential new harvesting and transport equipment was also provided.

Building on these results, the New Brunswick Department of Natural Resources and Energy Development (NBDNRED) and The Atlantic Canada Opportunities Agency (ACOA) mandated FPInnovations to assess and validate the incremental cost of harvesting and forwarding forest biomass (logging residues) to roadside using field trials of current harvesting systems operated in New Brunswick. The harvest systems selected for the field trials were cut-to-length applications with both 2-machine (harvester-forwarder) and 3-machine (feller buncher-processor-forwarder) systems. The field trials measured the quantity of logging residues recovered from the logging sites (oven-dry tonnes, odt) and the roadside cost of comminuted biomass in \$/odt. Each incremental process step was identified, and the associated cost reported (harvesting, processing, forwarding, piling down for drying and roadside processing for transportation).

New Brunswick is working towards the development of a bioeconomy strategy. In the development of this strategy, it is important for NBDNRED to understand the incremental costs associated with the harvest, processing, and transportation of forest biomass. The data generated from these operational trials provide a benchmark to help inform decision makers and stakeholders when evaluating the feasibility of future biomass utilization projects.

1.1. Challenges and Study Objectives

Integrating biomass recovery operations with traditional harvesting activities in the forest sector is critical to the successful implementation of a biorefinery plant in the region because of the very high costs of non-integrated harvesting of forest biomass. The impact on supply costs was measured under different integrated harvesting scenarios, while ensuring that fibre formats were compatible across scenarios.

The current study carried out a series of field trials to measure the cost of recovering logging residues. Understanding machine productivity and ultimately roadside wood/biomass cost will ensure that the cost of such treatments and the associated biomass values are well accounted for in the integration of this new supply chain to the regional fibre procurement processes currently in place. It allows fair compensation of all parties including loggers, landowners, and society at large, while ensuring loggers will be able to make the necessary investments (machines, training, etc.) required to conduct such operations. The benefits of this project lie in the opportunity to validate biomass supply availability and cost to emerging bioeconomy investors.

1.2. Industrial Collaborator

Chaleur Forest Products (CFP), the main collaborator, played an important role in this trial. They were tasked with carrying out field trials as instructed by FPI, which included on-site supervision of logging crews, road maintenance, harvesting and transporting forest biomass (logging residues) to the roadside of trial cut blocks. CFP owns sawmills in Belledune and Bathurst, and it also has a woodlands management division based in Miramichi that manages roughly 30% of the province's total Crown allocation. It should be noted that Chaleur Forest Products was purchased by Interfor effective December 1, 2022.

2. METHODOLOGY

The study took place on three different sites, each representing a typical stand from the eastern lowland ecoregion of New Brunswick: a mixedwood stand, a managed jack pine stand and a natural softwood stand. The three sites had similar trafficability characteristics, with no major operational constraints (flat ground, no obstacles, and good soil bearing capacity). All merchantable stems were harvested as part of the prescribed silvicultural treatment. The study blocks were located on Crown Land and were part of the wood volumes allocated to CFP through their Crown Timber License. CFP prepared the sites before the trial, including roads/landings construction and cut block delineation (a.k.a. flagging). In total, 7.9 ha were harvested with a cut-to-length (CTL) 2-machine system (harvester and forwarder), while 19.7 ha were harvested with a CTL 3-machine system (feller buncher, 2 processors and forwarder). These two systems are common in New Brunswick, and both had to be studied to understand how the integration of biomass recovery can be done within traditional harvesting activities. This integration is critical to the success of a biomass supply chain because it should reduce handling and facilitate logistics. In an earlier study, Volpé (2011) found integration could potentially lower harvesting/biomass recovery costs by 29% and increase the quality of recovered biomass. The trials were designed to determine how much biomass could be extracted using both systems under various integrated harvesting scenarios and at what cost. Each scenario is then compared using FPIinnovations national productivity database. Since 1995, FPIinnovations have used information collected from many studies across the Canadian jurisdictions to synthesize productivity functions for most forestry equipment. Over the years, software such as Interface, Interface Map and FPIInterface have offered our members and partners a way to incorporate estimates for productivity and cost of complex scenarios ranging from harvesting to transportation into their planning.

Figure 1 shows the location of the trial sites in northeastern New Brunswick, as well as the harvesting scenarios assigned to the cut blocks.

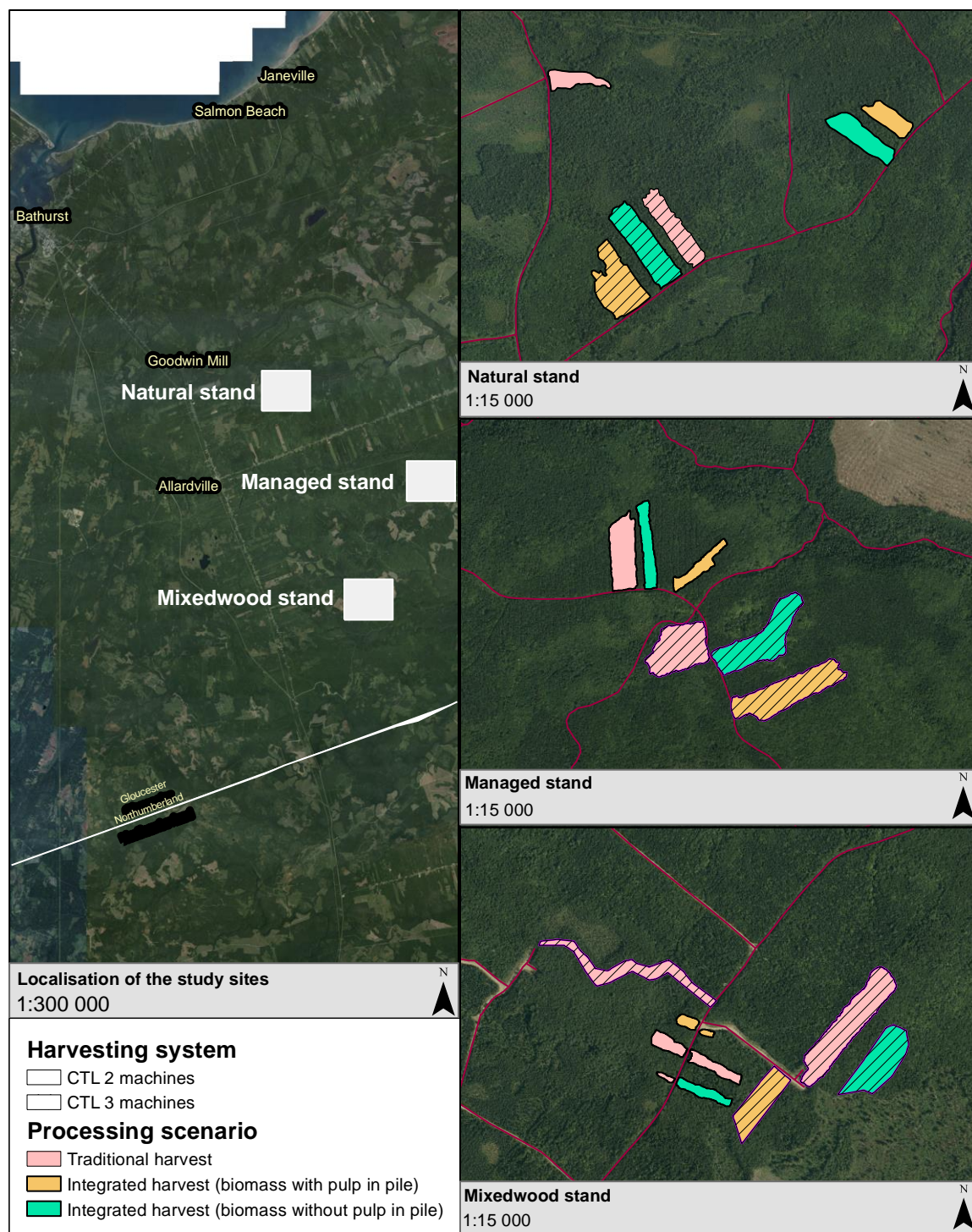


Figure 1. Trial blocks layout with the various harvest systems and biomass recovery variants.

2.1. Stump to roadside scenarios

The monitoring of harvest operations to measure the different time elements of harvest activities was done using FPInnovations standard time and motion study methods.

The overall project involved three different stands conditions, two harvesting systems and three pulpwood variants for each stand. A total of 18 studies were conducted throughout the project as shown in Figure 2. The pulpwood/biomass production scenarios were as follows:

1. Baseline harvest, topping at 10 cm, branches left at the stump (products: logs, pulp).
2. Integrated harvest without pulp in the biomass piles (products: logs, pulp, biomass).
3. Integrated harvest, with pulp in the biomass piles (products: logs, biomass).

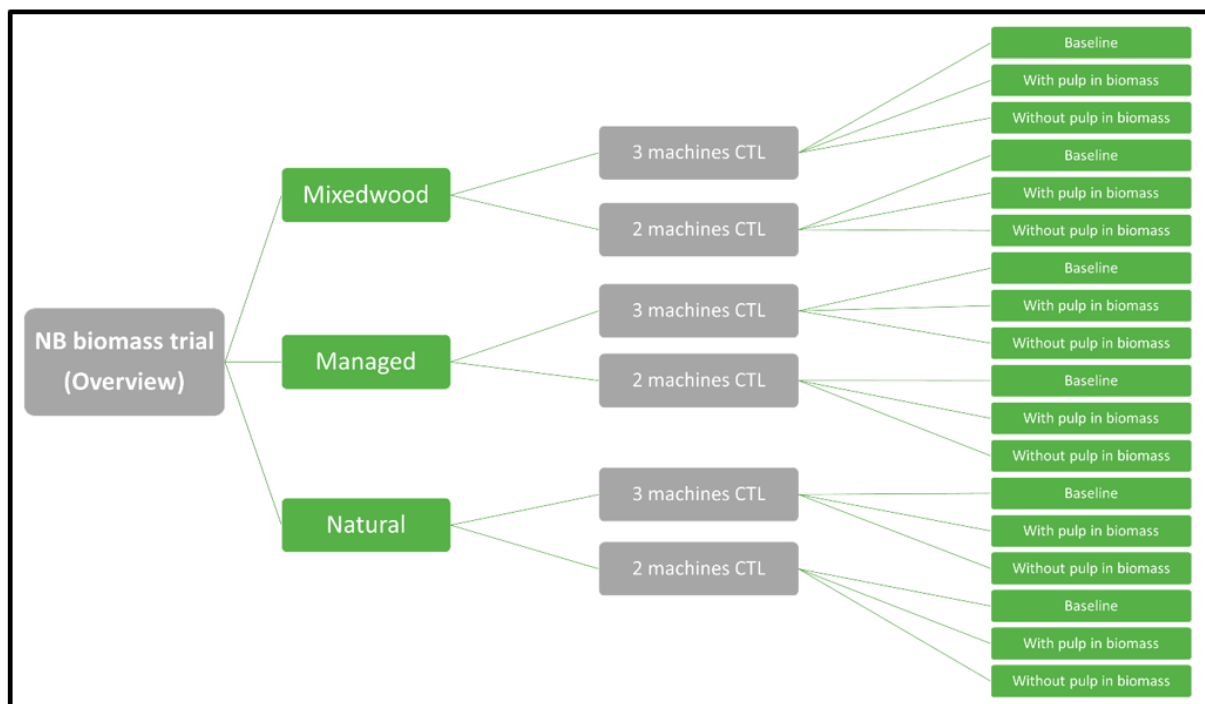


Figure 2. Project overview and the 18 harvesting scenarios.

The different harvesting guidelines allowed to measure the difference in recovered volumes and additional biomass potential of larger merchantable top diameter. This showed the effects on harvesting costs when increasing roundwood topping diameter and the recovery of larger logging residues (including residue forwarding and piling at roadside). This information will help understand the impacts of supply chain integration.

Table 1 provides the topping diameter guidelines approved by NBDNRED for this trial and the scenarios tested (baseline, with and without pulp).

Table 1. Topping guidelines for each scenario

Species	Topping guidelines over bark (cm)		
	Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles
Spruce—Fir—Jack Pine	7.5	7.5	10.8
Hemlock—Red pine—Tamarack	7.5	7.5	22.0
White Pine	7.5	7.5	18.0
Aspen	7.6	7.6	24.5
Hardwood	7.6	7.6	24.5

2.2. Equipment

> THREE-MACHINE SYSTEM

The 3-machine CTL system was owned by G.C. Entreprise Forestière Ltée. The feller-buncher was a Tigercat 845C equipped with a Quadco head (Figure 3). Following the buncher, two identical Doosan processors with LogMax 6000B heads were used. The extraction was done with an 18-tonne capacity Ponsse Buffalo King forwarder.



Figure 3. Three-machine cut-to-length harvesting system.

> TWO-MACHINE SYSTEM

This harvesting system uses a harvester and a forwarder (Figure 4). The harvester, a Landrich LR 2.0 equipped with a Ponsse H7 HD head was owned by Aurèle Mallais et fils Ltée (AMF). It was paired with G.C. Entreprise Forestière Ltée’s Ponsse forwarder for five weeks of the study, and with AMF’s forwarder for one week, a Tigercat 1075C with an upgraded boom, grapple and basket (25 tonnes capacity).



Figure 4. Cut-to-length harvesting using a 2-machine system.

2.3. Forest Inventory

Several steps are needed to measure the biomass recovery (by species and assortments) of an operation. The following inventories were required to measure the full biomass flow of recoverable fibre from stump to mill for the different scenarios.

1. Pre-Harvest Stand Inventory

The pre-harvest stand inventory was conducted by employees of NBDNRED during the summer of 2022. It consisted of standard timber cruises with variable radius prism plots (81 plots, 27 plots per stand type, minimum 3 plots per scenario).

2. Merchantable Volume Extracted

The volume of products processed by the harvester and processors was measured directly in the cut blocks by a CFP employee during harvesting. These data were paired with the time and motion study data to precisely evaluate the productivity of the machines. For each scenario, a registered N.B. scaler measured the merchantable volumes of roundwood extracted and piled at roadside. The piles were separated by scenario and identified with paint to avoid any confusion during logging and later transport and comminution operations.

3. Biomass Volumes Extracted From the Sites

The amount of biomass recovered in the different scenarios was estimated using the transport load slips. FPI and CFP collaborated to ensure the constant monitoring of comminution and transportation of the biomass volumes (Figure 5). Trucks hauling biomass residues were weighed at the Miramichi installations of Envirem Organics Inc.



Figure 5. Biomass extracted from the sites.

4. Post-Harvest Residual Volume Survey

For all scenarios, post-harvest assessment of woody volumes left on the ground was done using line transects (2 × 20 m long) (Wagner, 1968). Standing residual volumes were evaluated using fixed area circular plots. Figure 6 shows an example of data collection.



Figure 6. Post-treatment transects being performed in the managed stand without pulp in the biomass piles.

5. Sampling and Evaluation of Moisture Content

Samples of comminuted biomass were taken from each truck load and brought to the Wood Science and Technology Center in Fredericton for moisture content analysis (Figure 7). A 20 L sample of comminuted biomass per scenario was also taken to the FPI laboratory for granulometric analysis.



Figure 7. Bags of chipped biomass collected for moisture content analysis of each truck load.

2.4. Harvesting Productivity Measurements

The harvested area for each scenario was deemed to have enough productive machine hours (5-6 PMH) recorded to establish valid cost estimates. Based on the cruise stand volume and machine productivities, it was determined that each scenario required approximately from 0.5 to 2.0 ha of area depending on the system. The 3-machine system harvested a much larger area than the 2-machine system in the same amount of time and so more area was required to ensure sufficient timing duration for the study. The blocks harvested areas allowed for enough volume harvested to generate acceptable productivity estimates (detailed time and motion studies) for each machine, while also producing enough logging residue volumes to support the grinding operation.



Figure 8. The 3-machine system in the managed stand with pulp and biomass piles.

2.5. Biomass Grinding and Transportation

Residue grinding and transport are critical components of the biomass flow because of their high cost. FPI measured productivity using time and motion studies of the roadside grinding operations. The grinder was a tracked Morbark 4600XL with a 1050 HP engine. It was fed by a tracked Liebherr LH 30M Industry Litronic. Both machines were owned by Axcor Renewable Energy Inc. The grinder's conveyor was loading the comminuted biomass directly in the trailers. It was operating only when a transport truck was ready to be loaded. Figure 9 shows the complete grinding operation.



Figure 9. Grinding operation in mixedwood with pulp in the biomass piles scenario.

The comminuted biomass was shipped to Envirem Organics Inc., a Miramichi company which specializes in transformation and commercialization of organic bio-products for lawns, gardens, turf and agriculture. The transport distances were 79 km for the natural stand, 62 km for the managed stand, and 67 km for the mixedwood stand. The transportation was done by trucks from Axcor, Envirem, AMF and J.J. Allain. They each did one to three trips per day. The amount of biomass recovered in each scenario was estimated using the transport load slips.

3. RESULTS AND DISCUSSION

3.1. Pre-harvest inventory

NBDNRED chose the trial blocks from a mixedwood stand, a managed jack pine stand, and a natural softwood stand based on their structure and suitability to support the implementation of biomass recovery in Northern New Brunswick. The metrics that influence available biomass are tree size, stand volume, and species composition. The average stem and stand volume varied from 0.151 m³/stem and 171 m³/ha in the mixedwood block to 0.217 m³/stem and 229 m³/ha for the managed pine stand as indicated in Table 2. Species composition is also key when doing biomass recovery because some species are more conducive to biomass recovery (Figure 10).

Table 2. Average stocking, stem and stand volume per stand type.

Stand type	Stem volume (m ³ /stem)		Stand volume (m ³ /ha)		Stand density (stems/ha)		Proportion of softwood
	Live	Dead	Live	Dead	Live	Dead	(% of total vol)
Mixedwood	0.151	0.156	171	10	1131	64	53
Managed	0.217	0.129	229	24	1057	186	89
Natural	0.170	0.182	220	10	1295	55	83

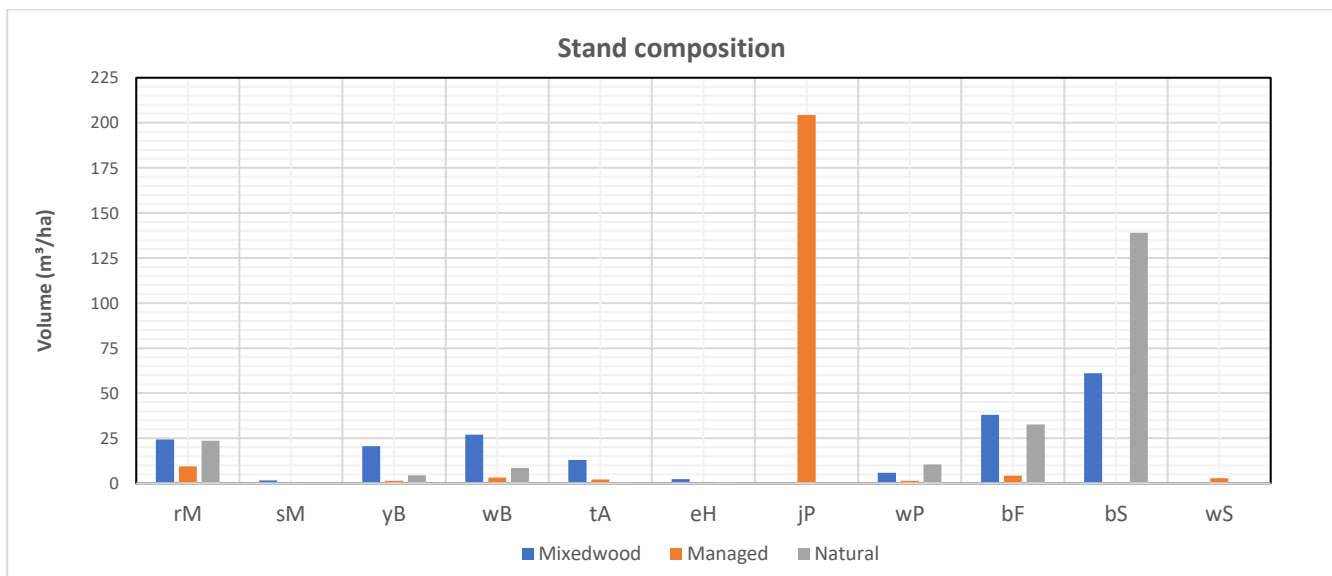


Figure 10. Species composition per stand type.

3.2. Productivity & Cost Analysis

From September to November 2022, productivity was measured every two weeks. The productivity was affected at different stages of harvesting depending on the scenario evaluated. To ensure compatible comparisons, results are provided using standardized data. To standardize the data, a ratio was calculated between the measured productivity, as determined from detailed timing, and the productivity predicted by FPI productivity models for the same conditions. By using the correct average harvested volume per tree, in this case 0.150 m³/tree, the ratio was applied to the productivity models. For the project, a standardized distance of 300 m was used for forwarding.

> CUT-TO-LENGTH HARVESTING USING THE 3-MACHINE SYSTEM

– Felling

The feller-buncher operator was very experienced. He was instructed to add, when feasible, the unmerchantable trees into the bunches instead of crushing them to the ground (Figure 11). The felling of unmerchantable trees represented less than 1% of the total machine productive time. As for the baseline observations, the operator was between 2% and 12% more productive than the prediction from the FPI national productivity database for stem volumes of 0.150 m^3 ($41.9 \text{ m}^3/\text{PMH}$).



Figure 11. Feller buncher bunching behind him to enable biomass processing.

Productivities measured in both biomass scenarios (with and without pulp in the biomass) were the same since the operator used the same technique. However, a 10% decrease from the baseline was observed when he was piling behind the machine versus the usual pattern which he had to do to help the processors in the biomass recovery trials. This trend can be seen in Figure 12. Eighty-one percent of the observations were within $\pm 20\%$ of the reference productivity in clearcut conditions for this type of machine and none were below the lower range limit of 80% of the national productivity model prediction.

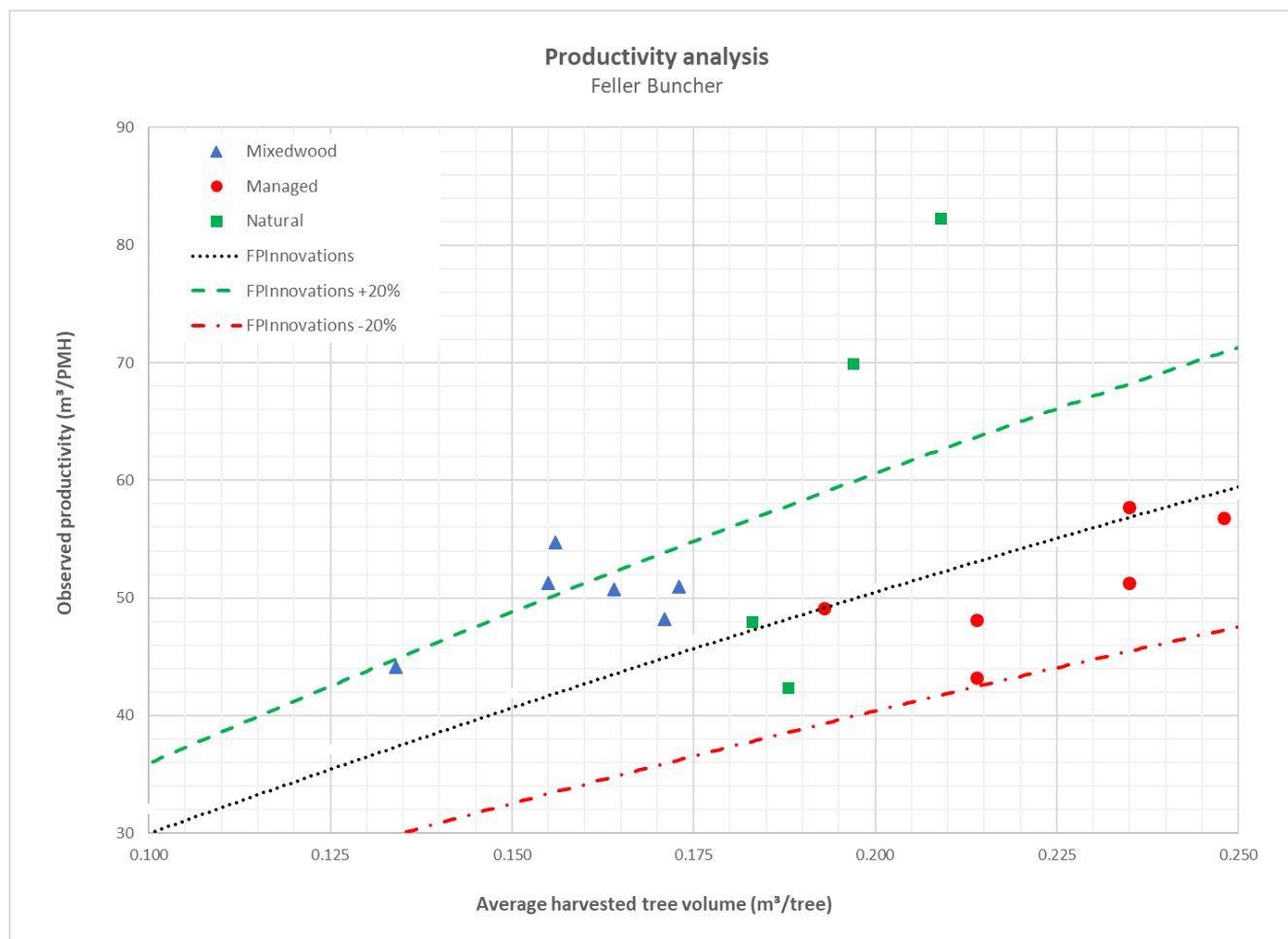


Figure 12. Feller-buncher productivity observations during the trials.

– Processing

Processor operators were relatively inexperienced. The results presented in this report represent an average of the performances of both operators in each harvesting/biomass recovery scenario. It should be noted that this phase was closely monitored so that the additional time required by the processors to handle the harvest residues could be calculated.

The productivity differences with FPI model predictions ranged from -60% (without pulp in the biomass for the mixedwood stand), to +53% (with pulp in the biomass for the managed stand). Regarding the lowest productivity (40%), it should be noted that this observation was made when the operators were in the learning curve for the specific operations. During that time, operators were trying to develop the optimal technique to sort biomass (Figure 13). When benchmarking the overall productivity observations with the national curve, 74% of them were within $\pm 20\%$ of the model. Also, there was no significant difference in productivity between the “baseline” and the “without pulp in the biomass” scenarios (Figure 14). This is normal given that the guidelines for these two scenarios were nearly identical. Most of the time, the differences were less than 1% and were primarily caused by the extra handling of biomass at the end of the processing cycle.



Figure 13. The two processors working in the mixedwood stand with pulp in the biomass pile scenario.

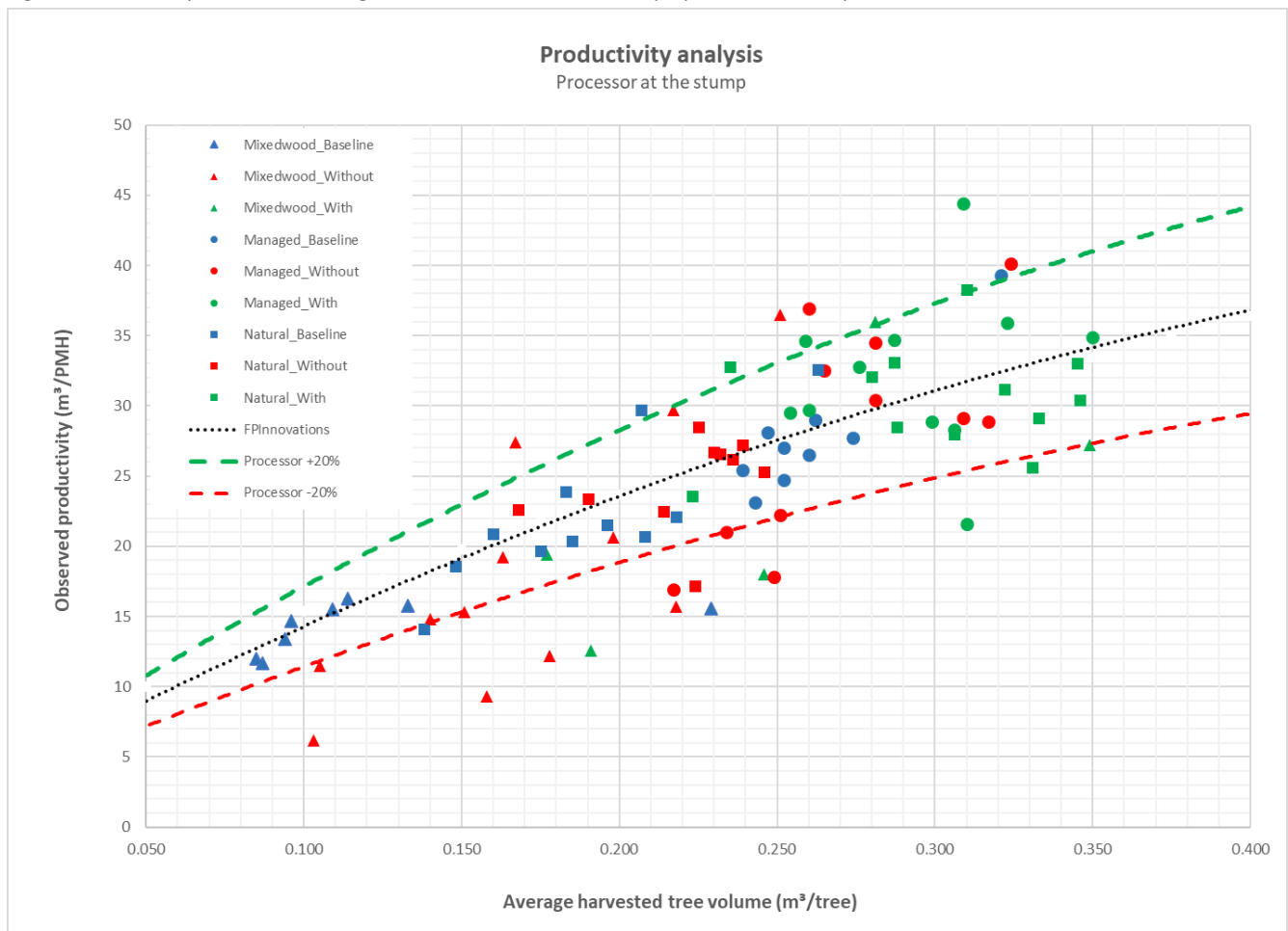


Figure 14. Processor productivity observations during the trials.

– Forwarding

The forwarder operator had over 30 years of experience. Forwarding productivity was generally higher with larger log sizes. It was also mostly above the national average (ranging from 70% to 203% or reference curve at a standardized volume of 0.150 m³/stem), as can be seen in Figure 15. As expected, due to the sorting of products and the variable log size, the productivity of the forwarder varied from one trip to another. The average volume per log increased with an increase in topping diameter, increasing productivity. Also, peaks in productivity were observed where trembling aspen was present since loading, unloading, moving to load activities were quicker with this specie, while requiring fewer loading points. Note that results from the “baseline” scenario and the “without pulp in the biomass” are the same since the guidelines (topping and roundwood products) were identical.

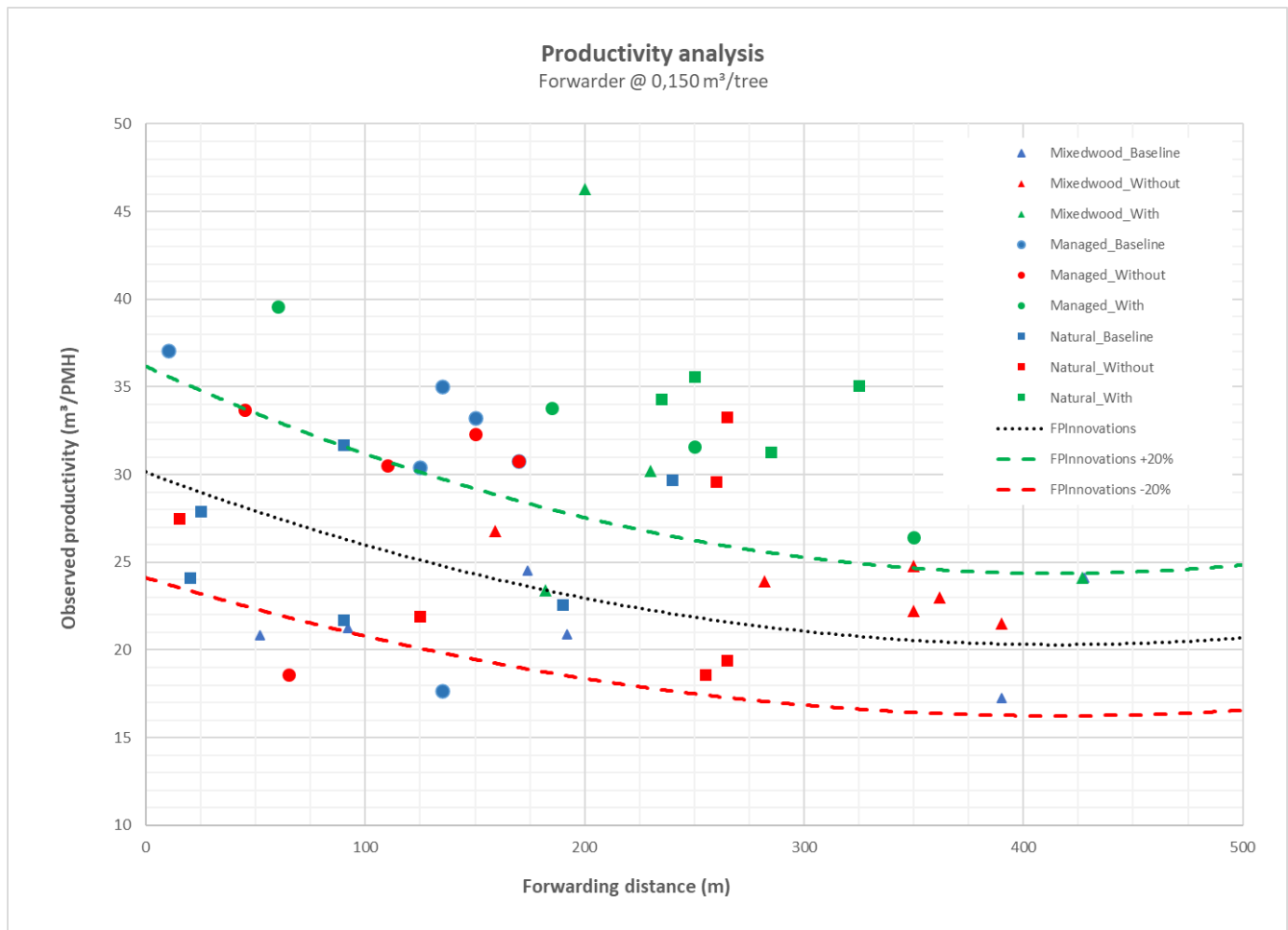


Figure 15. Forwarder productivity observations in the 3-machine system trials.

> CUT-TO-LENGTH HARVESTING USING THE 2-MACHINE SYSTEM

– Harvesting

During felling and processing, the harvester piled the merchantable wood on the left of the machine and the residues on the right. The residues were piled beside the trail to avoid contaminating the biomass by the machines and to facilitate their recovery by the forwarder (Figure 16). The detail timing aimed to estimate the additional time required by the harvester to handle the harvest residues. Overall, the scenario with pulp in the biomass piles provided the best results regardless of the site because processing time was less than in operations with pulp recovery.



Figure 16. The harvester working in the managed stand with pulp in the biomass piles scenario.

Most of the productivity observations (86%) were within $\pm 20\%$ of the FPI national model predictions. A deeper analysis shows that the scenario without pulp in the biomass had consistently lower productivity. This is predictable because of the addition of an extra product to the usual harvesting cycle (processing and handling biomass). The highest productivities were obtained in the “with pulp in the biomass” scenario (153% and 130% of reference curve) as shown in green in Figure 17.

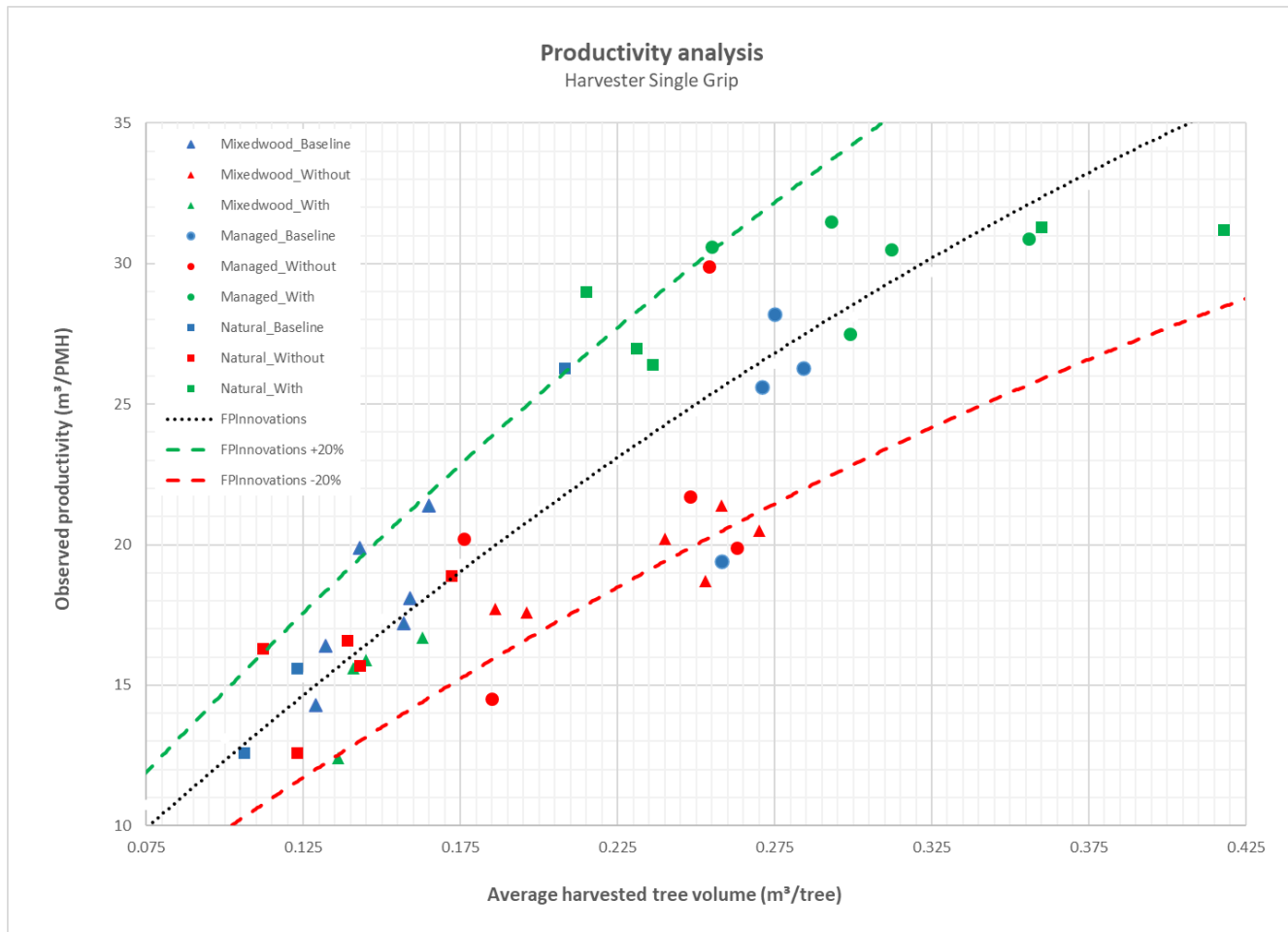


Figure 17. Harvester productivity observations during the trials.

– Forwarding

Two different operators were observed during forwarding in the two-machine system trials. The operator #1 and machine (18-tonne Ponsse Buffalo King) working in the mixedwood and managed stands was the same as in the three-machine system blocks. As already mentioned in the methodology, the operator #2 and the forwarder change in the natural stand (Figure 18). On average, one operator's productivity exceeded FPI's productivity model by +21% (operator #1), while the second operator's productivity was +24% higher (Figure 19). Because they were so close, there was no need for distinction between the two. The log forwarding productivities were usually higher than the national average (ranged from 64% to 176% of predictions). Much of the data (66%) observed are aligned with FPIInnovations' national productivity models.



Figure 18. Tigercat 1075C forwarder working in the natural baseline scenario.

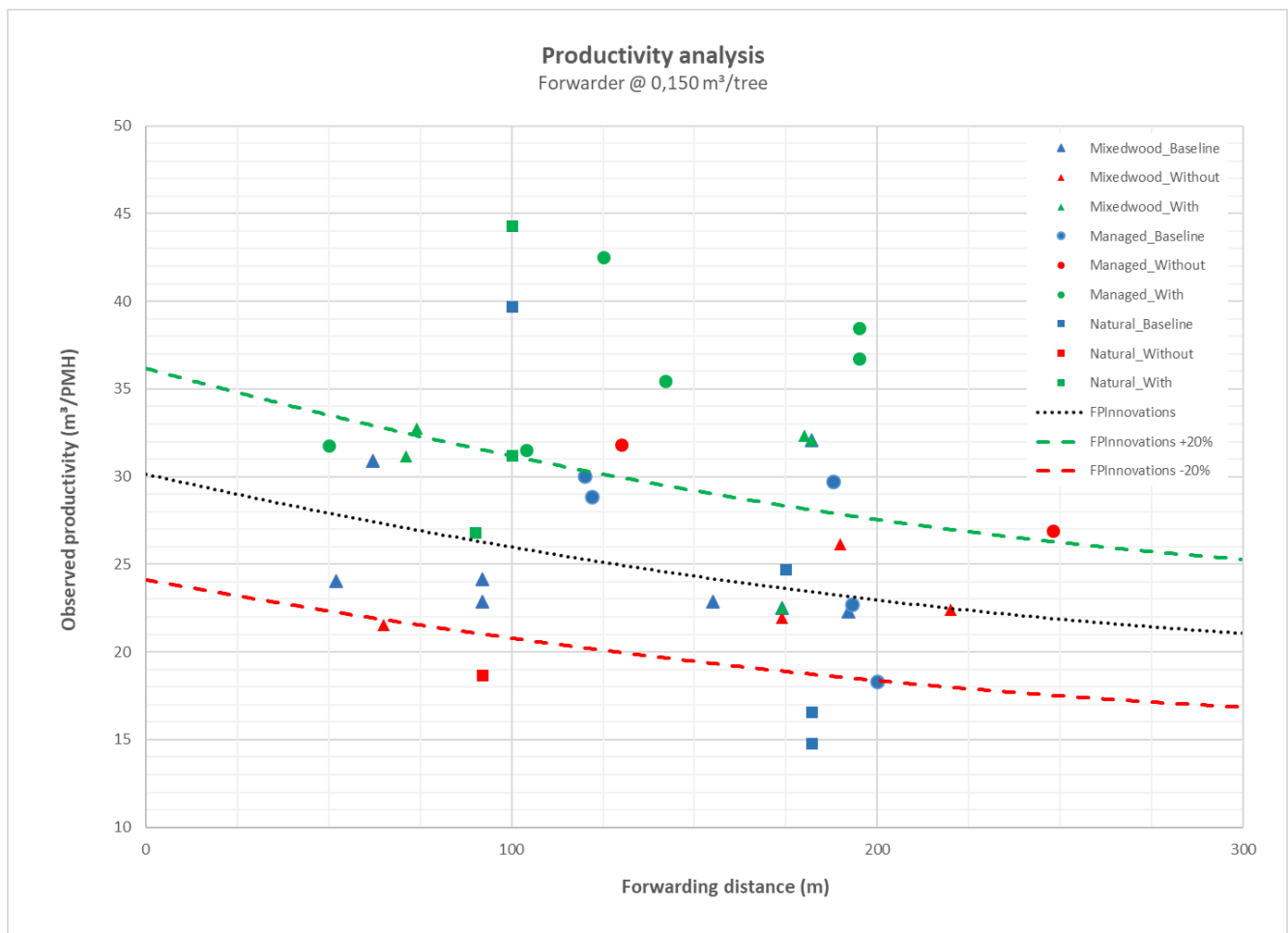


Figure 19. Forwarder productivity observations in the 2-machine system trials.

Table 3 provides a summary of all productivity observations recorded during the project. Detailed results from every harvesting/biomass recovery scenario are available in Appendix 1.

Table 3. Standardized productivity data per scenario at 0.150 m³/stem and 300 m forwarding distance

System	Stand type	Machine type	Measured productivity (m ³ /PMH)			
			Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles	FPI national database prediction
3 machines	Mixedwood	Feller Buncher	46.8	42.9	42.9	41.9
		Processor	17.2	16.9	20.4	19.8
		Forwarder	22.6	22.6	25.9	21.5
	Managed	Feller Buncher	44.7	40.7	40.7	41.9
		Processor	19.1	19.2	20.8	19.8
		Forwarder	21.8	21.8	27.5	21.5
	Natural	Feller Buncher	48.6	44.6	44.6	41.9
		Processor	19.2	19.2	20.6	19.8
		Forwarder	21.9	21.9	29.4	21.5
2 machines	Mixedwood	Harvester	17.4	17.1	18.4	17.3
		Forwarder	21.8	21.3	24.4	21.5
	Managed	Harvester	16.7	16.6	18.2	17.3
		Forwarder	25.8	25.8	32.8	21.5
	Natural	Harvester	17.0	17.2	19.0	17.3
		Forwarder	19.9	19.7	26.3	21.5

^a Estimate using FPI national productivity model in a clearcut context.

Direct harvest costs vary slightly depending on the stand type and the biomass recovery scenario (Table 4). Hourly operating costs of the feller buncher, processors and forwarder were calculated at \$180/PMH (productive machine hour) and \$200/PMH for the harvester (See Appendix 2 for costing details). The costs given in Table 4 reflect the fact that the study was done in the early implementation stage (except for baseline scenario) and are expected to decrease once operators become more experienced with the techniques. In general, the costs observed during trials are lower than those calculated using FPI productivity models. The roadside costs of the 2-machine system were lower than those of the 3-machine system by \$2.34/m³ to \$2.68/m³ depending on the scenario.

Table 4. Standardized estimated direct harvesting costs at 0.150 m³/stem and 300 m forwarding distance.

System	Stand type	Machine type	Cost (\$/m ³)			
			Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles	FPI national database prediction
3 machines	Mixedwood	Feller Buncher	4.28	4.67	4.67	4.77
		Processor	10.44	10.63	8.82	9.09
		Forwarder	7.96	7.96	6.96	8.37
		Roadside	22.68	23.26	20.45	22.23
	Managed	Feller Buncher	4.47	4.92	4.92	4.77
		Processor	9.42	9.40	8.64	9.09
		Forwarder	8.26	8.26	6.55	8.37
		Roadside	22.15	22.58	20.11	22.23
	Natural	Feller Buncher	4.12	4.49	4.49	4.77
		Processor	9.40	9.40	8.75	9.09
		Forwarder	8.22	8.22	6.12	8.37
		Roadside	21.74	22.11	19.36	22.23
2 machines	Mixedwood	Harvester	11.50	11.67	10.87	11.56
		Forwarder	8.27	8.47	7.36	8.37
		Roadside	19.77	20.14	18.23	19.93
	Managed	Harvester	11.99	12.04	10.99	11.56
		Forwarder	6.97	6.97	5.49	8.37
		Roadside	18.96	19.01	16.48	19.93
	Natural	Harvester	11.76	11.64	10.55	11.56
		Forwarder	9.07	9.12	6.84	8.37
		Roadside	20.83	20.76	17.39	19.93

3.3. Biomass Recovery

In the 3-machine system, the feller buncher operator was required to position the tree bunches behind the machine to facilitate processing. Positioning the bunches for biomass recovery accounted for 10% of the productive time for the biomass scenarios compared to the baseline (Figure 20).



Figure 20. Different feller buncher “move to bunch” techniques: A = Standard and B= Biomass recovery

Tops were placed on the trails opposite side of the roundwood logs in the 2-machine system to minimize handling. Positioning the tops for biomass recovery accounted for an average 17% of the harvester productive time in the “without pulp in the biomass” scenario and 29% in the “with pulp in the biomass” scenario (Table 5). Handling large tops was more difficult and time-consuming. Tops were left on the trail in the baseline block, and no productive time was spent dealing with them.

Table 5. Harvester biomass extra handling per scenario (% of PMH)

Stand type	Biomass handling (% of PMH)		
	Baseline no biomass	Without pulp in the biomass piles	With pulp in the biomass piles
Mixedwood	0	17	33
Managed	0	16	29
Natural	0	17	26

Forwarding Residues

The forwarding cycle time hauling biomass residues to roadside varied between scenarios, but the average load (odt/load) and the productivity (odt/PMH) was highest when no pulp was produced (Table 6). The forwarder productivity was estimated to range between 8.7 odt/PMH to 20.3 odt/PMH at a standardized 150 m forwarding distance (6.2 odt/PMH to 14.4 odt/PMH at 300 m).

These productivity results were expected based on the observed pulpwood variant (without vs. with) because regardless of stand type, the “with pulp in the biomass” scenario always showed higher productivity (Figure 21). The average biomass load size varied between 2.7 and 5.8 odt/load.

Table 6. Biomass residue forwarding productivity

Stand type	Biomass recovery scenario	Harvesting System	Average load size (odt)	Average productivity observed (odt/PMH)	Standardized productivity at 150 m (odt/PMH)	Standardized productivity at 300 m (odt/PMH)
Mixedwood	Without pulp	3 machines	2.8	7.4	9.5	7.8
		2 machines	3.0	9.7	8.8	6.2
Managed	With pulp	3 machines	4.9	18.7	14.4	10.8
		2 machines	3.6	15.6	11.4	8.5
Natural	Without pulp	3 machines	3.1	9.9	8.7	6.4
		2 machines	2.7	9.1	7.8	5.4
Mixedwood	With pulp	3 machines	4.6	13.5	11.3	8.4
		2 machines	3.6	14.3	11.2	7.8
Managed	Without pulp	3 machines	3.1	8.4	8.3	6.8
		2 machines	3.6	13.3	9.0	5.8
Natural	With pulp	3 machines	5.8	22.6	17.4	12.3
		2 machines	5.1	20.2	15.6	10.9



Figure 21. Forwarding residues in the managed stand with pulp in the biomass pile.

Figure 22 shows the productivity data collected during the residue forwarding. As in previous figures, the black line represents predictions from the FPI productivity model associated with biomass extraction and the red line is for merchantable wood productivity (estimation of the residue recovery productivity for an integrated operation). Note the presence of labels on the observations corresponding to the Tigercat forwarder (25 tonne capacity). All other observations are associated with the Ponsse forwarder (18 tonne capacity).

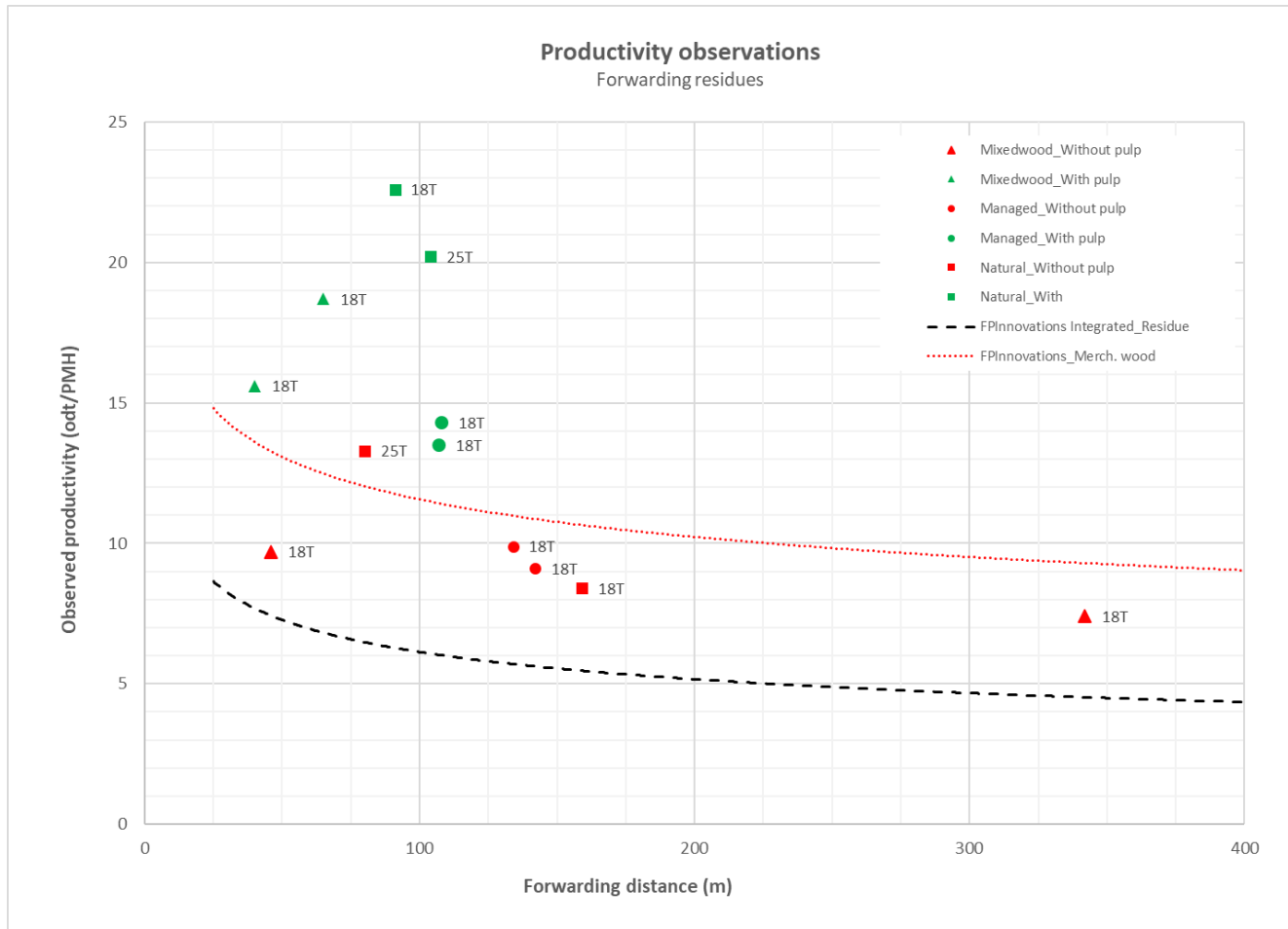


Figure 22. Residue forwarding productivity observations.

Grinding Operation

A horizontal grinder was used for this trial that lasted two weeks in November 2022 (Figure 23). The Morbark 4600XL (1050 HP) grinder owned by Axcor Renewable Energy Inc. featured an 8-inch grid. Loading a chip truck took between 11 and 40 minutes, with an average of 20 minutes per load (12.4 odt). The grinder was mostly idle, waiting for trucks.



Figure 23. Residue grinding and loading directly into chip vans.

Table 7. Residue grinding productivity

System	Stand type	Biomass recovery scenario	Number of loads	Total weight (odt)	Productivity (odt/PMH)	Cost (\$/odt) ^a
3 machines	Mixedwood	Without pulp	8	85	30.6	19.58
		With pulp	13	129	36.8	16.29
	Managed	Without pulp	6	80	37.7	15.93
		With pulp	13	136	28.7	20.90
	Natural	Without pulp	6	93	41.6	14.42
		With pulp	12	173	42.8	14.02
2 machines	Mixedwood	Without pulp	3	29	23.1	25.98
		With pulp	4	36	34.0	17.63
	Managed	Without pulp	3	30	49.0	12.24
		With pulp	3	36	42.9	13.99
	Natural	Without pulp	3	50	57.4	10.45
		With pulp	4	66	48.5	12.36

^a Grinder and loader costing estimated at \$600/PMH for this trial

4. BIOMASS RECOVERY

4.1. Biomass Flow

FPI measured the volume of harvesting residues recovered during the trials. A full biomass flow was generated using the post-harvest assessment at the stump, the quantity of biomass left at roadside and the quantity of biomass recovered in each scenario from the delivered truck weights at Envirem Organics Inc. (Detailed results provided in Appendix 3)

Post-Harvest Assessment

Post-harvest assessment (losses at the stump) surveys were conducted immediately after forwarding using the line transect survey method to measure slash on the ground and residual standing trees for each scenario.

Biomass Left Beneath Piles

The quantity of biomass left beneath piles (roadside losses) was measured. On all test sites, residues left beneath piles were generally too scattered to be recovered (Figure 24). A default loss at roadside value of 2% was applied to residues left beneath piles.



Figure 24. Biomass left beneath piles after the grinding operation (managed stand).

Biomass Recovered at Roadside

The quantity of biomass recovered at roadside in each scenario was based on the delivered truck weights. Each load slip was compiled and the total weight delivered was divided by the area covered by each harvesting scenario.



Figure 25. With pulp in the biomass pile scenario (mixedwood stand)

> MIXEDWOOD STANDS

Table 8 presents the biomass flow related to the different harvesting scenarios in the mixedwood stands and Figure 26 provides a visual representation of this flow. The total biomass available (at the stump and at roadside) ranged between 77.1 and 141.8 odt/ha. Technical recovery efficiency is an important indicator. For the 3-machine system, the technical recovery efficiency was 50% for the with pulp in the biomass scenario. A measured value of 37.6 odt/ha (post treatment) is higher than the one obtained under similar conditions for the 2-machine system (29.0 odt/ha). Biomass/merchantable volume ratio is very sensitive to changes in topping specifications as well as stand composition. In this site, the ratio varied from 0.26 odt/m³ to 1.56 odt/m³ depending on the scenario. The more contrast between topping guidelines, the more the ratios will vary.

Table 8. Biomass flow for mixedwood stands biomass scenarios.

Mixedwood stand Biomass flow	3 machines		2 machines	
	Without pulp in the biomass piles	With pulp in the biomass piles	Without pulp in the biomass piles	With pulp in the biomass piles
Total fibre (odt/ha)	152.4	159.4	185.2	173.5
Merchantable (odt/ha)	75.4	21.6	97.2	31.6
Residual trees (odt/ha)	0	0	0	0
Available biomass (odt/ha)	77.1	137.8	88.1	141.8
Losses at the stump (odt/ha)	37.6	47.0	29.0	46.1
Available at roadside (odt/ha)	39.5	90.8	59.1	95.7
Roadside losses (odt/ha)	0.8	1.8	1.2	1.9
Recovered biomass (odt/ha)	38.7	89.0	57.9	93.9
Technical recovery efficiency (%) ^a	50	65	66	66
Biomass/merchantable ratio (odt/m ³) ^b	0.26	1.56	0.27	1.14

^a Technical recovery efficiency = Recovered biomass/Available biomass.

^b Biomass/Scaled merchantable ratio = Recovered biomass/Merchantable

Biomass ratios (biomass/merchantable) of this magnitude (especially with pulp in the biomass scenario) are very impressive.

A typical mixedwood stand structure, for example, as encountered in the trials could have a biomass/merchantable ratio of 1.58 odt/m³. To demonstrate this, calculations were performed using the technical efficiency achieved by the 3-machine system in mixedwood. The breakdown in the biomass piles without pulp is shown in Figure 26 on the right, and the breakdown with both pulp and biomass is shown on the left. The transfer of available biomass from one scenario to another is the most important element to note. This effect is caused by the stand's hardwood composition as well as larger topping guidelines. The same patterns can be seen in other types of stands at different scales.

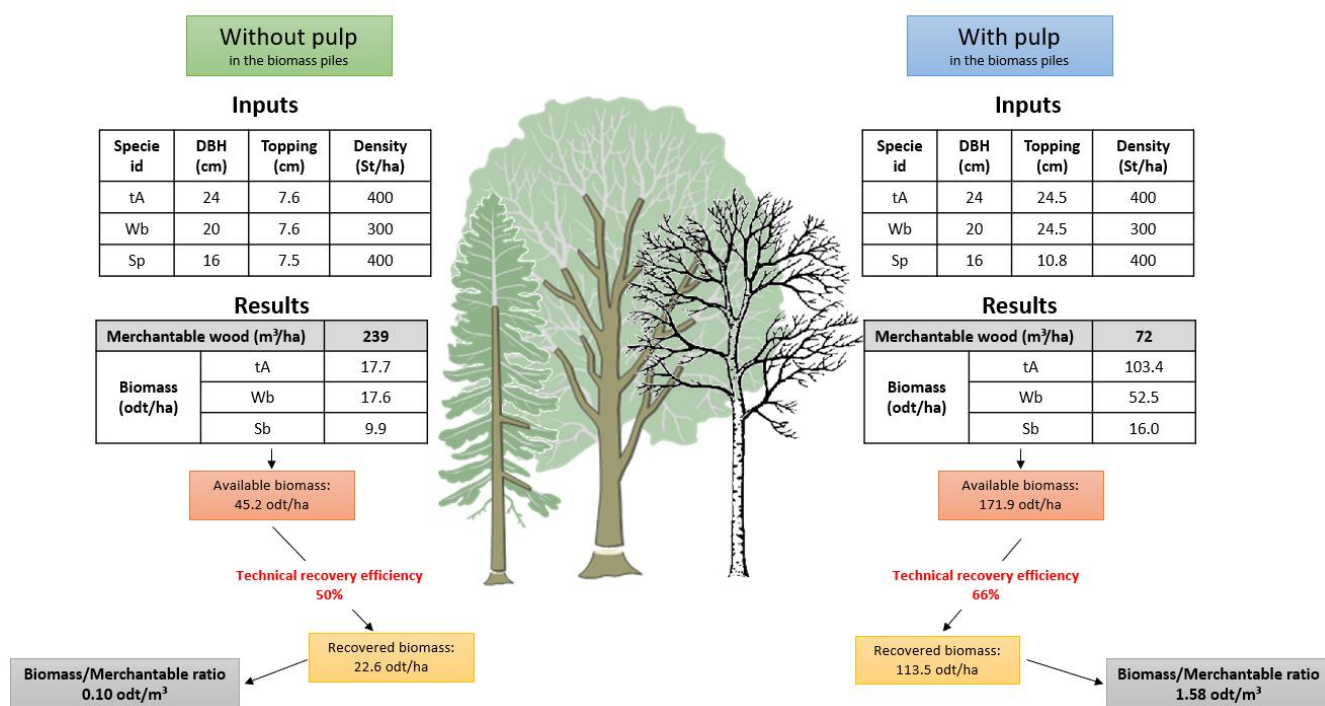


Figure 26. Breakdown of estimated biomass/merchantable ratio depending on the biomass scenarios.

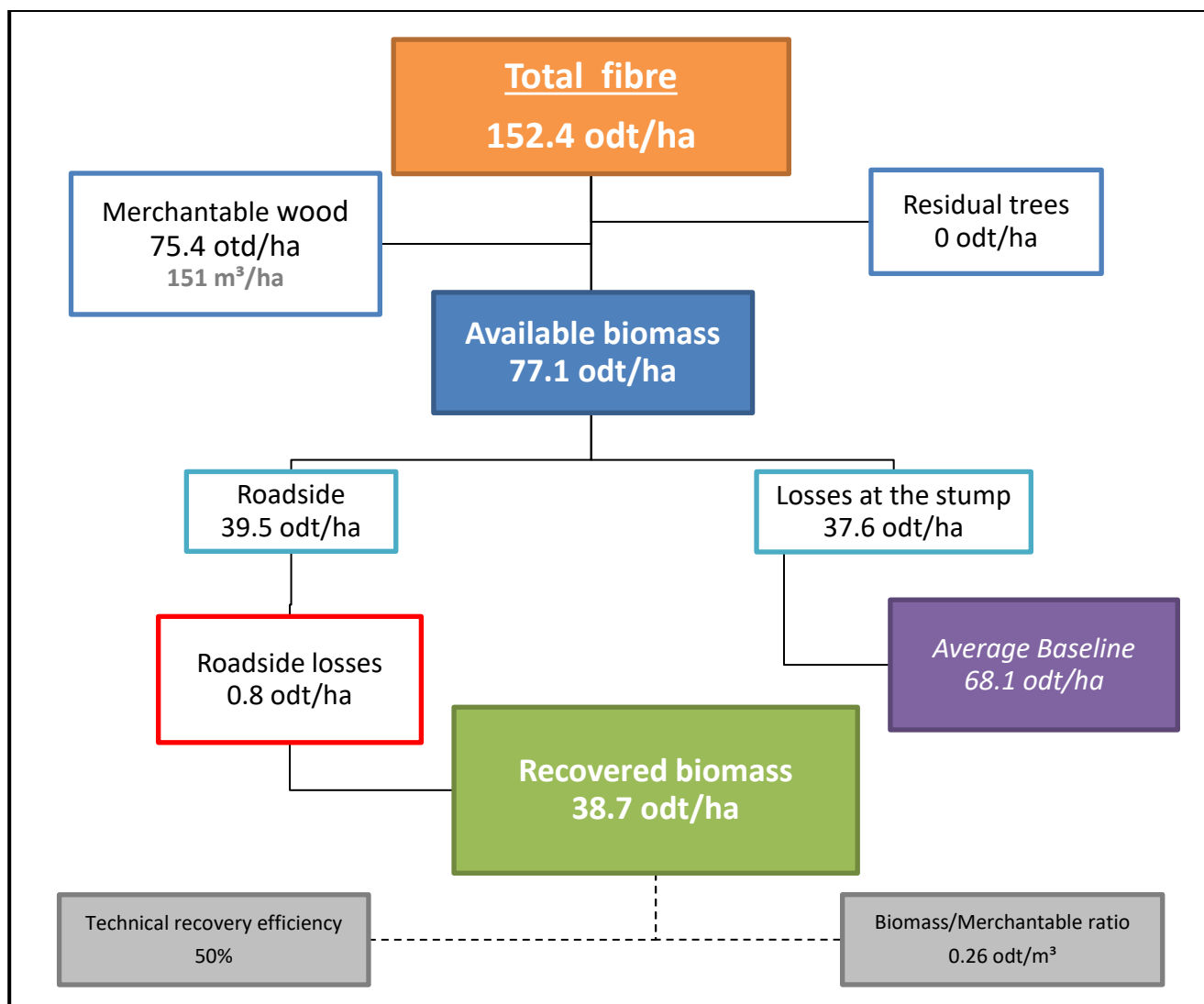


Figure 27. Biomass flow in the mixedwood stand with a 3-machine system in the without pulp in the biomass scenario.

> MANAGED STANDS

A summary of the trial results in the managed stand conditions are presented in Table 9 and Figure 28. As the managed stand was more homogenous than the mixedwood, the results were more consistent. Biomass recovery ratios (biomass/merchantable volume) varied from 0.17 odt/m³ to 0.20 odt/m³ for the without pulp in the biomass scenario, and 0.40 odt/m³ to 0.42 odt/m³ for the with pulp in the biomass scenario. From a technical recovery efficiency perspective, the 2-machine system is more efficient than the 3-machine system for biomass recovery (67% and 77% vs. 59% and 64%). The losses at the stump (32.8 odt/ha), which are directly related to the available biomass and technical recovery efficiency, were measured as high with the 3-machine system because of a single 24 cm piece in the post treatment sampling. This single piece caused a direct 5% decrease in the recovery efficiency (64% instead of 69%).

Table 9. Biomass flow for the managed stand biomass scenarios

Managed stands Biomass flow	3 machines		2 machines	
	Without pulp in the biomass piles	With pulp in the biomass piles	Without pulp in the biomass piles	With pulp in the biomass piles
Total fibre (odt/ha)	132.7	177.2	133.0	157.8
Merchantable (odt/ha)	78.2	83.2	83.4	83.8
Residual trees (odt/ha)	0	0	0	0
Available biomass (odt/ha)	54.5	94.0	49.6	74.0
Losses at the stump (odt/ha)	21.6	32.8	15.8	15.8
Available at roadside (odt/ha)	32.9	61.2	33.8	58.2
Roadside losses (odt/ha)	0.6	1.2	0.7	1.1
Recovered biomass (odt/ha)	32.2	60.0	33.1	57.0
Technical recovery efficiency (%) ^a	59	64	67	77
Biomass/merchantable ratio (odt/m ³) ^b	0.20	0.40	0.17	0.42

^a Technical recovery efficiency = Recovered biomass/Available biomass.

^b Biomass/Scaled merchant ratio = Recovered biomass/Merchantable

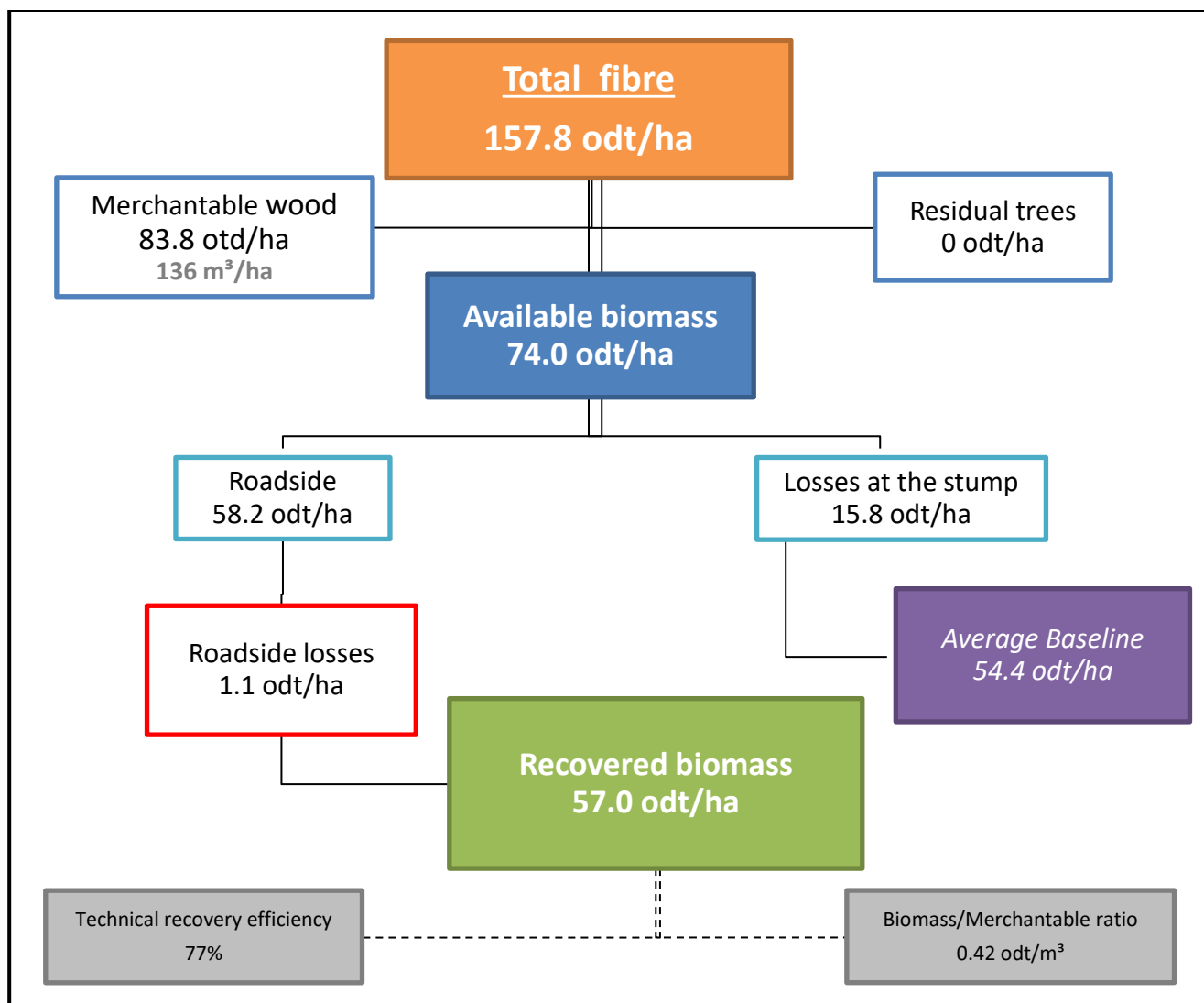


Figure 28. Biomass flow in the managed stand with the 2-machine system in the with pulp in the biomass scenario.

> NATURAL STANDS

The trial results in natural stands conditions are summarized in Table 10 and Figure 29. There is a clear difference between the 2 scenarios tested notwithstanding the system studied. Indeed, looking at technical recovery efficiency, similar differences of 12% to 13% are observed. Biomass recovery ratios (biomass/merchantable volume) ranged from 0.19 odt/m³ to 0.72 odt/m³, mainly influenced by the local species compositions of the natural stands.

Table 10. Biomass flow for the natural stands biomass scenarios

Natural stands Biomass flow	3 machines		2 machines	
	Without pulp in the biomass piles	With pulp in the biomass piles	Without pulp in the biomass piles	With pulp in the biomass piles
Total fibre (odt/ha)	141.9	162.7	150.8	158.3
Merchantable (odt/ha)	68.5	49.2	84.5	43.8
Residual trees (odt/ha)	0	0	0	0
Available biomass (odt/ha)	73.5	113.5	66.3	114.5
Losses at the stump (odt/ha)	28.2	30.6	25.7	29.5
Available at roadside (odt/ha)	45.3	82.9	40.6	85.0
Roadside losses (odt/ha)	0.9	1.6	0.8	1.7
Recovered biomass (odt/ha)	44.4	81.3	39.8	83.3
Technical recovery efficiency (%) ^a	60	72	60	73
Biomass/Merchantable ratio (odt/m ³) ^b	0.26	0.63	0.19	0.72

^a Technical recovery efficiency = Recovered biomass/Available biomass.

^b Biomass/merchant ratio = Recovered biomass/Merchantable

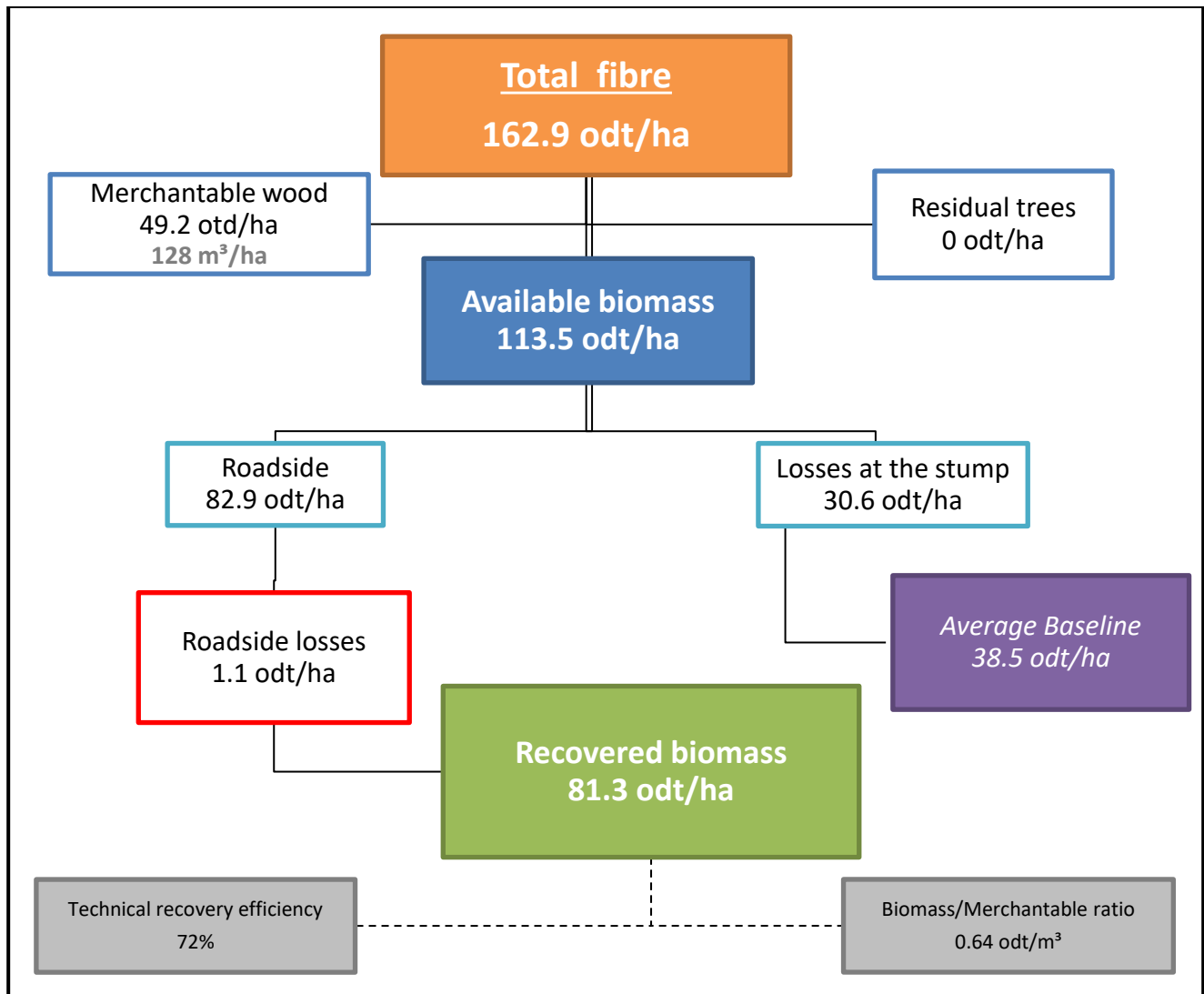


Figure 29. Biomass flow in the natural stand with the 3-machine system in the with pulp in the biomass scenario.

4.2. Moisture Content

Chip samples were collected during the November 2022 grinding operation (one sample per van) and their moisture content was measured (see Appendix 4) by the Wood Science and Technology Centre (WSTC) of the University of New Brunswick (UNB). Overall, 78 bags of samples were received and stored at - 6 °C. Table 11 provides the results of the moisture content analysis, showing an average moisture content for all samples of 42%.

Table 11. Moisture content of chip samples collected in November 2022 from all harvest sites

Stand type	3-machine system		2-machine system	
	Without pulp in the biomass piles	With pulp in the biomass piles	Without pulp in the biomass piles	With pulp in the biomass piles
Mixedwood	38%	41%	46%	44%
Managed	38%	40%	42%	42%
Natural	48%	41%	46%	45%
Average	42%			

4.3. Particle size

A particle size analysis was also done on the chip samples from the grinding operation (Figure 30). The Morbark 4600 XL grinder used an 8-inch (20 cm) grid.



Figure 30. Size classification of a wood chip sample from the grinding operation

Depending on the stand type, between 64% (managed stand, with pulp in the biomass) to 92% (natural stand, without pulp in the biomass) of the particles went through the 22 mm sieve and 7% (managed stand, with pulp in the biomass) to 38% (natural stand, without pulp in the biomass) through the 6 mm sieve. Figure 31 shows the particle sizes for each stand type.

Table 12. Particle size analysis

Stand type	Biomass recovery scenario	Particle size (%)					
		45 mm	22 mm	16 mm	6 mm	3 mm	0 mm
Mixedwood	Without pulp	11	8	23	33	9	16
	With pulp	14	10	22	33	10	11
Managed	Without pulp	11	11	27	31	9	11
	With pulp	36	14	26	17	4	3
Natural	Without pulp	8	6	18	30	15	23
	With pulp	28	15	23	24	6	4

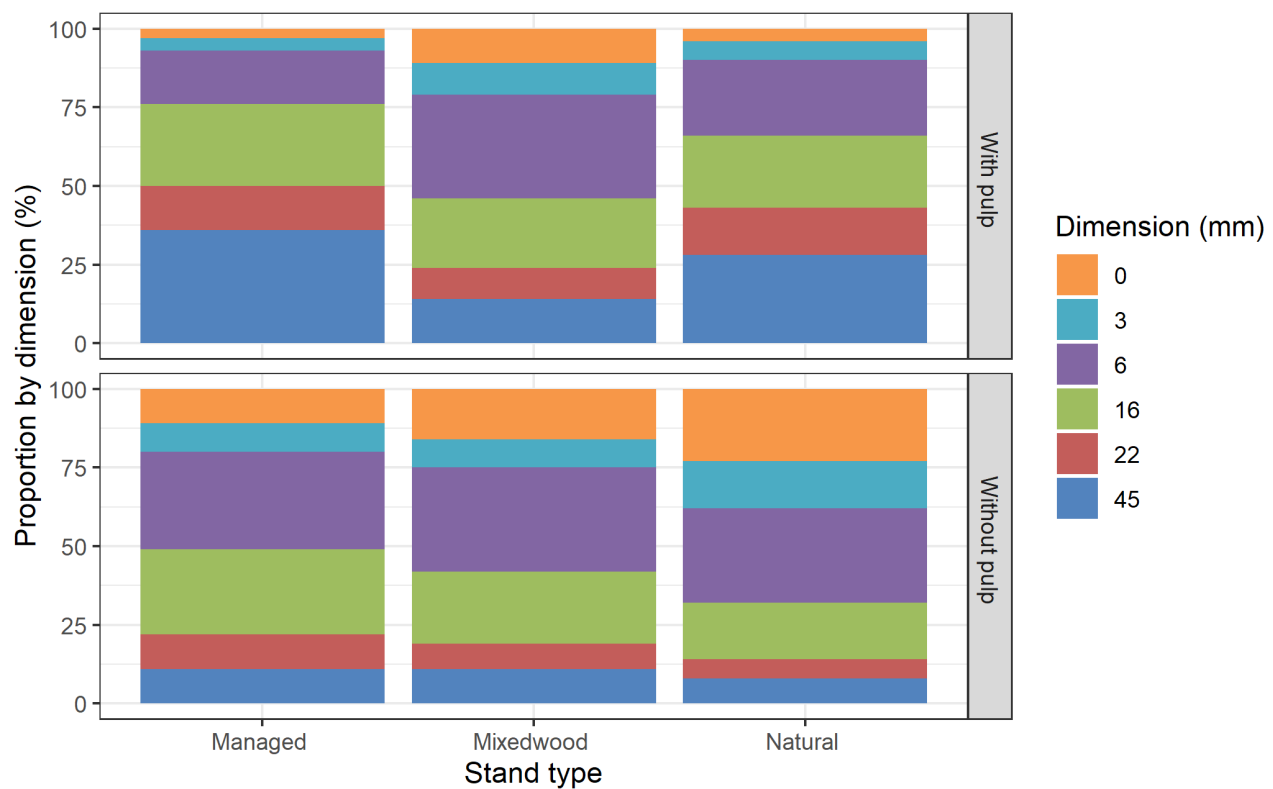


Figure 31. Particle size by stand and by biomass recovery scenario.

5. SUMMARY OF TRIAL RESULTS

Tables 13, 14 and 15 present estimated costs of comminuted biomass loaded in trucks at roadside (excluding transport cost) for the two harvesting systems and the three stand types. Also included in the tables are the key indicators related to integrated biomass recovery operation.

Table 13. Combined roadside costs of harvesting roundwood and biomass (loaded in trucks) for the two harvesting systems in mixedwood stands

Mixedwood stands Supply activities	Cost (\$/odt)			
	3 machines		2 machines	
	Without pulp in the biomass piles	With pulp in the biomass piles	Without pulp in the biomass piles	With pulp in the biomass piles
Baseline roadside harvesting cost	47.25		41.19	
Merchantable volume, roadside harvesting cost^a	48.46	42.60	41.96	37.98
Biomass extraction, total cost^b	51.40	44.11	60.16	53.09
Felling & processing/Harvesting	2.98	5.04	6.71	11.85
Residue forwarding ^c	17.64	11.58	16.27	12.41
Loading/grinding	19.58	16.29	25.98	17.63
Stumpage fees (residues only)	0.20	0.20	0.20	0.20
Roads (pads + maintenance)	5.00	5.00	5.00	5.00
Other fees (supervision, planning, etc.)	6.00	6.00	6.00	6.00
Round wood harvesting and biomass recovery indicators				
Harvesting relative cost (%) ^d	104	92	101	83
Technical recovery efficiency (%)	50	65	66	66
Biomass/merchantable ratio (odt/m ³)	0.26	1.56	0.27	1.14
Total biomass recovery (odt/ha)	39	89	58	94

^a Round wood harvesting cost under biomass recovery operation at 0.150 m³/tree

^b Impact on roundwood operation

^c Standardized distance of 150 m used

^d Roadside observed cost/FPIInnovations reference cost prediction

Table 14. Combined roadside costs of harvesting roundwood and biomass (loaded in trucks) for the two harvesting systems in mixedwood stands

Managed stands Supply activities	Cost (\$/odt)			
	3 machines		2 machines	
	Without pulp in the biomass piles	With pulp in the biomass piles	Without pulp in the biomass piles	With pulp in the biomass piles
Baseline roadside harvesting cost	64.77		55.44	
Merchantable volume. roadside harvesting cost^a	66.02	55.80	55.58	48.19
Biomass extraction, total cost^b	50.48	51.80	51.66	50.62
Felling & processing/Harvesting	2.66	3.77	8.22	11.14
Residue forwarding ^c	20.69	15.93	20.00	14.29
Loading/grinding	15.93	20.90	12.24	13.99
Stumpage fees (residues only)	0.20	0.20	0.20	0.20
Roads (pads + maintenance)	5.00	5.00	5.00	5.00
Other fees (supervision, planning, etc.)	6.00	6.00	6.00	6.00
Round wood harvesting and biomass recovery indicators				
Harvesting relative cost (%) ^d	99	87	104	87
Technical recovery efficiency (%)	59	64	67	77
Biomass/merchantable ratio (odt/m ³)	0.20	0.40	0.17	0.42
Total biomass recovery (odt/ha)	32	60	33	57

^a Round wood harvesting cost under biomass recovery operation at 0.150 m³/tree

^b Impact on roundwood operation

^c Standardized distance of 150 m used

^d Roadside observed cost/FPIinnovations reference cost prediction

Table 15. Combined roadside costs of harvesting roundwood and biomass (loaded in trucks) for the two harvesting systems in natural stands

Natural stands Supply activities	Cost (\$/odt)			
	3 machines		2 machines	
	Without pulp in the biomass piles	With pulp in the biomass piles	Without pulp in the biomass piles	With pulp in the biomass piles
Baseline roadside harvesting cost	48.31		46.29	
Merchantable volume, roadside harvesting cost ^a	49.13	43.02	46.13	38.64
Biomass extraction, total cost ^b	43.80	37.46	44.29	46.09
Felling & processing/Harvesting	2.11	3.38	8.36	12.42
Residue forwarding ^c	16.07	8.87	14.29	10.11
Loading/grinding	14.42	14.02	10.45	12.36
Stumpage fees (residues only)	0.20	0.20	0.20	0.20
Roads (pads + maintenance)	5.00	5.00	5.00	5.00
Other fees (supervision, planning, etc.)	6.00	6.00	6.00	6.00
Round wood harvesting and biomass recovery indicators				
Harvesting relative cost (%) ^d	99	87	104	87
Technical recovery efficiency (%)	60	72	60	73
Biomass/merchantable ratio (odt/m ³)	0.26	0.63	0.19	0.72
Total biomass recovery (odt/ha)	44	81	40	83

^a Round wood harvesting cost under biomass recovery operation at 0.150 m³/tree

^b Impact on roundwood operation

^c Standardized distance of 150 m used

^d Roadside observed cost/FPIinnovations reference cost prediction

Two vs. Three-Machine Systems

There were some notable differences between the operations of the two harvesting systems. At the deployment level, the 3-machine system is more complex because it requires larger blocks, since the feller-bunchers treat a large area quickly and because of the additional machines (processors) to be used. In addition, the feller buncher operator must adapt his felling technique (bunch behind the machine) to optimize processing. Table 16 shows the cost difference between the 3-machine system vs. the 2-machine system for the different scenarios. On average, the cost difference was \$2.54/m³ in favour of the 2-machine system.

Table 16. Difference in roadside cost between systems by stand types and biomass scenarios

Stand type	Cost difference between 3-machine system vs. 2-machine systems			
	Baseline Logs, pulp, no residues	Without pulp in the biomass piles	With pulp in the biomass piles	Average difference (\$/m ³)
Mixedwood	+2.91	+3.12	+2.22	+2.75
Managed	+3.19	+3.57	+3.63	+3.46
Natural	+0.91	+1.35	+1.97	+1.41
Average (\$/m³)	+2.34	+2.68	+2.61	+2.54

Another important difference is that the technical recovery efficiency of the 2-machine system is always equal or better than that of the 3-machine system (Table 17). The most likely causes of higher fibre losses with the 3-machine system are greater tree breakage from the feller buncher (e.g., felled trees going under the machine tracks, tree breakage when bunching) and the measuring system zero resetting losses with the processors.

Table 17. Technical recovery efficiency difference between systems by stand types and biomass scenarios

Stand type	Biomass technical recovery efficiency of 2-machine system vs. 3-machine system (%)	
	Without pulp in the biomass piles	With pulp in the biomass piles
Mixedwood	+16	+1
Managed	+8	+13
Natural	0	+1

6. BIOMASS INTEGRATION POTENTIAL

This study identified some challenges to implement biomass recovery in Northern New Brunswick. This section provides recommendations for best practices during planning, harvesting and comminution operations. Guidelines for residue collection should be prepared and a training program for residue collection should be implemented prior to launching biomass recovery operations.

NBDNRED

- Evaluate the sensitivity of sites targeted for forest biomass harvesting (Thiffault *et al.*, 2015).
- Eliminate any sensitive areas from targeted stands.
- Select the highest potential areas (based on access, transport distance, volume per ha, tree size, hardwood vs. softwood content).
- Define guidelines (scenarios) based on DNR best interests (ex.: pulp recovered as biomass in hardwood only).
- Establish a silviculture credit for residue recovery (\$/ha) to promote biomass recovery. Further, an integrated roundwood and residues operation greatly facilitates site preparation (Thiffault & Thiffault, 2019). Integrated operations significantly reduce the amount of residual standing trees and much of the residues left on the ground, especially larger diameter residues that impede site preparation. Previous studies have also shown a reduction of debris on the ground by 50% (Desrochers & Volpé, 2021). By removing residual trees and reducing the quantity of residues on the ground, site preparation costs are reduced. It also facilitates subsequent silvicultural work by removing obstacles on sites for tree planters and brush cutters (Desrochers 2020).

Industry (licensees)

- The recovery of biomass needs to be planned and integrated into roundwood harvesting operations. For new recovery operations to be effective, the best conditions available must be considered. The integration of operations is the key to success by minimizing extra handling of the biomass.
- Feller-buncher or harvester operators must be instructed to include dry and sound deadwood and non-commercial species in bunches.
- The harvester or processor operators need to position the tops at the edge of trails to facilitate their recovery by the forwarder—proper positioning will avoid wasted time for the forwarder.
- To permit recovery and avoid contamination, never travel on top of the residues.
- Even though results in this current project did not show any dramatic productivity losses when recovering biomass, it has been observed in past studies that some harvester and processor operators experienced productivity losses when having to position residues along the trails. This productivity loss is believed to decrease over time from 15% down to an estimated 5% in a mature operation (Desrochers & Volpé, 2017).
- Biomass recovery requires greater forwarder bunk capacity and adjustment of shifts schedules, and in many cases the addition of forwarding shifts.
- Prefer 20-ton or larger forwarders (7 odt/load) with large capacity bunks. Because of the limited capacity of the cranes and bunks of forwarders, long stem sections generated by increased topping guidelines

must be processed to shorter lengths (20 feet or less) to be handled efficiently by the forwarders (Figure 32).



Figure 32. Example of difficult to handle long stem sections for the forwarder.

- The space required to pile the residues at roadside, the width of the roads, the landing size required by the chipping operation and the time intervals between truck loads all present unique challenges of each operation. Managers should consider all these factors during the initial planning of the harvesting operation and road network. Selected piling and chipping locations should be well drained and exposed to the wind.
- Manage roadside areas for both roundwood and biomass piles.
- Set the location of the biomass piles based on the planned chipping operation.
- Schedule chipping/transport operation based on biomass seasoning, road access and equipment availability (e.g., trucks).
- Harvesting contractors must be paid for all properly piled biomass at roadside ready for recovery—an advance payment system like the one used for roundwood should be developed for biomass. The operation must be well explained, and contractors must perceive that these operations can be successful and profitable before they are willing to commit financially.

Contractors

- The forest industry sees major challenges in biomass recovery operations because of the significant capital and specialized labour requirements. Many machines and new operators will be needed to harvest the 300,000 odt/year available within the 150-km straight-line distance from the Port of Belledune (Figure 33, Desrochers & Volpé, 2019).

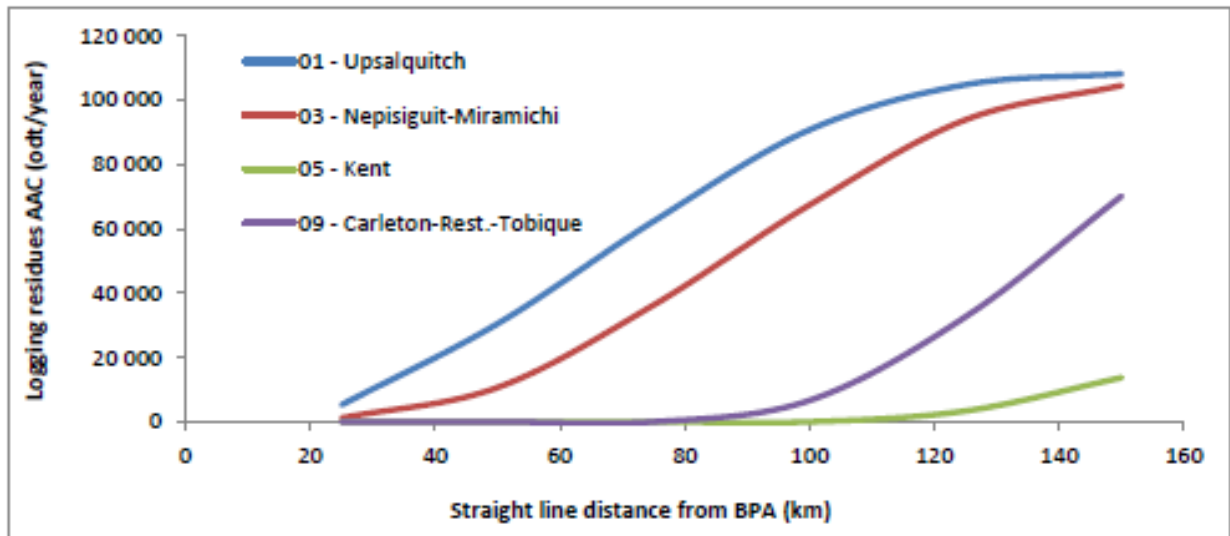


Figure 33. Forest biomass (logging residues) from AAC in Licenses 01, 03, 05 and 09 (<150 km of the Port of Belledune)

- Many forest contractors are small (one or two harvesting teams) and have limited financial resources to get involved in biomass recovery. The largest and well-known contractors should be targeted to set up a biomass recovery operation and demonstrate its viability and profitability. A fair and transparent price needs to be defined for biomass to attract new contractors.
- Integration of residue recovery with the extraction of merchantable wood works best when the forwarder is more productive than the harvester and therefore has idle time. The availability of forwarders varies, depending on the extraction distance and the number of products to sort. The availability of space at roadside to pile harvest residues is also an important factor to consider. The main advantages of integrated harvesting are a significant reduction in residue recovery costs and optimal forwarder utilization (by eliminating idle time). Where applicable, integrating the recovery of residues with the extraction of merchantable wood is strongly recommended.

7. CONCLUSION

A biomass recovery trial, including 18 combinations of stand types, harvesting systems and pulpwood/biomass recovery scenarios was conducted in Northern New Brunswick. Two cut-to-length systems (2-machine and 3-machine) currently used in the region were studied to measure how much biomass can be recovered from such operations and at what cost it can be delivered to Miramichi. The harvesting operations took place during 6 weeks from September to November 2022. Post-harvest site assessments were conducted to measure the leftover residues at the stump. Residue grinding operations took place in mid-November for all blocks.

A detailed biomass flow was produced for each scenario. Three different stand types were studied during these biomass trials based on their stand structure and species composition (mixedwood, managed and natural). Around 13 ha and 721 odt of biomass were harvested with the 3-machine system, and 4.5 ha and 247 odt with the 2-machine system. For each of the three stand types, three different processing scenarios were analyzed: (1) baseline with no biomass recovery (logs and pulp), (2) without pulp in the biomass and (3) with pulp in the biomass.

For each stand type and biomass scenario evaluated, the biomass recovery ratio was determined (odt/m³) by system. In the with pulp in the biomass scenario, increasing the topping diameter to 10.8 cm for softwoods and 24.5 cm for hardwoods led to an average biomass volume increase of 73% with the 2-machine system, and of 96% with the 3-machine system.

The time required by every machine to handle the biomass and load it at roadside was measured and a cost was calculated for every phase of biomass recovery. Recommendations were made to improve the operation.

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APPENDIX 1: DETAIL PRODUCTIVITY OBSERVATIONS

Mixedwood (3-machine system) Feller Buncher

Machine used	Units	Baseline no biomass	With/Without pulp in biomass piles
Machine used	-	Tigercat 845C	Tigercat 845C
Average harvested stem size	m ³ /stem	0.140	0.187
Productivity	Stems/PMH	333	316
Productivity	m ³ /PMH	46.8	49.6
Hourly rate	\$/PMH	200	200
Relative productivity ^a	%	112	102
Felling cost	\$/m³	4.28	4.03

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

Mixedwood (3-machine system) Processor

Machine used	Units	Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles
Machine used	-	Doosan Dx 225 LL	Doosan Dx 225 LL	Doosan Dx 225 LL
Average harvested stem size	m ³ /stem	0.111	0.170	0.111
Productivity	Stems/PMH	129	108	129
Productivity	m ³ /PMH	14.3	18.2	14.3
Hourly rate	\$/PMH	180	180	180
Relative productivity ^a	%	87	85	87
Processing cost	\$/m³	12.60	9.87	12.60

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

Mixedwood (3-machine system) Forwarder (logs)

Machine used	Units	Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles
Machine used	-	Ponsse Buffalo King	Ponsse Buffalo King	Ponsse Buffalo King
Average forwarding distance	m	278	235	242
Average cycle time	minutes	37	36	35
Logs per load	Qty	275	234	173
Average volume per log	m ³ /log	0.05	0.06	0.143
Volume per cycle	m ³	13.7	14.1	18.4
Productivity	m ³ /PMH	22.7	23.8	30.1
Hourly rate	\$/PMH	180	180	180
Relative productivity ^a	%	105	105	120
Log forwarding cost	\$/m³	7.94	7.58	5.99

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

Mixedwood (2-machine system) Harvester

Machine used	Units	Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles
Machine used	-	Landrich LR 2.0	Landrich LR 2.0	Landrich LR 2.0
Average harvested stem size	m ³ /stem	0.150	0.231	0.149
Productivity	Stems/PMH	116	100	123
Productivity	m ³ /PMH	17.4	23.2	18.3
Hourly rate	\$/PMH	200	200	200
Relative productivity ^a	%	100	99	106
Harvesting cost	\$/m³	11.50	8.62	10.90

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

Mixedwood (2-machine system) Forwarder (logs)

Machine used	Units	Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles
Machine used	-	Ponsse Buffalo King	Ponsse Buffalo King	Ponsse Buffalo King
Average forwarding distance	m	125	155	113
Average cycle time	minutes	38	41	23
Logs per load	Qty	334	244	270
Average volume per log	m ³ /log	0.047	0.070	0.074
Volume per cycle	m ³	15.8	17.2	19.8
Productivity	m ³ /PMH	24.7	25.3	27.9
Hourly rate	\$/PMH	180	180	180
Relative productivity ^a	%	101	99	114
Log forwarding cost	\$/m³	7.30	7.11	6.46

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

Managed (3- machine system) Feller Buncher

Machine used	Units	Baseline no biomass	With/Without pulp in biomass piles
Machine used	-	Tigercat 845C	Tigercat 845C
Average harvested stem size	m ³ /stem	0.203	0.203
Productivity	Stems/PMH	301	276
Productivity	m ³ /PMH	61.3	56.1
Hourly rate	\$/PMH	200	200
Relative productivity ^a	%	119	109
Felling cost	\$/m³	3.27	3.56

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

Managed (3- machine system) Processor

Machine used	Units	Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles
Machine used	-	Doosan Dx 225 LL	Doosan Dx 225 LL	Doosan Dx 225 LL
Average harvested stem size	m ³ /stem	0.257	0.275	0.294
Productivity	Stems/PMH	104	102	115
Productivity	m ³ /PMH	26.7	28.0	33.9
Hourly rate	\$/PMH	180	180	180
Relative productivity ^a	%	96	97	113
Processing cost	\$/m³	6.75	6.43	5.31

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

Managed (3- machine system) Forwarder (logs)

Machine used	Units	Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles
Machine used	-	Ponsse Buffalo King	Ponsse Buffalo King	Ponsse Buffalo King
Average forwarding distance	m	102	102	212
Average cycle time	minutes	33	33	39
Logs per load	Qty	224	224	191
Average volume per log	m ³ /log	0.070	0.070	0.108
Volume per cycle	m ³	15.6	15.6	20.6
Productivity	m ³ /PMH	28.3	28.3	31.8
Hourly rate	\$/PMH	180	180	180
Relative productivity ^a	%	102	102	128
Log forwarding cost	\$/m³	6.36	6.36	5.66

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

Managed (2- machine system) Harvester

Machine used	Units	Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles
Machine used	-	Landrich LR 2.0	Landrich LR 2.0	Landrich LR 2.0
Average harvested stem size	m ³ /stem	0.261	0.206	0.297
Productivity	Stems/PMH	86	101	99
Productivity	m ³ /PMH	24.5	20.7	29.3
Hourly rate	\$/PMH	200	200	200
Relative productivity ^a	%	96	96	105
Harvesting cost	\$/m³	8.16	9.66	6.83

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

Managed (2- machine system) Forwarder (logs)

Machine used	Units	Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles
Machine used	-	Ponsse Buffalo King	Ponsse Buffalo King	Ponsse Buffalo King
Average forwarding distance	m	179	189	135
Average cycle time	minutes	36	35	25
Logs per load	Qty	258	292	181
Average volume per log	m ³ /log	0.071	0.064	0.085
Volume per cycle	m ³	18.2	18.7	17.6
Productivity	m ³ /PMH	30.9	31.7	36.8
Hourly rate	\$/PMH	180	180	180
Relative productivity ^a	%	119	120	152
Log forwarding cost	\$/m³	5.83	5.68	4.89

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

Natural (3-machine system) Feller Buncher

Machine used	Units	Baseline no biomass	With/Without pulp in biomass piles
Machine used	-	Tigercat 845C	Tigercat 845C
Average harvested stem size	m ³ /stem	0.195	0.195
Productivity	Stems/PMH	314	288
Productivity	m ³ /PMH	61.1	56.1
Hourly rate	\$/PMH	200	200
Relative productivity ^a	%	123	113
Felling cost	\$/m³	3.89	4.24

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

Natural (3-machine system) Processor

Machine used	Units	Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles
Machine used	-	Doosan Dx 225 LL	Doosan Dx 225 LL	Doosan Dx 225 LL
Average harvested stem size	m ³ /stem	0.190	0.223	0.282
Productivity	Stems/PMH	117	110	108
Productivity	m ³ /PMH	22.2	24.5	30.4
Hourly rate	\$/PMH	180	180	180
Relative productivity ^a	%	97	97	104
Processing cost	\$/m³	8.11	7.34	5.91

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

Natural (3-machine system) Forwarder (logs)

Machine used	Units	Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles
Machine used	-	Ponsse Buffalo King	Ponsse Buffalo King	Ponsse Buffalo King
Average forwarding distance	m	105	195	273
Average cycle time	minutes	48	46	47
Logs per load	Qty	196	291	272
Average volume per log	m ³ /log	0.107	0.067	0.098
Volume per cycle	m ³	20.9	19.4	26.6
Productivity	m ³ /PMH	26.4	25.1	34.0
Hourly rate	\$/PMH	180	180	180
Relative productivity ^a	%	102	102	137
Log forwarding cost	\$/m³	6.81	7.16	5.29

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

Natural (2-machine system) Harvester

Machine used	Units	Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles
Machine used	-	Landrich LR 2.0	Landrich LR 2.0	Landrich LR 2.0
Average harvested stem size	m ³ /stem	0.150	0.134	0.259
Productivity	Stems/PMH	113	119	107
Productivity	m ³ /PMH	17.0	15.9	27.7
Hourly rate	\$/PMH	200	200	200
Relative productivity ^a	%	98	99	109
Harvesting cost	\$/m³	11.75	12.61	7.22

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

Natural (2-machine system) Forwarder (logs)

Machine used	Units	Baseline no biomass	Without pulp in biomass piles	With pulp in biomass piles
Machine used	-	Tigercat 1075C	Tigercat 1075C	Tigercat 1075C
Average forwarding distance	m	160	201	97
Average cycle time	minutes	51	44	39
Logs per load	Qty	437	510	317
Average volume per log	m ³ /log	0.041	0.027	0.071
Volume per cycle	m ³	17.9	13.6	22.5
Productivity	m ³ /PMH	21.7	18.7	34.5
Hourly rate	\$/PMH	180	180	180
Relative productivity ^a	%	92	92	122
Log forwarding cost	\$/m³	8.29	9.65	5.22

^a Relative Productivity = Observed Productivity/Estimated From FPI national database in the same conditions

APPENDIX 2: MACHINE COSTING

> CTL 3-machine system



Feller Buncher



Processor At Stump



Forwarder

Hourly cost (\$/PMH)	180	180	180
Purchase price (\$)	525000	555000	585000
Residual value (%)	10	10	10
Economic life (years)	5	5	5
Scheduled usage (PMH/year)	4050	4050	4050
Insurance (\$/year)	11550	12210	12870
Oil and lubricants (\$/PMH)	5.09	4.35	3.24
Utilization rate (%)	80	75	75
Repairs (\$)	525000	610500	585000
Fuel consumption (L/PMH)	45	30	30
Profits/risks (%)	10	10	10
Other costs (\$/year)	0	0	0
Interest rate (%)	10	10	10
Fuel (\$/L)	1	1	1
Operator cost (\$/h)	30	30	30

> **CTL 2-machine system**



Shortwood Harvester



Forwarder

Hourly cost (\$/PMH)	200	180
Purchase price (\$)	650000	585000
Residual value (%)	10	10
Economic life (years)	5	5
Scheduled usage (PMH/year)	4050	4050
Insurance (\$/year)	14300	12870
Oil and lubricants (\$/PMH)	4.95	3.24
Utilization rate (%)	75	75
Repairs (\$)	747500	585000
Fuel consumption (L/PMH)	30	30
Profits/risks (%)	10	10
Other costs (\$/year)	0	0
Interest rate (%)	10	10
Fuel (\$/L)	1	1
Operator cost (\$/h)	30	30

APPENDIX 3: BIOMASS LOAD DELIVERIES



Load Deliveries

Date In: Selected Date [Nov 14, 2022 00:00:00 , Nov 24, 2022 23:59:59]

Show_M3: = Y

Show_Cord: = N

Chaleur Forest Products Inc.

Scale	TC #	Date	In	Out	Sp	Product ID	Gross(GMT)	Tare(GMT)	Net (GMT)	M3
ENVI	181954	11/22/22	12:00:00	12:00:00	SO	BIOMASS	47.1	20.1	27	35.613
ENVI	181955	11/22/22	12:00:00	12:00:00	SO	BIOMASS	47.55	20.06	27.49	36.259
ENVI	181956	11/22/22	12:00:00	12:00:00	SO	BIOMASS	53.06	21.03	32.03	42.248
ENVI	181957	11/23/22	12:00:00	12:00:00	SO	BIOMASS	47.99	19.94	28.05	36.998
ENVI	181958	11/23/22	12:00:00	12:00:00	SO	BIOMASS	52.73	21.65	31.08	40.995
ENVI	181959	11/23/22	12:00:00	12:00:00	SO	BIOMASS	55.98	21.43	34.55	45.571
ENVI	181960	11/23/22	12:00:00	12:00:00	SO	BIOMASS	49.63	23.36	26.27	34.65
ENVI	181961	11/23/22	12:00:00	12:00:00	SO	BIOMASS	42.78	19.22	23.56	31.076
ENVI	181962	11/23/22	12:00:00	12:00:00	SO	BIOMASS	47.56	21.89	25.67	33.859
ENVI	181963	11/23/22	12:00:00	12:00:00	SO	BIOMASS	41.84	21.72	20.12	26.538
ENVI	181964	11/24/22	12:00:00	12:00:00	SO	BIOMASS	45.7	21.16	24.54	32.368
ENVI	181965	11/24/22	12:00:00	12:00:00	SO	BIOMASS	45.15	21.43	23.72	31.287
ENVI	181966	11/24/22	12:00:00	12:00:00	SO	BIOMASS	45.65	19.15	26.5	34.954
ENVI	181967	11/24/22	12:00:00	12:00:00	SO	BIOMASS	47.9	19.74	28.16	37.143
ENVI	181968	11/24/22	12:00:00	12:00:00	SO	BIOMASS	50.98	23.21	27.77	36.629
ENVI	181969	11/24/22	12:00:00	12:00:00	SO	BIOMASS	49.99	21.87	28.12	37.09
ENVI	181970	11/24/22	12:00:00	12:00:00	SO	BIOMASS	48	21.78	26.22	34.584
ENVI	181971	11/24/22	12:00:00	12:00:00	SO	BIOMASS	33.87	20.99	12.88	16.989
ENVI	181972	11/24/22	12:00:00	12:00:00	SO	BIOMASS	56.71	21.64	35.07	46.257
ENVI	181973	11/24/22	12:00:00	12:00:00	SO	BIOMASS	48.41	19.06	29.35	38.713
ENVI	181974	11/24/22	12:00:00	12:00:00	SO	BIOMASS	48.1	19.69	28.41	37.473
ENVI	181975	11/24/22	12:00:00	12:00:00	SO	BIOMASS	51.62	23.1	28.52	37.618
ENVI	181976	11/24/22	12:00:00	12:00:00	SO	BIOMASS	53.83	22.3	31.53	41.588
ENVI	181977	11/24/22	12:00:00	12:00:00	SO	BIOMASS	50.4	21.31	29.09	38.37
ENVI	181978	11/24/22	12:00:00	12:00:00	SO	BIOMASS	53.11	21.6	31.51	41.562
ENVI	181901	11/14/22	12:00:00	12:00:00	SO	BIOMASS	35.93	21.14	14.79	19.508
ENVI	181902	11/14/22	12:00:00	12:00:00	SO	BIOMASS	36.2	21.09	15.11	19.93
ENVI	181903	11/14/22	12:00:00	12:00:00	SO	BIOMASS	37.44	21.04	16.4	21.632
ENVI	181904	11/14/22	12:00:00	12:00:00	SO	BIOMASS	39.02	21.7	17.32	22.845
ENVI	181905	11/14/22	12:00:00	12:00:00	SO	BIOMASS	40.26	20.96	19.3	25.457
ENVI	181906	11/14/22	12:00:00	12:00:00	SO	BIOMASS	39.17	21.15	18.02	23.768
ENVI	181907	11/14/22	12:00:00	12:00:00	SO	BIOMASS	38.61	21.05	17.56	23.162
ENVI	181908	11/14/22	12:00:00	12:00:00	SO	BIOMASS	35.92	21.94	13.98	18.44
ENVI	181909	11/14/22	12:00:00	12:00:00	SO	BIOMASS	40.28	21.46	18.82	24.824
ENVI	181910	11/14/22	12:00:00	12:00:00	SO	BIOMASS	42.5	20.98	21.52	28.385
ENVI	181911	11/14/22	12:00:00	12:00:00	SO	BIOMASS	43.27	21.01	22.26	29.361
ENVI	181912	11/15/22	12:00:00	12:00:00	SO	BIOMASS	40.02	21.4	18.62	24.56
ENVI	181913	11/15/22	12:00:00	12:00:00	SO	BIOMASS	37.99	21.37	16.62	21.922
ENVI	181914	11/15/22	12:00:00	12:00:00	SO	BIOMASS	37.55	21.11	16.44	21.684
ENVI	181915	11/15/22	12:00:00	12:00:00	SO	BIOMASS	38.3	22.3	16	21.104
ENVI	181916	11/15/22	12:00:00	12:00:00	SO	BIOMASS	37.79	21.34	16.45	21.698
ENVI	181917	11/15/22	12:00:00	12:00:00	SO	BIOMASS	38.42	21.38	17.04	22.476
ENVI	181918	11/15/22	12:00:00	12:00:00	SO	BIOMASS	38.7	21.35	17.35	22.885
ENVI	181919	11/15/22	12:00:00	12:00:00	SO	BIOMASS	35.4	22.1	13.3	17.543
ENVI	181920	11/15/22	12:00:00	12:00:00	SO	BIOMASS	37.03	21.33	15.7	20.708
ENVI	181921	11/15/22	12:00:00	12:00:00	SO	BIOMASS	33	21.28	11.72	15.459
ENVI	181922	11/15/22	12:00:00	12:00:00	SO	BIOMASS	36.55	21.34	15.21	20.062
ENVI	181923	11/15/22	12:00:00	12:00:00	SO	BIOMASS	38.2	22.48	15.72	20.735
ENVI	181924	11/15/22	12:00:00	12:00:00	SO	BIOMASS	36.66	21.27	15.39	20.299
ENVI	181925	11/16/22	12:00:00	12:00:00	SO	BIOMASS	36.88	21.3	15.58	20.55
ENVI	181926	11/16/22	12:00:00	12:00:00	SO	BIOMASS	40.97	21.5	19.47	25.681
ENVI	181927	11/16/22	12:00:00	12:00:00	SO	BIOMASS	39.61	22.66	16.95	22.357
ENVI	181928	11/16/22	12:00:00	12:00:00	SO	BIOMASS	36.94	21.72	15.22	20.075
ENVI	181948	11/21/22	12:00:00	12:00:00	SO	BIOMASS	45.8	21.7	24.1	31.788
ENVI	181949	11/21/22	12:00:00	12:00:00	SO	BIOMASS	44.72	20.18	24.54	32.368
ENVI	181950	11/21/22	12:00:00	12:00:00	SO	BIOMASS	38.84	21.68	17.16	22.634
ENVI	181951	11/21/22	12:00:00	12:00:00	SO	BIOMASS	46.91	21.3	25.61	33.78
ENVI	181952	11/21/22	12:00:00	12:00:00	SO	BIOMASS	45.98	21.8	24.18	31.893
ENVI	181953	11/21/22	12:00:00	12:00:00	SO	BIOMASS	28.1	21.6	6.5	8.574
ENVI	181929	11/17/22	12:00:00	12:00:00	SO	BIOMASS	36.42	21.32	15.1	19.917
ENVI	181930	11/17/22	12:00:00	12:00:00	SO	BIOMASS	38.45	21.34	17.11	22.568
ENVI	181931	11/17/22	12:00:00	12:00:00	SO	BIOMASS	38.18	21.22	16.96	22.37
ENVI	181932	11/17/22	12:00:00	12:00:00	SO	BIOMASS	40.2	20.7	19.5	25.721
ENVI	181933	11/17/22	12:00:00	12:00:00	SO	BIOMASS	39.41	21.08	18.33	24.177
ENVI	181934	11/17/22	12:00:00	12:00:00	SO	BIOMASS	39.61	21.24	18.37	24.23
ENVI	181935	11/17/22	12:00:00	12:00:00	SO	BIOMASS	38.84	21.14	17.7	23.346
ENVI	181936	11/17/22	12:00:00	12:00:00	SO	BIOMASS	38.94	20.7	18.24	24.059
ENVI	181937	11/17/22	12:00:00	12:00:00	SO	BIOMASS	41.8	21.56	20.24	26.697
ENVI	181938	11/17/22	12:00:00	12:00:00	SO	BIOMASS	39.48	21.27	18.21	24.019
ENVI	181939	11/18/22	12:00:00	12:00:00	SO	BIOMASS	41.23	21.68	19.55	25.786
ENVI	181940	11/18/22	12:00:00	12:00:00	SO	BIOMASS	43.95	21.55	22.4	29.546
ENVI	181941	11/18/22	12:00:00	12:00:00	SO	BIOMASS	28.82	21.22	7.6	10.024
ENVI	181942	11/18/22	12:00:00	12:00:00	SO	BIOMASS	37.68	21.89	15.79	20.827
ENVI	181943	11/18/22	12:00:00	12:00:00	SO	BIOMASS	40.48	20.6	19.88	26.222
ENVI	181944	11/21/22	12:00:00	12:00:00	SO	BIOMASS	46.62	21.94	24.68	32.553
ENVI	181945	11/21/22	12:00:00	12:00:00	SO	BIOMASS	43.82	21.72	22.1	29.15
ENVI	181946	11/21/22	12:00:00	12:00:00	SO	BIOMASS	42.25	19.65	22.6	29.809
ENVI	181947	11/21/22	12:00:00	12:00:00	SO	BIOMASS	45.38	21.36	24.02	31.682

APPENDIX 4: MOISTURE CONTENT PER LOAD

Sample ID	Date	Strand Type	Harvesting Sys	Biomass Treatment	Tray Weight	Green Wet+tray Weight	After 24 Hours	After another 2 hours	Wet based Moisture Content	Oven-dry based Moisture Content
1	Nov.14	Mixedwood	3 machines	Without pulp	79.96	1783.88	1162.22	1161.90	36.50%	57.49%
2	Nov.14	Mixedwood	3 machines	Without pulp	81.67	1592.75	1024.44	1024.98	37.57%	60.19%
3	Nov.14	Mixedwood	3 machines	Without pulp	82.63	1813.44	1081.79	1082.28	42.24%	73.14%
4	Nov.14	Mixedwood	3 machines	Without pulp	81.37	1592.70	1103.28	1103.84	32.35%	47.81%
5	Nov.14	Mixedwood	3 machines	Without pulp	81.96	1861.25	1160.71	1161.53	39.33%	64.81%
6	Nov.14	Mixedwood	3 machines	Without pulp	81.62	1829.14	1112.06	1112.77	40.99%	69.47%
7	Nov.14	Mixedwood	3 machines	Without pulp	80.18	1533.65	1007.32	1006.66	36.26%	56.88%
8	Nov.14	Mixedwood	3 machines	Without pulp	80.55	1510.78	980.66	980.69	37.06%	58.89%
9	Nov.14	Mixedwood	3 machines	With pulp	80.54	1866.00	1140.52	1141.46	40.58%	68.29%
10	Nov.15	Mixedwood	3 machines	With pulp	83.10	1853.86	1108.35	1108.49	42.09%	72.69%
11	Nov.15	Mixedwood	3 machines	With pulp	79.85	1979.78	1111.61	1111.23	45.71%	84.21%
12	Nov.15	Mixedwood	3 machines	With pulp	82.14	1778.66	1139.26	1139.58	37.67%	60.44%
13	Nov.15	Mixedwood	3 machines	With pulp	81.89	1869.69	1128.60	1129.38	41.41%	70.67%
14	Nov.15	Mixedwood	3 machines	With pulp	80.32	1894.96	1204.04	1204.75	38.04%	61.38%
15	Nov.15	Mixedwood	3 machines	With pulp	80.07	1927.95	1236.14	1235.79	37.46%	59.89%
16	Nov.15	Mixedwood	3 machines	With pulp	80.67	1791.29	1087.60	1088.56	41.08%	69.72%
17	Nov.15	Mixedwood	3 machines	With pulp	80.14	1883.15	1122.67	1122.55	42.19%	72.97%
18	Nov.15	Mixedwood	3 machines	With pulp	77.85	1750.96	1077.33	1077.70	40.24%	67.34%
19	Nov.15	Mixedwood	3 machines	With pulp	81.34	1799.43	1122.18	1122.90	39.38%	64.95%
20	Nov.15	Mixedwood	3 machines	With pulp	78.83	1798.36	1103.75	1104.01	40.38%	67.73%
21	Nov.15	Mixedwood	3 machines	With pulp	80.38	1864.55	1169.92	1169.42	38.96%	63.83%
22	Nov.15	Mixedwood	2 machines	With pulp	81.48	1844.55	1190.00	1190.41	37.10%	58.99%
23	Nov.15	Mixedwood	2 machines	With pulp	81.29	1786.04	1024.00	1024.36	44.68%	80.77%
24	Nov.15	Mixedwood	2 machines	With pulp	80.47	1802.72	1071.61	1072.19	42.42%	73.66%
25	Nov.16	Mixedwood	2 machines	With pulp	78.88	1965.89	1122.15	1122.35	44.70%	80.84%
26	Nov.16	Mixedwood	2 machines	Without pulp	81.11	1913.74	1175.57	1176.70	40.22%	67.27%
27	Nov.16	Mixedwood	2 machines	Without pulp	79.57	1783.87	1024.24	1024.16	44.58%	80.43%
28	Nov.16	Mixedwood	2 machines	Without pulp	82.15	1842.38	1126.69	1126.72	40.66%	68.51%
29	Nov.17	Managed	3 machines	With pulp	80.15	1848.60	1089.40	1090.13	42.89%	75.10%
30	Nov.17	Managed	3 machines	With pulp	82.19	1760.15	1138.25	1139.13	37.01%	58.76%
31	Nov.17	Managed	3 machines	With pulp	80.38	1819.19	1162.44	1163.11	37.73%	60.59%
32	Nov.17	Managed	3 machines	With pulp	80.63	1779.75	1190.41	1191.55	34.62%	52.95%
33	Nov.17	Managed	3 machines	With pulp	80.83	1780.32	1039.95	1040.49	43.53%	77.09%
34	Nov.17	Managed	3 machines	With pulp	80.48	1803.44	1057.27	1057.77	43.28%	76.30%
35	Nov.17	Managed	3 machines	With pulp	80.08	2034.05	1208.93	1209.52	42.20%	73.00%
36	Nov.17	Managed	3 machines	With pulp	81.25	1780.67	1052.88	1053.01	42.82%	74.88%
37	Nov.17	Managed	3 machines	With pulp	82.19	1755.01	1102.17	1102.59	39.00%	63.94%
38	Nov.17	Managed	3 machines	With pulp	80.90	1912.43	1028.36	1028.46	48.26%	93.29%
39	Nov.18	Managed	3 machines	With pulp	80.81	1828.94	1187.67	1188.66	36.63%	57.79%
40	Nov.18	Managed	3 machines	With pulp	81.14	1854.99	1123.01	1122.74	41.28%	70.30%
41	Nov.18	Managed	3 machines	With pulp	79.29	1813.29	1100.87	1101.64	41.04%	69.61%
42	Nov.18	Managed	3 machines	Without pulp	81.49	1801.04	1109.57	1110.35	40.17%	67.13%
43	Nov.18	Managed	3 machines	Without pulp	79.65	1802.78	1124.66	1124.51	39.36%	64.91%
44	Nov.21	Managed	3 machines	Without pulp	82.67	1844.58	1167.35	1167.57	38.42%	62.40%
45	Nov.21	Managed	3 machines	Without pulp	81.24	1930.35	1205.72	1206.25	39.16%	64.36%
46	Nov.21	Managed	3 machines	Without pulp	82.31	1787.31	1196.39	1196.49	34.65%	53.03%
47	Nov.21	Managed	3 machines	Without pulp	79.89	1878.58	1187.06	1187.24	38.44%	62.43%
48	Nov.21	Managed	2 machines	With pulp	81.26	1861.02	1046.68	1047.72	45.70%	84.15%
49	Nov.21	Managed	2 machines	With pulp	81.02	1904.47	1093.88	1093.93	44.45%	80.02%
50	Nov.22	Managed	2 machines	With pulp	82.13	1891.47	1106.55	1107.55	43.33%	76.45%
51	Nov.21	Managed	2 machines	Without pulp	80.23	1860.82	963.08	963.89	50.37%	101.50%
52	Nov.21	Managed	2 machines	Without pulp	81.27	1840.56	1080.06	1080.14	43.22%	76.13%
53	Nov.21	Managed	2 machines	Without pulp	82.89	1891.68	1108.68	1108.86	43.28%	76.30%
54	Nov.22	Natural	3 machines	Without pulp	83.05	1891.52	969.06	968.75	51.02%	104.19%
55	Nov.22	Natural	3 machines	Without pulp	80.99	1831.76	1014.66	1015.27	46.64%	87.39%
56	Nov.22	Natural	3 machines	Without pulp	80.80	1953.94	976.79	977.40	52.13%	108.92%
57	Nov.23	Natural	3 machines	Without pulp	80.77	1899.31	1084.50	1085.18	44.77%	81.06%
58	Nov.23	Natural	3 machines	Without pulp	82.78	1822.57	973.11	972.78	48.84%	95.48%
59	Nov.23	Natural	3 machines	Without pulp	81.59	1934.57	1061.90	1062.10	47.08%	88.98%
60	Nov.23	Natural	3 machines	With pulp	81.89	1749.98	1089.26	1089.33	39.61%	65.58%
61	Nov.23	Natural	3 machines	With pulp	80.79	1982.45	1234.70	1234.89	39.31%	64.77%
62	Nov.23	Natural	3 machines	With pulp	80.08	1698.68	1020.57	1019.88	41.94%	72.23%
63	Nov.23	Natural	3 machines	With pulp	81.63	1513.89	956.69	956.42	38.92%	63.73%
64	Nov.24	Natural	3 machines	With pulp	79.58	1937.14	1130.77	1131.01	43.40%	76.67%
65	Nov.24	Natural	3 machines	With pulp	81.12	1864.60	1121.50	1120.33	41.73%	71.62%
66	Nov.24	Natural	3 machines	With pulp	81.04	1781.27	951.93	952.19	48.76%	95.17%
67	Nov.24	Natural	3 machines	With pulp	81.58	1831.88	1158.29	1158.51	38.47%	62.53%
68	Nov.24	Natural	3 machines	With pulp	81.38	1821.98	1115.62	1116.14	40.55%	68.21%
69	Nov.24	Natural	3 machines	With pulp	80.74	1779.89	1118.17	1119.34	38.88%	63.60%
70	Nov.24	Natural	3 machines	With pulp	80.24	1991.82	1243.96	1244.76	39.08%	64.15%
71	Nov.24	Natural	3 machines	With pulp	80.99	1826.23	1124.36	1125.04	40.18%	67.16%
72	Nov.24	Natural	2 machines	Without pulp	81.06	2006.43	1053.88	1054.18	49.46%	97.86%
73	Nov.29	Natural	2 machines	Without pulp	82.02	2080.89	1193.62	1193.65	44.39%	79.81%
74	Nov.24	Natural	2 machines	Without pulp	79.82	1950.09	1114.75	1116.10	44.59%	80.48%
75	Nov.24	Natural	2 machines	With pulp	82.75	1948.62	1146.49	1146.73	42.98%	75.37%
76	Nov.24	Natural	2 machines	With pulp	80.57	1835.36	1067.54	1068.07	43.73%	77.70%
77	Nov.24	Natural	2 machines	With pulp	80.27	1898.46	1065.52	1066.18	45.78%	84.42%
78	Nov.24	Natural	2 machines	With pulp	79.28	2037.04	1107.37	1107.98	47.46%	90.31%
Average									41.70%	72.35%
St.Dec									0.040	0.123



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