Forest biomass as part of silvicultural systems and its potential contribution to the low-carbon transition of heavy industries

Part 1: Forest biomass procurement as a silvicultural tool for site regeneration

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Forest biomass procurement as a part of silvicultural systems and its potential contribution to the low-carbon transition of heavy industries.

Part 1: Forest biomass procurement as a silvicultural tool for site regeneration

Edited by Evelyne Thiffault (Université Laval) and Nelson Thiffault (Natural Resources Canada)

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Executive summary

Studies of the economics of using forest biomass for bioenergy often show that profitability is hard to achieve unless supported by policies and/or regulations (Kizha & Han, 2016; Murphy et al., 2010; Sarkar & Kumar, 2009). This is a major obstacle to the large-scale deployment of forest bioenergy when competing with low-cost fossil options available to industry. However, when considering the entire silvicultural system, from harvest to a re-established stand of trees, there is an increasing recognition that the recovery of forest biomass can play a positive role in contributing to silvicultural objectives, and reducing the cost and effort to properly prepare the site for effective planting or re-establishment of natural regeneration. However, the actual savings that this may procure are not well documented. If biomass recovery is initiated and this influences the rate of re-establishment, survival, growth and yield of the regenerating stand relative to a reference silvicultural system without bioenergy, this in turn can also influence the net carbon balance of implementing bioenergy.

The report presents results from two case studies that were carried out with support of local industry and other stakeholders, one in Australia and one in Canada, comparing silvicultural systems with and without biomass recovery. Those case studies respectively discuss:

- the operational costs of recovering forest biomass and operational costs in the preparation of the site for effective re-establishment specifically looking at cost avoidance of not having to move or remove unrecovered forest biomass on the site, and
- the quantity and quality of microsites and environmental conditions for seedling growth created by biomass recovery relative to a reference system.

The Australian case study took place in the Toolara State Forest Southern Pine resource managed by HQPlantations (HQP), Queensland's largest forest plantation manager. We analysed Cut To Length (CTL) and Whole Tree (WT) harvesting systems and associated site-preparation activities and costs. This project benefits growers by providing data to support ongoing operations and a review of economic incentives for recovering biomass for external buyers. With HQP, we took advantage of having two different harvest systems, one of which mimics a feasible approach for biomass recovery (long log/ whole tree) that others globally are already using to recover biomass to get a base harvest cost with and without biomass recovery (CTL). The sites left after the two operations are very much a site with heavy biomass recovery (long log – ignoring roadside piles) and one with little or no recovery (CTL). The main goal is to establish the difference in costs to site preparation for the two conditions.

Results from this case study make it possible to conclude that harvesting systems and biomass removal directly impact site preparation costs. The economic ramifications of these decisions should be considered when developing a harvest and subsequent regeneration plan. Furthermore, market value recovery and revenue generation by virtue of log markets also needs to be taken into account when reviewing the aforementioned figures. This study clearly identifies a reduction in site preparation costs due to biomass harvesting, which would likely vary from AUS$100-600/ha (0.2-1.3 AUS$/m^3). Furthermore, the enabling system (WT in this case) also contributes a significant financial incentive to produce roadside biomass (savings of up to AUS$6,300/ha [AUS$13.5/m^3]). The findings of this case study indicate a site preparation incentive of AUS$600/ha combined with system incentive of AUS$6,300/ha for a total of roughly $6,900/ha ($15/m^3) in favour of a biomass harvesting model.

The Canadian case study, for its part, was based in the region of Côte-Nord in northeastern Quebec, which is currently facing a severe outbreak of spruce budworm (SBW), an insect that causes considerable defoliation of coniferous trees. This causes major degradation of the wood supply available for harvesting. After defoliation, the wood becomes unfit for processing into timber and pulp, which mostly only process good-quality merchantable wood from coniferous trees. Degraded coniferous trees are therefore often just left on the cutblocks, along with intolerant hardwoods for which the demand is also very low. However, the establishment of bioenergy supply chains in the region creates a market for degraded coniferous trees and intolerant hardwoods that would otherwise

be left as residues on the ground in regular timber harvesting operations.

In Côte-Nord, forest operations and sawmill companies teamed up with a technology supplier to design and build a plant producing bioenergy in the form of a bio-based pyrolysis oil, comparable to fossil-based heavy oil, from forest biomass. The main feedstock for this plant is unused trees and tree parts that are left over in regular timber harvesting operations, i.e. degraded coniferous wood and intolerant hardwoods. Planning and procurement of wood for timber and biomass for bioenergy are coordinated and performed in the same stands in an area currently severily defoliated by SBW. Good-quality merchantable wood from coniferous trees is directed to the sawmill, whereas degraded coniferous wood and intolerant harwoods are sent to the bioenergy plant.

The overall objective of the case study was to assess the effect of biomass procurement in SBW-affected stands as a component of a forest management system aimed at both (i) procuring wood for timber and biomass for bioenergy, and (ii) establishing regeneration on clearcut areas. Based on a limited number of replicates, biomass procurement in the form of degraded trees and intolerant hardwoods along with harvesting of sawn timber increased the number of seedlings and suitable microsites in the cutovers, and the exposure of mineral soil (a better seed bed than forest floor for regeneration establishment), and reduced the obstacles for establishment of regeneration and site preparation. However, difference between treatments (with/without biomass procurement) was not large and variability was high. Also, both treatments had, on average, a sufficient stocking of seedlings and would not require planting under current silviculture guidelines. Nevertheless, with timber harvesting only, one out of four plots was below 60% stocking (the minimum target to maintain site productivity), two plots were at 60%, and one was above; for plots with biomass procurement, one plot out of four was below the threshold, one was at 60% and two plots were above. The overall stocking of seedlings and suitable microsites was on average just above 60% for timber harvesting only, whereas it was much higher (75%) for the treatment with biomass procurement. Another field campaign will be carried out during 2019 to increase the number of blocks and allow for proper statistical comparisons of harvesting treatments. Further field data collection will help clarify whether there is a trend for biomass procurement to be more conducive to creating better regeneration conditions in those SBW-affected stands. Further data will also allow comparing the costs of procurement of wood for timber and biomass for bioenergy, and the costs of site preparation. A more detailed analysis will thus make it possible to assess whether biomass procurement in those types of stands provide benefits in terms of costs of regeneration after harvest, and also whether differences in regeneration patterns can translate into carbon sequestration differences.

These two case studies, conducted in environments that differ greatly in terms of their ecology, constraints to tree growth, and industrial structure, illustrate that harvesting systems and biomass removal can directly impact site preparation costs. Further data acquisition is necessary to verify some emerging trends. However, the results presented here support that the economic ramifications of harvesting systems and biomass procurement operations should be considered when developing harvest and subsequent regeneration plans.

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Introduction

Studies of the economics of using forest biomass for bioenergy often show that profitability is hard to achieve unless supported by policies and/or regulations (Kizha & Han, 2016; Murphy et al., 2010; Sarkar & Kumar, 2009). This is a major obstacle to the large-scale deployment of forest bioenergy when competing with low-cost fossil options available to industry. However, when considering the entire silvicultural system, from harvest to a re-established stand of trees, there is an increasing recognition that the recovery of forest biomass can play a positive role in reducing the cost and effort to properly prepare the site for effective planting or re-establishment of natural regeneration, though the actual savings are not well documented.

If biomass recovery is initiated and this influences the rate of re-establishment, survival, growth and yield of the regenerating stand relative to a reference silvicultural system without bioenergy, this in turn influences the net carbon balance of implementing bioenergy. For example, if biomass recovery is a silvicultural practice that leads to improved planting microsite availability and quality, higher tree growth and faster C sequestration, the net GHG effect of replacing the fossil fuel with biomass is improved. Moreover, if biomass procurement translates into less machinery operations overall to achieve suitable microsites for regeneration establishment, either naturally or through planting, this would further improve the net GHG outcome.

The following report presents results from two case studies that were carried out with support of local industry and other stakeholders, one in Australia and one in Canada, comparing silvicultural systems with and without biomass recovery. Those case studies respectively discuss:

- Operational costs of recovering forest biomass and operational costs in the preparation of the site for effective re-establishment specifically looking at cost avoidance of not having to move or remove unrecovered forest biomass on the site, and
- Quantity and quality of microsites and environmental conditions for seedling growth created by biomass recovery relative to the reference system.

Case Study 1: Alternative harvest systems and their impact on site preparation and biomass recovery economics based on a Southern Pine plantation resource in south-east Queensland, Australia

Michael D. Berry

University of the Sunshine Coast, Forest Industries Research Centre (FIRC)

Note: All financial values in Australian Dollars (AUD). Yearly average conversion rates for 2018 are: 1 AUD = 0.747 USD, 0.633 EUR, 0.969 CAD

Introduction

The USC Forest Industries Research Centre (FIRC) completed research to help establish the net economic value of recovering forest biomass including its impact on silviculture and site preparation. This case study took place in the Toolara State Forest Southern Pine resource managed by HQPlantations (HQP), Queensland's largest forest plantation manager. We analysed Cut To Length (CTL) and Whole Tree (WT) harvesting systems and associated site-preparation activities and costs. This project benefits growers by providing data to support ongoing operations and a review of economic incentives for recovering biomass for external buyers.

With HQP, we took advantage of having two different harvest systems, one of which mimics a feasible approach for biomass recovery (long log/ whole tree) that others globally are already using to recover biomass to get a base harvest cost with and without biomass recovery (CTL). The sites left after the two operations are very much a site with heavy biomass recovery (long log – ignoring roadside piles) and one with little or no recovery (Cut to Length). The main goal is to establish the difference in costs to site preparation for the two conditions. This was done completing harvesting studies as well as some basic observational studies/ information interviews of the different steps in the site preparation from post-harvest to ready to plant.

Study Area

The study area was located within Toolara State Forest, north-east of Gympie in south-east Queensland, on HQPlantations-managed land (Figure 1). Each site assessed was approximately 0.3 ha, compared to the compartment size which ranged from 90 to 120 hectares. The CTL harvesting was completed in compartment 5 Taurus while the WT harvesting was done in compartment 98 North Dempster.

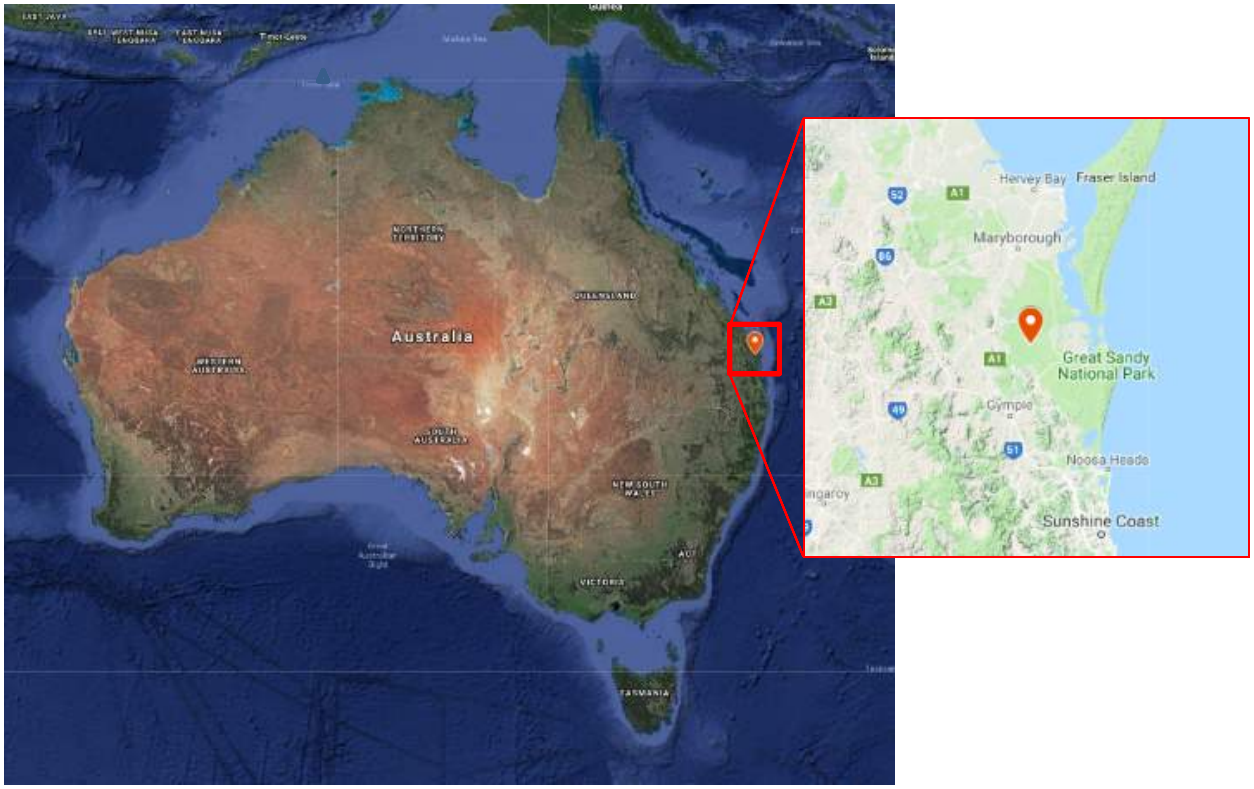

Figure 1. Australian context of trials. Inset Toolara Southern Pine plantation estate north-east of Gympie, Queensland

The characteristics of each site are shown in **Table 1**. The CTL harvesting site was a 32-year-old F2 Hybrid Pine (*Pinus elliottii x P. caribaea var. hondurensis*) stand with approximately 28m predominant height, 37.8cm Diameter Brest Height Over Bark (DBHOB) and 394 stems per hectare (sph) stocking density that was clearfall harvested in November 2018. The WT harvesting site consisted of 30-year-old Caribbean Pine (*P. caribaea* var. *hondurensis* (PCH)) with approximately 30m predominant height, 40.9cm DBHOB and 293 sph stocking density that were clearfalled in November 2018.

Table 1. Study Site Characteristics for both harvesting systems

Site Characteristic	CTL System	WT System
Area (ha)	0.31	0.32
Mean DBHOB (cm)	37.8	40.9
Mean Height (m)	27.8	30.3
Mean Tree Volume (m^3)	1.19	1.38
Stems per hectare (sph)	394	293

Research Methods

Two different harvesting methods were used to clearfall harvest the sites. **Table 2** describes the machine types used in each harvesting method. An elemental time and motion study was used to evaluate machine productivity. Productivity was calculated from whole tree volumetric values as determined by the pre-harvest inventory (sampling of each diameter, 25% of tree heights combined with a representative volume equation supplied by HQP) and productive machine hours, excluding all delays (PMH). The ALPACA model, developed by the CRC for Forestry and AFORA and based on more than 200-time studies conducted by the CRC for Forestry Harvesting and

Operations Program, was used to estimate the cost of operations (expressed as dollars per productive machine hour, excluding delays $/PMH), as well as provide a baseline for anticipated production costs based on previously published studies.

Table 2. Harvesting methods and machines

Table 2. Harvesting methods and machines

Harvesting Method	Equipment	Est. Cost ($/PMH)*
Cut to Length (CTL)	Harvester/ Processor - Komatsu 951 with Komatsu S172 Head	275.55
	Forwarder - Komatsu 8903	275.55
Whole Tree (WT)	Feller Buncher - Tigercat 860C with Hotsaw Tigercat Head model 5702	275.55
	Processor - Komatsu PC 270LC with Waratah 623C Head	213.63
	Grapple Skidder - Tigercat model 632E	240.65

*ALPACA Model Estimates

Figure 2. Cut to Length System: (left) Harvester/ Processor (right) Forwarder

Figure 3. Whole Tree Harvesting System: (left) Feller Buncher, (centre) Processor, (right) Grapple Skidder

The two different harvest areas were then assessed for likely site preparation operations to follow to enable re-establishment of the next rotation of plantation. With CTL operations, slash material is spread out over the planting area while with WT harvesting operations, there is a lower slash level through the general plantation area and accumulated piles along the roadside. Within this region, typical operations include the use of a Chopper Roller (CR), a dozer-based machine towing a multi-tonne drum roller with blades to break up slash material, an excavator used to windrow the material (move material into lanes away from the planting locations), or using an excavator to move roadside material (either to collect and burn or spreading roadside piles to allow for future planting [lane clear]) (Figure 4).

Figure 4. Site Preparation Operational Activities: (left) Chopper Roller, (centre) Excavator conducting CTL windrow, (right) Roadside pile after excavator manipulation prior to burning.

General site preparation best practices and costs were surveyed throughout the regional plantation area to develop an envelope of costs associated with the two systems within a range of typical residue (left biomass) conditions. These conditions were subjectively rated from high to low for WT and CTL sites based on normal conditions where overall left slash may vary from 10 GMt/ha (on a low WT site excluding roadside slash) to 100 GMt/ha (on a high slash volume CTL site). The survey data obtained was then used to develop an economic framework to evaluate the impact of biomass on costs.

Results

Results are first presented for the systems (time and motion studies) followed by the derived site preparations costing model.

The systems costs results are presented in terms of productivity and costing on a $/ha and $/m^3 as observed and as estimated using the ALPACA reference for each system. Results for each machine are then presented to provide further detail on time breakdown and productivity factors.

PRODUCTION COSTS – CTL SYSTEM

Table 3 presents the productivity and costing for each component of the CTL harvesting method. Forwarding was the most expensive element in this study. Harvester/Processor averaged 74 m^3/PMH while the forwarder averaged 57 m^3/PMH. This ultimately yielded costs of roughly $3,880/ha ($8.6/m3) (Table 3). The cost of loading material onto trucks and associated transport and overhead costs are not included in this study. For reference, the ALPACA model anticipated roughly $5,250 ($11.6/ha) for this configuration, a nearly 40% increase due to lower than anticipated productivity values.

Table 3. Productivity and Costs of CTL method

Machine	Study Observations			ALPACA Model		
	Productivity (m^3/PMH)	Cost ($/m^3)	Cost ($/ha)	Productivity (m^3/PMH)	Cost ($/m^3)	Cost ($/ha)
Harvester/ Processor	73.8	3.73	1691.1	54.1	5.09	2307.5
Forwarder	57.0	4.83	2190.1	42.3	6.51	2951.2
Total:		**8.6**	**3881.2**		**11.6**	**5258.7**

Harvester - Processor

The Harvester-Processor spent most of its total time processing followed by position, moving, clearing brush and stacking logs (Figure 5). The Harvester-Processor becomes more and more productive as the tree volume increases, as more volume is handled per cut and felling with an average productivity of 74 m^3/PMH (Figure 6).

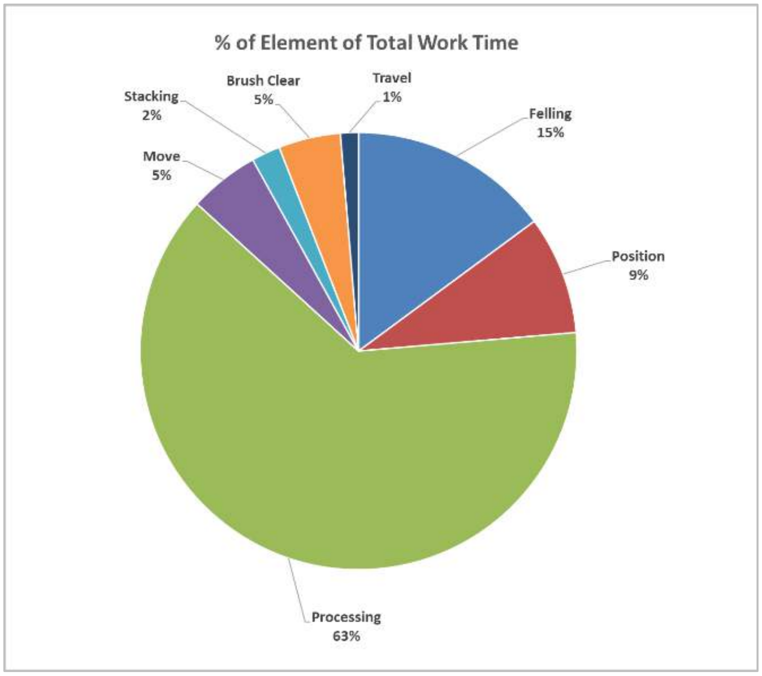

Figure 5. Harvester/ Processor – Time breakdown (% of working time)

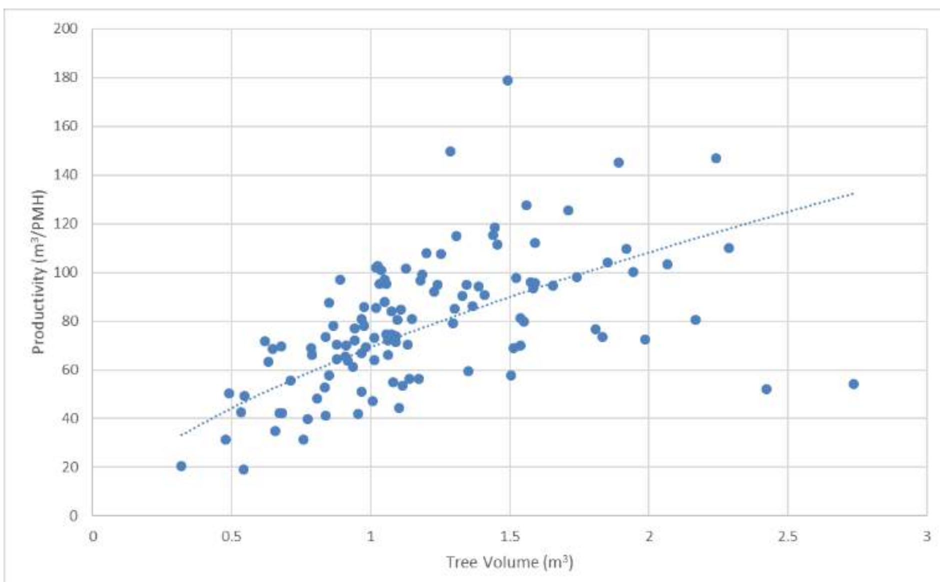

Figure 6. The effect of tree volume on Harvester/Processor Productivity

Forwarder

The Forwarder's average productivity was approximately 57 m^3/PMH based on an average forwarding distance of 140m (ranging from 56m to 205m). Roughly half of the time forwarding was devoted to loading and moving while loading (51%), followed by unloading logs (29%) and time while travelling (19%) (Figure 7).

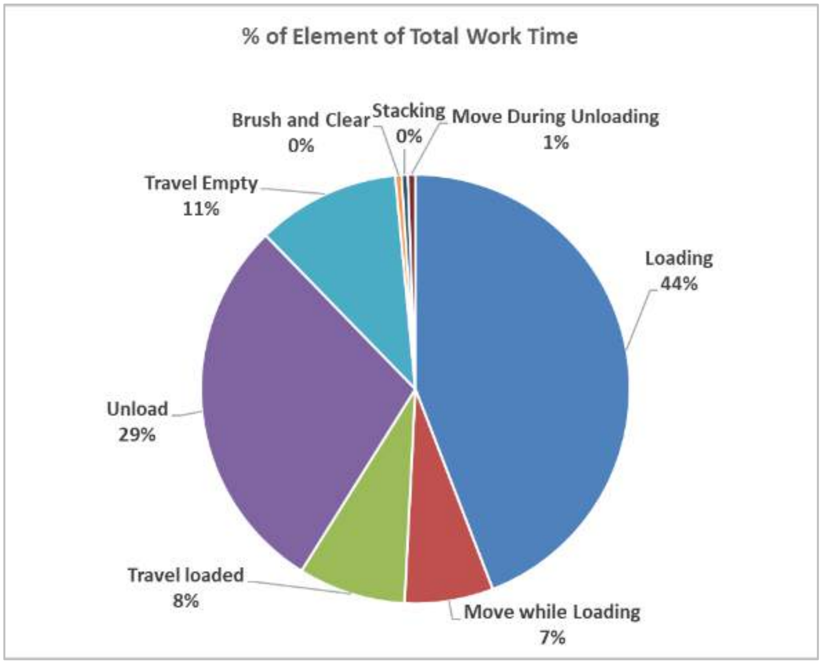

Figure 7. Forwarder – Time breakdown (% of working time)

Product size (Figure 8) affected productivity. As log size increases so did productivity. Forwarder distance also has a negative effect on productivity though this relationship was harder to distinguish given the small sample size and variable log size.

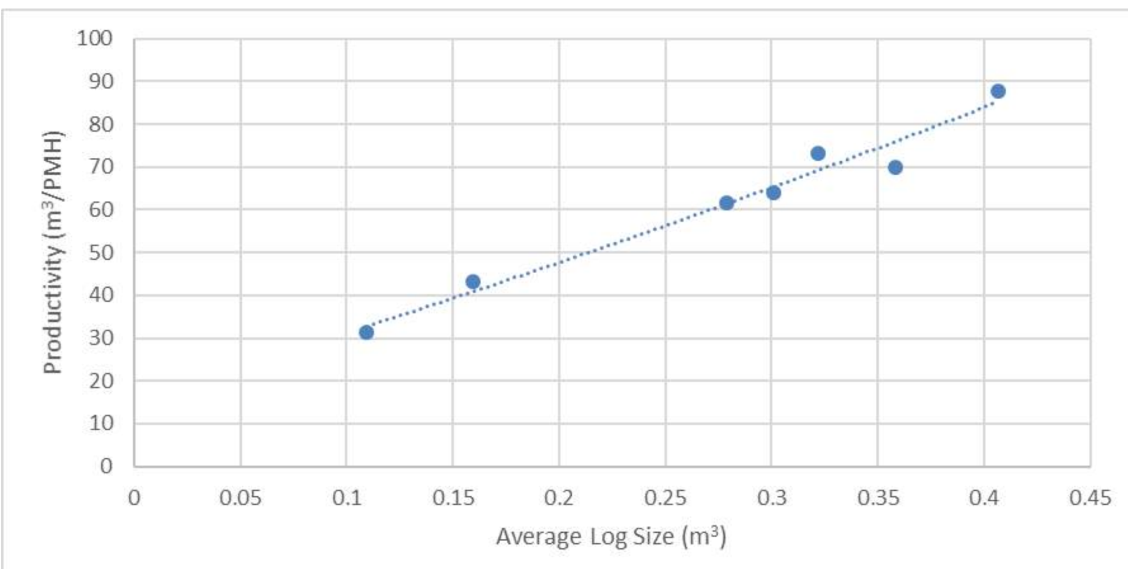

Figure 8. Impact of log size on productivity (1 way forwarding distance = 100m)

PRODUCTION COSTS – WT SYSTEM

Table 4 presents the productivity and costing for each component of the WT harvesting method. Processing and skidding were found to be the most expensive components of the WT method. Overall, this system was found to cost roughly $3.1/m^3 or $1,365/ha. Similar to the CTL method, truck loading and associated transport are not included in this study. It is important to note that with this particular WT harvest system in use at Toolara, a large ‘stem loader’ is brought to site to load trucks (given the larger log size which averaged 17m in length) while the CTL system utilized the forwarder to load the trucks. For a better comparison, both mobilization as well as loading costs should be considered (see discussions). For reference, the ALPACA model anticipated $2,900/ha ($6.6/m^3) for this configuration, more than double the costing due to lower anticipated productivity values. This is primarily because the ALPACA Model assumes less efficient productivity values for skidding and processing material. As previously noted, the observational study was based on a small-scale harvest in ideal conditions.

Table 4. Productivity and Costs of WT method

	Study Observations			ALPACA Model*		
Machine	**Productivity (m^3/PMH)**	**Cost ($/m^3)**	**Cost ($/ha)**	**Productivity (m^3/PMH)**	**Cost ($/m^3)**	**Cost ($/ha)**
Feller Buncher	376.4	0.73	320.0	467.0	0.59	258.0
Skidder	217.3	0.98	429.8	76.2	3.16	1380.7
Processor	171.3	1.40	614.2	74.5	2.87	1253.7
Total:		**3.1**	**1364.0**		**6.6**	**2892.4**

Note: Feller Buncher Productivity estimates based on Adebayo et al. 2007 study (not ALPACA) due to hot saw operation

Feller Buncher

The feller buncher recorded an average productivity of 376 m^3/PMH equating to roughly $320/ha ($0.73/m^3). The machine spent most of its time felling trees (66%) and moving from stem to stem (32%) (**Figure 9**). Trees with higher DBH produce higher felling and bunching productivity where there is nearly a doubling in productivity between a stem diameter of 35cm compared with 55cm (**Figure 10**).

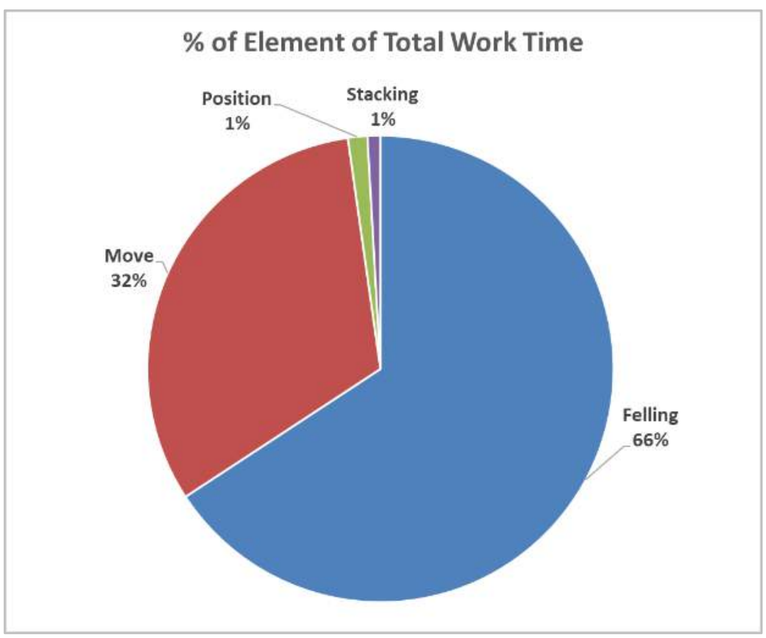

Figure 9. Feller Buncher – Time breakdown (% of working time)

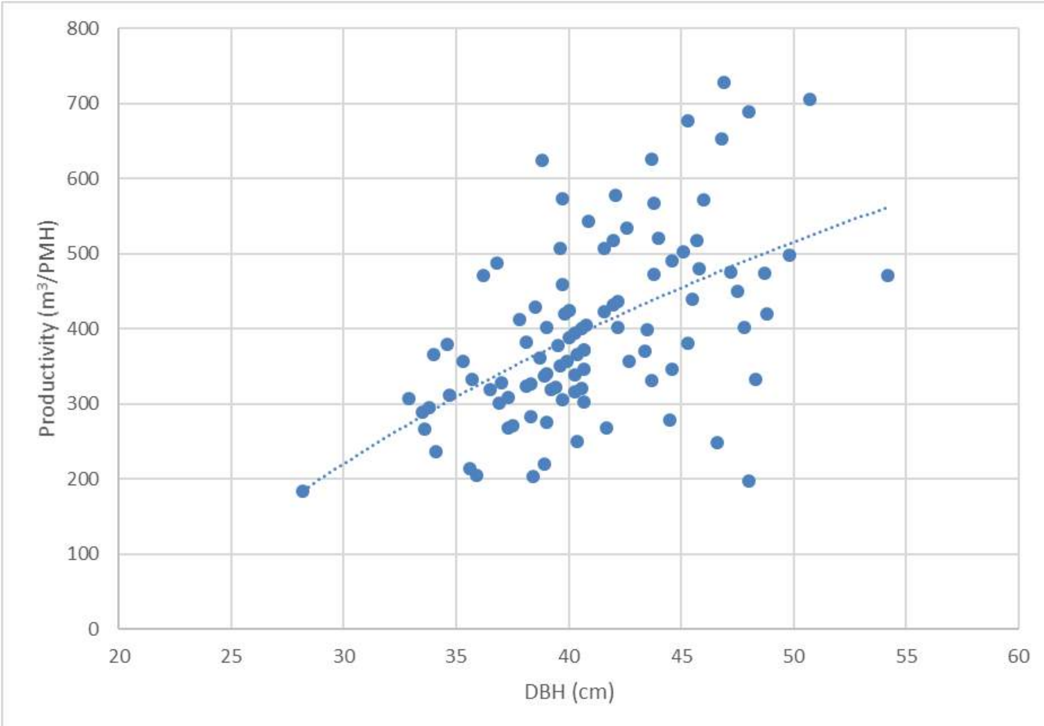

Figure 10. Effect of DBH on (Hot saw) Feller Buncher productivity

Grapple Skidder

The grapple skidder had an average productivity of about 217 m^3/PMH ($430/ha) with an average skidding distance of 45m. Nearly half of the time was spent travelling (empty and loaded). Other large time components included loading, unloading and stacking piles (Figure 11). As extraction distance increases productivity decreases (Figure 12).

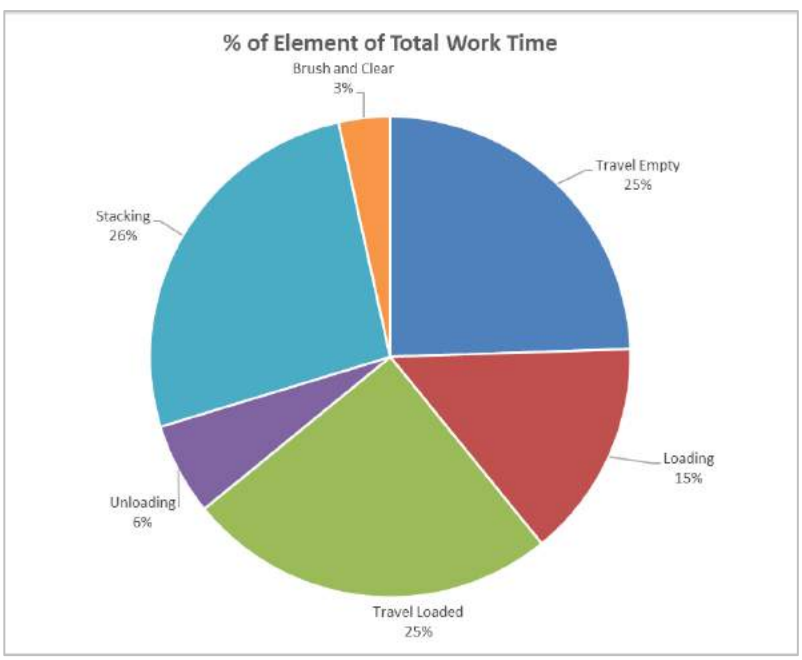

Figure 11. Skidder – Time breakdown (% of working time)

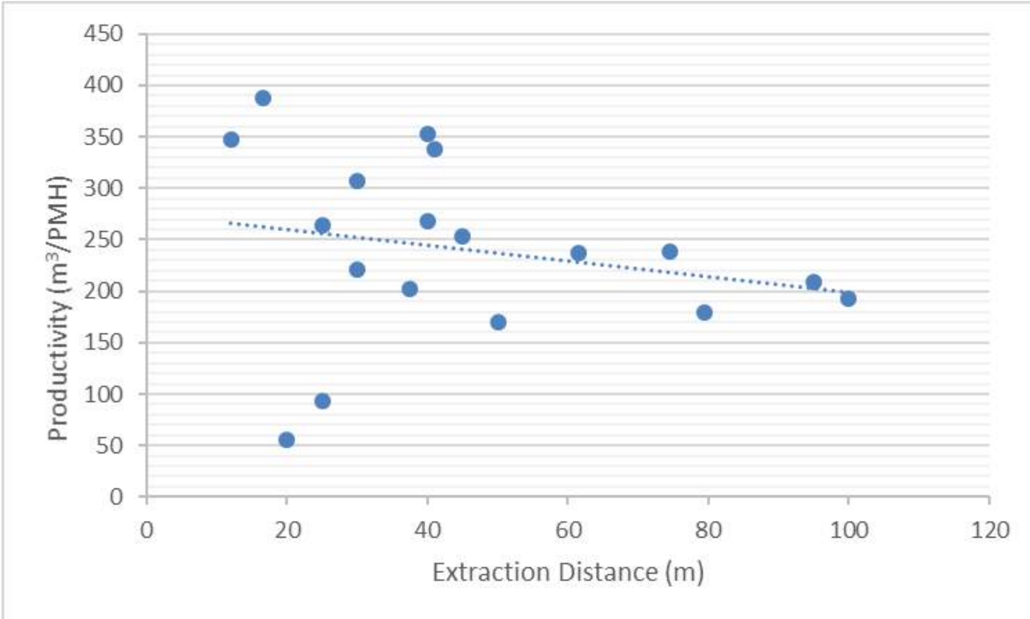

Figure 12. Impact of Extraction Distance (1 way) on skidding productivity

Processor

The processor had an average productivity of about 171 m^3/PMH ($614/ha). Nearly 80% of the productive time was spent processing while the remainder was positioning with some stacking (Figure 13). As tree volume increases productivity also increases (Figure 14).

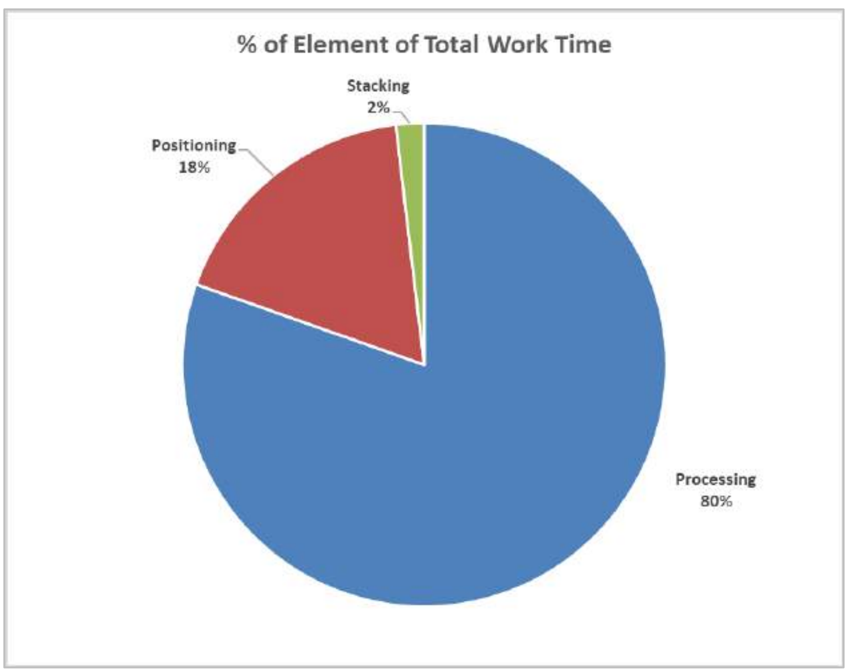

Figure 13. Processor – Time breakdown (% of working time)

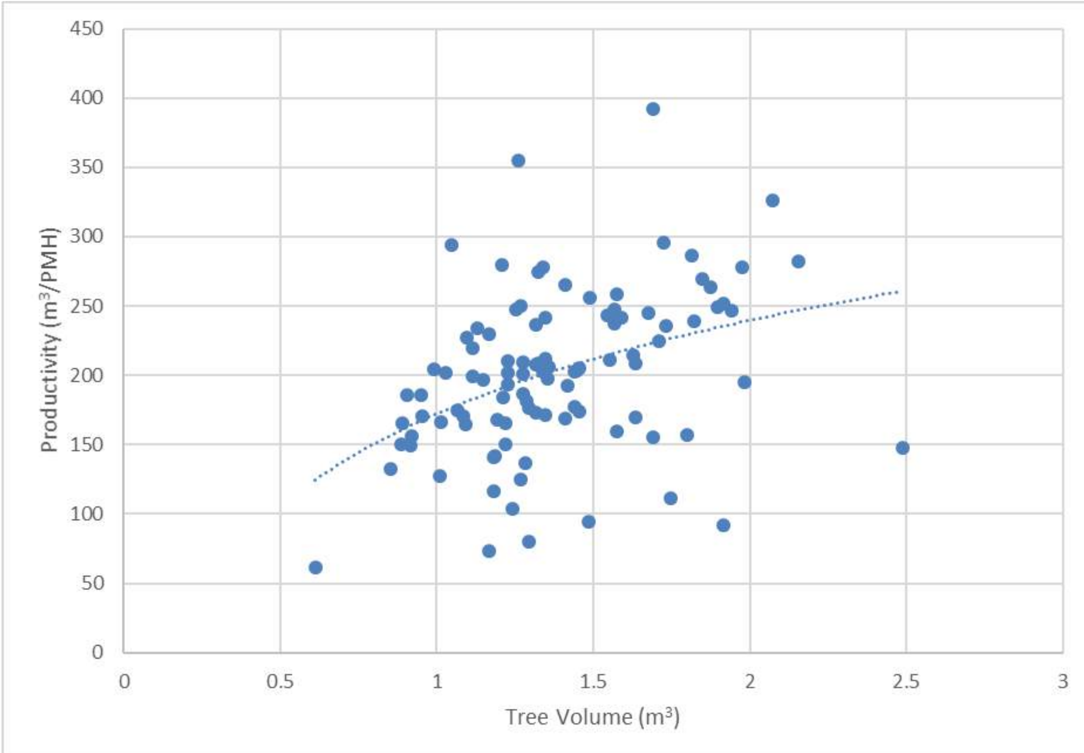

Figure 14. Effect of tree volume on processor productivity

RETAINED BIOMASS AFTER HARVESTING

The amount of slash remaining after harvest depends on a number of factors including the harvest system utilized, species, products/markets and tree handling. In this case, after using the nonagon line transect method (O'Hehir and Leech 1997), harvest residues above a 3 cm overbark diameter was estimated as being roughly 37 GMt/ha in the CTL site and 21 GMt/ha on the whole tree harvested site. These sites are subjectively classified as high residue loading for the CTL site and medium loading for the WT site based on feedback from HQPlantations.

SITE PREPARATION COST – BEST PRACTICES MATRIX

After consultation with HQP staff in charge of site preparation activities for the next rotation of plantation establishment, generic matrices for typical operations and costs regarding site preparation activities were developed for CTL (Table 5) and WT (Table 6) harvested sites carrying varying levels of harvest debris.

Table 5. Generic Site Preparation procedures and costs – Cut to Length System. CR = Chopper Roller, GPA = General Plantation Area, Windrow = Excavator used to move material into windrow orientation.

Slash Level	Frequency	Area	Treatment	Cost ($/ha)
High	75%	GPA	Windrow	900
		Additional	None	
		Notes:	May lose productive rows	
Medium-Low	25%	GPA	CR @ 100%	300
		Additional	None	
		Notes:	Light enough for only CR required	

If a biomass harvesting plan were in place under the whole tree system, the resulting roadside debris pile would ideally be eliminated. **Table 6** provides an estimate of the full treatment (with roadside treatment) and an estimate without roadside pile treatment for comparison.

Table 6. Generic Site Preparations procedures and costs – Whole Tree Harvesting Systems with and without Pile Manipulation. CR = Chopper Roller, GPA = General Plantation Area Lane Clear = Excavator used to clear productive planting rows

Slash Level	Frequency	Area	Treatment	Costs of Site Prep ($/ha) Full Treatment	No Pile
High - No Burn	25%	GPA	CR @ 100%	670	400
		Roadside	Lane Clear		
		Notes:	Full CR and must clear planting row		
High - Burn		GPA	CR @ 100%	500	400
		Roadside	Pile + Burn		
		Notes:	Burning is Cheap but can be risky		
Medium	50%	GPA	CR @ Tree Line	516	300
		Roadside	Lane Clear		
		Notes:	Targeted CR, Clear planting row		
Low	25%	GPA	CR @ Tree Line	416	200
		Roadside	Lane Clear		
		Notes:	Occassional CR, Clear planting row		

It is important to note that these values are highly dependent on the particular site with extraneous factors including future planting considerations/ costs, drainage/ slope, species, current row spacing, current mounding conditions, machine constraints (clearance, access, availability, etc.), time since last harvest (regrowth/ wildling conditions) and other legacy issues including row orientation.

Based on the above referenced matrices it is estimated that general site preparations for a typical debris load site would cost around $900/ha for the CTL site and $300/ha for the WT harvested site without roadside material handling ($516 with roadside pile).

ECONOMIC INCENTIVES FOR BIOMASS HARVESTING

Based on the results presented herein it appears that the economic incentive for moving towards a WT system from a site preparation perspective is generally in the neighbourhood of $230-400/ha. This relative incentive varies depending on the specific site. There may also be a dis-incentive for whole tree harvesting from a site preparation cost perspective when slash materials are low given the additional excavator (lane clearing) work likely required to handle the WT roadside material. These figures are in the same general range as other studies in the literature looking at site preparation costs (Wrobel-Tobiszewska et al. 2015, Gan and Smith 2007).

If the WT roadside pile is assumed to be removed (as in biomass harvesting) then the relative incentive for biomass harvesting increases with typical savings of $500-600/ha except in very low residue sites ($100/ha). The below matrix in Table 7 illustrates the relative incentives at different residue levels which will be compared with our nominal harvesting system costs.

For this case study with High CTL slash levels and Medium WT Slash levels there is an anticipated $600/ha cost savings.

Table 7. Economic Incentive for Biomass Harvest per Biomass Level

Slash Level	Economic Incentive ($/ha) Full Treatment	No Pile
WT: High - No Burn CTL: High	230	500
WT: High - Burn CTL: High	400	500
WT: Medium CTL: High	384	600
WT: Low CTL: Medium/Low	-116	100

Discussion

Discussions within this report include 1) a comparison of studied systems addressing site specific variations, 2) a discrete discussion and analysis which attempt to normalize the variables and costs, and 3) a concluding discussion on economic incentives for biomass harvesting.

COMPARING SYSTEMS

System costs depend on all of the unique variables related to harvesting beyond equipment including stem specifics (species, stocking, tree size, age), site characteristics (geometry, row direction, extent of mounding, extraction distances, wet weather access) and other extraneous variables that inevitably impact a direct comparison. Regarding the lower costing values recorded for the whole tree harvesting system in this study, it is important to note that the following considerations could easily change the relative economics within this study:

Mobilization costs - were not included in this study, the WT system has two additional mobilizations (Processor & Loader) when compared with the CTL system

Loader – The WT uses a separate loader for truck loading while the CTL system employs the forwarder for this operation. These operations and subsequent cost differences are not accounted for in this base study.

Stand Characteristics – Tree volumes in the WT system were larger (by around 24% on average) thus making the operation for felling/ processing and skidding more efficient.

Site Geometry & Extraction Distances – The CTL system averaged roughly triple (140m vs. 45m) the extraction distances thus increasing associated costs.

Extraction Product Volume – was not analysed in this study which may also affect the final economics of the systems. Whole tree volume equations provided by HQP were used for estimations, no reconciliation with product volume was available.

Markets & Logs – Processing for different products and markets inevitably plays a role in the overall productivity (number of cuts, number of logs to handle, transport, load etc.). In this case the WT system had on average 2-3 product logs while the CTL had 4-5 product logs.

Value Recovery – Harvesting system costs is only one piece of the economics of value recovery. While it may be more cost effective to choose one system over another based on harvesting costs the overall value and financial impact of the harvest depends on what products and what subsequent revenue is produced. These merchandising and value consequences are not considered.

System Complexity – Having more machines on site can inevitably lead to the higher likelihood of a breakdown on any given machine, though the processes can be decoupled for more flexibility. Similarly, only having two machines also leaves the contractor open to issues if there is a breakdown with insufficient flexibility to adapt workflows.

Small Study – This study represented idealized conditions (weather, production, access, etc.) on a small area with operators being filmed for the operations which they knew would take only 30mins – 2 hours to complete. It is not unreasonable to think a 'sprint' mentality may have set in and skew productive values to the high end.

Slope – Both sites were on gentle to flat terrain (typical of much of the Toolara estate) with line of sight throughout the whole operation making the conditions very favourable for high productivity.

NORMALIZED PRODUCTIVITY AND SYSTEM COSTS

To normalize the systems for similar operational results and costs one must make adjustments for extraction distance and stem size as well as include mobilization and loading costs. This was done in two different ways 1) adjusted productivity and costs without the inclusion of a loader (Table 8) and with a loader based on ALPACA productivity and costing assumptions (Table 9). The CTL system was taken as a baseline and the WT system was modified based on its derived productivity curves presented within the results. Key assumptions are as follows:

Mobilization Costs – Fixed at $1,000/ mobilization spread out over an average block size of 100 ha.

Stem Size – Changed to an average of 1.19m^3/ stem equivalent (38.7 cm diameter) for the feller buncher and processor using productivity curves derived from the CTL system motion study.

Extraction Distance – WT system average extraction distance was increased from 45m to 140m.

Loader (Base) – Assume no difference in cost.

Loader (ALPACA) – Forwarder/ loader (CTL) and separate large loader (WT) modelled for comparison. In this case, based on ALPACA estimates, the Forwarder/Loader assumed to have a cost of $275/PMH with Productivity of 24.2 m^3/PMH while a Separate Loader was modelled with a cost of $168/PMH and productivity of 60 m^3/PMH.

Table 8. Governing productivity assumptions for the equipment.

	Productivity (m^3/PMH)		
Machine	**Base**	**Adjusted**	**ALPACA**
Harvester/ Processor	73.8	73.8	54.1
Forwarder	57.0	57.0	42.3
Forwarder - Loader*		24.2	24.2
Feller Buncher	376.4	353.8	424.0
Skidder	217.3	168.0	76.2
Processor	171.3	156.9	74.5
Loader*		60.0	60.0

*Estimates from the ALPACA Model

From this comparison the whole tree harvesting system is much more economical, by a factor of three originally and, following adjustments as described, approximately 2.5x more economical for this specific study, with a difference of approximately $2,300-2,500/ha (~$5/m^3) for each case and the reference ALPACA scenario (Table 9**).** As an important caveat, this comparison is not completely unbiased as previously discussed. But it does show the importance of reviewing system costs and productivity in relation to site preparation activities and relative costs.

Table 9. Normalized System Costs without Loader (Base as observed, Adjusted with outlined productivity adjustments and ALPACA baseline assumptions).

		Cost ($/ ha)			Cost ($/m^3)		
	Machine	**Base Case**	**Adjusted**	**ALPACA**	**Base Case**	**Adjusted**	**ALPACA**
	Harvester/ Processor	1691	1691	2307	3.7	3.7	5.1
CLT	Forwarder	2190	2190	2951	4.8	4.8	6.5
	Forwarder-Loader	-	-	-	-	-	-
	Mobilization	-	20	20	-	2.2	2.2
	TOTAL:	**3881**	**3901**	**5279**	**8.6**	**10.8**	**13.8**
	Machine	**Base Case**	**Adjusted**	**ALPACA**	**Base Case**	**Adjusted**	**ALPACA**
	Feller Buncher	320	341	258	0.7	0.8	0.6
	Skidder	430	626	1381	1.0	1.4	3.2
WT	Processor	614	595	1254	1.4	1.4	2.9
	Loader*	-	-	-	-	-	-
	Mobilization	-	40	40	-	2.3	2.3
	TOTAL	**1364**	**1602**	**2932**	**3.1**	**5.9**	**8.9**
	COST (CTL-WT)	**2517**	**2299**	**2346**	**5.4**	**4.9**	**4.9**

Extending this analysis to include an assumption for the loader cost and productivity based on the ALPACA model, the overall economic incentive for utilizing the whole tree system from a harvesting perspective climbs to roughly $6,300/ha (~$14/m^3) in all cases (**Table 10**).

Table 10. Normalized System Costs with Loader (Base as observed, Adjusted with productivity adjustments and ALPACA assumptions).

		Cost ($/ ha)			Cost ($/$m^3$)		
	Machine	**Base Case**	**Adjusted**	**ALPACA**	**Base Case**	**Adjusted**	**ALPACA**
CLT	Harvester/ Processor	1691	1691	2307	3.7	3.7	5.1
	Forwarder	2190	2190	2951	4.8	4.8	6.5
	Forwarder-Loader	5158	5158	5158	11.4	11.4	11.4
	Mobilization	-	20	20	-	2.2	2.2
	TOTAL:	**9040**	**9060**	**10437**	**20.0**	**22.2**	**25.2**
	Machine	**Base Case**	**Adjusted**	**ALPACA**	**Base Case**	**Adjusted**	**ALPACA**
WT	Feller Buncher	320	341	258	0.7	0.8	0.6
	Skidder	430	626	1381	1.0	1.4	3.2
	Processor	614	595	1254	1.4	1.4	2.9
	Loader*	1234	1234	1234	2.8	2.8	2.8
	Mobilization	-	40	40	-	2.3	2.3
	TOTAL	**2598**	**2836**	**4167**	**5.9**	**8.7**	**11.7**
	COST (CTL-WT)	**6441**	**6223**	**6270**	**14.0**	**13.5**	**13.5**

ECONOMIC INCENTIVES FOR BIOMASS HARVESTING

The lower harvesting costs of the WT system coupled with the economic incentive from a site preparation perspective ($100-600/ha) indicates the overall incentive may range from $2,400/ha to over $7,000/ha depending on slash levels, productivity and loader costing assumptions. This also indicates the relative value of site preparation savings is small compared to harvest system savings (where site preparation savings are about 2-20% of the anticipated system savings). These figures must then be put into the context of markets and products – for example additional revenue (and value) from an efficient CTL system may offset the additional costs of harvesting and site preparation compared to a WT harvesting system.

Conclusions and Recommendations

Harvesting systems and biomass removal directly impact site preparation costs and the economic ramifications of these decisions should be considered when developing a harvest and subsequent regeneration plan. Furthermore, market value recovery and revenue generation by virtue of log markets also needs to be taken into account when reviewing the aforementioned figures.

This study clearly identifies a reduction in site preparation costs due to biomass harvesting, which would likely vary from $100-600/ha (0.2-1.3 $/$m^3$). Furthermore, the enabling system (WT in this case) also contributes a significant financial incentive to produce roadside biomass (savings of up to $6,300/ha [$13.5/m^3]).

The findings of this case study indicate a site preparation incentive of $600/ha combined with systems incentive of $6,300/ha for a total of roughly $6,900/ha ($15/m^3) in favour of a biomass harvesting (Whole Tree Systems) model.

In line with previous discussions, the following items are suggested for further review and evaluation:

Comparable Sites - A more closely related systems comparison including all possible factors such as stem size, machine selection, markets and extraction distance would provide a better comparison of systems and subsequently biomass harvesting considerations and baselines.

Study Harvesting System Variation - Similar investigations into alternative WT harvesting systems, where the stems are processed into a wider range of shorter (CTL) logs at roadside, compared to the WT harvest and roadside stem processing (and loading) system described in this report.

Site Preparation Decision Support Matrix - Development of a decision support matrix to evaluate best practices of site preparation depending on condition of existing site, residue level, harvesting type and other associated externalities. This would help guide decision making in a more regimented way to delve into the site-specific nuisances.

Productivity Studies Literature Review - A review of system productivity norms and costing through a desktop exercise may provide more telling results as to the underlying financial motivations for CTL compared to whole tree harvesting in different environments, as single studies are always site specific.

Site Preparation Productivity Studies – Time and motion productivity studies for specific site preparation tasks and machines (along with broad based assumptions) would yield a more robust comparison.

Value Recovery & Revenue Comparison - Evaluation of the differences in value recovery and revenue from one system compared to another (market side) would provide the revenue side of the equation and thus the relative economic benefit and incentive for biomass harvesting.

Modified Harvest Systems - CTL harvesting systems can also be modified to serve as a biomass harvesting method, this was not addressed within this report but should be further evaluated and the literature reviewed.

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Case study 2: Integration of forest biomass procurement as a silvicultural tool in logging operations in spruce budworm-affected stands (Quebec, Canada)

Daniel Gouge[1,2], Nelson Thiffault[1], Evelyne Thiffault[2]

1: Canadian Wood Fibre Centre, Natural Resources Canada, Quebec City, Canada.

2: Research Centre on Renewable Materials, Laval University, Quebec City, Canada.

Introduction

The forest landscapes of eastern Canada, notably the region of Côte-Nord in northeastern Quebec, are currently facing a severe outbreak of spruce budworm (SBW), an insect that causes considerable defoliation of coniferous trees (Figure 15). SBW causes cyclical epidemics, with an average return of 30-40 years. The majority of affected trees die, with balsam fir (*Abies balsamea* (L.) Mill.) and white spruce (*Picea glauca* (Moench) Voss) being severely affected by this defoliating insect (MFFP, 2018). When the foliage supply from these species becomes sparser, the budworms also attack black spruce (*Picea mariana* (Mill.) BSP). The result is a major degradation of the wood supply available for harvesting. After defoliation, the wood becomes unfit for processing into timber and pulp (Barrette et al. 2015). Degraded trees are therefore often just left on the cutbock.

Figure 15. Defoliated balsam fir stand following a severe spruce budworm outbreak (MFFP, 2018)

Boreal forests of Côte-Nord also contain an important share of intolerant hardwood species, such as trembling aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marshall), which are not used by the conventional wood product industrial network in this region. Therefore, because of the absence of a market for degraded woods and intolerant hardwoods, substantial volumes of wood are unused and left on cutbocks, often in the form of downed woody debris.

In Côte-Nord, Rémabec and Arbec, which perform forest operations and operate a timber sawmill in Port-Cartier, along with the technology supplier Ensyn, collaborated to design and build a plant producing bioenergy in the form of a bio-based pyrolysis oil, comparable to fossil-based heavy oil, from forest biomass. The outcome is the Bioenergy AE plant, located in Port-Cartier. The Bioenergy AE project was completed in 2017 and there are plans to produce about 40 million litres of bio-based pyrolysis oil per year (Groupe Remabec, 2018). The main feedstock for this plant is unused trees and tree parts that are left over in regular timber harvesting operations, i.e. degraded coniferous wood and intolerant hardwoods. Planning and procurement of wood for timber and biomass for bioenergy are coordinated and performed in the same stands around Port-Cartier, an area currently severely defoliated by SBW. Good-quality merchantable wood from coniferous trees is directed to the sawmill, whereas degraded coniferous wood and intolerant harwoods are sent to the bioenergy plant.

Procurement of biomass may have direct and indirect effects on future regeneration and site preparation costs. Regeneration stocking and density are critical factors determining forest productivity (Drew and Flewelling 1979). They directly depend upon successful tree regeneration following harvesting (Burton et al. 2003), which, in turn, is influenced by many factors including seed and propagules sources and down woody debris (Thiffault et al. 2015). Debris can indeed affect microenvironment, which directly influences resource availability (air and soil temperatures, nutrients, water and light) (e.g. Trottier-Picard et al. 2014). For example, a study carried out in Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) stands in Washington state in the United States (Harrington et al. 2018) showed that coarse woody debris retention had a positive effect on the survival, vigour and growth of planted trees. Conversely, the retention of coarse debris increases the risk of fire over a limited period of about five years (Harrington et al., 2018). However, studies conducted in Canada suggested that retention of high quantities of debris –that might otherwise be used as a bioenergy source– might have a negative effect on the survival of regeneration caused by the difficulty of planting and the reduction in the abundance of suitable microsites for the establishment of seedling, either naturally or through planting (Fleming et al., 2006). Site preparation treatments must then be used to create a good environment for the establishment and growth of naturally established or planted regeneration, as well as to enable and facilitate reforestation work (Örlander et al. 1990; Prévost 1992; Löf et al. 2012). An abundance of woody debris can cause an increase in site preparation costs in managed forests; it can also create habitats for plant-damaging animals (Sullivan and Sullivan, 2014).

Objectives

The overall objective of this project was to study the integration of forest biomass procurement as a silvicultural tool in logging operations in the boreal forest stands of Côte-Nord. More specifically, the goal of this project was to assess the effect of biomass procurement in SBW-affected stands as a component of a forest management system aimed at both (i) procuring wood for timber and biomass for bioenergy, and (ii) establishing regeneration on clearcut areas. The research objectives were therefore:

- To assess how biomass procurement along with timber harvesting influences the quantity and quality of suitable microsites for the regeneration establishment;
- To assess site preparation requirements and costs based on the quantity of harvested biomass;
- To estimate biomass supply costs (in dollars per oven-dry metric tonne), taking into account the effect of this supply on land preparation costs.

The practical objective was to determine a maximum return with respect to volumes of harvested biomass (which will determine net profit resulting from the conversion of this biomass into renewable fuel oil), and quantities of residual wood left on the site (which will have an impact on the costs of bringing harvested sites into production).

Research area

The study area (Figure 16) is located about 25 km northwest of the city of Port-Cartier in the region of Côte-Nord, and near the southern boundary of the black spruce – feather moss bioclimatic domain. Within this area, we established reseach plots in the southern part of the region (Figure 16).

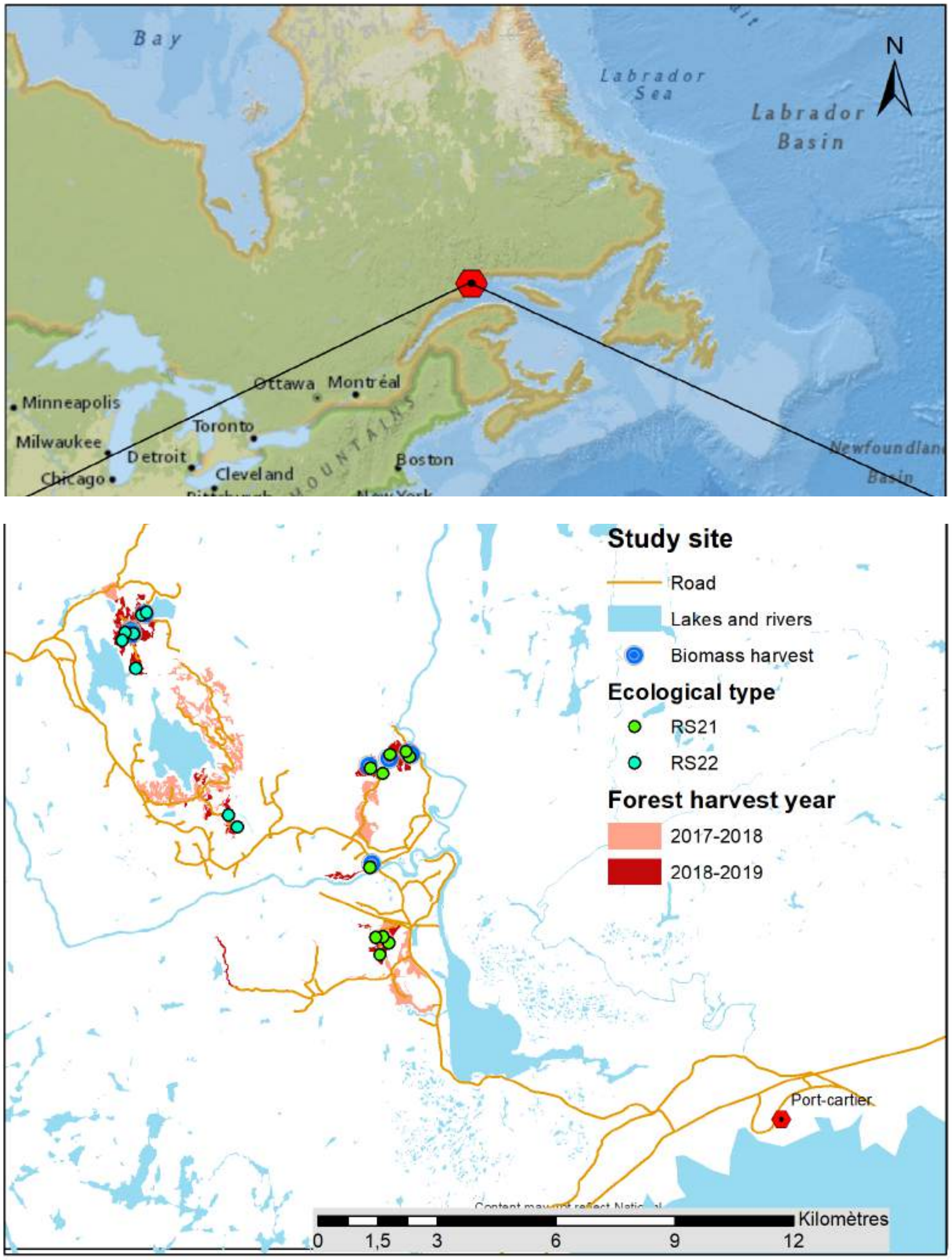

Figure 16. Study area and location of experimental plots

Methods

We established an experimental design consisting of randomized blocks. Each block (replicate) is composed of a pair of plots, each pair consisting of 1) one plot that had undergone merchantable timber harvesting for the sawmill, and 2) one plot having undergone both merchantable timber harvesting and biomass procurement in the form of degraded wood from coniferous species plus whole trees from intolerant hardwood species, intended for the bioenergy plant producing bio-based pyrolysis oil.

Within a block, the soil and stand ecological characteristics, as expressed by the ecological type according to Quebec ecological classification, were kept constant. The following ecological types were included in the design, due to their abundance in the region:

- **RS21**: Black spruce stand on thin to thick mineral soil deposits, coarse soil texture, and xeric or mesic drainage (Morneau and Landry, 2010);
- **RS22**: Black spruce stand on thin to thick mineral soil deposits, medium soil texture, and mesic drainage (Morneau and Landry, 2010).

The level of SBW defoliation of trees prior to logging was also taken into account and was kept constant within a block. Defoliation was assessed using aerial data, but could not be validated with field measurements prior to logging; the assessment of defoliation therefore carries some uncertainty.

Plots were established *a posteriori*, i.e. by identifying cutblocks with and without biomass procurement and establishing pairs of plots with constant ecological characteristics. To avoid pseudoreplication (Hurlbert, 1984), we kept a minimum distance of 400 m between plots of the same treatment, but belonging to different pairs (different blocks). Figure 17 shows an example of a cutblock located on a RS22 ecological type, that has not undergone biomass procurement (hence the abundance of woody debris).

Photo credit: Daniel Gouge

Figure 17. Cutblock in the study area that has not undergone biomass procurement operations

Figure 18 presents the layout of a circular experimental plot (11.28 m-radius). The abundance of fine woody debris (FWD; diameter of 1.1-5 cm) and coarse woody debris (CWD; diameter>5 cm) were estimated along two perpendicular 20-m transects; decomposition class of both FWD and CWD was assessed, and the diameter of each piece of CWD was measured. Presence of regeneration (seedlings of >15 cm in height), % cover of competing vegetation (ericaceous, graminoids, herbaceous, commercial and non-commercial hardwoods, and rosacea), presence of suitable microsites (see below), type of substrate (forest floor, buried wood, decayed wood, rocks, bedrock, mineral soil, water) were assessed in 10 microplots distributed along these transects. We assessed microsite quality based on provincial and regional operational guidelines. In summary, good microsites (at least 20 cm x 20 cm) were defined as having less than 5 cm of humus and more than 15 cm of mineral soil, were exempt of competing vegetation so that light availability was high, were not heavily compacted or submitted to flooding, were not scalped in a radius larger than 1 m, and were devoided of obtacles to planting (woody debris, stumps, rocks, etc.). The abundance of seedlings and microsites was assessed relative to a scenario with a tree density target of 2000 stems/ha. In each plot, abundance of seedlings and microsites were therefore assessed in ten 5-m^2 microplots, and expressed as the proportion of microplots with seedlings and/or suitable microsites.

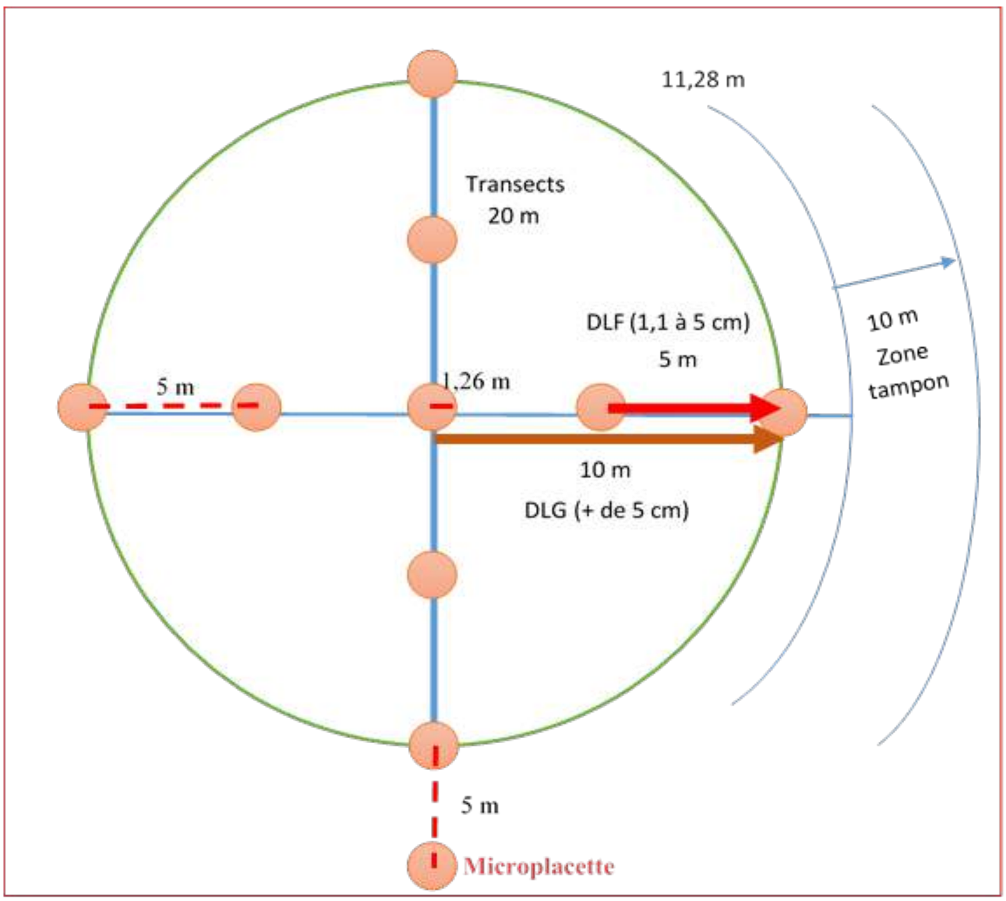

Figure 18. Representation of a sample plot used to assess the effect of biomass harvesting on regeneration success and land preparation requirements.

Calculations and statistical analyses

Using the data collected along the transects, we used the following equations to determine the volume (m^3/ha) and mass (oven-dry metric tonnes) of fine and coarse woody debris:

$$\text{CWD volume} = \left(\frac{\frac{\pi \times \pi}{8}}{\text{length of transects}}\right) \times \left(\sum_{\text{i}=1}^{n}((\text{debris diameter i})^2)\right)$$

$$\text{CWD mass} = \left(\frac{\frac{\pi \times \pi}{8}}{\text{length of transects}}\right) \times \left(\frac{\sum_{i=1}^{n}((\text{debris diameter i})^2 \times \text{density of i})}{1{,}000}\right)$$

$$\text{FWD volume} = \left(\frac{\frac{\pi \times \pi}{8}}{\text{length of transects} \times \text{number} \times (3)^2}\right)$$

$$\text{FWD weight} = \left(\frac{\text{FWD volume} \times \text{average density}}{1{,}000}\right)$$

$$\text{Total volume} = \text{CWD volume} + \text{FWD volume}$$

$$\text{Total mass} = \text{CWD mass} + \text{FWD mass}$$

Where:

CWD volume = total volume (m^3/ha) of coarse woody debris

FWD volume = total volume (m^3/ha) of fine woody debris

CWD mass = total mass (oven-dry metric tonne/ha) of coarse woody debris

FWD mass = total mass (oven-dry metric tonne /ha) of fine woody debris

Length of transects = the total length (in metres) over which fine or coarse woody debris were tallied

Density is the coefficient of wood density (g/cm^3) based on the species and its decomposition class (data taken from Canada's National Forest Inventory).

n = total number (quantity) of tallied pieces of woody debris

i = a given piece of woody debris

Number = total number (quantity) of fine woody debris over the length of the transect where it was estimated

Preliminary analysis

During an initial field campaign carried out in October 2018, four blocks (four pairs of sample plots = 8 plots in total) were installed in cutblocks representing the RS22 ecological type, giving a first indication of the effects of biomass procurement for creating adequate conditions for establishment of regeneration. The logging operations had been carried out during the previous winter (winter of 2017-2018).

WOODY DEBRIS

Table 11 and 12 present the summary of total volume and mass of woody debris (including fine and coarse debris) without and with biomass procurement along with timber harvesting. Note that the stump volume varied independently of the biomass procurement treatment.

Table 11. Volumes (m3/ha) and mass (oven-dry metric tonne/ha) of woody debris on RS22 ecological type cutting areas that have not undergone biomass procurement.

Quantity of woody debris - Timber harvesting only - No biomass procurement				
Plot ID	Without stumps		With stumps	
	Volume (m^3/ha)	Mass (oven-dry metric tonne/ha)	Volume (m^3/ha)	Mass (oven-dry metric tonne/ha)
10	165.9	61.2	170.9	63.3
12	70.4	26.7	78.9	29.8
15	113.7	43.3	132.1	50.2
13	130.3	45.0	155.9	52.7
Mean	120.1	44.1	134.5	49.0
Standard deviation	39.6	14.1	40.4	14.0

Table 12. Volumes (m3/ha) and mass (oven-dry metric tonne/ha) of woody debris on RS22 ecological type cutting areas that have undergone biomass procurement.

Quantity of woody debris - Timber harvesting and biomass procurement				
Plot ID	Without stumps		With stumps	
	Volume (m^3/ha)	Mass (oven-dry metric tonne/ha)	Volume (m^3/ha)	Mass (oven-dry metric tonne/ha)
9	54.8	19.4	63.4	22.6
11	71.2	25.5	78.5	28.0
14	68.2	21.1	90.5	28.6
16	59.2	22.3	64.4	24.2
Mean	63.3	22.1	74.2	25.9
Standard deviation	7.7	2.6	12.9	2.9

Unsurprisingly, the quantity of woody debris left on site was clearly higher when there was no biomass procurement operations following harvesting; biomass procurement reduced by about half the amount of residues left. We can also estimate that operations procured about 57 m^3 or 22 oven-dry tonnes of biomass. On plots with biomass procurement, woody debris were still abundant, i.e. 63 m^3/22 oven-dry tonnes (excluding stumps), which is in the range of quantities of leftover residues following biomass harvesting operations reported for boreal forests in Quebec (Thiffault et al. 2015). The leftover quantities suggest that there are still some obstacles to regeneration establishment and site preparation operations, even with biomass procurement; on the other hand, the abundance of leftover debris might reduce the risks, if any, associated with soil fertility loss.

MICROSITES AND REGENERATION

Tables 13 and 14 present the proportion of microplots with at least one seedling or suitable microsite, out of a total of 10 microplots.

Table 13. Abundance of regeneration (seedlings >15 cm) and suitable microsites assessed in 5-m² microplots in areas that have not undergone biomass procurement.

Regeneration and microsites – Timber harvesting only – No biomass procurement			
Plot ID	Proportion (%) of microplots with…		
	at least 1 seedling > 15 cm	at least 1 suitable microsite	at least 1 seedling >15 cm OR 1 suitable microsite
10	60	10	60
12	60	20	70
15	40	10	40
13	80	0	80
Mean	60	10	63
Standard deviation	16	8	17

Table 14. Abundance of regeneration (seedlings >15 cm) and suitable microsites assessed in 5-m² microplots in areas that have undergone biomass procurement.

Regeneration and microsites – Timber harvesting and biomass procurement			
Plot ID	Proportion (%) of microplots with…		
	at least 1 seedling > 15 cm	at least 1 suitable microsite	at least 1 seedling >15 cm OR 1 suitable microsite
9	30	40	60
11	60	30	70
14	90	0	90
16	80	20	80
Mean	65	23	75
Standard deviation	26	17	13

Tables 13 and 14 show that the abundance of microsites increased with biomass procurement operations. This may be related to the increased machinery traffic that exposed the mineral soil. Also, wood removal reduced debris load and increased the amount of light reaching the microsites. However, the effect of biomass procurement on the abundance of seedlings was not as important.

SUBSTRATE

Figures 19 and 20 show the difference between the types of substrate observed in areas without and with biomass procurement, based on the average of 10 observations per plot.

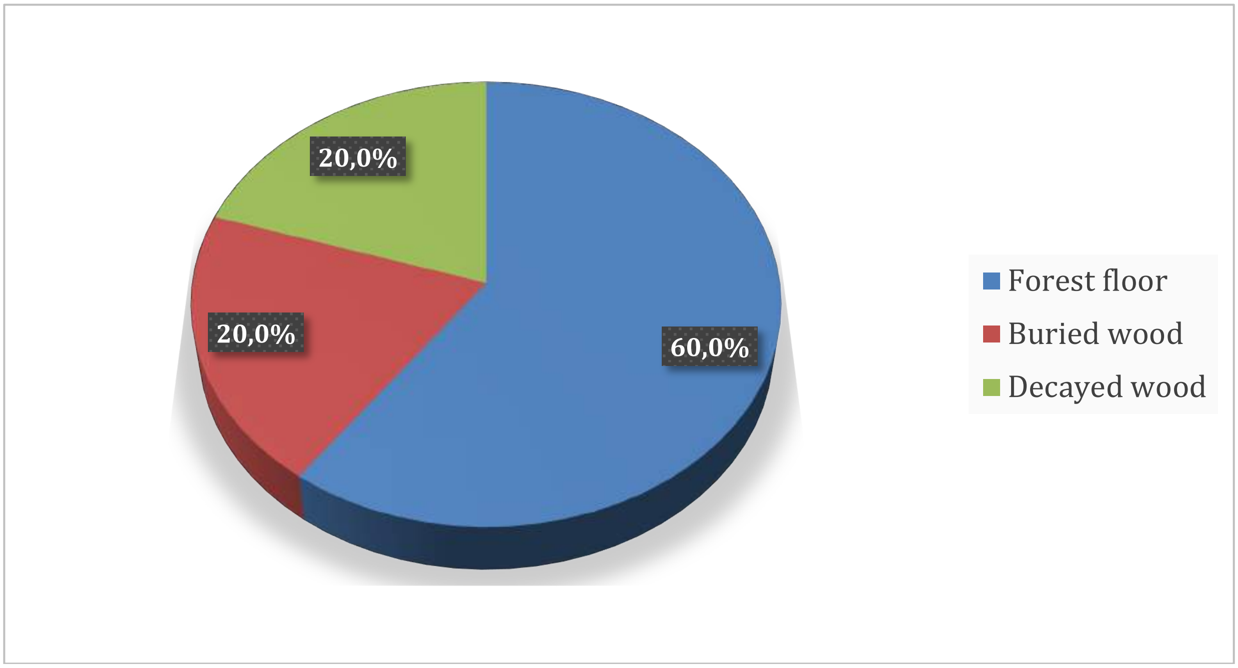

Figure 19: Type of substrate observed in RS22 ecological type cutting areas that have not undergone biomass procurement.

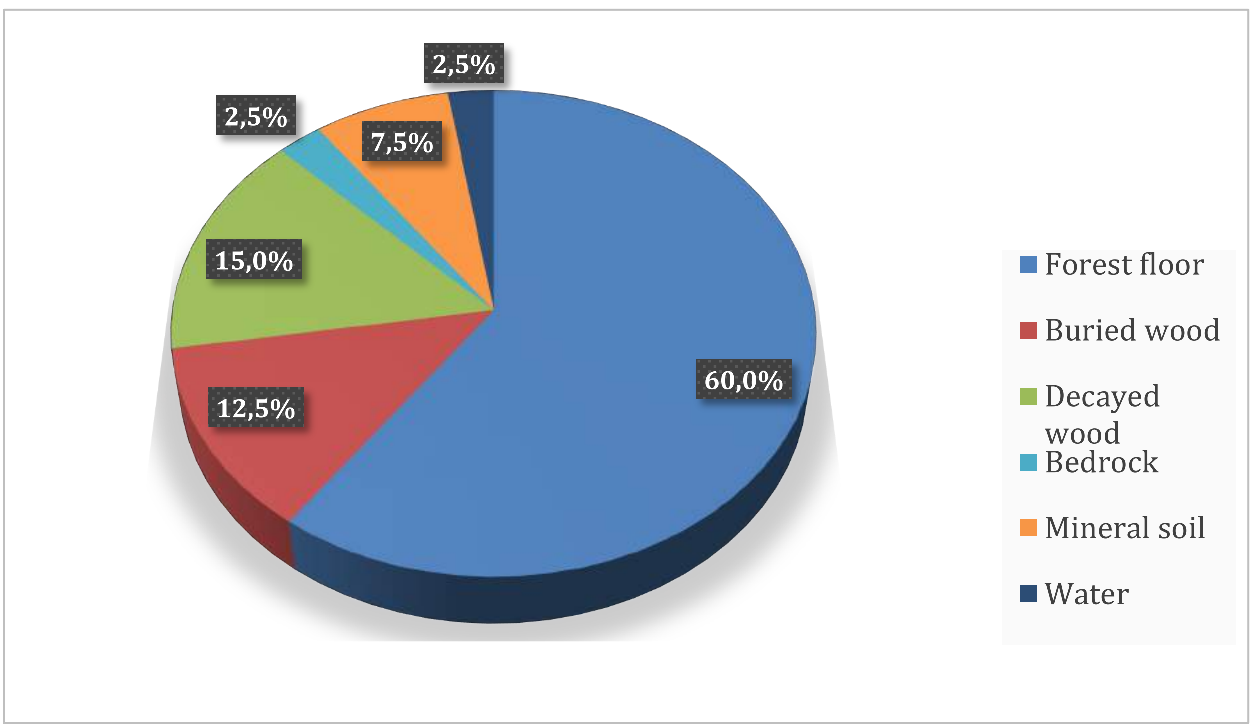

Figure 20: Average substrate observed in RS22 ecological type cutting areas that have undergone biomass procurement.

Substrate coverage was more variable in plots that had undergone biomass procurement. In addition, the abundance of buried and decayed wood decreased by at least 10% with biomass procurement. It appears that removal of biomass was efficient in exposing the mineral soil. Conversely, biomass procurement might have created water-filled ruts or exposed bedrock.

COMPETING VEGETATION

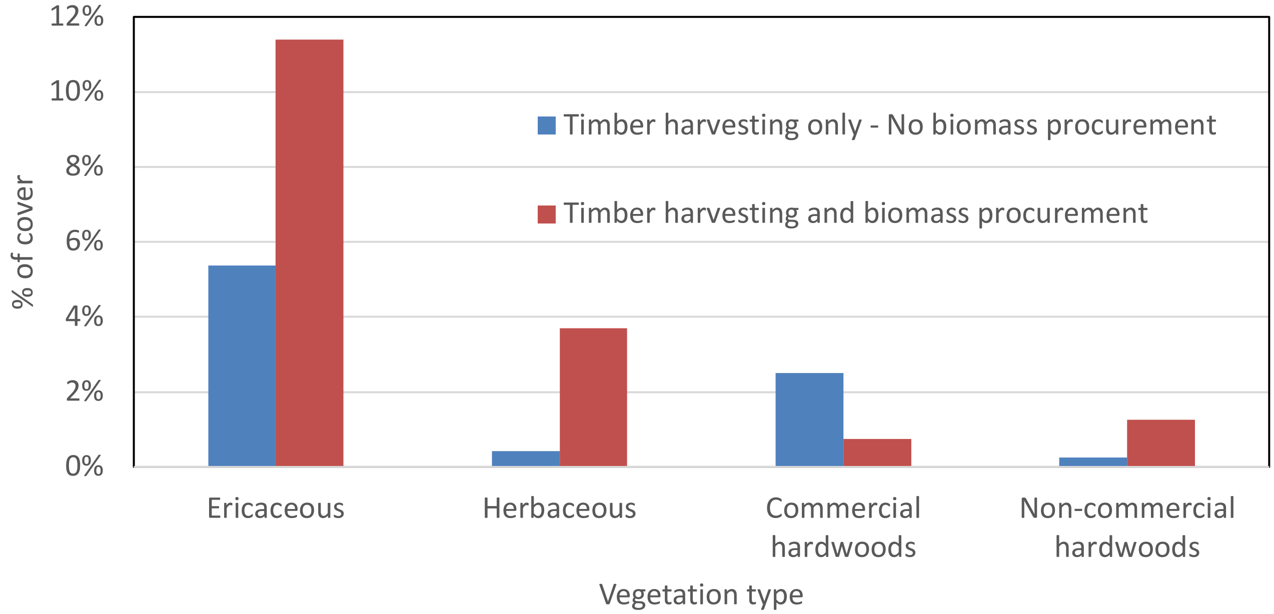

Figure 21: Average percentage of cover of competing species observed in cutting areas with and without biomass harvesting

Figure 21 shows the abudance of competing vegetation according to treatments. Results suggest that competing vegetation was more abundant after timber harvesting with biomass procurement than following harvesting only. This suggests that biomass procurement may create competing vegetation problems, especially by ericaceous species. This need to be further investigated, as species from the ericaceae family exert strong competition for soil nutrients, with significant negative impact on conifer regeneration nutrition and growth (Mallik 2003). However, the total cover of competing vegetation was still low, i.e. about 17% in plots with biomass procurement, which is below the threshold of 50% cover over which competition is considered to significantly affect conifer regeneration (MFFP, 2016).

Conclusion

Based on a limited number of replicates, biomass procurement in the form of degraded trees along with harvesting of sawntimber increased the number of seedlings and suitable microsites, and the exposure of mineral soil (a better seed bed than forest floor), and reduced the obstacles for establishment of regeneration and site preparation. However, difference between treatments (with/without biomass procurement) was not large and variability was high. Whereas a boreal site is usually considered as non-regenerated and to require reforestation activities when its conifer stocking is less than 40% (Pominville and Doucet 1993), a threshold of about 60% conifer stocking is about the minimum for a stand to reach maximum yield at maturity (Pominville and Ruel 1995). According to this threshold, both treatments have, on average, a sufficient stocking of seedlings and would not require planting. Nevertheless, with timber harvesting only, one out of four plots was below the 60% threshold, two plots were at 60%, and one was above; for plots with biomass procurement, one plot out of four was below the threshold, one was at 60% and two plots were above. The overall stocking of seedlings and suitable microsites was on average just above 60% for timber harvesting only, whereas it was much higher (75%) for the treatment with biomass procurement. Another field campaign will be carried out during 2019 to increase the number of blocks and allow for proper statistical comparisons of harvesting treatments. Further field data collection will help clarify whether there is trend for biomass procurement to be more conducive to creating better regeneration conditions in those SBW-affected stands. However, recent research shows that there is a general tendency for free-to-grow conifer stocking to improve between year ~5 and ~10, especially under low competing level of commercial shade-intolerant hardwoods (Ménard et al. 2019). Hence, the increase of competition cover that we have observed following biomass removal might affect conifer recruitment at the juvenile stage, although the stands have already reached a regeneration level ensuring productivity.

Further data will allow a comparison of the costs of procurement of wood for timber and biomass for bioenergy, and the costs of site preparation. A more detailed analysis will thus make it possible to assess whether biomass procurement in those types of stands provide benefits in terms of costs of regeneration after harvest, and also whether differences in regeneration patterns can translate into carbon sequestration differences.

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