Integrated land management using small-scale harvesting operations for biomass utilization

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Dr Michael. D Berry

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Dr. Michael D. Berry[1]

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

Executive Summary

Research was conducted to evaluate small-scale biomass harvesting as a silvicultural thinning treatment for forest management in the Private Native Forests (PNF) of Southeast Queensland. This study analysed integrated land management in the rural Australian context through a field study around small scale operations. Four different plots and operational treatments were analysed to better understand the complexity of the resource and operational considerations to support integrated land management. An analysis of the resulting product yields and machine productivity were assessed and then coupled with hypothetical chipping assumptions to determine approximate costs of production and recovery. Furthermore, this document also outlines proposed further research and considerations resultant from this study.

Introduction

In recent years there has been an increasing interest in 1) better management of Australian private native forests for increased productivity and higher long term value and 2) the utilization of woody biomass for products ranging from pellets to boiler fuel to landscape material with feedstock sourced from both softwood plantations and private native hardwood estates.

GMT Logging and Private Forest Service Queensland (PFSQ) with support from USC FIRC and QDAF collaborated to execute this scoping project to evaluate the use of mechanised methods for biomass recovery in the private native resource. At present the vast majority of the PNF resource is over-stocked and in a degraded state with limited forest management. Mechanised thinning is a promising alternative to chopper-rolling and traditional thinning (with a tordon axe) which leave dead tree biomass as waste on the forest floor. Biomass thinning, as a saleable product, may help make silvicultural thinning treatments viable and allow effective forest management of the resource To date, this treatment option has not been well tested in the region.

Motivation for this project are two-fold. Firstly to gauge the regional and landscape variations associated with biomass availably to evaluate the commercial viability of PNF biomass harvest. Secondly, and more broadly, to determine associated environmental impacts, long-term value implications (stand dynamics) and market impacts (saw-log, poles, biomass, etc.).

The USC Forest Industries Research Centre (FIRC) assisted with data collection to complete an analysis of the biomass availability, operational productivity and economics associated with trial interventions.

Ultimately, biomass harvesting is being evaluated as a means to enable more effective and productive long-term integrated land forest management. This will lead to better utilization and management of this domestic resource.

Study Area

The study area was located near Mt. Urah in Southeast Queensland (the hinterland between Gympie and Maryborough) at a property of Ergon Energy (**Figure 1**). Four 2ha sites were used in this study.

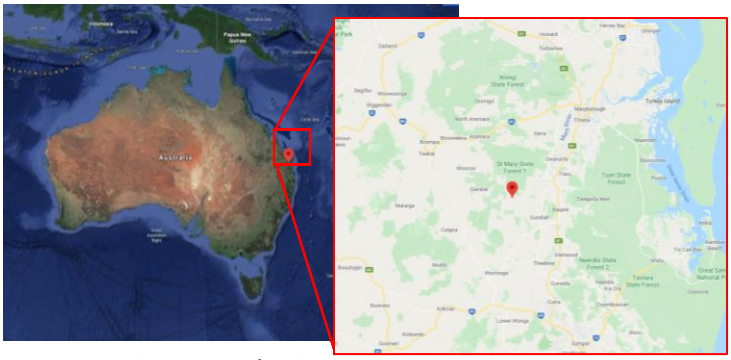

Figure 1. Australian context of trials. Inset Mt. Urah Trial location south-west of Maryborough, Queensland.

Four 2ha sites with different characteristics (stand densities, diameter classes, species composition and expected quality) were chosen (**Table 1, Figure 2**). Each of the 4 sites were paired with a different operational biomass harvesting treatment for evaluation and review (see Research Methods and Table 2).

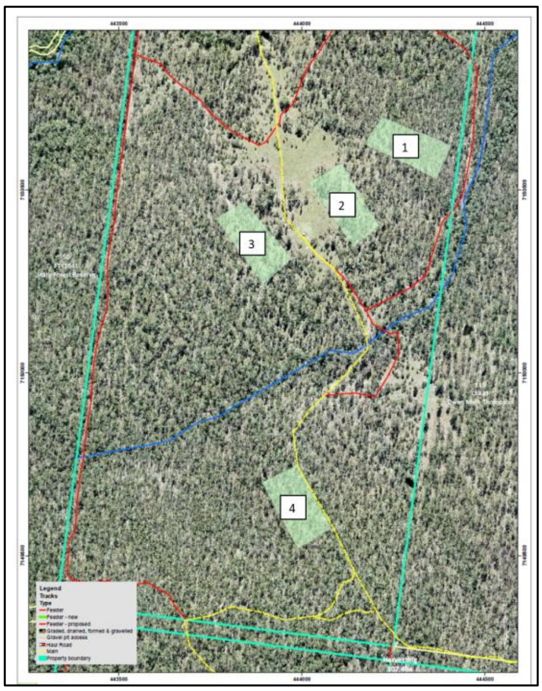

Figure 2. Trial Plot Layout and associated numbering.

Table 1. Study Site Characteristics and Biomass assumptions for plots

	Plot				
Site Characteristic	**1**	**2**	**3**	**4**	**Source**
Area (ha)	2	2	2	2	
Dominate Species	GBX	SPG	ACA/SPG	SPG/MIX	PFSQ
Original stems per hectare (sph)	618	743	891	806	PFSQ
Retained stems per hectare (sph)	72	110	91	135	PFSQ
Mean DBHOB (cm) (Treat & >10cm)	18.63	15.68	13.09	16.55	PFSQ+
% of Stems treated & > 10cm	51%	33%	49%	64%	PFSQ+
Retained Mean Tree Height (m)	30.91	26.84		28.63	USC
Mean Tree Volume (m3)	0.226	0.132	0.083	0.194	[1]
Mean Tree Mass (tonnes)	0.256	0.150	0.094	0.219	[1]

[1] Paul et. al. 2016
Above-ground biomass:(ABG(kg)) = EXP{(-2.016 + 2.375LN(DBH)} x 1.067
Note: Dry Biomass converted to Volume based on 30% MC and dry density of 790kg/m3 **Note:** Stems <10cm not included in volume analysis

Plots were characteristic of the private native forest resource with a variety of species, diameter classes and quality depending on site location and historic interventions. Plots 1, 2 and 3 were generally flat whereas plot 4 had a gradual slope of <10%. Spotted Gum (SPG) was generally the dominate commercial species with Gum-topped Box (GBX), Acacia ('wattles') also common, along with Grey Ironbark (GRI), and Forest Red Gum (FRG) present at low densities. The sites were harvested (decoupled biomass harvest then a commercial sawlog/poles harvest) in May and June of 2020.

Research Methods

Plot inventory was performed using standard methods developed by PFSQ for the PNF resource with line sampling of approximately 170m long and 10m wide resulting in a sample size of about 0.2ha or 10% of each plot. Plots were then paint marked for retention, treatment (biomass harvesting) and product extraction (pole/ sawlog) in accordance with long-term growth and management objectives. For clarification a biomass harvest (silvicultural thinning) was preformed first followed by a decoupled harvest of conventional products.

Four different harvesting methods were used to selectively harvest biomass at each of the sites based on the treated classification. **Tables 2, 3 and 4** describe the treatments and associated machines used in each harvesting method. Instantaneous time and motion studies were used to evaluate machine productivity. Productivity was calculated from the number of stems harvested, associated average stem volumes and time. Volumetric values were calculated based on inventory data supplied by PFSQ (10% area sample pre-harvest) with a representative biomass equation as per Paul et al. 2016. Standard machine rate models and equipment costing were used to determine costs (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 (Sessions et al. 2021).

Table 2. Conceptual Treatments for each plot

Plot	Treatment
1	First Pass of limited whole-tree shearing (to due large stem size and saftey concerns) Second Pass cleanup w/ whole-tree harvesting followed by whole-tree skidding extraction
2	Mini-excavator with shearing-head using (2) techniques [process on ground vs. process in tree] used to harvest followed by Forwarder Extraction
3	Traditional Harvest to optimize for forwader + Forwarder Extraction
4	More Intense Harvest (smaller end diameter) + Forwarder Extraction

Note: Plots 2,3,4 - biomass was processed into forwarder lenghts (~6m) for extraction
Note: A Feller-Buncher was used in each plot to fell and process Poles/ Sawlogs
Note: Feller-Buncher also used to fell large biomass logs, these are NOT included in biomass volume measure

Table 3. Machines used for each plot and associated treatment

	Equipment		
Plot	**Harvest**	**Extraction**	**Sawlog Harvest**
1	Kobelco SK135SR w/ TMK 400 Shear Head Ponsse King Scorpion w/ H7 Head	John Deere 748E Skidder	Tigercat LS855D
2	Kobelco SK135SR w/ TMK 400 Shear Head	Ponsse Eelephant King Forwarder	Tigercat LS855D
3	Ponsse King Scorpion w/ H7 Head	Ponsse Eelephant King Forwarder	Tigercat LS855D
4	Ponsse King Scorpion w/ H7 Head	Ponsse Eelephant King Forwarder	Tigercat LS855D

Please note systems, machines and techniques utilised were those available and may not represent ideal configurations or techniques for a commercial scale operation. Nevertheless, the machinery used is typical of that used in other forests (i.e. hoop pine plantations) in the region.

Table 4. Approximate machine rate costing for equipment

Equipment Costs	$/PMH
MINI-EXCAVATOR w/ Shear Head	145.19
PONSSE Harvester/ Processor	246.86
PONSSE FORWARDER	214.87
FELLER BUNCHER	222.35
SKIDDER	183.10

Note: 85% Utlisation Rate Assumed

Additionally, estimated chipping productivity and costs were based off in-field data samples and the CRC for Forestry chipping productivity model based of hundreds of chipping studies domestically and from around the world.

Results and Discussion

Operational results regarding biomass recovery and the productivity of the trailed systems/techniques (based on instantaneous time and motion studies and course production values) are presented then proceeded by an extension into hypothetical chipper productivities and associated supply chain costs for discussion purposes.

Results for each machine are presented to provide further detail time breakdown and productivity factors associated with each trial plot The treatment results are presented in terms of productivity (stems, m^3 or tonnes/hr) and costing ($/ha and $/m^3$) from the operations observed as noted herein.

Biomass Harvest Recovery

Data from the forwarder's on-board scale was used determine total biomass recovered (plots 2-4) while the skidded material from plot was roughly estimated. These figures paired with PFSQ's inventory data and the stem count from the feller-buncher was used to generate the following biomass (theoretical and harvested values) (**Table 5**) as outlined in Berry 2021b.

Table 5. Estimated Biomass Availability and Recovery per plot (see Berry 2021b).

Value	1	2	3	4
Original stems per hectare (sph)	618	743	891	806
Retained stems per hectare (sph)	72	110	91	135
Mean DBHOB (cm) (Treat & >10cm	18.63	15.68	13.09	16.55
% of Stems treated & > 10cm	51%	33%	49%	64%
Mean Tree Volume (m3)	0.226	0.132	0.083	0.194
Mean Tree Mass (tonnes)	0.256	0.150	0.094	0.219
Stems Harvested (sph)	28	11	12	33
Biomass_Theory (tonnes/ha)	**68.08**	**30.29**	**36.51**	**89.40**
Biomass_Theory (m3/ha)	**60.04**	**26.71**	**32.20**	**78.84**
Recovered (tonnes/ha)	**45.00**	**18.76**	**17.50**	**31.75**
Recovered (m3/ha)	**39.68**	**16.54**	**15.43**	**28.00**
% Recovery	66%	62%	48%	36%

NOTE: Plot 1 Biomass Recovery = Estimated Guess

Observed Recovery from the sites ranged from 17-45 tonnes/ha (15-40 m3/ha).

Operational Productivity for Biomass Harvest

Operational productivity for both the Biomass Harvest and the commercial sawlog harvest is evaluated herein along with a crude estimation of costs.

Biomass harvesting is composed of two distinct operations – harvesting (or felling) of the stems and extraction of those stems to a centralised site. Subsequent chipping of the biomass can occur at this location but can also occur in-field (e.g. recovery of uncommercial sawlog heads).

Harvesting Per Plot (Shear or Traditional Harvester)

Harvesting (felling) productivity can be measured in m3/hr, tonnes/hr or stems/hr and then extended to in financial terms for any of these metrics. Results from the study are highlighted below (**Figure 3**). Volume and weights are related to recovered biomass (i.e. what was eventually picked up with forwarder) whereas stems are actual stems felled during the operation. As such harvesting productivity as described depends on the stand itself as well as techniques used for recovery (amount of overall biomass recovered).

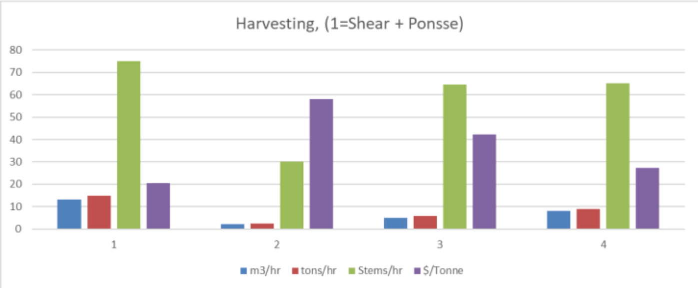

Figure 3. Summary of Harvesting (Felling) productivity, note harvesting observations of Plot #3 were not observed, estimated values are provided in the figure. Plot 1 included a mix of whole tree shearing and traditional harvesting.

From this data, we can broadly see that productivity widely ranged depending on site and technique (e.g. stems/hr from 30-70 and m3/hr from <5 to 11).

Most importantly here is likely the stems/hour as this would more accurately portray base system productivity. As such we see that the shearing head when whole tree felling (plot 1) is similar to the harvester (Ponsse) felling and processing (~60-80 stems/hr) whereas the shearing head felling and processing has around half of this productivity (~30stems/hr) and thus higher operational costs for the same tonnage extracted. The extent to which this cost more depends on the actual productivity, quality of stems and costs of machines. This is an important point of consideration and a preferred system cannot be chosen on this information or study alone.

Notes on Mini-Excavator with Shearing Head

As noted, productivity values for Plot 2 were generally low given the shearing head operation which sought to merchandise material in-field for a forwarder, two ways to merchandise in-field were explored (at Tree and on Ground). These values dramatically increased in Plot 1 where whole trees were cut for skidder extraction. Plot 1 also included time for the harvester to 'clean up' the site as many trees were too large for the mini-excavator though still showed a higher tonnage/hr and lower cost of production, through this again depends on ones assumption of recoverable material and is not a fully fair comparison.

Additional research into the shearing head as a viable option for most likely whole tree operations is warranted. Additionally further review of the potential for shearing head efficiently should be reviewed (as this study included suboptimal equipment set and inexperienced forestry operator for shearing trials).

Instantaneous observations for each plot and system are provided below (**Figures 4, 5 and 6**):

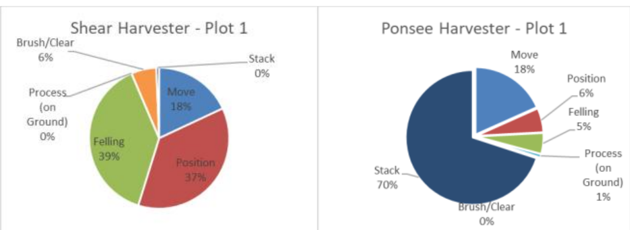

Figure 4. Time Study Results for harvesting/ felling in plot #1.

Note in Plot #1 shear whole tree harvesting was followed up with harvester cleaning up as many stems were too large for the shear to handle.

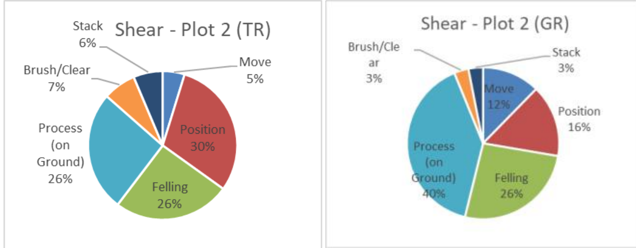

Figure 5. Time Study Results for harvesting/ felling in plot #2.

In plot #2 two shearing operations (in Tree and on Ground) were explored as noted, similar productivity as found for both with differences in time spent positioning vs. processing. In comparison the whole tree shearing (**Table 6**) shows much more time felling and positioning and no processing as anticipated).

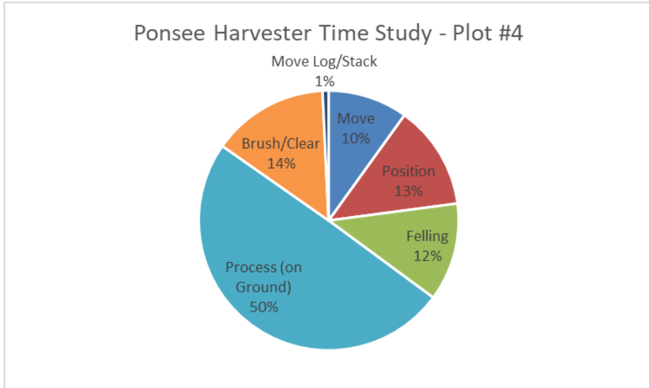

Figure 6. Time Study Results for harvesting/ felling in plot #4.

In this plot #4 the harvester was optimising for biomass accumulation, we see that nearly half the time was spent processing with nearly equal time spent on moving in-bush, clearing, positing and felling.

Extraction Productivity (Forwarding or Skidding)

Forwarder productivity varied depending on the plot productivity associated with larger stem sizes and increased productive volume (hence the lower productivity in plot 3). Forwarding distances were all thought to be comparable at 200-400 metres. Productivity values varied from roughly 10-16 tonnes/hr (9-14m3/hr) which depending on site equates to roughly 13-20 $/tonne **(Figure 7).** Plot 1 was the only plot that utilised a skidder as such this data is very limited. Skidder productivity was also based on the assumption that 2500kg were moved in each pass, values in this report approximate the productivity to the same extraction distances. In this respect productivity was found to be roughly 25 tonnes/hour (22 m3/hr). This equate to a costing of roughly half that of forwarding for this resource though more trials should be completed to verify especially since the final volume was estimated and the average tree diameter was the largest among all plots.

Figure 7. Forwarding and Skidding Productivity results. Plot #1 used a skidder while plots 2-4 used a forwarder.

Sawlog Harvest Productivity

Feller-Bucher Productivity

The same Feller-Buncher was used across each of the trial plots, its productivity in stems/hr and costing in $/h and $/ha are illustrated below (**Figure 8**). This harvest was decoupled from the biomass harvest and as such is not equated to generated biomass. Furthermore, the products (sawlogs and poles) captured from this harvest are not analysed. As previously noted, the feller-buncher also felled a portion of large biomass trees (<5/ha).

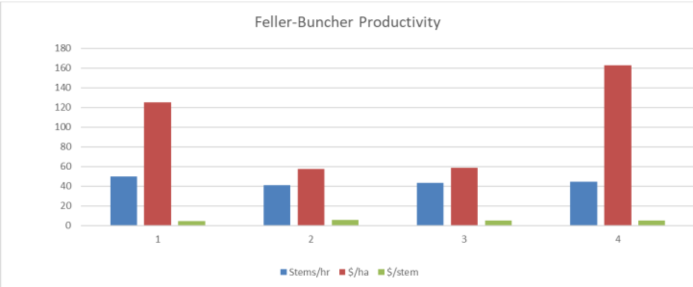

Figure 8. Feller-Buncher Productivity

Feller buncher productivity appears to be consistent (stems/hr) across each landscape with only slightly higher productivity in more dense stands (**Figure 9**), thus similar costing on a per stem basis (~$5/stem) and variable costing on a hectare basis.

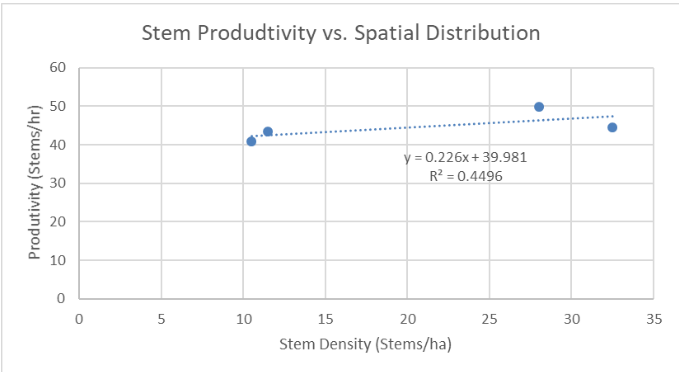

Figure 9. Feller-Buncher Productivity vs. Stem Density

Instantaneous observations for each plot are provided below (**Figure 10**):

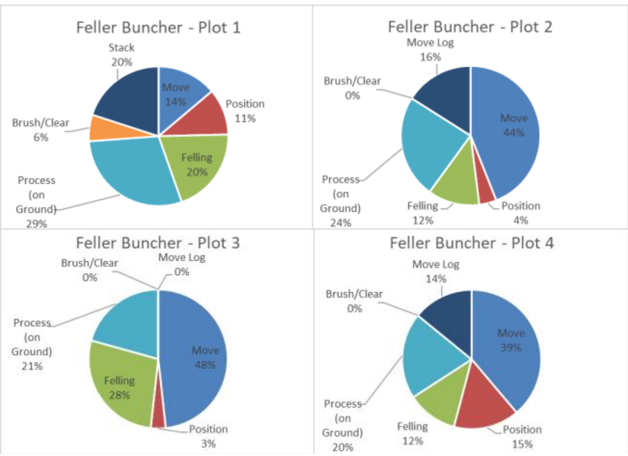

Figure 10. Feller Buncher Time and motion study results

The time and motion studies show differences in time spent moving positioning, felling, processing, stacking, etc. with less movement correlated to higher stand density as expected, though given the very small sample size (.5-1.5 hours) this data likely is not very useful.

Conceptual Chipping Values

NOTE: Chipping was not initially included as part of this study, the figures below are conceptual only and based on the assumption that one might have access to a BRUKS forwarder-mounted chipper.

The USC FIRC Chipping model was used to estimate chipping productivity and costs based on a 500hp BRUKS forwarder mounted chipper with the capability of chipping to roadside into a truck and in-field into its own bin and then transported to roadside. This limited analysis is based on limited collected data in the field as well and rough estimates. To this effect, the following key assumptions were made to simulate chipping: 1) an average piece size of .085m3 , 2) 30% moisture content along with 3) an assumption of 90% utilisation of equipment at roadside (chip directly into truck) and 50% utilisation in field (chipping into its own bin).

Given these assumptions, productivity and costing would likely range from 8 – 19 tonnes/SMH with costs from $19-30/tonne (**Figure 11**).

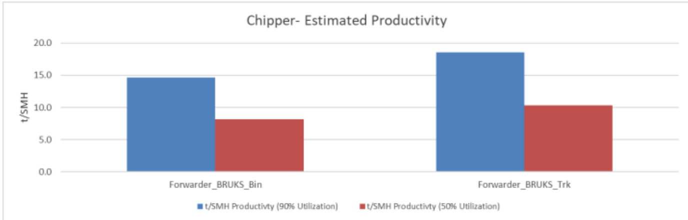

Figure 11. Chipping Productivity Assumptions for (2) 500hp BRUKS forwarder mounted chipper (chipping into bin and into truck with 50% and 90% utilisation).

Please note – as piece size increases productivity increases, as moisture content decreases thus tonnage/hour productivity decreases - rates can easily change +/- 20% or more. Additionally, a BRUKS chipper was assumed for both infield and roadside chipping (1.2M AUD) whereas a truck mounted or flatbed chipper would be higher power and likely cheaper to operate at roadside (as low as $12/tonne and >30tonnes/hr) though unable to recovery in-field material. It is also assumed that the feedstock is low-grade generating a biomass chip (as opposed to pulp).

Cost Estimates of Trial Plots

An estimate for the relative costs based of production (excluding transportation) of these trials including chipping (at say $25/tonne) is shown in the **Figure 12**. Costs for extraction and chipping of head material is not included in this analysis.

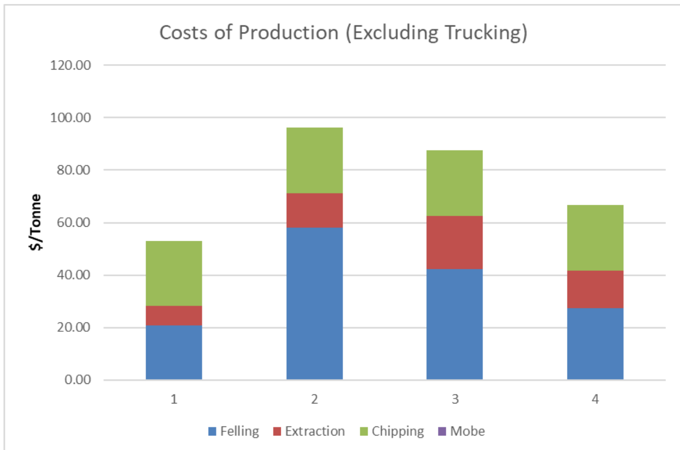

Figure 12. Costs of chip production ($/tonne), to convert to $/m3 multiple the values by .88.

Based on the specific trial conditions and equipment which of course include elements of learning, exploration and inefficient operation the costs felling/harvesting ranged from roughly $30-70/tonne excluding chipping and roughly $50-100/tonne including chipping. Lowest cost of production (Plot 1) was associated with the highest biomass stand using the cheapest felling option (whole tree shear) and the cheapest extraction method (skidding vs. forwarding) not to mention the assumed recovery figure. Plot 2 was the most costly due to the inefficient shear head felling and processing in the stand with the lowest biomass potential and smaller stem size.

For the two plots that used experienced operating and the harvester for felling and processed coupled with the forwarder ranged from $40-60/ tonne (excluding chipping). The lower value (plot #4) was associated with a stand that had the highest theoretical biomass potential coupled with an operational goal for higher recovery compared with the higher value (plot #3) which was associated with the near lowest biomass potential and small tree size. Given this, these values probably show an appropriate range given the equipment utilised.

It is anticipated as more appropriate equipment is used and more is known about best practices for operations in these conditions there is significant room for increased productivity and reduction of costs.

Please note these costs does not account for any mobilisation costs, infrastructure upgrading costs (roads, etc.), transportation costs, etc. which would also be a part of commercial operations to market. To note, transportation costs may easily exceed $.2o/km/tonne or $20/tonne for every 100km to market.

Conclusions and Recommendations

This preliminary study highlights the biomass and operational considerations inherent in any biomass recovery harvest in the Australian native forest resource towards an goal of integrated land management practices. It provides a first look at some of the important considerations one must consider when using mechanisation for biomass in this setting, namely the importance of underlying stand conditions (stand density, DBH, etc.) and anticipated sawlog/pole recovery for biomass yields and operational efficiencies for every element the harvest sequence (felling, extraction, chipping, etc.). These underlying assumptions will dictate every other metric (e.g. stem/hr productivity, resultant benchmarking yields, average piece size for extraction and chipping, stand density for feller-buncher, etc.).

It is important to note that the stands harvested were managed for forestry as opposed to mixed forestry and grazing and thus likely had higher stocking than associated with many other properties, Some key values for biomass, productivity and costing are summarized below (**Table 6**):

Table 6. Summary of Results.

	Value	1	2	3	4
	System	Shear + Skid	Shear + FW	Harvester+ FWD	
Biomass	Biomass_Theory (m3/ha)	60.04	26.71	32.20	78.84
	Mean DBHOB (cm) (Treat & >10cn	18.63	15.68	13.09	16.55
	Recovered (m3/ha)	39.68	16.54	15.43	28.00
	Estimated_Top Volume (m3/ha)	9.18	1.01	4.06	8.36
Felling	Stems/hr	75.10	30.27	64.51	65.04
	m3/hr	13.23	2.21	5.14	8.00
Ext.	m3/hr	21.71	14.34	9.32	13.12
Cost	$/m3	31.85	80.82	71.04	47.23
	$/tonne	28.09	71.27	62.65	41.65

Note: Excludes Chpping Cost

Given this study, we can say generally that as theoretical biomass (and/or mean DBH) increases => recovery increases, top volume increases, felling productivity increases, forwarding productivity increases and overall costing decreases.

In particular, likely:

- ➔ As theoretical biomass increases => Felling productivity increases (with lower costs)
- ➔ As DBH increases => Extraction productivity increases (with lower costs)
- ➔ As theoretical biomass increases => Overall costs of production decreases
- ➔ Felling Stems/hr is likely constant with operational system

The nuances of each of these elements has yet to be fully understood though this report provides a general methodology to contextualize the resource and associated operations along with a baseline to compare future studies.

Overall, a broader range of conditions and operational harvesting methods needs to be explore to more fully understand the issues and complexity of biomass recovery systems in private native stands. This study further illustrates the potential viability for integrated land management where silvicultural thinning maybe economical way to generate a co-product but this must be further researched.

Further Research Suggestions and Notes:

This study highlights an abundance of supplemental questions, considerations and areas for further research, many of which are itemized below:

Harvesting

- Best practice whole tree shearing compared with vs. Harvester?
- Optimal size of harvester/ processor (connected with average DBH)?
- Integrated Sawlog Harvest & Biomass Harvest vs. Decoupled?
- Skidding vs. Forwarding – Economics, Environmental Impacts?
- Comparison with Global Productivity Studies?

Merchandising and Products

- Roadside vs. In-Field Chipping – Productivity and Quantities
- Connection with Regional and/or Local Hubs?

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FIRC – Rick Mitchell

Notes:

All financial values in Australian Dollars (AUD)

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Appendix

Bulk Operational Trial Times (2ha plots):

Plot	Machine	Required	Time (Hrs) PHM
1	Small excavator	Time to cut fall biomass stems	6
	Harvester	Time to cut fall biomass stems/ Clean Up	4
	Large Feller Buncher	Time taken to fall sawlog/poles and process tops	1.15
	Skidder	Time taken to skid bio mass stems/sawlog residues	[1]
	Skidder	Time taken to skid sawlog/poles	[2]
2	Small Excavator	Time to fall & process biomass stems	15
	Forwarder	Time to extract biomass logs only	[1]
	Large Feller Buncher	Time taken to fall sawlog/poles and process tops	0.5
	Skidder	Time taken to skid sawlog/poles	[2]
3	Harvester	Time to cut fall biomass stems	6
	Forwarder	Time to extract biomass logs only	[1]
	Large Feller Buncher	Time taken to fall sawlog/poles and process tops	0.5
	Skidder	Time taken to skid sawlog/poles	[2]
4	Harvester	Time to cut fall biomass stems	7
	Forwarder	Time to extract biomass logs only	[1]
	Large Feller Buncher	Time taken to fall sawlog/poles and process tops	1.5
	Skidder	Time taken to skid sawlog/poles	[2]

[1] Forwarder and Skidder cycles observed.
[2] Final Skidding not observed

MORE INFORMATION
Dr. Michael Berry
Forest Industries Research Centre University of the Sunshine Coast
USC – Locked Bag 4
Maroochydore DC Qld 4558 Australia
Tel: +61 7 5459 4643 | Email: mberry1@usc.edu.au

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