Bulletin 9: April 2010

Preliminary results: volume recovery comparison of different harvesting systems in short-rotation hardwood plantations

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Introduction

Short-rotation hardwood plantations are grown to produce a single product: high-quality pulp chips. Several harvesting systems are currently used in Australia to effectively produce this product. The various systems can generally be placed into two groups: those that produce wood chips at the roadside in the plantation (in-field chipping, IFC) and those that produce logs in the plantations that are then transported to a central facility to be converted to chips (in this bulletin we are discussing cut-to-length at the stump, CTL, and whole tree with roadside processing, WT). Many drivers influence the choice of one system over another, including site conditions, tree size and form, cost, quality of product produced, equipment availability and the total volume recovery.

The harvesting and operations program of the CRC for Forestry has started to explore whether the pulp chip volume that can be recovered by in-field chipping differs significantly from that recovered by roadside processing.

The CRC’s first two field trials have produced markedly different results, highlighting the need for further data collection under more controlled conditions. However some interesting results may help guide industry partners considering different options for harvesting pulp chips.

In the first trial, conducted in Western Australia, the comparison of harvesting systems was made on two separate sites and examined the relative recovery between an IFC system and a WT operation. Since both systems used similar felling and extraction methods, the comparison looks purely at the difference in volume recovered between the IFC and the WT systems. The second trial, conducted in Victoria, used an IFC system similar to the Western Australian trial, but contrasted it with a CTL system including a harvester. Both harvest systems were run equally across the same location to eliminate the standing volume difference experienced in the first trial. With the inclusion of a different felling phase, this second trial compares the overall volume recovery difference between harvest systems.

Trial one: Western Australia

Study description

Detailed time and motion and volume recovery studies were conducted on two *Eucalyptus globulus* (blue gum) plantations with two different harvesting systems: an IFC operation as described in Figure 1 and a WT (roadside processing) system as depicted in Figure 2. The conditions at the two study sites in Western Australia are detailed in Table 1.

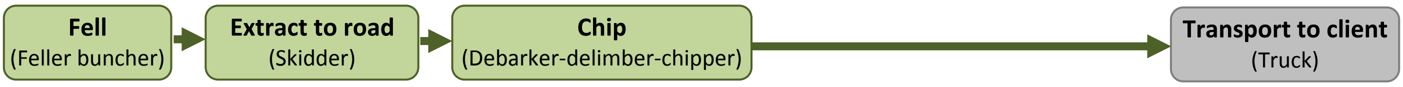


Figure 1: IFC system description and flow

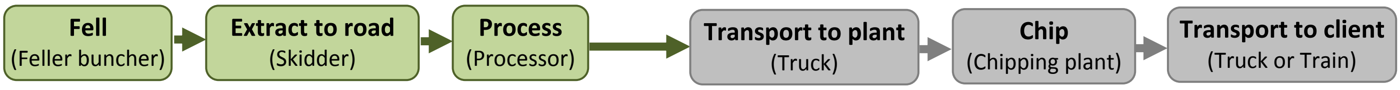


Figure 2: WT system and flow with roadside processing into logs

	IFC site	WT site
Age (yr)	13	11
Area (ha)	1.52	1.07
Estimated standing volume (m^3/ha)	113	156
Stocking (sph)	640	760
Average tree size (m^3/tree)	0.178	0.205

Table 1: Study site conditions for Western Australian trial

Results

Although considerable difference between the sites made comparison of pure volume recovery difficult, the results show a very clear difference between the volume delivered by the two systems. Table 2 shows a summary of the recovery results, showing a difference of 20% between the two systems.

	IFC site	WT site
Pre-harvest inventory (m^3/ha)	113	156
Delivered (t/ha)	140	163
Recovery (%)	124	104

Table 2: Volume recovery results for Western Australian trial

Figure 3 shows that the feller buncher was more productive on the WT site than the IFC site. Skidder productivity was also higher on the WT site as shown in Figure 4. The skidder was also far more sensitive to skid distance on the WT site. One reason why skid distance had less impact on skidder productivity in the IFC site was because the skidder on that site had the added task of managing, removing and redistributing residue from the chipper at the roadside, which is independent of skid distance.

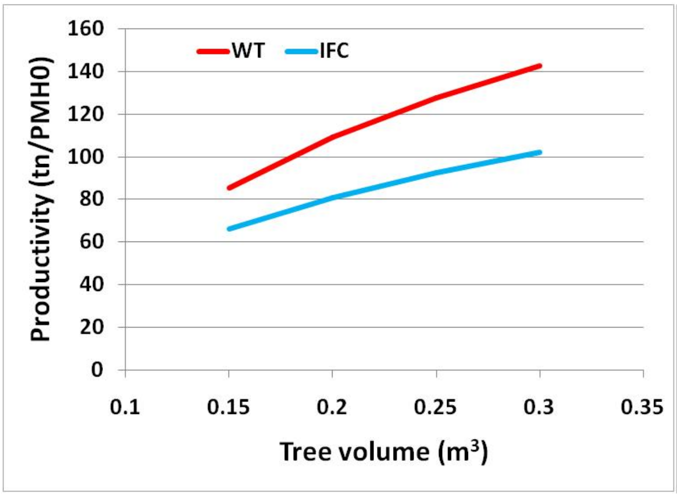


Figure 3: Feller buncher productivity

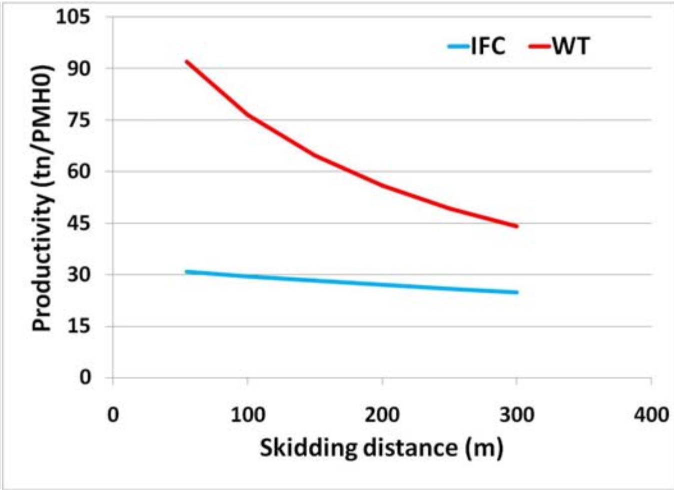
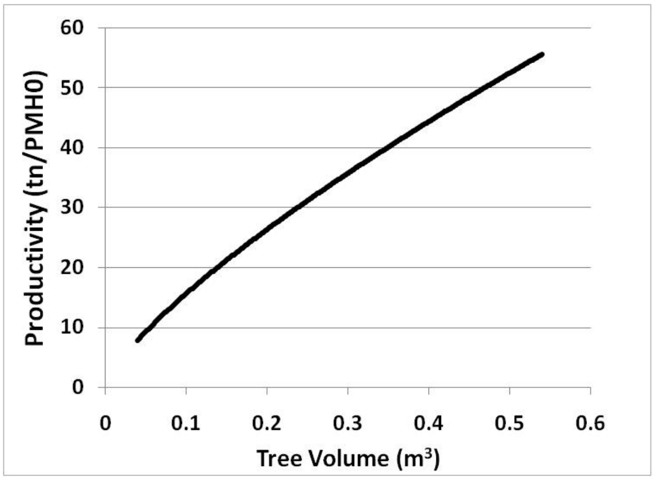


Figure 4: Skidder productivity



As expected, the processing of logs at the roadside was significantly influenced by tree size (as shown in Figure 5). The roadside chipper, because of its ability to process multiple stems, was less influenced by the range of tree sizes and achieved an average productivity of 33.9 t/PMH$_0$[1] with 71% utilisation of study time, where most of the delays were the result of waiting for wood.

Figure 5: Roadside processor productivity

Trial two: Victoria

Study description

The second study was undertaken exclusively to look at volume recovery in a low-yielding *E. globulus* plantation. Two different harvesting systems were evaluated: an IFC operation as depicted in Figure 6, and similar to that in the Western Australian trial, and a CTL system as depicted in Figure 7, which is a standard Scandinavian-style system using a single grip harvester for felling and processing.

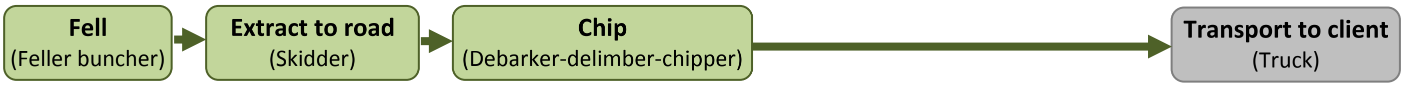


Figure 6: IFC system description and flow

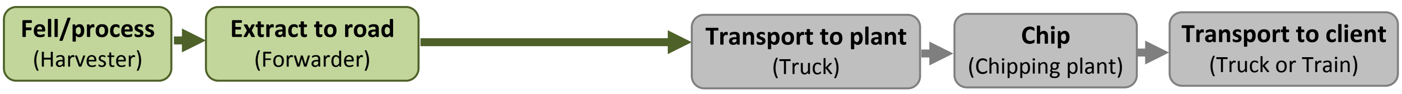


Figure 7: CTL system and flow with processing of logs at the stump

[1] Productive machine hour excluding all delays

The site in Victoria had a pre-harvest standing volume of 105 m^3/ha and an average tree size of 0.13 m^3/tree. The trial covered an area of 3.93 ha (2.02 ha harvested by the IFC system and 1.91 ha by the CTL system). To ensure the two systems worked in identical conditions, the study site was divided into alternating two-row strips as shown in Figure 8. IFC operations were conducted on the light strips and CTL on the dark strips.

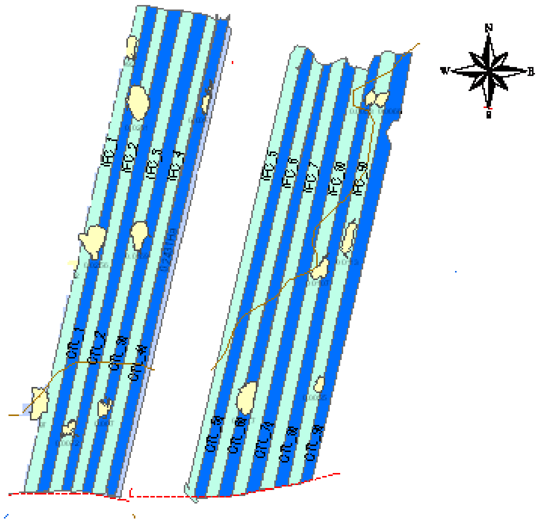


Figure 8: Study site layout for volume recovery trial in Victoria

Results

In this study the volume recovery achieved by the two systems was very close. The difference would be considered negligible, considering the potential errors in data collection.

Table 3 shows the nominal 1.4% difference between the two systems. There were no notable field observations to explain why the results were so close when the expectation, based on the earlier trial, was for the IFC to have significantly better volume recovery. Given that the harvester operator was experienced in working with the very small tree size involved in the study, his experience may have improved the CTL result. Further, the small tree size may have resulted in a greater amount of breakage and fibre loss in the flail chain portion of the IFC process than would be experienced with bigger trees.

	IFC site	CTL site
Pre-harvest inventory (m^3/ha)	105	105
Delivered (tn/ha)	98.3	96.8
Recovery (%)	93.6	92.2

Table 3: Volume recovery results for Victorian trial

Take-home messages

- In these comparative investigations, recovery was higher in the IFC system than in the roadside processing systems, although in smaller stem sizes with CTL the advantage seems to diminish significantly.
- Considering the recovery and productivity rates obtained in these trials, further research is warranted with strict controls to ensure both systems work in identical stand conditions across the range of expected conditions for industry.

More information

For more information, visit the CRC for Forestry website at http://www.crcforestry.com.au/research/programme-three/index.html

CRC for Forestry

BULLETIN 27

June 2012

Volume recovery comparison for four different harvesting methods in short-rotation blue gum plantations

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Introduction

The majority of Australian hardwood plantations have been planted with the intention of harvesting high quality woodchips for export, with a rotation of eight to 12 years. Currently, there are numerous harvesting methods operating to produce pulpwood chips in Australia. They can be broadly placed into three categories:

- Cut-to-length (CTL): The trees are processed into short logs (~5 m) at the stump, and forwarded to roadside for transport.
- Whole tree to roadside (WTR): The trees are felled, bunched and skidded to roadside as whole trees, for processing into long logs (~10m) prior to transport.
- In-field chip (IFC): The trees are felled, bunched and skidded to the roadside as whole trees, then processed into wood chips, and loaded directly onto trucks for transport. In this study two different in-field chippers were used—one using a delimbing and debarking flail integrated with the chipper (IFC-DDC) and the other using a chipper with a separate flail machine for delimbing and debarking (IFC-F/C).

This study follows up preliminary results from the volume recovery comparison (CRC for Forestry Bulletin 9, April 2010). This bulletin provides further results, comparing volume recovery from a broader range of harvesting methods currently in use. It covers one aspect of an overall research project, which also collected data for the analysis of machine and method productivity, reviewed issues associated with transport, and compared woodchip quality output between methods.

It also compares the yields in delivered green metric tonnes (GMt) and bone dry metric tonnes (BDMt) from four different harvesting methods currently operating in *Eucalyptus globulus* (blue gum) plantations in Western Australia.

Study description

The study was conducted on a blue gum plantation in south-west Western Australia. All products produced during the study were delivered to the APEC chip mill in Albany. The study site was an area of 5.95 hectares and was a first rotation (1R), 10.5 year old (planted in 2000) blue gum plantation. The study investigated the four harvest methods, CTL, WTR, IFC-DDC and IFC-F/C, under the following conditions:

- Each harvest method worked in uniform stand conditions. The layout of the site consisted of eight adjacent gullets. Each gullet was three rows of trees wide (~12 m) and ~500 m long.

- Each method harvested two gullets, as shown in Figure 1, and worked within normal operating procedures.
- Feller-bunchers were required to leave 100–150 mm stump height to enable coppicing of the second rotation (2R). Therefore, this study could not take into account the potential to reduce stump height with some methods.
- The harvest of the study site occurred over nine consecutive days, in January 2011.
- Every truckload of pulpwood chips or logs was closely monitored to ensure the weight was accurately attributed to each gullet. Restrictions were not placed on the timing of delivery in order to ensure the study corresponded as closely as possible to normal operations.

The diameter and heights of 38% of the trees were recorded to estimate the average tree size and volume of the stand, enabling a productivity analysis of harvesting equipment.

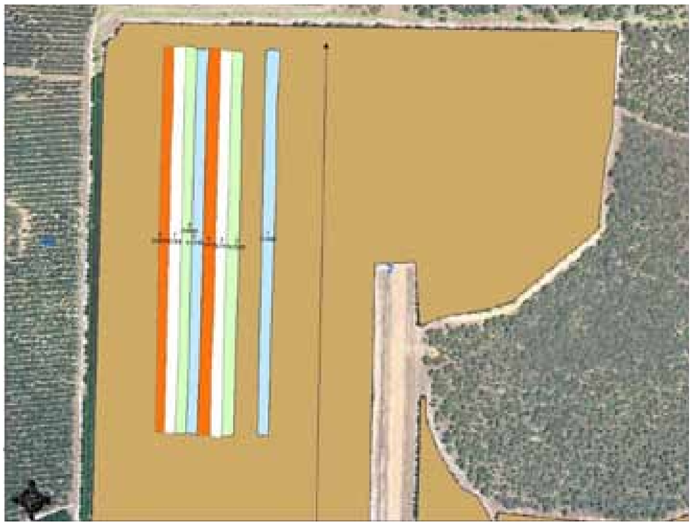

Figure 1. Layout of the study site

Each gullet was mapped accurately, using a GPS to obtain the exact area for each individual method.

Detailed time and motion and volume recovery studies were undertaken on each harvesting method. The equipment used and the process for each method is described below (Figure 2).

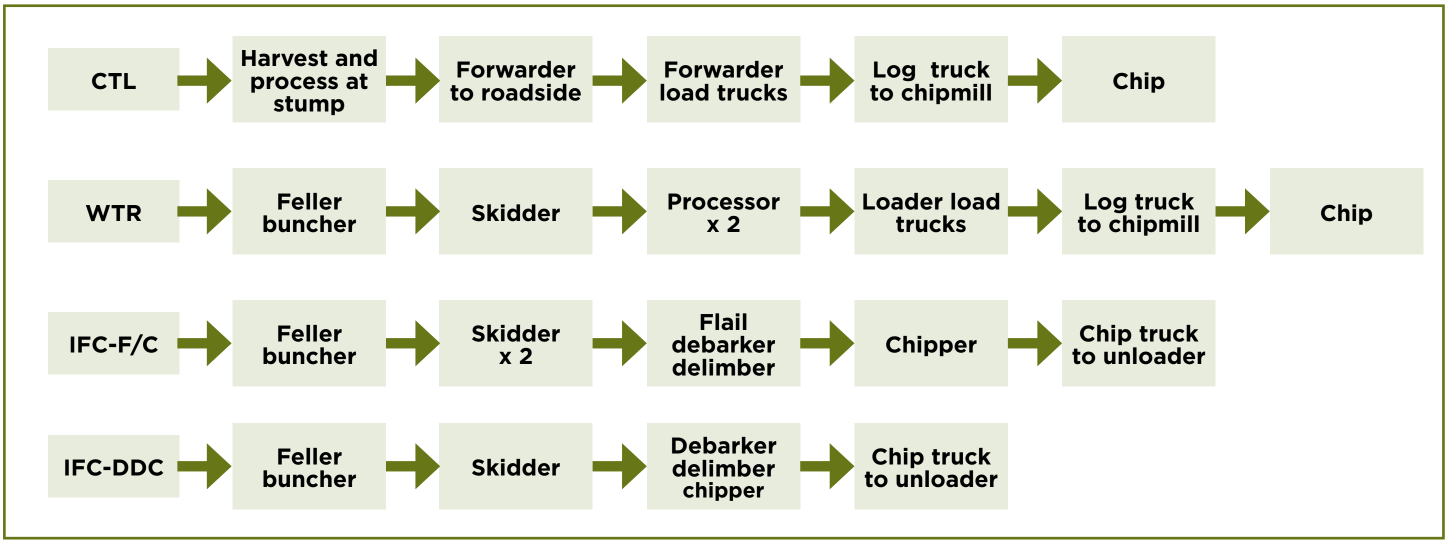

Figure 2. Equipment used and process for each harvest method

Results

Tables 1, 2 and 3 show the pre-harvest estimated tonnes and actual weight delivered in GMt and BDMt for each harvest method. Table 2 shows the delivered weight, adjusted by piece size to enable a direct comparison of the methods in the same stand conditions.

When compared with the other methods, the delivered weight produced by the CTL method was affected by the delivered wood age. CTL logs were, on average, eight hours older than the WTR and 24 hours older than the IFC and, therefore, had more time to dry out. These results have been taken into account in the BDMt calculations in Table 3, by using 40.75% moisture content for CTL and WTR, and 43.5% for the IFC methods.

It was observed during the study that the single grip harvester and processors used in the production of logs (CTL and WTR methods) had excellent utilisation of the trees with a small end diameter of 5 cm. However these machines can only process the stemwood, while the in-field chippers can process the whole tree, including all branches and tree tops.

Table 1. Estimated yield from the plantation

Harvest method	Area (ha)	Original stocking (sph)	Merch trees		Merch volume	
			(n)	(sph)	(GMt/ha)	(BDMt/ha)*
CTL	1.52	791	4337	729	128.4	64.2
IFC-F/C	1.45					
IFC-DDC	1.46					
WTR	1.53					

*Assumes 50% moisture content of standing trees

Table 2. Delivered weight comparison in GMt

Harvest method	Delivered weight (piece size adjusted)		Difference	Rank
	(GMt)	(GMt/ha)	(Est. wt to del'd wt, %)	
CTL	206.7	136.0	6%	4
WTR	224.3	146.6	14%	3
IFC-F/C	232.7	160.5	25%	2
IFC-DDC	236.8	162.2	26%	1

Table 3. Delivered weight comparison in BDMt

Harvest method	Delivered weight		Difference	Rank to account for rain
	(BDMt)	(BDMt/ha)	(Est. wt to del'd wt, %)	
CTL	123.7	81.4	27%	4
WTR	128.5	84.0	31%	3
IFC-F/C	130.9	90.3	41%	2
IFC-DDC	134.3	92.0	44%	1

It was also noted that, within this particular stand, the final stocking of merchantable trees could vary. Stocking variation can affect available standing volume, from which recovery is calculated. Standing volume was calculated on 38% of standing trees and this subset confirmed some variability across the whole stand, between the methods and gullets.

The study was conducted in a continuous sequence to eliminate any inconsistencies caused by a variation in the weather conditions. However during a period of the study, an unseasonal, heavy rainfall event occurred during the felling, processing and loading phases of the WTR method gullets. Weather stations in the area indicated rainfall over the two days in excess of 30 mm. These wet conditions make it difficult to directly compare the WTR yield in GMt with the other methods because the moisture content of the wood was 44.1%—higher even than the in-field chipped wood. A ranking was applied to the results (Table 3) to take this rainfall event into account.

Reduced stump heights, which are typical for feller-buncher operations, will somewhat improve the volume recovery from the methods using this equipment.

Once at the mill and prior to chipping, CTL and WTR logs passed through a flail to remove any passenger bark. This bark was collected and weighed, with the results presented in Table 4.

Table 4. Delivered passenger bark

Harvest method	Bark weight (tn)	Bark %
CTL	1.0	0.48%
WTR	2.14	0.89%

Chip samples were collected and analysed from each harvest method. Eight samples were taken; one from each trailer of delivered chips or logs (see Table 5 for results).

Generally, chip samples reached specified size and bark requirements; however there were a few exceptions. Four out of eight (50%) samples of oversize (>28.66 mm) from WTR and two out of eight (25%) from IFC-F/C were above specification. Five out of eight bark samples (62%) from the IFC-DDC were above specification, putting this result well over the 0.5% prescribed limit, and bark content of the chips from this method was higher than other harvesting methods under the study conditions (Table 5).

Table 5. Chip sample results

Harvest method	>28.66 mm	>22.2 mm	>9.5 mm	>4.8 mm	<4.8 mm	Bark
CTL	3.68%	36.12%	53.10%	6.11%	0.97%	0.02%
WTR	5.17%	27.53%	59.26%	6.86%	1.08%	0.11%
IFC-F/C	3.36%	16.31%	68.24%	9.88%	2.03%	0.18%
IFC-DDC	3.07%	20.35%	66.50%	7.87%	1.53%	0.67%

Take-home messages

- There is less volume recovery from CTL and WTR harvesting operations in blue gum plantations than from IFC harvest operations.
- Moisture content can have a substantial impact on the weight of pulpwood chips delivered, with wood age being a contributing factor.
- Bark content of chips produced by IFC-DDC in the study conditions is a potential problem for meeting required quality specifications and should be monitored carefully.

Organisations supporting this research

Albany Plantation Export Company (APEC) supported this research by providing access to its plantation, contractors, equipment and resources.

More information

CRC for Forestry website:
http://www.crcforestry.com.au/research/programme-three/index.html

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BULLETIN 29

June 2012

Comparing the efficiency of four harvesting methods in a blue gum plantation in south-west Western Australia

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Introduction

Harvesting operations form the lion's share of plantation management costs. As a result, it is important to select the appropriate harvesting method to achieve lower total logging costs from the stump to the mill gate. This study compared the cost-productivity of four harvesting methods: cut-to-length (CTL), in-field chipping using a delimbing and debarking flail integrated with the chipper (IFC-DDC), in-field chipping using a chipper with a separate flail machine for delimbing and debarking (IFC-F/C) and whole tree to roadside (WTR).

Study area and research method

The study area was located in a *Eucalyptus globulus* plantation in south-west Western Australia, 58 km from the delivery point for all the products—the APEC chip mill. The study site covered 5.95 ha of flat terrain. Average diameter at breast height over bark (DBHOB) and tree volume were 17.8 cm and 0.207 m^3, respectively. Stocking was about 729 stems per ha. Four different harvesting methods were used to harvest the site. Table 1 describes the machine types used in each harvesting method.

Table 1. Harvesting methods and machines

Harvesting method	Type
CTL	Caterpillar harvester/processor Valmet forwarder (for extraction and loading trucks) Truck
(IFC-F/C)	Tigercat feller-buncher Tigercat skidder 630C and Tigercat skidder 630D Husky Precision flail Husky Precision chipper Truck
(IFC-DDC)	Caterpillar feller-buncher Caterpillar skidder Peterson Pacific delimber, debarker chipper (DDC) Truck
WTR	Timberking feller-buncher Caterpillar skidder Two Caterpillar processors Caterpillar loader Truck

A detailed time and motion study was used to evaluate machine productivity. Productivity was calculated from the delivered green metric tonnes (GMt) (derived from truck weights) and productive machine hours, excluding all delays (PMH_0). The ALPACA (Australian logging productivity and cost appraisal) model, developed by the CRC for Forestry, was used to estimate the cost of operations. The fuel consumption of each machine was also recorded during the operation. The four different harvest areas were sampled to estimate the amount of retained biomass, or 'left-slash', remaining on each site after harvesting.

Results

Production costs

Table 2 presents the productivity, cost and fuel consumption for each component of the CTL harvesting method. Harvesting and processing are the most expensive components of the CTL method. The cost of chipping the logs at the mill still needs to be investigated and should be added to the costs in Table 2.

Table 2. Productivity, cost and fuel consumption of CTL method

Machine	Productivity (GMt/PMH_0)	Cost ($/GMt)	Fuel consumption (l/GMt)
Harvester/ processor	15.47	17.35	0.95
Forwarder (extraction)	30.69	5.80	0.42
Forwarder (loading)	73.15	2.43	0.18
Truck	47.63	5.04	-
Total		**30.62**	**1.55**

Table 3 shows the productivity, cost and fuel consumption for each machine used in the IFC-F/C harvesting operation. Skidding was the most costly component of this method, with the highest fuel consumption rate per GMt. The main reason for this was that two skidders were used to extract the trees to roadside.

Table 3. Productivity, cost and fuel consumption of in-field chipping by IFC-F/C

Machine	Productivity (GMt/PMH_0)	Cost ($/GMt)	Fuel consumption (l/GMt)
Feller-buncher	97.26	2.55	0.33
Grapple skidder (two skidders)	58.17	12.02	1.58
Flail	57.80	5.98	0.77
Chipper	58.18	6.59	1.24
Truck	57.34	4.19	-
Total		**31.33**	**3.92**

The productivity, cost and fuel consumption results for the IFC-DDC harvesting operation are presented in Table 4. Using this harvest method, the feller-buncher recorded lower productivity than the other harvest methods in this trial and did not meet the feller-buncher productivity benchmark (Bulletin 12). This was attributed to the use of an inexperienced operator. Chipping was the most expensive component of this method, with an average cost of $9.50/GMt. However, this was lower than the IFC-F/C chipping cost ($12.57/GMt). The fuel consumption rate for the IFC-DDC chipper was higher than the IFC/FC chipper. But the IFC-DDC had a lower harvesting cost than the IFC-F/C and two skidders (Tables 3, 4).

Table 4. Productivity cost and fuel consumption of in-field chipping with IFC-DDC

Machine	Productivity (GMt/PMH_0)	Cost ($/GMt)	Fuel consumption (l/GMt)
Feller-buncher	61.77	4.13	0.61
Grapple skidder	38.70	5.05	0.87
Chipper	45.34	9.50	2.32
Truck	47.41	5.06	-
Total		**23.74**	**3.80**

The last method was the WTR method, producing logs with two processors (Table 5). This resulted in the highest cost and fuel rate for the processing phase of the trial. The cost of chipping the logs at the mill needs further investigation and should be added to the costs in Table 5. The skidder in the whole tree method did not clean up the debris. However, for IFC-DDC (Table 4), the skidder removed the debris, in addition to tree extraction, resulting in a longer work time and lower skidding productivity.

Grapple skidders were used in both the IFC-DDC and WTR methods. The skidder in the WTR method has been used for about 1800 hours and the skidder in the IFC-DDC had accumulated 3800 hours of use. The IFC-DDC skidder had higher fuel consumption, which could be attributed to the age of the machines (Tables 4, 5).

Table 5. Productivity cost and fuel consumption of WTR

Machine	Productivity (GMt/PMH_0)	Cost ($/GMt)	Fuel consumption (l/GMt)
Feller-buncher	86.67	3.04	0.53
Grapple skidder	58.57	3.02	0.35
Processor (two procesors)	48.79	18.39	3.42
Loader	67.42	2.19	0.31
Truck	43.81	5.48	-
Total		**32.12**	**4.61**

Sensitivity of machine productivity

Based on the statistical analysis, the longer the extraction distance, the lower the productivity (Figure1). Larger trees increase the productivity of the feller-buncher in the IFC-F/C (Figure 2), IFC-DDC and WTR methods. Larger skidding distances will reduce the productivity of the skidder (Figure 3), similar to the forwarding operation. The skidding distance significantly affected the productivity of the skidders for in-field chipping and whole tree methods. In the WTR method, the productivity of the processors was affected by tree size and the fact that two operators were needed for this operation. Larger trees resulted in higher processor productivity.

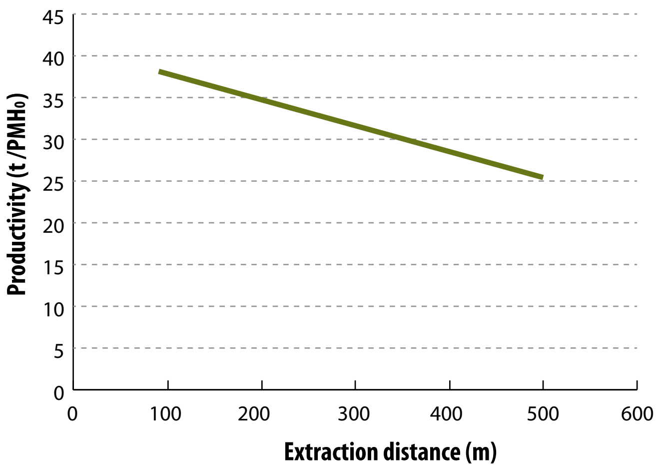

Figure 1. Impact of extraction distance on forwarding productivity (CTL method)

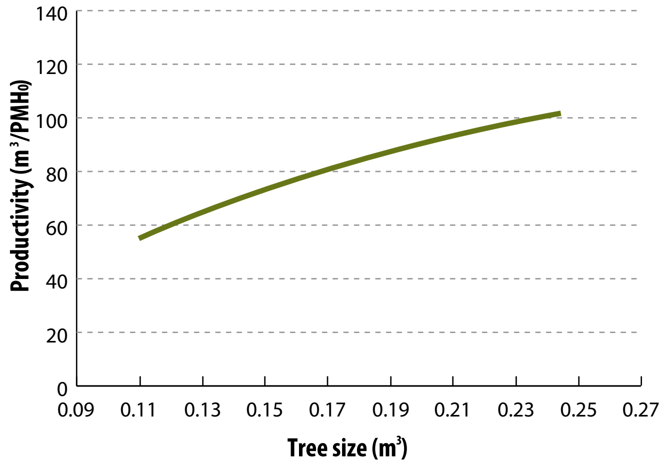

Figure 2. Impact of tree size on productivity of feller-buncher (IFC-F/C)

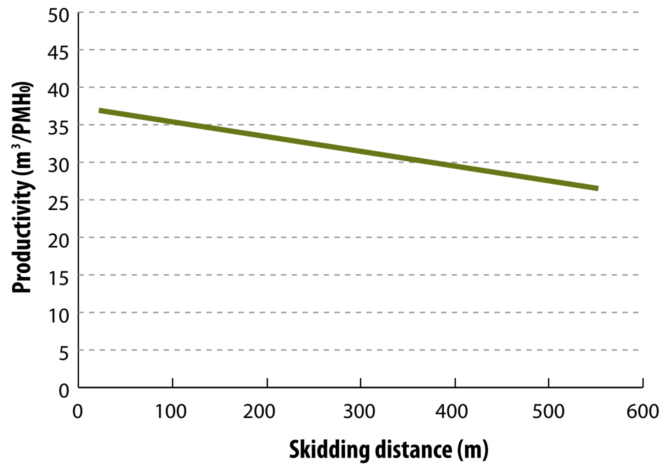

Figure 3. Impact of skidding distance on productivity of skidder (IFC-F/C)

Retained biomass after harvesting

The CTL harvest method retained higher biomass residues on the site after harvest (58.7 GMt/ha). The other methods left very small amounts of biomass at the site, as they extracted the whole trees to the roadside.

Table 6. Retained biomass after harvesting operation

Harvesting method	Retained biomass (GMt/ha)
CTL	58.7
IFC-DDC	4.2
IFC-F/C	6.5
WTR	7.7

Take-home messages

- The cheapest harvest method in this trial was in-field chipping by the chipper with a combined flail (IFC-DDC). For the WTR and CTL methods, chipping costs at the mill need to be investigated.
- The WTR method was found to be an expensive method with the highest fuel consumption.
- Transportation costs (truck costs) for log transport (CTL and WTR) are higher than transporting the chips from in-field chipping operations.
- The CTL method left the most residues at the site after harvest. The other methods left less than 8 GMt/ha. The ecological impact of biomass removal on site sustainability needs further investigation.

Organisations supporting this research

Albany Plantation Export Company (APEC) supported this research by providing its plantation, equipment and resources.

More information

CRC for Forestry website:
http://www.crcforestry.com.au/research/programme-three/index.html

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