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Programme: Harvesting and Logistics

Project Number: 3.4 **Report No.: H055**

JAS Volume Measurement on Mechanised Processors

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Date: 26 January 2022

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EXECUTIVE SUMMARY

Measurement of the volume of logs to the Japanese Agricultural Standard (JAS) is a common practice at the ports or log yards for sales within export log supply chains. Forest Growers Research Ltd proposed a system that will automatically attach an individual log identification tag (log ID) to logs by the grapple processor at time of log manufacture in the forest. The opportunity arises to link the log ID to the diameter, length, and hence volume of the log as it is manufactured and thereby bypass the need for JAS measurement and tagging of export logs at the ports. There have been no reported studies on the accuracy of JAS measurement based on processor data files from well-calibrated log grapple processors. This study makes a first step towards addressing that knowledge gap for *Pinus radiata* in New Zealand.

Five processing machines at various locations around New Zealand were included in this study: two in the Bay of Plenty, one in the central North Island, one in Hawkes Bay, and one in Otago. To derive JAS diameters, log small end diameter under bark (SEDUB) processor measurements were rounded down to even centimetres for logs 140 mm and over and to the nearest centimetre for logs under 140 mm SEDUB. JAS volumes were also determined using the standard equation for logs under 6 m in length. Diameters and volumes were compared at the individual log level with JAS measurements made in the forest by an expert check-scaler at one of the five locations. At the other four locations the processor-based JAS diameters and volumes were compared with measurements made by manual scalers (or automated scaling systems) at the batch level since individual logs were not tagged in the forest at these locations.

Overall JAS volume biases ranged between -2.2% and +23.9%. Individual grade volume biases ranged between -5.9% and +30.7%. The high positive biases, overall and for an individual grade, related to a machine that had not been recently calibrated.

The study indicated that the required standard for JAS volume bias, expected from manually or automatically scaling logs at ports (less than +/- 3%), could be met with well calibrated processors. One of the five machines met this standard for overall volume bias, and volume biases for one quarter of the individual grades studied also met this standard.

Implementing a processor-based JAS volume measurement system would require establishment of independent auditors who would undertake check-scaling samples of logs. Regular calibration of diameter measurements will be vital for the success and acceptance of the system by all parties concerned. Such systems have been accepted in parts of Scandinavia.

INTRODUCTION

The Forest Growers Research Limited Programme Te Mahi Ngahere i te Ao Hurihuri – Forestry Work in the Modern Age commenced on 1 January 2019. The programme outlines a pathway for the New Zealand forest industry to develop innovative harvesting technologies in forestry automation and robotics that will address labour shortages, reduce forestry value chain costs, improve economic viability of harvesting small forests and enhance long term sustainability through reducing environmental impact and making harvesting jobs safer for workers (Forest Growers Research Limited 2018).

One of the projects within the research programme is development of an automated individual log ID tagging and tag reading system. Individual log ID has great potential for improving production efficiencies in the log value chain from stump to mill or port. These systems can ensure that the right log product is allocated to the end-product for which it is best suited, and they can help to control costs and maximise customer service. Tagging and tracking of logs is a common practice within export log supply chains.

One of the features of this system will be to automatically attach a log ID tag to logs by the grapple processor during log manufacturing in the forest. The opportunity then arises to link the log ID to the diameter, length, and hence volume of the log as it is manufactured. Since stems are processed large end first, the tags must be placed on the large end of each log if processor machine productivity is not to be compromised.

Export log measurement to the Japanese Agricultural Standard (JAS)

Over 60% of New Zealand's plantation forest harvest is exported as logs (Forest Owners Association 2021). Logs are scaled to the JAS[1] standard, before they are exported, either at the port or at a satellite yard prior to delivery to the port. This scaling is used to derive an estimate of the total log volume (Ellis and Crawley 2014).

JAS scaling is based on measurements of two diameters on the small end of the log; one of which is the smallest under bark diameter through the geometric centre of the log end, and the other measurement is the diameter perpendicular to the smallest diameter which is also through the geometric centre of the log end (Figure 1). Nodal swelling around branch stubs requires a reduction in diameter measurements so that JAS volume is not over-estimated (Figure 2). Each of the diameters is rounded down to the nearest even centimetre (single centimetres for diameters below 14 cm). The JAS diameter (JDUB) is based on the shortest axis unless there is a difference of at least 6 cm between the short and long axes. If the shortest axis is 40 cm or larger, two centimetres are added for every 8 cm difference between shortest and longest diameters.

Scaling in New Zealand is undertaken by both automated and manual systems. Scaling companies monitor the accuracy of their systems by sub-sampling scaled logs and carefully remeasuring them using "check-scalers" who are experts in their field. The maximum bias allowed for logs scaled on a truck or on a rail wagon is +/- 3% of load volume. Murphy and McIvor (2018) reported JAS volume

[1] JAS = Japanese Agricultural Standard.

biases of +0.88% for manual scaling and -0.04% for automated scaling compared with check-scaler measurements of 898 A-grade export radiata pine logs. Kosolofski (2013) reported that when check scales of imported logs are performed in China, the tolerance for acceptance of a parcel of logs is one percent (1%). Kosolofski (2013) does not say whether the volume comparison is JAS m^3 or not, but it is likely to be Guo Biao m^3 (Ellis and Crawley 2014).

Figure 1. Under bark measurement of log diameters for JAS scaling of volume on a log with no nodal swelling.

Figure 2. Under bark measurement of log diameters for JAS scaling of volume on a log with nodal swelling.

Log measurement on a grapple processor

Over 95% of commercial forest volume harvested in New Zealand is cut into logs using mechanised processing machines (Visser and Obi 2020). Most of the mechanised log processors use the Standard for Forest machine Data and communication (StanForD) protocol for recording log data (Skogforsk 2007). Among the many attributes that can be linked to each log are the stand from which the log was harvested, its grade, its small and large end diameters, its length, and its location up the stem. An individual log ID number can also be allocated to the log and stored in the StanForD files.

StanForD stem files (.STM files) include measurements of log diameter at 10 cm increments along the stem. StanForD individual production files (.PRI files) include measurements of the LED and SED for each log that has been cut from a stem. The sensors for over bark diameter (DOB) measurement are placed either in the upper delimbing knives or in the feed rollers. Modern processor heads usually record at least three points around the stem at each measurement point (Figure 3).

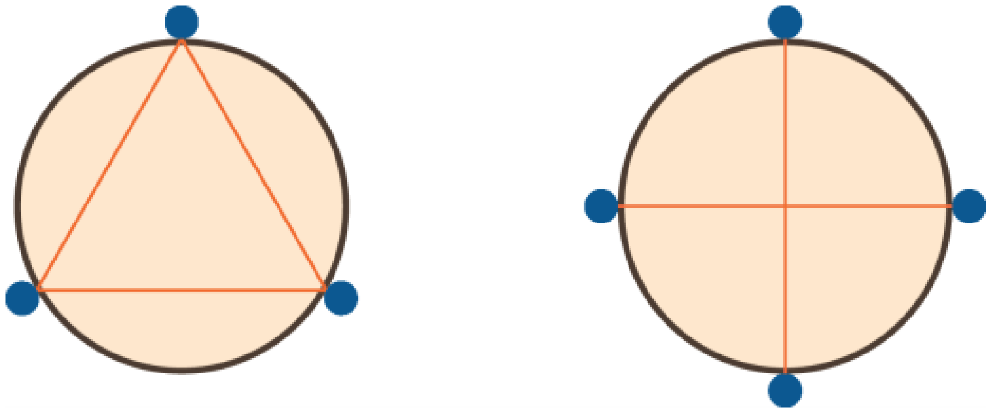

Figure 3. Modern processor heads calculate the over bark stem diameter as the diameter of a circle, either through triangulation based on three measurement points or as the average diameter in two perpendicular measurement orientations stem.

If the processor records an increasing diameter for the stem, when measuring from butt to top, such as over a knot (branch stub or nodal swelling), the computer will filter the measurements and create a "flat area" until the diameter measurement returns to normal (Figure 4). Over bark diameters are converted to under bark diameters (DUBs) using a bark thickness model.

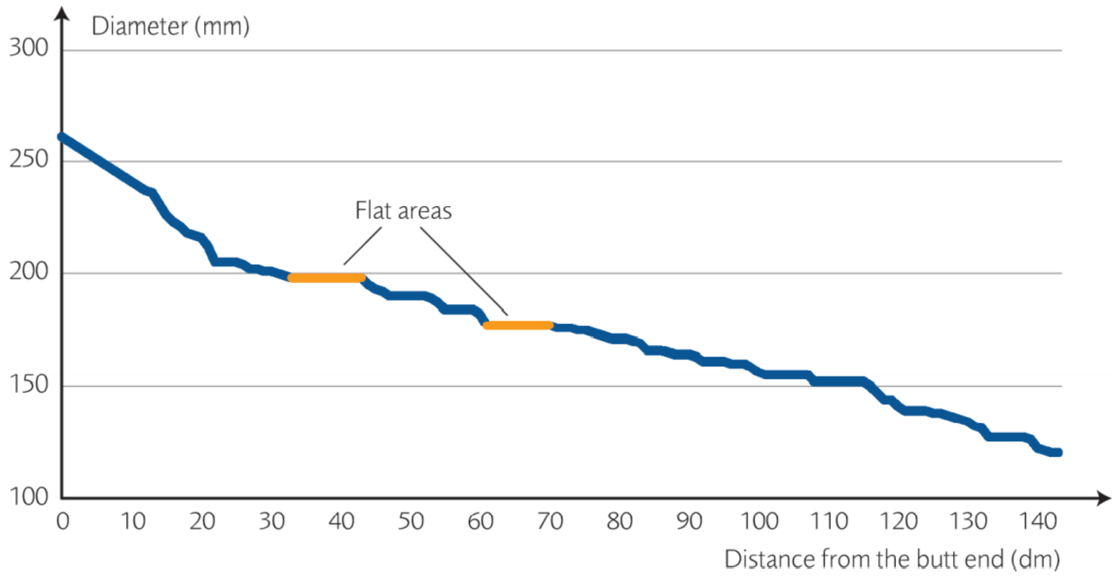

Figure 4. The processor's measuring device records a stem profile (blue), where the diameter decreases towards the top. The on-board computer algorithm filters out diameter increases and

creates "flat areas" in the stem profile until the diameter starts to decrease again (Source: Nordstrom and Hemmingsson, 2018).

Objectives

To the best of our knowledge, there have been no reported studies on the accuracy of JAS measurement based on STM or PRI data files from well-calibrated log grapple processors. This study makes a first step toward addressing that knowledge gap for *Pinus radiata* in New Zealand.

The main objectives of this study were to:

- Compare JAS volume measurements based on log processing machine data and volumes based on measurements by a world class expert scaler ("check-scaler"). (Referred to as Trial 1 in this report).
- Compare JAS volume measurements based on log processing machine data and volumes based on measurements by random scalers (or scaling systems if automated systems are used) from multiple regions around New Zealand. (Referred to as Trial 2 in this report).

STUDY METHODS

Trial 1

Trial 1 was carried out in an unpruned *Pinus radiata* stand located in the Eastern Bay of Plenty region on 19 April 2021. A harvesting crew, known for using well-maintained and calibrated log processing equipment, was selected for the trial.

The log processing head used in the trial was a Woodsman Pro 850. The crew was asked to calibrate the processor for length and diameter measurement prior to commencement of the trial – preferably within a few days. We were told that this had been done. The PRI file indicated, however, that the processor had last been formally calibrated for length five months earlier on 2 November 2020 and for diameter two months earlier on 19 February 2021.

To reduce the complexity of the trial and the time involved, the processor operator was asked to cut four grades of export logs plus a domestic pulp grade. The export grades and nominal lengths were as shown in Table 1. Domestic pulp logs were not of interest in this trial. A target of 50 logs per export grade was set for the trial.

Table 1. Log grades, lengths and target log counts used in Trial 1

Log grade	Nominal length (m)	Target log count
A	3.6	50
K	3.6	50
KI	3.6	50
KIS	3.8	50

Stems had been felled and extracted to the roadside before commencement of the trial. The operator would process a stem into logs and then wait until the check-scaler had measured and recorded the "true" DUBs to the nearest millimetre and the JDUBs rounded down to the nearest 2 cm (or 1 cm for logs with diameters below 14 cm). The check-scaler also recorded log-end features, such as nodal swelling, which would result in a reduction in JAS volume diameter. The number of logs in each grade, as determined by the check-scaler, was separately recorded for each stem. Once the target number of logs for a specific grade was reached, "true" and JAS measurements by the check-scaler were discontinued – although all export grades in the trial were continued to be processed by the machine operator. Because of the good tree form in the stand in which the trial was being carried out, there were few stems with KI grade logs in them. The processor was moved to three nearby landings to find sufficient KI grade logs to meet the target. The target was not met by the end of the day when the trial was finished.

The PRI file was downloaded from the processor's computer and the small end DOB's and DUB's for the export log grades extracted from the file. The diameters were rounded down to the appropriate JDUBs; e.g., 299 mm became 28 cm JAS, and 139 mm became 13 cm JAS. Both Processor JDUBs and Check-Scaler JDUBs were then squared (DSq) and quadratic mean JDUBs calculated for the processor and the check-scaler – since these give a better indication of volume bias for the processor measurement system. JAS volume for logs under 6 m in length is calculated using the formula:

$$V = JDUB^2 * L/10000$$

where V = volume in JAS m^3, JDUB = JAS diameter in cm, and L = nominal length in m.

Paired t-tests were used to determine if there were statistically significant differences in the mean squared diameters at the 95% confidence level between the processor-based JAS measurement system and the check-scaler. The JAS volume bias, compared with the check-scaler, was also calculated for each export log grade and for all export grades combined. A positive bias meant the processor-based system over-estimated JAS volume and vice versa.

Trial 2

In 2018/19 the overall distribution by volume of radiata pine log grades exported from all New Zealand ports was approximately 8% pruned logs, 50% A grade logs, 23% K grade logs, 10% KI grade logs, and 8% KIS grade logs.

Trial 2 was carried out between 3 August and 15 November 2021 at four sites scattered around New Zealand. In Trial 2 an attempt was made to mimic this distribution for 10 truckloads of logs produced by each harvesting crew while reducing the complexity of load management by converting these percentages to the nearest 10%. Harvesting crews operating in pruned stands were asked to produce 1 load of pruned logs, 5 loads of A grade logs, 2 loads of K grade logs, 1 load of KI grade logs, and 1 load of KIS grade logs. In unpruned stands, the load of pruned logs was replaced with an additional load of A grade logs.

The forest companies participating in the trial were asked to select harvesting crews known for using well-maintained and calibrated log processing equipment. As in Trial 1, each crew was asked to calibrate the processor for length and diameter measurement prior to commencement of the trial. Harvesting crews are referred to as Crew A, Crew B, Crew C and Crew D to maintain anonymity for both the crew participating in the trial and the forest owner.

Crew A

Trial 2 with Crew A was carried out on 3rd and 4th August 2021 in an unpruned *Pinus radiata* stand in the Hawkes Bay region.

Figure 5. Woodsman 750 PRO on Cat 522 base machine

The log processing head used in the trial was a Woodsman Pro 750 on a Caterpillar 522 base machine (Figure 5). The PRI file indicated that the processor had last been formally calibrated for length on 2nd August 2021 and for diameter on 3rd August 2021; i.e., the day before the trial commenced and the day of the trial.

Trees near the edge of a landing were felled, mostly before the start of the trial, and then processed after the trial began. The processor operator was asked to cut four grades of export logs plus a domestic pulp grade. The export grades and nominal lengths were as shown in Table 2.

Once the target number of loads were cut for a grade, the operator cut about 7 short pieces of waste, which were easy to identify in the PRI file. The orders in which grade targets were reached were communicated to the research team and manually recorded. Once a grade target was reached the operator could continue to cut the grade, but these additional logs were of no interest for the trial and were stacked separately from trial logs.

Loads of trial logs could be sent to the port as they were produced. Load dockets were marked as being part of a trial. Where too many logs had been produced by the processor, they were left on the landing and their JDUBs manually measured by forest company staff[2]. These logs were then subtracted from the log count produced by the processor.

[2] Assessment of JDUBs by forest company staff could be a source of bias since the staff are not experts in JAS scaling.

Table 2. Log grades, lengths and target load counts used in Trial 2

Crew	Grade	Nominal lengths (m)	Target load count
A	A	5.8	6
	K	5.8	2
	KI	2.9	1
	KIS	3.8	1
B	A	3.8	2
		5.1	4
	K	3.8	2
	KI	3.8	1
	KIS	3.8	1
C	Pruned	6.0	1
	A	5.8	5
	K	3.8	2
	KI	3.6	1
	KIS	3.8	1
D	Pruned	5.1	1
	A	3.8	1
		5.8	4
	K	3.8	1
		5.8	1
	KI	3.8	1
	KIS	3.6	1

Logs sent to the port were scaled on-truck using ISO Ltd.'s automated scaling system. The PRI file was downloaded from the processor's computer and the small end DOBs and DUBs for the export log grades extracted from the file. The diameters were rounded down to the appropriate JDUB. Both Processor JDUBs and ISO-scaled JDUBs were then squared (DSq) and quadratic mean JDUBs calculated for the processor and the scaling system.

Unpaired t-tests were used to determine if there were statistically significant differences in the mean squared diameters at the 95% confidence level between the processor-based JAS measurement system and the scaling system used at the port. The JAS volume bias, compared with the scaling system, was also calculated for each export log grade and for all export grades combined. A positive bias meant the processor-based system over-estimated JAS volume and vice versa.

Crew B

Trial 2 with Crew B was carried out on 9th September 2021 in an unpruned *Pinus radiata* stand in the Central North Island region. The log processing head used in the trial was a Waratah 625C on a Hitachi 350 base machine (Figure 6). The processor operator said the processor had been calibrated recently, however, it was later found that the PRI file indicated that the processor had last been formally calibrated for length on 11th July 2019 and for diameter on 29th January 2020. The operator, towards the end of the trial, indicated that the diameter measurements may be "a bit off" – confirming that he did not think the measurements were accurate.

Figure 6. Waratah 625C on Hitachi 350 excavator base

The study methods used for Crew B were very similar to those described for Crew A. Stems which had been extracted to roadside prior to the commencement of the trial were processed into four grades (Table 2). Once a grade target was reached the operator could continue to cut the grade but these additional logs were of no interest for the trial and were stacked separately from trial logs.

Loads of the logs were sent to the port where they were scaled on-truck using ISO Ltd's automated scaling system. Where too many logs had been produced by the processor, they were left on the landing and their JAS diameters manually measured by forest company staff. These logs were then subtracted from the log count produced by the processor. Note that in some cases the log counts still did not match exactly. This was considered when determining volume biases.

Small end DOBs and DUBs for the export log grades were extracted from the PRI file and the diameters were rounded down to the appropriate JDUB. Unpaired t-tests were used to determine if there were statistically significant differences mean squared diameters and in squared diameter distributions at the 95% confidence level. The JAS volume bias, compared with the scaling system, was also calculated for each export log grade and for all export grades combined.

Crew C

Trial 2 with Crew C was carried out on 17th August 2021 in a pruned *Pinus radiata* stand in the Otago region. The log processing head used in the trial was a Woodsman 850 PRO on a Madill 3800C base machine (Figure 7). The PRI file indicated that the processor had last been formally calibrated for length on 6th August 2021 and for diameter on 16th August 2021.

The study methods used for Crew C were very similar to those described for Crews A and B. There were some differences:

- Pruned as well as unpruned export logs were cut (Table 2).
- Logs were scaled on-truck at the port using C3 Ltd.'s automated scaling system.

- The trial was interrupted by a nation-wide COVID lockdown which meant that target load volumes were not met for K grade and KIS grade logs; these were half a load and a tenth of a load short, respectively.

Figure 7. Woodsman 850 PRO on Madill 3800C excavator base

<u>Crew D</u>

Trial 2 with Crew D was carried out on 15th November 2021 in a log yard in the Bay of Plenty region. The log processing head used in the trial was a Waratah 625C on a Sumitomo SH 370 base machine (Figure 8).

Figure 8. Waratah 625C on Sumitomo SH 370 excavator base

The processor had last been formally calibrated for diameter on 13th November 2021. The study methods used for Crew D were very similar to those described for Crews A, B and C. There were some differences.

- Pruned as well as unpruned export logs were cut (Table 2).
- Small end DUBs were extracted from the processor's PRI file using ForestPHD's STICKS software and provided by the forest company.
- Logs were scaled on-rail wagons using C3 Ltd's manual scaling system.
- A grade (3.8 m) and KI grade (3.8) logs were commingled on one wagon and mislabelled. Data for these log grades were analysed as a single unit.

RESULTS

Trial 1

A total of 177 logs were measured in Trial 1 (Table 3). As noted in the Study Methods section, there were difficulties in finding enough KI grade logs to meet the target of 50 logs per grade.

The differences between processor DUB measurements and processor DOB measurements, were 1 to 9 mm less for small end diameters ranging between 122 mm and 616 mm; differences were positively related to log diameter. An approximate ratio of DUB/DOB for this trial was 0.98.

The mean bias in processor DUB measurements, compared with "true" DUB measurements, was + 6 mm. The mean biases, by grade, were +12, +11, +4, and -1 mm for KI, A, K, and KIS grades, respectively.

The quadratic mean JDUBs based on processor measurements were +0.1 to +1.9 cm greater than the quadratic mean JDUBs based on the check-scaler's measurements: the difference being lowest for KIS grade logs and highest for KI grade logs. The mean DSq values for the processor-based measurements were significantly different from check-scaler measurements for A, K, and KI logs, but not for KIS logs.

More than a fifth of all logs (22%) were assessed by the check-scaler as needing a diameter reduction due to a log end defect. The majority of these (17%) were due to knots or swelling and the remainder were due to machine damage and splits (5%). Less than 0.6% of logs were assessed as needing a diameter increase due to being out-of-round.

Compared with the check-scaler's measurements, the processor-based JDUB measurements resulted in an overall positive bias of +6.8% in JAS volume[3]. The mean JAS volume bias was least for KIS grade logs (1.2%) and greatest for KI grade logs (+10.3%). Ignoring for the moment the effects of log end conditions on volume bias, variability in biases was greater with small logs than large logs (Figure 9).

The processor volume bias for logs with an end condition (nodal swelling, machine damage, etc.) that required a diameter reduction was almost twice as large (+11.1%) as logs that had no end condition (5.5%).

[3] Note that these bias estimates differ from those shown in a preliminary report due to an earlier misinterpretation of log grades.

Table 3. Mean JAS diameters, test statistics and volume biases by log grade for Trials 1 and 2

Trial	Crew ID	Grade	Log Count Processor	Quad Mean JDUB Processor	Quad Mean JDUB Scaler	t-Statistic for DSq	DSq means the same at 95% level	JAS Volume bias compared with Scaling System or Check Scaler (%)
1		A	50	37.7	36.4	7.681	No	7.1
		K	53	27.3	26.5	5.086	No	6.3
		KI	24	38.9	37.0	4.372	No	10.3
		KIS	50	19.6	19.5	0.503	Yes	1.2
		All	177					6.8
2	A	A	182	37.7	38.4	-0.827	Yes	-3.1
		K	147	25.2	25.0	0.633	Yes	1.2
		KI	94	33.5	34.0	-0.432	Yes	-2.5
		KIS	210	17.7	18.0	-1.072	Yes	-3.8
		All	633					-2.2
	B	A38	134	40.3	36.9	3.924	No	19.5
		A51	181	43.0	38.2	6.348	No	26.6
		K	145	30.8	28.0	2.871	No	20.4
		KI	65	44.4	38.8	3.623	No	30.7
		KIS	209	21.6	22.2	-1.444	Yes	-4.6
		All	734					23.9
	C	Pruned	23	48.6	48.0	0.306	Yes	-0.1
		A	170	40.1	38.9	1.756	Yes	6.1
		K	74	25.4	24.3	2.477	No	10.7
		KI	57	39.0	38.2	0.571	Yes	4.2
		KIS	113	25.1	23.5	1.793	Yes	8.9
		All	437					5.7
	D	Pruned	41	43.8	43.2	0.511	Yes	-5.9
		A58	197	37.5	36.8	1.336	Yes	0.3
		K58	124	26.5	25.0	6.655	No	14.3
		K38	71	25.3	24.5	2.280	No	7.2
		A3.8 & KI38	171	33.6	32.7	9.294	Yes	1.2
		KIS	162	22.1	20.1	1.475	No	21.3
		All	766					3.2

DSq = JAS Diameter Squared, Quad Mean JDUB = Quadratic Mean JAS Diameter

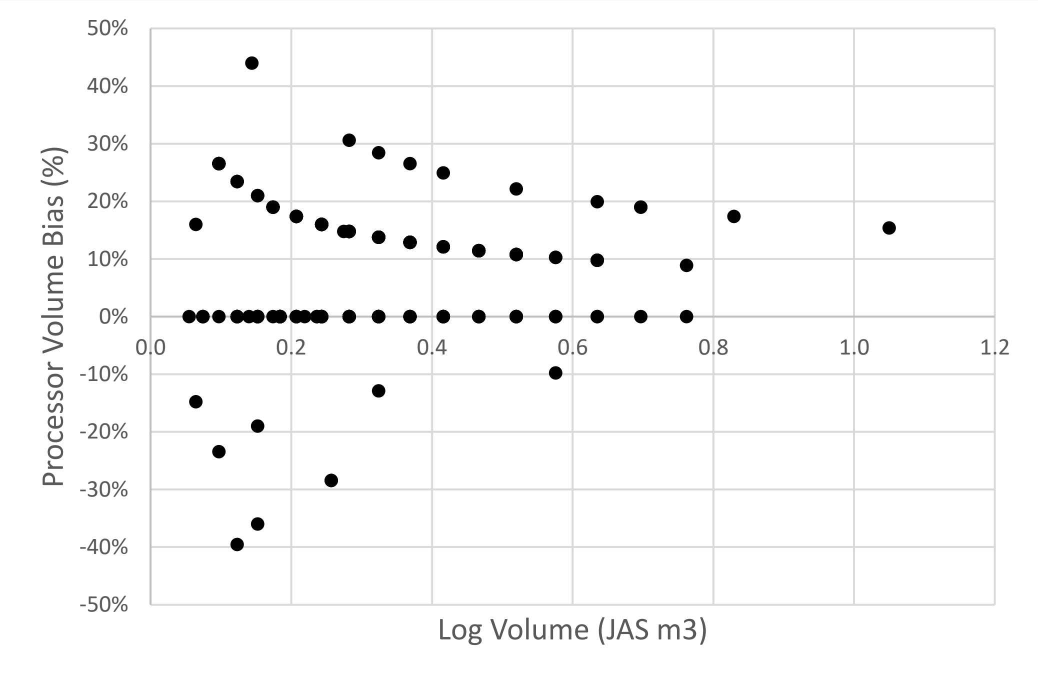

Figure 9. Effect of log size on processor JAS volume bias

Trial 2

Processor-based JDUBs tended to be overestimated in three of the four harvesting crews, resulting in overall positive biases in JAS volume estimates compared with the scaling systems. JDUBs were underestimated for the fourth crew, resulting in an overall negative volume bias.

<u>Crew A</u>

A total of 633 logs were processed by Crew A in Trial 2 (Table 3).

The differences between processor DUB measurements and processor DOB measurements, were 1 to 12 mm less for small end diameters ranging between 96 mm and 676 mm; differences were positively related to log diameter. An approximate ratio of DUB/DOB for this trial was 0.98.

The quadratic mean JDUBs based on processor measurements were -0.7 to +0.2 cm greater than the quadratic mean JDUBs based on the scaling system measurements: the difference being smallest for K grade logs and greatest for A grade logs. There were no statistically significant differences for any of the log grades in mean DSq values for the processor-based measurements compared with the scaling system measurements.

1.5% of logs were assessed by the automated scaling system as needing a diameter increase due to being out-of-round.

Compared with the scaling system measurements, the processor based JDUB measurements resulted in an overall negative bias of -2.2% in JAS volume. The JAS volume bias was positive for

K grade logs (+1.2%) and negative for A grade (-3.1%), KI grade (-2.5%) and KIS grade (-3.8%) logs.

Crew B

A total of 734 logs were processed by Crew B (Table 3).

There was no difference between processor DUB and DOB measurements, i.e., bark thickness was calculated as being zero by the processor's on-board computer. The ratio of DUB/DOB for this trial was, therefore, 1.00.

The quadratic mean JDUBs based on processor measurements were -0.6 to +5.6 cm greater than the quadratic mean JDUBs based on the scaling system measurements: the difference being smallest for KIS grade logs and greatest for KI grade logs. There were statistically significant differences for all the log grades, except KIS, in mean DSq values for the processor-based measurements compared with the scaling system measurements.

1.9% of logs were assessed by the automated scaling system as needing a diameter increase due to being out-of-round.

Compared with the scaling system measurements, the processor based JDUB measurements resulted in an overall positive bias of +23.9% in JAS volume. The JAS volume bias was positive for A grade 3.8 m, (19.5%), A grade 5.1 m (26.6%), K grade (20.4%), and KI grade (30.7%) logs and negative for KIS (-4.6%) grade logs. We reiterate, at this point, that the processor for this crew had not been formally calibrated for diameter in almost two years and partway through the trial the operator indicated that diameter measurements might be "a bit off".

Crew C

A total of 437 logs were processed by Crew C (Table 3).

The differences between processor DUB measurements and processor DOB measurements, were 1 to 12 mm less for small end diameters ranging between 107 mm and 671 mm; differences were positively related to log diameter. An approximate ratio of DUB/DOB for this trial was 0.98.

The quadratic mean JDUBs based on processor measurements were +0.6 to +1.6 cm greater than the quadratic mean JDUBs based on the scaling system measurements: the difference being smallest for pruned logs and greatest for KIS grade logs. There was a statistically significant difference for K grade logs alone in mean DSq values for the processor-based measurements compared with the scaling system measurements.

2.5% of logs were assessed by the automated scaling system as needing a diameter increase due to being out-of-round.

Compared with the scaling system measurements, the processor based JDUB measurements resulted in an overall positive bias of +5.7% in JAS volume. The JAS volume bias was positive for all grades, except pruned logs (-0.1%) and ranged from +4.2% for KI grade logs to +10.7% for K grade logs.

Crew D

A total of 766 logs were processed by Crew D (Table 3).

The differences between processor DUB measurements and processor DOB measurements, were 4 to 11 mm less for small end diameters ranging between 194 mm and 580 mm; differences were positively related to log diameter. An approximate ratio of DUB/DOB for this trial was 0.98.

The quadratic mean JDUB based on processor measurements were +0.6 to +2.0 cm greater than the quadratic mean JDUBs based on the scaling system measurements; the difference being smallest for pruned logs and greatest for KIS grade logs. There was a statistically significant difference for K and KIS grade logs in mean DSq values for the processor-based measurements compared with the scaling system measurements, but not for the other grades.

Around 0.5% of logs were assessed by the manual scaling system as needing a diameter increase due to being out-of-round.

Compared with the scaling system measurements, the processor based JDUB measurements resulted in an overall positive bias of +3.2% in JAS volume. The JAS volume bias was positive for all grades, except pruned logs (-5.9%) and ranged from +0.3% for A grade 5.8 m logs to +21.3% for KIS grade logs.

DISCUSSION

Data was gathered from five sites around New Zealand where radiata pine stems were being processed into logs. The data allowed comparisons to be made between diameter and volume measurements estimated by processing machines and log scaling systems using check-scalers.

Trial 1 included the only set of measurements where comparisons could be made between "true" DUBs and processor DUBs. The mean processor bias was +6 mm and this varied between grades from -1 to +12 mm. Bardoul (2018) reported a mean processor (Waratah HTH 625C) bias of -7 mm for DUB. Saathof (2014) reported a mean processor (Waratah HTH 625C) bias of -16 mm, which also varied with grade (from -6 to -28 mm), but his biases were based on DOB, not DUB, measurements.

For the five sites, it was determined that bark was modelled in the processors' on-board computers as being either not present or very thin if compared with published reports on *Pinus radiata* bark thickness. For example, mean DUB/DOB ratios of 0.93 have been reported by Gordon (1983), compared with 0.98 to 1.00 in these trials. Bark thickness estimates based on Gordon's report would be at least four to five times greater than those estimated by the processing machines for logs at the sites included in this study. Strandgard and Walsh (2011) found that the bark thickness model, which is most used on harvesting machines in Australia, underestimates radiata pine bark thickness on the lower trunk and overestimates it on the upper trunk. This is caused by the equation modelling bark thickness as a constant proportion of DOB, whereas *Pinus radiata* provenances grown in Australia have thicker bark on the lower stem when mature.

The implication of underestimating bark thickness, if bark is present, is that processor DUBs and JDUBs would be over-estimated and JAS volumes positively biased. If bark is not present or is over-estimated, true DUBs and JDUBs will be under-estimated.

The importance of regularly calibrating log processing machines has been stressed elsewhere (e.g., Andersson and Dyson 2002, Nieuwenhuis and Dooley 2006) and is strongly evident from these New Zealand trials. The overall JAS volume bias for the one machine that had not been formally calibrated prior to the trial was an order of magnitude greater (+24%) than the four machines that had been calibrated for diameter within a few days of the trial (-2% to +7%).

For all the machines studied, there was no consistency in the size of the volume bias between grades. For example, Crew C, which had the median overall JAS volume bias, had -0.1% bias for pruned logs and +10.7% bias for K grade logs. There was also no consistency between machines in the ranking of the absolute volume biases. For example, KIS grade logs had the second highest or highest volume biases for Crews A, C and D but the lowest volume biases for Trial 1 and Crew B.

Part of any positive bias caused by the processor will be due to the different underlying assumptions behind small end diameter measurements. JAS assumes that the log end is "elliptical" and bases JDUB on the diameter of the smallest axis, whereas processors assume the log end is circular and would base JDUB on the average diameter.

Part of the JAS volume bias between the processor and scaled measurements will also be due to the processor measurements not including diameter deductions due to end conditions. Long term studies, based on check-scaler measurements, indicate that 30% to 65% of export logs may require a diameter reduction due to end conditions (J. Ellis, pers. comm.). This compares with 22% requiring diameter deductions in Trial 1. Check-scalers are more likely to identify and record logs requiring a diameter deduction than scalers who only need to identify end conditions. Ignoring the results from Crew B, where the processor had not been recently calibrated, the mean JAS diameter and volume biases were higher for Trial 1 than for Crews A, C and D. This difference is likely to be due to the check-scaler identifying a greater proportion of logs requiring a diameter deduction.

The results from studies of the machines in Trials 1 and 2 indicate that mechanised processors could potentially meet the required standard of JAS volume biases being less than +/- 3%; one of the five machines met this standard for overall volume bias, and volume biases for one quarter of the individual grades studied met this standard. The biases, however, tended to be greater than those reported by Ellis (2007) (-0.5% to +2.5%) and more recently by Murphy and McIvor (2018).

In some Scandinavian countries, the data from harvesting machines are accepted as the basis for wood trading. For example, Biometria, the Swedish timber measurement association, handles data from over 3000 harvesting machines (Edlund 2020). The harvesting machines are expected to be in good condition mechanically and calibrated regularly. Audits of the measurements are undertaken by a third party. Volume measurements are expected to be within +/- 3%. Machine-measured volumes can be revised based on the results of the audits (Bjorklund 2007). A similar system could be implemented in New Zealand for JAS volume measurements on processors[4]. The system would, , require acceptance by the buyers, sellers and producers of export logs. It would also require establishment of independent auditors who would undertake check-scaling samples of logs and monitoring that the processing machines are being regularly calibrated.

[4] Radiata pine tends to have larger branches and thicker bark than many Scandinavian species. These features would make a payment system based on volume challenging but not unsurmountable.

SUMMARY

The study of five mechanised processing machines indicated that the required standard for JAS volume bias (< +/- 3%) expected from manually or automatically scaling logs at ports could be met. The study compared JAS volume measurements based on diameter measurements recorded in StanForD mechanised data files with scaler or check-scaler measurements.

One of the five machines met this standard for overall volume bias, and volume biases for one quarter of the individual grades studied also met this standard. Implementing a processor-based JAS volume measurement system would require establishment of independent auditors who would undertake check-scaling samples of logs. Regular calibration of diameter measurements will be vital for the success and acceptance of the system by all parties concerned.

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