WORKING REPORT 1272–2026

Wood Value Trial 2025

Björn Hannrup, Astrid Bygge, Emil Edin, Lovisa Engberg Sundström, Johan J. Möller, Mats Richardson, Anders Rowell & John Arlinger

Measurement of cutting time during a frosty field day.

Contents

skogforsk

Uppsala Science Park, 751 83 Uppsala
skogforsk@skogforsk.se
skogforsk.se

Quality review (internal peer review) was conducted during May 2026 by Maria Iwarsson Wide, Programme Director, Value-Creating Ecosystem Services, and Petrus Jönsson, Programme Director, Production and Supply Systems. Subsequently, Magnus Thor, Director of Research, reviewed and approved the publication for release on 17 June 2026.

Editor: Anna Franck, anna@annafranck.se
 ISSN 1404-305X

Foreword

In Skogforsk's Wood Value Trials, harvesters from the leading machine manufacturers are studied with regard to how well they recover timber value in final felling. Similar trials have been conducted on four previous occasions since 1995. This report describes the implementation and results of the Wood Value Trial carried out in autumn 2025. The purpose of the studies was to provide an up-to-date description of how different harvesters perform in key areas, to relate the results to development over time and thereby contribute to driving technical development forward. The studies were funded through Skogforsk's framework programme and through membership fees from members of the StanForD group.

The current Wood Value Trial was carried out in autumn 2025 in northern Uppland, Sweden, with Stora Enso as the host. Contact persons at Stora Enso were Anna Femling, Jenny Medén and Martin Whillans.

During the field trial, a large number of people from the machine and control-system manufacturers participating in the trial contributed:

Eco Log
Thomas Lindström
Roger Vahlberg (operator)

SP Maskiner
Magnus Hansson
Anders Johansson
Anders Svensson

Dasa
Hampus Alfengård

John Deere
Erik Kindlund
Antti Korkiakoski
Niclas Malmberg (operator)
Heikki Pyykkö
Frans Sjölander
Thomas Åström

Komatsu
Daniel Linder
Per Lysebäck (operator)
Marcus Persson
Johannes Svegbo
Fredrik Tjernberg
Tobias Värnlund

Log Max
Gustav Leonardsson
Erik Palm
Dennis Peil
Henrik Persson
Roger Nylén (operator):
Boda Skogstjänst AB

Logset
Andreas From
Tom Knipström
Nicklas Nygård
Magnus Pedersen
Dan Österåker
Daniel Dahlström (operator):
ELK Skogsentreprenad AB

Ponsse
Esko Havimäki
Marko Savolainen
Peter Sundlöf
Edwin Andersson (operator):
Håkan Andersson Skogsvård AB

Rottne
Fredrik Carlsson
Mathias Paulsson (operator)

In the study, Jonas Hemmingsson and Maria Östlund from Biometria carried out the manual reference measurements of log length and diameter. All other reference measurements were performed by Skogforsk personnel.

Study design, contacts with participating companies and data analysis were carried out by a working group consisting of Astrid Bygge, Emil Edin, Lovisa Engberg Sundström, Björn Hannrup, Johan J. Möller, Mats Richardson and Anders Rowell, all from Skogforsk, and John Arlinger from JDA Forest.

Sincere thanks to everyone who contributed to the studies!

Björn Hannrup (Project Manager)

Summary

In cut-to-length harvesting, the bucking systems of harvesters and their wood handling are key factors in achieving a high recovery of timber value. On four previous occasions, in 1995, 2001, 2006, and 2016, Skogforsk has conducted tests of bucking systems from leading manufacturers. The current test, *Wood Value Trial 2025*, was carried out using a similar setup as in the previous tests and aimed, under production-like conditions, to compare seven machine systems in terms of dimension measurement, bucking, cross-cutting, log processing, and compliance with central requirements and rules in the StanForD2010 standard. New for the latest trial was an evaluation of the harvesters' accuracy in positioning stems and logs.

Wood Value Trial 2025 was carried out in northern Uppland, Sweden, with Stora Enso as the land host. The machine systems were tested in three stages. In the first stage, chain speed during cutting and cutting time were measured. In a second stage, 30 Norway spruce stems and 10 Scots pine stems per machine system were harvested. Measurement data from these stems formed the basis for evaluation of control functions, dimension measurement, value optimized bucking, harvest damage, and positioning. In the final stage, all machine systems harvested stems corresponding to approximately 500 sawlogs. Based on these stems, the machine systems' length distribution bucking and control of pulpwood bucking were evaluated.

The machine systems' dimension measurement was evaluated by comparing the machine measurements with manual control measurements of length and diameter. The manual control measurements were performed by quality technicians from Biometria. In the analysis, the proportion of measurements within ±2 cm of the control measurements for lengths and within ±4 mm for diameters was calculated. The analysis also included calculation of the standard deviation between the machine measurements and the control measurements.

The results for length measurements showed that the average proportion of measurements within ±2 cm for all machine systems was 91.6 percent for sawlog products, and that the standard deviation was 1.4 cm. For the two harvesters that showed the best length measurement performance, the corresponding values were 99 percent and 0.9 cm, respectively. The differences noted between harvesters, except for one harvester that had a calibration error, were not statistically significant. Compared with the results from the previous wood value trial (2016), however, a statistically significant improvement in length measurement accuracy was observed. The favourable development noted since 1995 has thereby continued.

For diameter measurements, the average proportion of measurements within ±4 mm of manual control measurements for all machine systems was 79.1 percent, and the standard deviation was 3.78 mm. For six of the harvesters, the differences in the proportion of measurements within ±4 mm were small, ranging from 78 to 82 percent. Larger differences were noted in standard deviation, ranging from 3.0 to 4.1 mm. Compared with previous wood value trial, no improvement was noted for the proportion of measurements within ±4 mm, but a statistically significant improvement in standard deviation was observed. This indicates that the limiting factor for diameter measurement is primarily the calibration procedure rather than measurement capability.

The manual control measurements of length and diameter of the logs from the 30 spruce stems were also used to evaluate the accuracy of the harvesters' volume determination. For six of the seven machine systems, the deviations between total under-bark volume calculated in the harvesters and calculated from manual control measurements were within ±2 percent. For one of the machine systems, a larger deviation was noted due to the use of an incorrectly configured bark function.

The bucking yield (value recovery) indicates how well the harvester's bucking utilises the theoretical maximum timber value. In the test, the bucking yield, based on harvester-measured length and diameter data, varied between 98.8 and 99.3 percent for the participating machine systems. On average, the bucking yield was 99.1 percent, which is 0.3 percentage points higher than in 2016. The high bucking yields show that value optimized bucking performs well in all machine systems, thanks to accurate stem predictions and well-functioning value optimisation. The bucking yield based on control-measured length and diameter data varied between 96.1 and 98.4 percent, with an average of 97.8 percent. This is 0.5 percentage points higher than in 2016. When the evaluation is based on control measurements instead of harvester measurements, the bucking yield decreases, which is caused by measurement errors in the harvesters' length and diameter measurement.

Follow-up of the harvesters' length distribution showed that length distribution bucking generally worked well. Except for one machine system, the measured length distribution degrees were in line with reference values from simulations of bucking of the same stems. Six of the seven machine systems supported minimum diameter search according to StanForD 2010, but the evaluation of functionality indicated potential for improvement in the harvesters' handling of stem tops. A proposed target for final felling of spruce is that both the mean and median values for diameter at the last cut should be below 60 mm given that the normal minimum diameter for pulpwood is 50 mm under bark in Sweden.

For all machine systems, chain speed during cutting in wood was below the maximum allowed value of 40 m/s. A novelty in this year's trial was that three of the machine systems were equipped with rotational speed sensors in the saw motor, resulting in improved initial calibration of chain speed. Results from measurements of cutting time showed an even spread between machine systems. The system with the shortest cutting time was approximately 16 percent faster than the system with the longest cutting time. Differences were greatest at smaller log diameters and generally decreased with increasing size. Compared with the Wood Value Trial 2016, no clear change in average cutting time could be observed.

Follow-up of the harvesters' wood handling showed that the proportion of logs with deep spike damage was unchanged compared with the 2016 test. For three of the machine systems (John Deere, Rottne and Komatsu), no logs had spike penetration exceeding 7 mm. For the remaining four machine systems, the proportion of logs with penetration exceeding 7 mm exceeded the limit of 5 percent according to the Swedish timber measurement regulations.

On average, 48 percent of the logs had bucking splits at the butt end and 23 percent at the top end, when cut without support. The splits were on average 67 mm long at the butt end and 53 percent at the top end. The results for split proportion were almost identical to those from the Wood Value Trial 2016, but there was a tendency for slightly shorter splits. The lowest proportion and shortest splits were noted for the John Deere system in this year's test.

Follow-up of bark damage showed that, on average for all machine systems, 4.1 percent of the log circumference had bark damage down to the wood surface and 6.2 percent down to the inner bark, respectively. The energy value of the removed bark was estimated to average 3 SEK per m^3sub of harvested timber. The extent of bark damage was similar to that observed in the timber value trials 2016.

For all tested control systems, reading of instruction files according to StanForD 2010 (oin, pin and spi) worked well, and for six of the seven machine systems, these could also be updated during ongoing production. However, it was noted that although species instruction files (spi) can be updated during production in most control systems, the workflow could be simplified. Production reporting is now established, with many functions implemented, such as tracking of machine movements and stem codes. Two control systems (three machine manufacturers) had implemented StanForD 2010 version 4.1 during the test, which is the latest version. This includes new functions for operational monitoring, positioning, such as highly accurate crane tip positioning, simplified down time recording, and new bark functions (e.g. for Swedish birch).

Positioning of stems (stump position) had been implemented by Ponsse, John Deere and Komatsu. Due to a technical fault, Ponsse did not use RTK correction during the trial and showed an average error of 1.38 m with a combined standard deviation of 0.98 m. John Deere and Komatsu both used RTK correction; John Deere showed an average error of 0.23 m (combined standard deviation 0.25 m) and Komatsu an average error of 0.16 m (combined standard deviation 0.19 m). These results are very good, as they indicate the possibility of clearly distinguishing individual trees during harvesting.

Only Komatsu had implemented log positioning in this trial and reported both the centre point and orientation of the logs. The centre point had an average error of 0.42 m and a combined standard deviation of 0.52 m. The average error for orientation was 7.4 degrees with a standard deviation of 4.2 degrees. Given the additional challenges involved in positioning logs compared with stems, these results can be considered very good.

The results from the positioning tests show that both stems and logs can be positioned with very high precision. This information will very likely lead to valuable applications in the near future. All manufacturers should work towards implementing positioning solutions for stems and logs.

In summary, the results from Wood Value Trial 2025 show that the participating machine systems, with reservations for the remarks highlighted in this report, have: (i) a very high ability to utilise timber value in final felling, and (ii) good compliance with central requirements and rules according to StanForD 2010. The steady increase in harvesters' capability to utilise timber value observed since 1995 has continued in this year's test, but there are signs of a slowdown. To prevent this favourable development from stagnating, it is important that technical development of harvesters continues, with a focus on timber value. One possible approach is to develop technology that improves handling of value-affecting factors, such as stem curvature and rot in the wood.

Background

Well-functioning bucking optimization systems are essential for achieving high recovery of timber value. On four previous occasions, in 1995, 2001, 2006 and 2016, Skogforsk has conducted tests of machine systems from the leading manufacturers (Sondell & von Essen 1996, Möller et al. 2002, Möller et al. 2008 and Nordström et al. 2018). The tests have been carried out using a similar experimental design, and the machine systems have been evaluated regarding dimension measurement, bucking, volume calculation and general functionality. In the three most recent tests, an evaluation of the harvesters' wood handling was also included. In 2012, a smaller test was carried out focusing on bucking functionality according to StanForD 2010 (Möller et al. 2013).

The current test, Wood Value Trial 2025, was conducted between 22 October and 28 November 2025 in a final-felling stand north of Söderfors in northern Uppland, Sweden. Stora Enso was the land host. The evaluation of the machine systems and the harvesters' wood handling was performed in a similar manner to the previous tests. In the current test, the accuracy of the harvesters' positioning of individual trees and logs was also evaluated.

Purpose

The purpose of the trial was to compare large final-felling harvesters and their control systems from the leading manufacturers under production-like conditions. The experimental design was similar to that used in previous tests, with the aim of enabling development over time to be described.

The results are intended to provide guidance for manufacturers' further development of the machine systems, as well as information for users and researchers. The factors primarily studied were the systems' precision in length and diameter measurement, bucking outcome, general functionality of the bucking computers, and implementation of system functions in StanForD 2010. In addition, the machine systems' efficiency in cross-cutting logs and their damage levels in terms of bucking splits, bark damage and spike damage were studied. New for the current trial was an evaluation of the accuracy of the machine systems' positioning of individual trees and logs.

Conditions and study design

General conditions

The trial was carried out in a final-felling stand dominated by Norway spruce (*Picea abies*) north of Söderfors in northern Uppland, Sweden, during the period 22 October to 28 November 2025. The trees included in the main trial had a mean stem volume of 0,86 m^3sub/stem, corresponding to a diameter at breast height of 32 cm. Before the test, the participants were given the opportunity to set up and calibrate their machine systems at the test site. The harvesters were operated by the participants' own operators.

Data collection

The machine systems were tested in three stages. In the first stage, a check was performed to ensure that chain speed during cutting in wood did not exceed the maximum permitted value of 40 m/s, and the machine systems' cutting time was measured when cutting discs from logs of different dimensions.

In a second stage (the main test), control functions, value optimized bucking, dimension measurement, harvest damage and positioning were evaluated based on single-tree processing of 30 Norway spruce stems and 10 Scots pine stems per machine system. Only trees that were relatively free from defects, such as double tops and large sweeps, were selected. The diameter distribution was similar for the different machine systems (Table 1). The evaluation followed the design used in previous wood value trials.

Table 1. Minimum, mean, and maximum values for diameter at breast height (DBH) of the 30 spruce stems.

DBH (mm)	Min.	Mean	Max.
Log Max	240	308	435
Ponsse	214	313	397
Logset	257	319	418
John Deere	213	321	406
Eco Log	198	320	415
Rottne	229	315	431
Komatsu	257	319	393

On the 30 Norway spruce stems, manual control measurements of length and diameter, follow-up of value optimization bucking, and control measurement of stump position were carried out. After these measurements, bucking splits as well as spike and bark damage were measured. For the ten pine stems, automatic log-type bucking, i.e. butt log or other log, was tested with the green-knot bucking function activated. For the first and second logs from the pine stems, manual control measurements of log position and orientation were carried out.

In a third stage, all machine systems harvested stems corresponding to approximately 500 Norway spruce sawlogs in an adjacent part of the stand. Based on these stems, the machine systems' length-distribution bucking and control of pulpwood bucking were evaluated.

During the studies, the machine systems stored length and diameter measurements for all harvested stems in hpr files. The machine systems were set to store diameter values every tenth cm along the stems. In the analyses, the hpr files were used together with other StanForD2010 files, such as operational monitoring files (mom), control and calibration files (hqc), and instruction files (oin, pin, spi).

Eco Log
Base machine: Eco Log 590G
Head: EC 661 LF
Bucking computer: Forester H70 1.11
Feeding rolls: SP Skelett soft
Diameter measurement: Upper delimbing knifes
Length measurement: Measurement wheel

John Deere
Base machine: John Deere 1470H
Head: H425
Bucking computer: TimberMatic H 1.2
Feeding rolls: JK Ribrollers
Diameter measurement: Upper delimbing knifes
Length measurement: Measurement wheel

Komatsu
Base machine: Komatsu 951
Head: C144 MY23
Bucking computer: Maxi XT 1.24.0.55885 D
Feeding rolls: Ribbhjul/fingervals
Diameter measurement: Upper delimbing knifes
Length measurement: Measurement wheel

Log Max
Base machine: Tigercat 1165
Head: Log Max 5000V
Bucking computer: Log Mate 510 2.5.13
Feeding rolls: Casted Light Weight
Diameter measurement: Feeding rolls and lower delimbing knife
Length measurement: Measurement wheel

Logset
Base machine: Logset 12H
Head: Logset TH80
Bucking computer: TOC-MD v 5.3
Feeding rolls: Mense V-Tec
Diameter measurement: Upper delimbing knifes
Length measurement: Measurement wheel

Ponsse
Base machine: Ponsse Scorpion Giant
Head: New Ponsse H7
Bucking computer: Opti 5G 3.2.12
Feeding rolls: Plate spike
Diameter measurement: Upper delimbing knifes
Length measurement: Measurement wheel

Rottne
Base machine: Rottne H21E
Head: EGS706
Bucking computer: Forester H70 1.11
Feeding rolls: Finnskogsvalsen
Diameter measurement: Upper delimbing knifes
Length measurement: Measurement wheel

Figure 1. Systems tested in Wood Value Trial 2025.

Tested systems

In Wood Value Trial 2025, large single-grip harvesters from seven different manufacturers were tested, with a total of six different control systems (Figure 1). The participants themselves chose which machine system (harvester model and control system) they wanted to test; the only guideline was that the harvester should be intended for final felling in Sweden and that the control system should be available on the market no later than 2026. The focus of the control-system test was on new functionality according to StanForD 2010, with the aim that as many control systems as possible should use the latest version, 4.1. The tested control systems are presented in Table 2.

Table 2. The tested control systems model of bucking computer, program version and operating system. The table also shows what schema version of StanForD2010 the control system reported and read instructions in as well as information on 4.1 launch and possibilities to update to version 4.1.

	ROTTNE, ECO LOG (DASA)	PONSSE	JOHN DEERE	KOMATSU	LOG MAX	LOGSET
Bucking computer	D7	Opti8+	HPC21	MHC-2	Log Mate 510	Logset TOC-MD
Program version	Forester H70 1.11	Opti 5G 3.2.12	TimberMatic H 1.2.draft	MaxiXT 1.24.0.55885 D	2.5.13	TOC-MD v5.3
Operating system	Win 10	Win 10	Win 10	Win 10	Win 10	Linux/ Win 10
StanForD 2010-version	4.1*	3.6	4.1*	3.6	3.5	3.1
Probable time of release for version 4.1	2026	2027	2026	2026	2026	2027
Oldest control system that will be updateable to version 4.1	all Forester systems	Opti 5G**	G- and H-series	MaxiXT	Log Mate 510	–

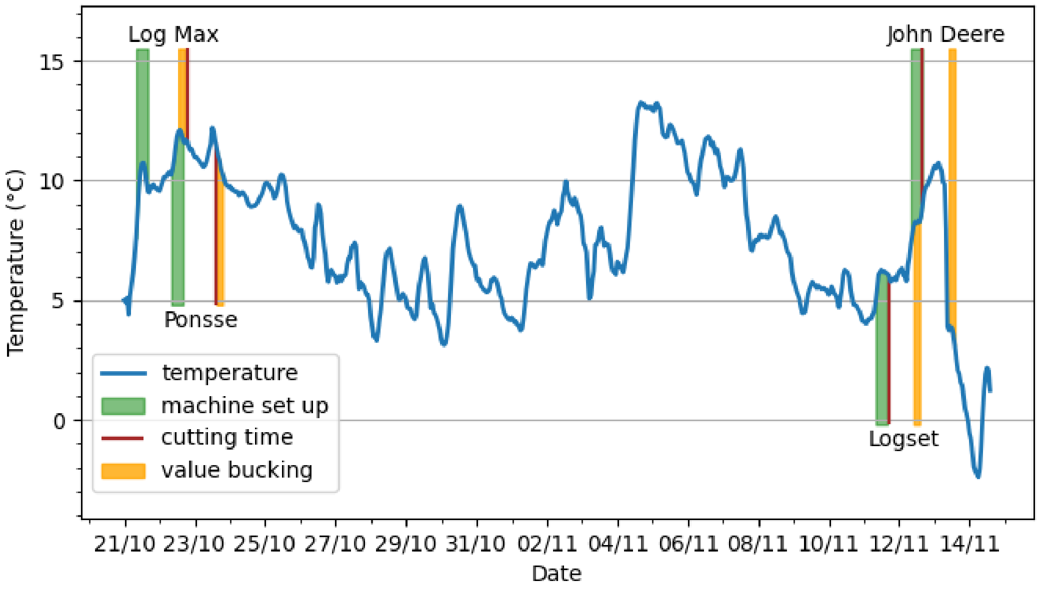
*At the time of the trial Forester H70 1.11 and TimberMatic H were not available with StanForD 2010 version 4.1 on the market.

** Also Opti 4G made in 2021 or later.

Weather conditions during the test period

Temperature variation during the Wood Value Trial 2025 was greater than the temperature variation during the most recent preceding wood value trials. During the first part of the test period, when the tests for Log Max, Ponsse, Logset and John Deere were conducted, the temperature remained consistently above zero degrees (Figure 2, upper). Thereafter, the temperature decreased, and during the later part of the test period, when the tests for Eco Log, Rottne and Komatsu were conducted, the temperature alternated below and above zero degrees (Figure 2, lower).

Temperature variation around zero degrees affects calibration of the harvesters' length measurement, because the penetration depth of the contact measuring wheel differs between frozen and unfrozen wood. Calibrating the length measurement was therefore more challenging for the manufacturers that conducted the test during the later part of the test period. For Rottne, the temperature conditions were particularly challenging. On the day when the harvester was set up and calibrated, the temperature was around zero degrees. During the night, the temperature fell, and on the following day, when the test was conducted, the temperature was around minus five degrees.



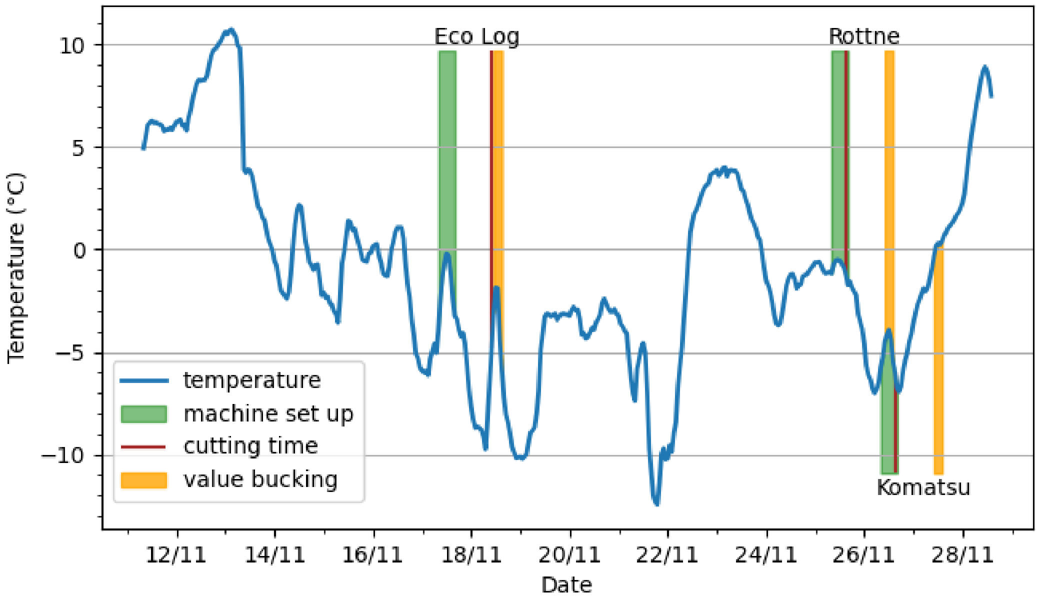


Figure 2. Temperature variation during the test period. Temperature is reported hourly as the average of measurements from three nearby SMHI weather stations.

Study 1: Measurement of length and diameter

Photo: Emeli Ekblad, Eco Log

Purpose

The purpose of the study for length and diameter measurements was to evaluate how well the harvesters measured the correct lengths and diameters of the logs that were processed.

Material and methods

All harvesters in the study used a length-measuring wheel mounted in the feed path of the harvester head to measure log length. Two main measurement methods were used to determine log diameter:

1. Measurement using sensors in the feed roller arms, where the measurement values were combined with values from a sensor in the lower delimbing knife together with a fixed reference point in the frame of the harvester head. This method was used by Log Max.
2. Measurement using sensors in the upper delimbing knives. For John Deere, Komatsu, Logset, Ponsse and Rottne, sensors were used in the two movable delimbing knives, while the third delimbing knife, the top knife in the feed path of the harvester head, was regarded as a fixed reference point. For Eco Log, the top knife in the feed path of the harvester head was movable and equipped with a sensor. Diameter measurement for Eco Log was therefore carried out using sensors mounted in all three upper delimbing knives.

The evaluation of length and diameter measurements was carried out on the 30 spruce stems harvested during the value-bucking test. For these stems, length and diameters were control-measured for all logs, except those with defects such as top breakage. The control measurements were performed according to the procedures for quality assurance of harvester measurement (Biometria 2026) by two measurement technicians from Biometria. The procedure involves length measurement and cross-callipering of over-bark diameters at one-metre intervals. On the butt log, a first measurement is taken at breast height, and at the top of each log a measurement is taken 10 cm from the end. Harvester measurements (M1) and manual control measurements (M2) were reported in hqc files and analysed as follows for both length and diameter:

- The mean of the deviations between the harvester measurements and the control measurements, M1–M2. A positive value indicates that the machine measured too high a value, and a negative value indicates that the machine measured too low a value. The mean deviation represents the systematic error between the harvester and the control measurement and is affected by how the machine has been calibrated.
- The standard deviation of the differences between the control measurements and the harvester measurements. A small standard deviation indicates that repeated harvester measurements have low dispersion and that the measurement function is of high quality.
- Empirical hit rate for the harvesters' length and diameter measurements relative to the control measurements. For length, this is defined as the proportion of measurements within ±2 cm of the corresponding control measurement, and for diameters it is defined as within ±4 mm of the corresponding control measurement. This measure provides a clear picture of how well the harvester measurements correspond to reality and gives an empirical synthesis of mean error and standard deviation, as well as indicating what level of accuracy external stakeholders can expect from harvester measurements.

The analysis was carried out separately for logs belonging to all products and for the subset of logs belonging to the sawlog and small-diameter sawlog products. In all analyses, logs with measurement errors exceeding ±10 cm for length and ±20 mm for diameter were excluded. In addition, diameter measurements on logs whose lengths showed measurement errors greater than ±10 cm were also excluded, because this leads to excessive uncertainty in the positional information for the diameter measurements. A summary of the total number of registered measurement points and the number of measurement points used for both diameter and length measurements is shown by all manufacturers in Table 3.

Table 3. Total number of registered measurement points and the number of measurement points included in the result calculations in accordance with the criteria specified above.

	Diameter measurements			**Length measurements**		
Machine systems	Total	Included	Prop. (%)	Total	Included	Prop (%)
Log Max	631	630	99,8	146	141	96,6
Ponsse	660	660	100,0	147	147	100,0
Logset	761	761	100,0	149	145	97,3
John Deere	660	660	100,0	147	142	96,6
Eco Log	704	697	99,0	149	148	99,3
Rottne	697	694	99,6	154	147	95,5
Komatsu	701	701	100,0	158	152	96,2
All machines	4 814	4 803	99,8	1 050	1 022	97,3

A separate analysis was carried out of the harvesters' stem-holding performance. The analysis was performed using the model developed at Skogforsk (Hannrup et al. 2020 & Hannrup et al. 2023) and implemented in the hprStamhållning software (Skogforsk, hprStamhållning). Input data to the Skogforsk model consist of the harvesters' high-resolution diameter vector, containing diameter values at every decimeter along the harvested stems. Output from the model consists of a stem-level estimate of measurement precision in diameter measurement. Measurement precision is expressed as the dispersion of the machine's measurements in terms of deviations between the machine measurement and a simulated reference measurement carried out by quality technicians from Biometria. The dispersion measure used is the predicted standard deviation per stem (in mm) for the deviation between the quality technician's reference measurement and the harvester's diameter measurement.

In the analysis of the harvesters' stem-holding performance, the Norway spruce stems from the value-bucking and length-distribution bucking tests were used. The relationship between the harvesters' stem-holding performance during length-distribution bucking and value optimized bucking was analysed. The predicted standard deviations from length-distribution bucking were derived by calculating each harvester's general relationship between diameter at breast height and predicted standard deviation, and then using these relationships to calculate predicted standard deviations corresponding to each harvester's mean diameter at breast height from value optimized bucking. This adjustment of the predicted standard deviation for length-distribution bucking makes the results from value optimized bucking and length-distribution bucking comparable.

Results and discussion

Length measurement

Figure 3 shows the results for the proportion of logs within ±2 cm for all manufacturers. The results are shown for all products and for the sawlog product only. The blue bars show the actual results, and the grey bars show what could have been achieved with optimal calibration. The error bars show 95 percent confidence intervals. For further information, see Appendix 1 (hypothesis testing for length measurements). All manufacturers showed very good results, except for Rottne. In Rottne's case, the result was strongly affected by incorrect calibration due to difficult calibration conditions (Figure 2). This incorrect calibration can be seen in the large difference between the possible result given ex-post optimal calibration and the actual result in Figure 3.

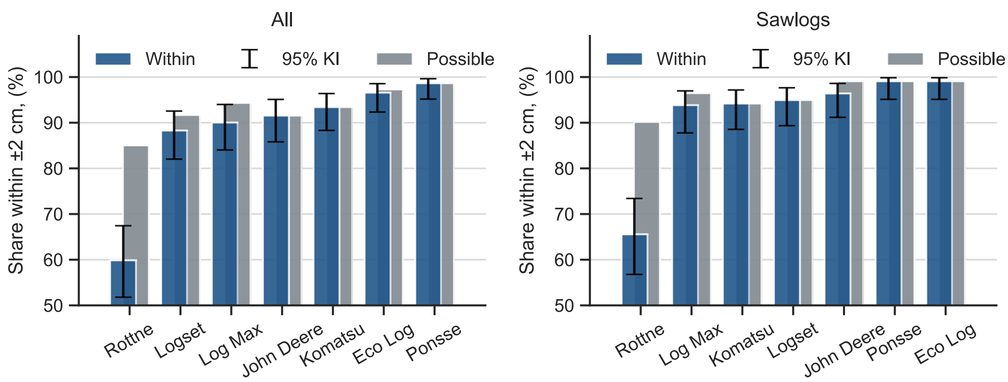


Figure 3. Proportion of logs within ±2 cm. Blue bars indicate actual values, and the grey bars indicate values achievable with perfect calibration. All products on the left and sawlog products on the right. Note that the y-axis is truncated.

Figure 4 shows the standard deviations for all products and for the sawlog product separately. The error bars again show 95 percent confidence intervals. Further details are provided in Appendix 1 (Hypothesis testing for length measurements).

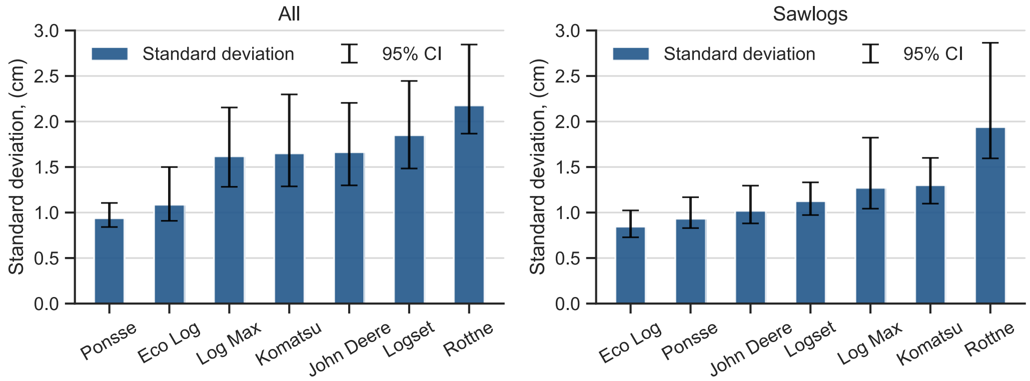


Figure 4. Standard deviations for the length measurements for all manufacturers. All products on the left and sawlog products on the right.

Table 4 presents a summary of the results in which the material has been divided into butt logs and other logs. All length measurements for all manufacturers can also be found in Appendix 1 (Length measurements).

Table 4. Mean value, standard deviation, and proportion within ±2 cm. The results are presented for all products and for sawlog products only, in both cases divided into butt logs, other logs, and total.

	All products			Sawlog products		
Log Max	Butt logs	Other	Total	Butt logs	Other	Total
Mean value (cm)	0,90	0,86	0,87	1,04	0,73	0,80
Standard deviation (cm)	1,51	1,64	1,62	1,46	1,20	1,27
Within ±2 cm (%)	83,3	91,9	90,1	84,0	96,6	93,8

	All products			Sawlog products		
Ponsse	Butt logs	Other	Total	Butt logs	Other	Total
Mean value (cm)	0,17	0,39	0,35	0,14	0,21	0,20
Standard deviation (cm)	0,86	0,95	0,94	0,87	0,95	0,93
Within ±2 cm (%)	100,0	98,3	98,6	100,0	98,8	99,1

	All products			Saw log products		
Logset	Butt logs	Other	Total	Butt logs	Other	Total
Mean value (cm)	-0,34	0,99	0,72	-0,39	0,43	0,24
Standard deviation (cm)	1,12	1,90	1,85	1,11	1,05	1,13
Within ±2 cm (%)	96,6	86,2	88,3	96,4	94,4	94,9

	All products			Sawlog products		
John Deere	Butt logs	Other	Total	Butt logs	Other	Total
Mean value (cm)	-1,50	0,06	-0,27	-1,46	-0,37	-0,64
Standard deviation (cm)	1,12	1,63	1,66	1,12	0,81	1,02
Within ±2 cm (%)	83,3	93,8	91,5	85,7	100,0	96,4

	All products			Sawlog products		
Eco Log	Butt logs	Other	Total	Butt logs	Other	Total
Mean value (cm)	0,02	0,23	0,19	0,02	0,01	0,01
Standard deviation (cm)	1,17	1,06	1,08	1,18	0,72	0,85
Within ±2 cm (%)	96,7	96,6	96,6	96,2	100,0	99,1

	All products			Sawlog products		
Rottne	Butt logs	Other	Total	Butt logs	Other	Total
Mean value (cm)	-0,32	-1,78	-1,48	-0,19	-1,92	-1,51
Standard deviation (cm)	2,68	1,92	2,18	2,63	1,43	1,94
Within ±2 cm (%)	70,0	57,3	59,9	72,4	63,4	65,6

	All products			Sawlog products		
Komatsu	Butt logs	Other	Total	Butt logs	Other	Total
Mean value (cm)	-0,73	0,34	0,13	-0,68	0,05	-0,12
Standard deviation (cm)	1,93	1,50	1,65	1,98	0,94	1,30
Within ±2 cm (%)	80,0	96,7	93,4	78,6	98,9	94,2

The best results for length measurements, considering both the proportion within ±2 cm and the standard deviation, were obtained by Ponsse and Eco Log, both of which had 99 percent of measurements within ±2 cm for the sawlog product. However, it is difficult to demonstrate significant differences between the majority of manufacturers. This does not necessarily mean that differences do not exist, but a large statistical dataset is required to demonstrate differences when seven manufacturers are to be compared with one another. Appendix 1 (hypothesis testing for length measurements) provides further description of the hypothesis testing. If Rottne's calibration problem is corrected for, all systems measured lengths very well.

Comparisons with results from previous years are shown in Figure 5. As in previous years, the results shown here are for the sawlog products. The favorable trends for both the proportion within ±2 cm and the standard deviations have continued, although they show signs of beginning to level off. In hypothesis testing against results from previous years, both results are significant. In this test, the proportion within ±2 cm was 91,6 percent and the standard deviation was 1,44 cm overall for all manufacturers. Because Rottne's results were strongly affected by its calibration, the results with Rottne excluded are also shown as dashed data points, which clearly improves the overall results. Appendix 1 (Historical results) contains a table with these values.

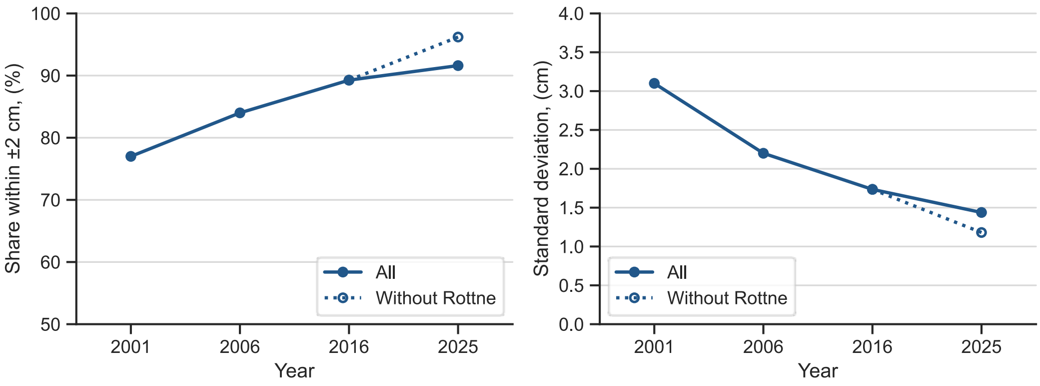


Figure 5. Comparison with results from previous years. The proportion within ±2 cm is shown on the left and the standard deviation on the right.

Diameter measurement

Figure 6 shows the proportion of diameters that fell within ±4 mm. The results are divided into all products and the sawlog products only. The error bars show 95 percent confidence intervals in the same way as for the length measurements. The grey bars show what would be possible to achieve with perfect calibration.

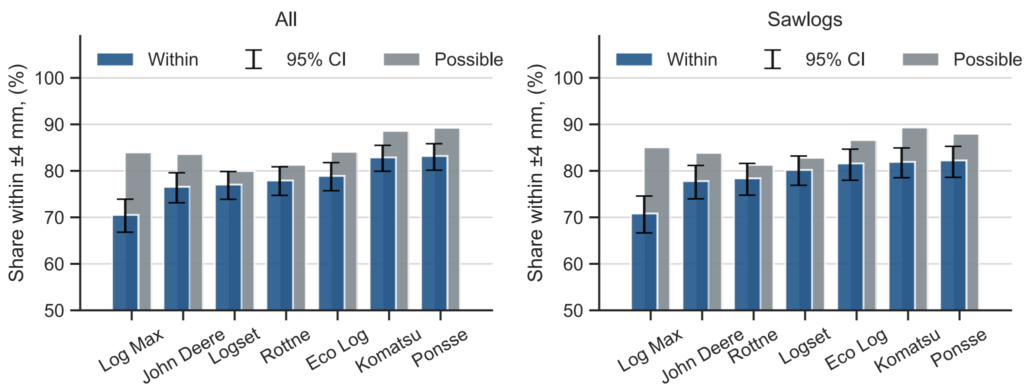


Figure 6. Proportion of diameter measurements within ±4 mm, with actual values shown in blue and values achievable with optimal calibration shown in grey. All products on the left and sawlog products on the right. Note that the y-axis is truncated.

The standard deviations for the diameter measurements are shown in Figure 7, where the products are again divided into all products and the sawlog products only. The error bars show 95 percent confidence intervals. More information is provided in Appendix 1 (Hypothesis testing for diameter measurements).

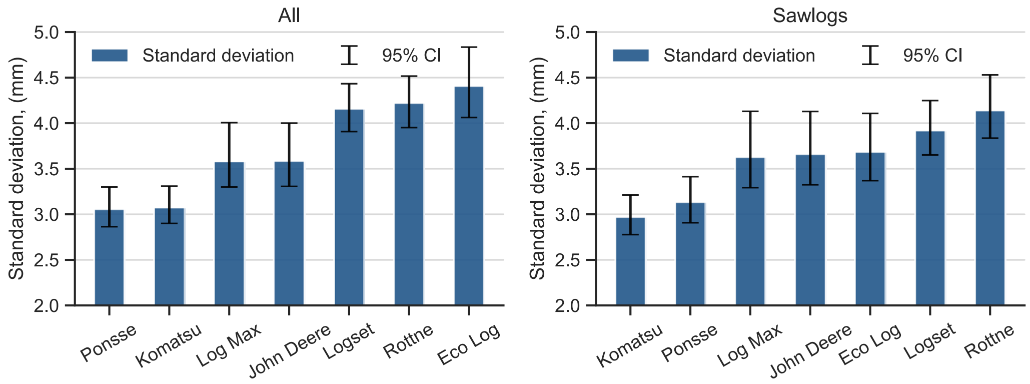


Figure 7. Standard deviations for the diameter measurements. All products on the left and sawlog products on the right. Note that the y-axis is truncated.

The standard deviation reported here is the total standard deviation for all measurement points during the test across all diameter classes. This standard deviation is affected by the calibration of the machines. This is because section calibration shifts the mean values for the different diameter classes individually and thereby affects the dispersion of the total dataset. The standard deviation therefore represents what each machine system achieved during the test, given the calibration settings applied. The results for standard deviations corrected for calibration are shown in Appendix 1 (Corrected standard deviations for diameter measurements). The effect is that, on average, the standard deviation is reduced by 0,23 mm for all products and by 0,18 mm for the sawlog products.

Table 5 shows the results for diameter measurements for all products divided by diameter class, as well as aggregated values for all products and for the sawlog products separately. All diameter measurements can also be found in Appendix 1 (Diameter measurements) for all manufacturers.

Table 5. Mean value, standard deviation, and proportion within ±4 mm for all products divided into diameter classes, together with overall values for all products and for the sawlog products.

Log Max	-100	-200	-300	-400	-500	**All**	**Saw logs**
Mean value (mm)	-3,43	-2,64	-2,93	0,74	-	-2,48	-2,41
Standard deviation (mm)	3,60	3,07	3,06	5,21	-	3,58	3,63
Within ±4 mm (%)	65,7	71,8	68,5	79,7	-	70,5	70,8
Ponsse	-100	-200	-300	-400	-500	All	Saw logs
Mean value (mm)	-0,13	-1,93	-1,42	-2,47	-	-1,67	-1,88
Standard deviation (mm)	2,03	2,64	2,79	4,41	-	3,06	3,13
Within ±4 mm (%)	93,5	84,7	87,2	60,2	-	83,2	82,2
Logset	-100	-200	-300	-400	-500	All	Saw logs
Mean value (mm)	-3,13	-0,39	0,88	2,48	-3,00	0,39	0,71
Standard deviation (mm)	4,53	4,00	3,71	4,35	5,72	4,16	3,92
Within ±4 mm (%)	55,8	77,4	81,5	69,7	66,7	77,0	80,2
John Deere	-100	-200	-300	-400	-500	All	Saw logs
Mean value (mm)	-1,98	-2,40	-1,66	-0,46	-	-1,73	-1,53
Standard deviation (mm)	3,90	2,88	3,27	5,17	-	3,59	3,66
Within ±4 mm (%)	67,4	77,8	78,9	69,2	-	76,5	77,8
Eco Log	-100	-200	-300	-400	-500	All	Saw logs
Mean value (mm)	5,09	0,06	-1,62	0,73	-	-0,22	-0,92
Standard deviation (mm)	5,92	3,28	3,35	5,67	-	4,41	3,69
Within ±4 mm (%)	51,5	87,1	80,0	75,3	-	78,9	81,6
Rottne	-100	-200	-300	-400	-500	All	Saw logs
Mean value (mm)	1,79	2,56	-0,52	-0,83	-6,50	0,48	-0,02
Standard deviation (mm)	4,34	3,96	3,90	3,75	1,80	4,22	4,14
Within ±4 mm (%)	71,2	78,9	79,5	76,0	25,0	77,9	78,4
Komatsu	-100	-200	-300	-400	-500	All	Saw logs
Mean value (mm)	0,23	-0,64	-2,13	-3,41	-	-1,78	-2,06
Standard deviation (mm)	3,07	2,86	2,68	3,55	-	3,08	2,97
Within ±4 mm (%)	87,5	89,2	83,1	69,2	-	82,9	81,9

For the diameter measurements, Komatsu and Ponsse performed best; however, as with the length measurements, it was difficult to demonstrate statistically significant differences. With respect to the proportion of measurements within ±4 mm, only Log Max stood out, and it was also the only manufacturer for which significant differences could be demonstrated relative to the others. This can largely be explained by a calibration error. Regarding the standard deviations, both Ponsse and Komatsu showed significant differences compared with the manufacturers that performed the worst, but otherwise the manufacturers were relatively similar. The results of the hypothesis testing are presented in Appendix 1 (Hypothesis Testing for Diameter Measurements).

The stem ovalities, estimated as the difference between the cross-caliper diameter measurements for the various manufacturers, ranged from 5.2 to 7.2 mm on average during the test, with an overall mean stem ovality of 6.2 mm, compared with an average ovality of 4.7 mm in 2016. However, analysis of the effect of ovality on diameter measurement errors revealed no clear relationship for any manufacturer in this test. Data for all manufacturers is presented in Appendix 1 (Ovality).

Figure 8 compares the results of this test with those from previous tests. In this case, the comparison is based on the sawlog products, consistent with previous years. For the proportion of measurements within ±4 mm, the positive trend has levelled off and reached 79.1%. No significant difference could be demonstrated compared with the 2016 test. For the standard deviations, the favorable trend continues, and the difference relative to 2016 is significant. In this test, the overall standard deviation across all manufacturers was 3.78 mm. These results indicate that the current limiting factor in diameter measurement performance is calibration rather than the measurement capability of the machines themselves. A table containing these values is provided in Appendix 1 (Historical Results).

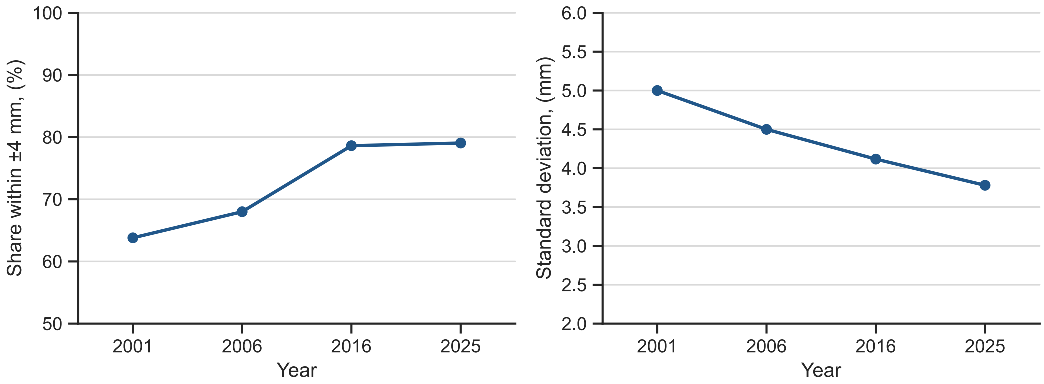


Figure 8. Comparison with results from previous years. The proportion within ±4 mm is shown on the left and the standard deviation on the right. Note that the y-axis does not start at 0.

Calculation of Under-Bark Volume

The harvesters' calculation of log volume is based on measurements of diameter and length. Consequently, the accuracy of the volume estimate depends on the accuracy of the diameter and length measurements. For the calculation of under-bark volume, it is also essential that the correct bark function is applied, ensuring an accurate estimation of bark thickness. In addition, the butt-taper function, which extrapolates the diameter vector from the first diameter measurement down to the felling cut, influences the volume determination of butt logs.

To evaluate the volume calculation, the under-bark volume of all logs from the 30 Norway spruce trees was recalculated as a control. The control calculation used the reference-measured diameter vector (diameter over bark), the correct bark function, and the correct butt-taper function. Any discrepancies between the volume reported by the harvester and the control-calculated volume may therefore be affected by measurement accuracy, the bark function, and the butt-taper function. The results of the control calculation are presented in Table 6 and Figure 9.

Table 6. Total under-bark log volume for logs from the 30 spruce trees according to the harvester's reporting and according to the control calculation, together with the percentage deviation.

	Volume according to harvest (m^3sub)	Volume according to control measurement (m^3sub)	Deviation (%)
Log Max	23,481	23,893	-1,72
Ponsse	24,620	24,863	-0,98
Logset	25,002	23,979	4,27
John Deere	24,846	25,174	-1,30
Eco Log	25,026	25,129	-0,41
Rottne	26,534	26,667	-0,50
Komatsu	27,540	28,116	-2,05

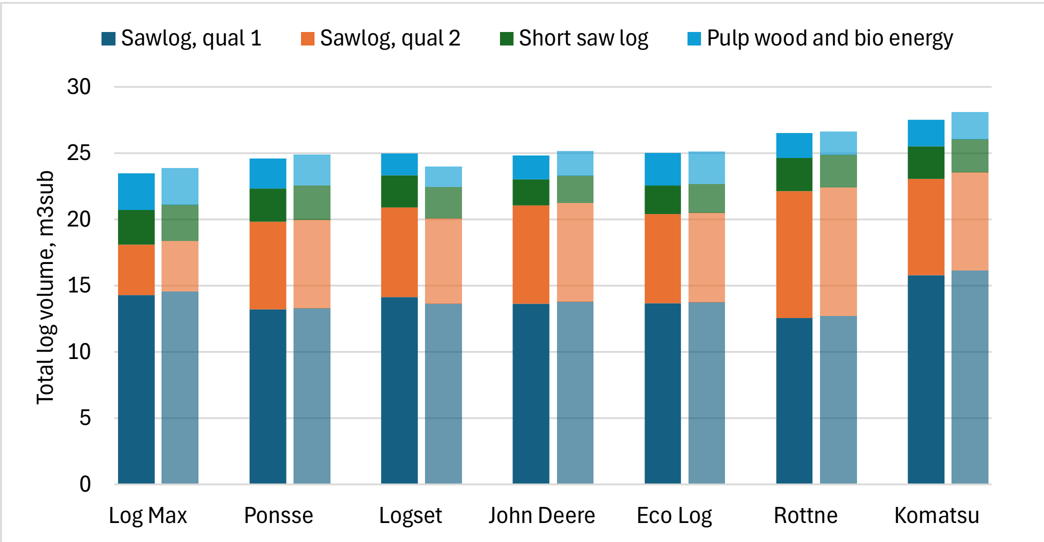


Figure 9. Total under-bark log volume per assortment according to the harvester's reporting (bars on the left) and according to the control calculation (bars on the right).

The largest deviation was observed for Logset, followed by Komatsu and Log Max. The deviation for Logset was attributable to the use of an incorrect bark function, which resulted in a systematic underestimation of bark thickness. The deviations for Log Max and Komatsu were most likely caused by underestimation in diameter measurement: for Log Max, a relatively large overall underestimation of 2.48 mm across all logs, and for Komatsu, a smaller overall underestimation but one that was concentrated among logs in the larger diameter classes (see Table 5). From a geometric perspective, a given diameter error in larger logs results in a greater deviation in total volume than the same diameter error occurring only in smaller logs.

Stem Grasping

There was a strong relationship between the harvesters' predicted standard deviation in length distribution bucking and value optimized bucking (Figure 10). This indicates that the harvesters were ranked very similarly with respect to stem grasping performance during the processing of stems in the distribution bucking test and during the processing of stems in the value optimized bucking test. The exception was Eco Log, which tended to exhibit poorer stem grasping relative to the other manufacturers during distribution bucking than during value optimized bucking.

Furthermore, the relationship between stem grasping performance in distribution bucking and value optimized bucking indicated that, for a given tree size, the predicted standard deviation was slightly lower during value optimized bucking than during length distribution bucking. This was most likely due to the lower processing speed during value optimized bucking compared with distribution bucking, which was conducted at a normal production rate. However, the difference was small, amounting to 0.3 mm across all manufacturers.

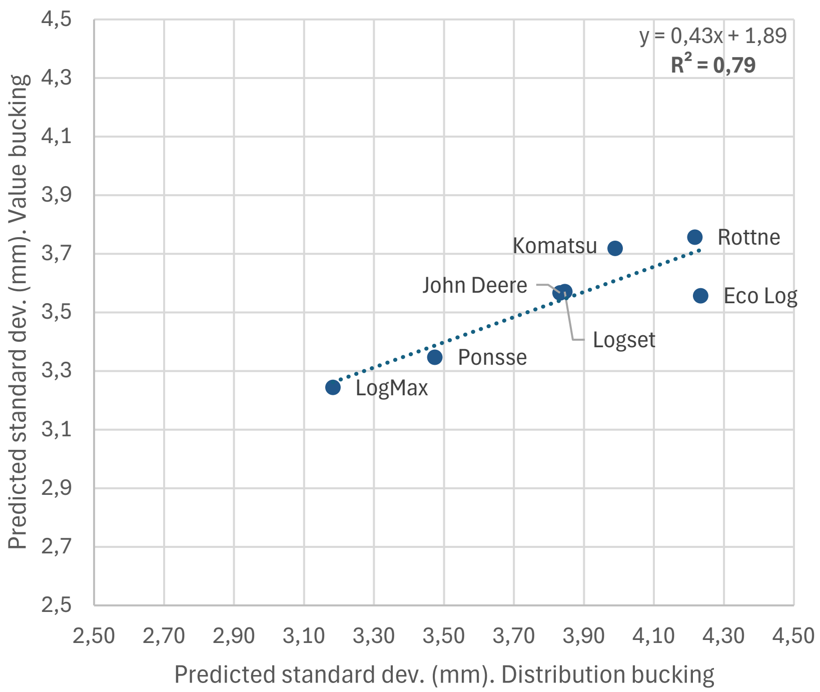


Figure 10. Relationship between the predicted standard deviation during processing of stems from length distribution bucking and value optimized bucking.

Figure 11 presents a comparison between the harvesters' predicted standard deviation during the processing of stems in the value optimized bucking test and the standard deviation obtained from the manual control measurement of the corresponding stems. The two measures of harvester diameter-measurement precision produced an identical ranking of the harvesters for Rottne, Logset, Eco Log, John Deere, and Ponsse. The exception was Komatsu, for which the predicted standard deviation indicated a higher level of variability than was actually observed in the manual control measurements.

Data for Log Max was excluded from the comparison, as the stem-grasping model was developed for harvester heads equipped with diameter measurement in the upper delimbing knives.

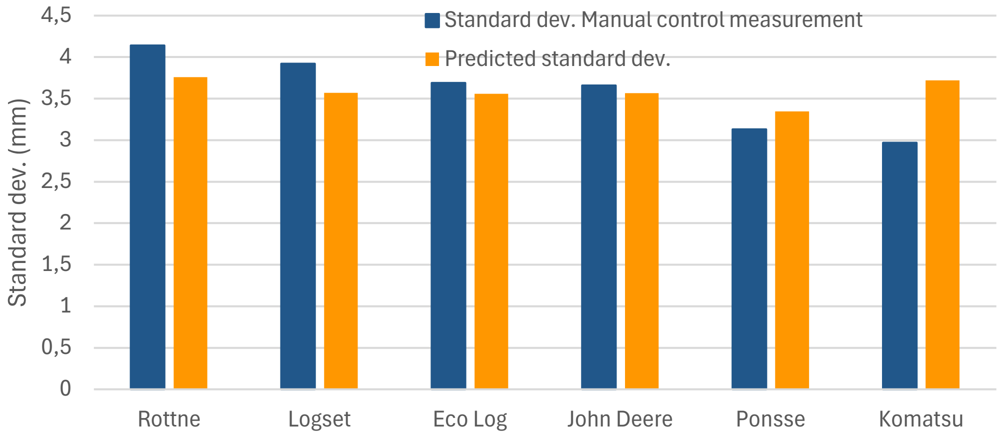


Figure 11. Comparison between the predicted standard deviation for stems processed by value optimized bucking and the standard deviation from the manual control measurement of the corresponding stems.

Study 2: Bucking control

Objective

This study aimed to evaluate the machine systems' control of bucking with respect to

- bucking quality: primarily the timber value achieved from value-optimized bucking, the distribution degree achieved in distribution bucking, and the top diameters achieved at the final cutting point;
- compliance with bucking instructions, including restrictions related to stem quality and log type, restriction matrices, and sound knot bucking; and
- the possibility of updating control settings during ongoing production.

Material and methods

The data collection was conducted in three steps as shown in Table 7. Skogforsk provided bucking instructions (oin, spi and pin files), which were loaded into the machine systems via a USB stick before and during each step. The program Timan 5.0 (Skogforsk, Timan) was used to prepare bucking instructions, and the program SilviA (CGI, beta version 2025.3.0) was used to create files with different versions of StanForD 2010.

Table 7. The set-up of the collection of harvested production data (hpr) and quality control data (hqc).

Step	Evaluation	Implementation
Step 1	Value-optimized bucking and compliance with bucking instructions	Value-optimized bucking of 30 Norway spruce and 10 Scots pine stems of different stem grades (stem grades registered manually). Manual control measurements of all spruce stems, including top lengths up to a 50-mm diameter.
Step 2	Updating of control settings	Processing of a number of stems to record the results of successive updates to pin, oin, and spi. In addition, for use in Study 3, single and multi-tree felling and multi-tree processing of a number of stems/bundles and registering of some stem codes.
Step 3	Distribution bucking and handling of tops	Distribution bucking of a large number of stems until reaching 500 spruce timber logs. In addition, for use in Study 3, quality control of some control stems (also rejected control stems), registering of stem codes and registering of reasons for machine downtime.

Product instructions

Product instructions (pin) used during the tests were based on Stora Enso's normal product instructions. Some modifications were made to ensure that all aspects of the bucking that were to be evaluated would be covered. For example, some length classes for sawlog products were added. A summary of products used is provided in Table 8 and Table 9, and details of the product instructions are given in Appendix 2.

For the value-optimized bucking (Step 1), price matrices for the sawlog products were generated using Timan's Autopris tool (Engberg Sundström et al. 2025), which automatically generates price matrices based on a desired length distribution. For the distribution bucking (Steg 3), price matrices with the same price in each cell were used. For all sawlog products, the cutting window was 2–3 cm.

During Step 2, an updated product instruction was loaded via USB. The updated pin contained a new price matrix for one of the products in Step 1.

Table 8. Product instructions used during the test of value-optmized bucking (Step 1). The table shows, for each product, key aspects of the product matrices, accepted stem grades, and log type restrictions.

Tree species	Product	Matrices	Grades	Restrictions
Spruce	Sawlogs qual 1	Six length classes, of which one forbidden. Price matrix that prioritizes three length classes.	1	
	Sawlogs qual 2	Six length classes, of which one forbidden. Price matrix that prioritizes three length classes.	1-2	
	Short sawlogs		1-2	
	Spruce pulpwood	See Pulpwood in Table 9.	1-6	
	Coniferous pulpwood	See Pulpwood in Table 9.	1-7	
	Bioenergy		1-8	
Pine	Sawlogs qual 1		1	Buttlogs only
	Sawlogs qual 2		2	No buttlogs
	Sawlogs qual 3		1-3	
	Sawlogs qual 4		1-4	
	Short sawlogs		1-4	
	Pulpwood		1-7	

Table 9. Product instructions used during the test of distribution bucking (Step 3).

Tree species	Product	Matrices
Spruce	Sawlogs qual 1-2	Six length classes, of which one forbidden. Homogeneous price matrix. Volume-based length distribution that prioritizes three lengths. Max. allowed deviation from optimal bucking value 6 %. Smallest diameter class 180 mm.
	Short sawlogs	One length class. Smallest diameter class 130 mm.
	Pulpwood	TopLogFreeBuck activated. Length classes at 30-cm intervals between 300-510 cm. Volume-based length distribution that prioritizes three lenghts, with one being highly prioritized. Max. allowed deviation from optimal bucking value 5 %. Smallest diameter class 30 mm. Smallest diameter class with automatic cuts allowed 50 mm. Homogeneous price matrix, however with substantially lower prices in smallest diameter classes (for evaluation of TopLogFreeBuck functionality).
	Bioenergy	

Species group instructions

The species group instructions (spi) followed the Swedish recommendation (StanForD, Skogforsk), implying, for example, that Skogforsk's bark functions were used. The starting qualities were 1 and 3 for Norway spruce and Scots pine, respectively. Automatic detection of sound knot quality (grade 2) was also activated for Scots pine.

During Step 2, an updated species group instruction was loaded via USB. The updated spi contained new stem codes for one of the tree species.

Object instructions

An object instruction (oin) contains product identities for the products to be produced on a given object, and otherwise no information critical to the conduct of the test. Steps 1-3 were treated as separate objects and therefore had their own object instruction.

During Step 2, updating the object instruction was tested. The updated oin contained additional products.

Selection of stems and stem qualities

To enable comparison of the machine systems' performance, similar sets of 30 Norway spruce stems were required for the value-optimized bucking in Step 1. Therefore, an active selection of spruce stems was made before harvesting. The criteria were that the spruce stems should be free from stem defects or damage and have a distribution of diameters at breast height (DBH) according to Table 10.

Apart from the 30 spruce stems harvested in Step 1, no detailed stem selection was made.

Table 10. The target DBH distribution of the 30 spruce stems, and the DBH distribution obtained for each machine system.

DBH (cm)	< 25	25–30	30–35	> 35
Target (number of stems)	2	9	12	7
Log Max	3	11	13	3
Ponsse	2	10	11	7
Logset	0	8	18	4
John Deere	1	8	14	7
Eco Log	1	10	11	8
Rottne	1	9	15	5
Komatsu	0	9	14	7

During the value-optimized bucking test, the machine operator was instructed to make manual registrations of stem quality as described below, in order to test the machine systems' quality-dependent bucking functionality. The machine systems were configured so that the manual changes in stem quality were registered at the current position of the delimbing knives (that is, not at the previous or next cut, as is often default). In all cases where two qualities were used, the change was made after approximately 2 metres of feeding from the felling cut.

For approximately 15 spruce stems, no manual registration was made, in which case the starting quality according to the species group instruction (quality 1) was expected to be registered for the entire stem. For approximately five spruce stems, quality 2 was registered for the entire stem. For approximately five spruce stems, two qualities were registered: a lower quality in the butt end (qualities 2, 6, 7 and 8), followed by quality 1. In addition, the machine operator was instructed to manually shorten one sawlog for a couple of spruce stems.

For four Scots pine stems, no manual registration was made, in which case the starting quality according to the species group instruction (quality 3) was expected to be registered for the entire stem or, if supported by the machine system, automatically changed to sound-knot quality (quality 2) at the calculated diameter. For the remaining five pine stems, starting qualities 1 and 4 were registered (again with an expected automatic change to sound-knot quality at the calculated diameter). For machine systems without automatic registration of sound-knot quality, starting quality 2 was registered for one pine stem.

During distribution bucking, no manual registration of stem quality was made.

Evaluation methods

The analyses in the study were based primarily on production data (hpr) and quality-control data (hqc).

Support for bucking functions was reported by the machine manufacturers via questionnaires, and compliance with supported bucking functions was assessed by analyzing production data. In addition to commercially available editors for xml files, the programs Timan, hprAnalys and Virkesvärde are useful for such analyses.

To calculate the total timber value from production data, Timan's follow-up tool Aptupp was used. Aptupp calculates the timber value achieved by the harvester, then performs a bucking simulation of the same stems and calculates the simulated timber value. The simulated timber value is regarded as the theoretical maximum value, since the stem profiles are known during simulation (while harvesters are only aware of an estimated stem profile upon making the bucking decisions). The so-called *bucking degree* is defined as the timber value achieved by the harvester divided by the theoretical maximum value and is used as an indication of the performance of the harvester's bucking optimization. The analysis in Aptupp was carried out on stem profiles based on both harvester measurement (hqc-M1) and manual control measurement (hqc-M2), the latter including manual measurements of the top. Appendix 3 gives a description of how differences between the machine systems in how the stem profile is registered in production data, as well as stems with top breakage, were handled in the analysis.

To calculate the distribution degree, the program hprAnalys was used. What distribution degree is achievable depends on the stand characteristics, particularly the stem sizes (average DBH). Therefore, a reference value was calculated and used as baseline in the evaluation. The reference value is the distribution degree achieved from bucking simulation of the same stems using Timan's simulation tool Aptan. In the evaluation, it is the difference of the distribution degree to the reference value that is of interest.

Production data were used to analyze top diameters at the final cut.

The possibility of updating bucking instructions during ongoing harvesting was recorded manually at the time of testing.

Results and discussion

Support for and compliance with bucking functions

Table 11 presents the machine systems' compliance with basic and specific bucking functions during the test, based on analysis of production data.

Table 11. Compliance with bucking functions. The table indicates if the bucking function works as expected and/or follows the StanForD 2010 rules (Ok), if the function is unsatisfactory (U), or if the funciton is not supported (–).

	Rottne, Eco Log (Dasa)	Ponsse	John Deere	Komatsu	Log Max	Logset
Value optimized bucking	Ok	Ok	Ok	Ok	Ok	Ok
Length distribution bucking	Ok	Ok	Ok	Ok	Ok	U
Free cut on top log incl. minimum diameter search (TopLogFreeBuck)	Ok	Ok	Ok	Ok	Ok	–
Free cut on all other logs	Ok	Ok	Ok	Ok	Ok	Ok
Stem quality restrictions	Ok	Ok	Ok	Ok	Ok	Ok
Log type restrictions	Ok	Ok	Ok	Ok	Ok	Ok
Restriction matrices with forbidden lengths	Ok	Ok	Ok	Ok	Ok	Ok
Automatic sound-knot bucking	Ok*	–	Ok*	Ok*	–	–
Skogforsk's bark functions	Ok*	Ok	Ok	Ok	Ok	U
Butt end extrapolation (ButtEndProfileExtrapolation)	Ok	Ok	Ok	Ok	Ok	Ok*

*See comments in the running text.

Bucking with stem quality and logtype restrictions, as well as restriction matrices with prohibited lengths, are correctly implemented in all machine systems. For Log Max and Logset, there were occasional automatic cuts of logs in lengths classes where only manual cuts were allowed. However, since this involved only a few logs (only 1–3 pulpwood logs during the distribution bucking test), it is not considered a serious issue.

Sound-knot bucking is implemented in the Rottne, Eco Log, John Deere and Komatsu systems. However, it is not activated automatically through the instruction in the spi file but requires manual activation in the machine. In particular, the setting defining from which qualities automatic change to sound-knot quality is permitted requires manual input.

Butt end extrapolation functions are correctly implemented in all machine systems. Applying the function means that the diameter below the stem height of 130 cm (from felling cut) is extrapolated in a standardized way, according to the ButtEndProfileExtrapolation instruction in the spi file. All machine systems except Logset record which butt end extrapolation function is used in both hpr and hqc data.

Skogforsk's bark functions (Hannrup 2004) for Scots pine and Norway spruce are implemented in all machine systems. In StanForD 2010 version 4.1, the spi file may contain multiple selectable bark functions per tree species and the selection is controlled in the oin file, i.e., different objects may use different bark functions. This is correctly implemented by the machine systems that support version 4.1 – Rottne, Eco Log, and

John Deere. Rottne and Eco Log also support Skogforsk's new bark function for birch (Hannrup et al. 2020, Hannrup et al. 2022), which was also enabled in StanForD 2010 version 4.1.

Logset underestimated spruce bark thickness by approximately 4.5 mm. Logset has not been able to explain this deviation. For Ponsse, bark thickness was underestimated by approximately 0.5 mm, which was explained by rounding by truncation of bark thickness to whole millimetres instead of normal rounding. The error has been noted by Ponsse and will be corrected.

Bucking quality – Value optimized bucking

Figure 12 presents bucking degrees based on harvester-measured and manually control-measured length and diameter data from value-optimized bucking of 30 spruce stems. The bucking degree indicates how well the harvester's bucking captures the theoretical maximum timber value (100 percent in the figure) achieved by Aptupp's bucking simulation of the same stems.

Some deviation from the theoretical maximum timber value is expected and has primarily two causes. One reason is that the harvester's bucking optimization is based on a prediction of the stem taper – the stem profile is known to the harvester only from the felling cut up to the current position of the harvester head – which means that the harvester's bucking computer may make a different bucking decision than the theoretically optimal. Another reason is that the harvester's length and diameter measurements include measurement errors, which will affect the bucking degree when based on control-measured data. For example, sawlogs that prove to be too small in diameter or too short, and therefore must be rejected (that is, are assigned a reject price that is substantially lower than the sawlog price; here the pulpwood price has been used as the reject price) will reduce the bucking degree.

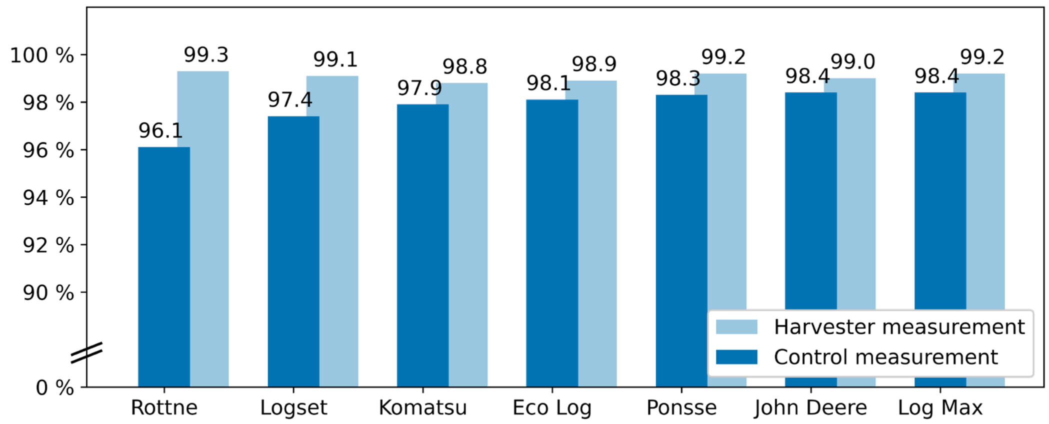


Figure 12. Bucking degrees based on harvester-measured and manually control-measured length and diameter data from the value bucking of 30 spruce trees. One hundred percent corresponds to the theoretical maximum timber value achieved when stem profiles are completely known. Note that the y-axis is broken.

The bucking degree based on harvester-measured length and diameter data varied between 98.8 and 99.3 percent, averaging 99.1 percent. This is 0.3 percentage points higher than the average achieved during the wood value trials in 2016. The high bucking degrees show that the bucking optimization functions well in all machine systems, owing to accurate stem profile predictions and well-functioning value optimization.

The bucking degree based on control-measured length and diameter data varied between 96.1 and 98.4 percent, averaging 97.8 percent. This is 0.5 percentage points higher than in 2016. When the evaluation is based on control measurements instead of harvester measurements, the bucking degree generally decreases, because logs may then have to be rejected due to undesirable length or diameter. The relatively large drop in bucking degree for Rottne is a direct consequence of Rottne's relatively large measurement errors, which were partly due to calibration issues caused by a dramatic change in temperature during the test (see Study 1). This clearly shows the importance of high accuracy in the harvester's length and diameter measurement, as well as the importance of calibration, in order to achieve close to maximum timber values. For Logset, the bucking degree analysis was complicated by unexpected registration of stem quality in production data, leading to the exclusion of two of the 30 spruce stems in the Logset dataset. This makes the evaluation for Logset uncertain. Regarding Logset's previously mentioned incorrect bark function, this was compensated for in the analysis, so that Logset's bucking degrees are not affected by underestimated bark thickness.

Figure 13 presents total log volume by assortment according to control measurement of the harvester's bucking, as well as according to the theoretically optimal bucking from Aptupp's bucking simulation of the same stems. For Rottne and Komatsu, the control-measured sawlog volume is visibly lower than the theoretical optimum, as a result of rejected logs. This explains the slightly lower bucking degrees of 96.1 and 97.9 percent achieved by these machines (Figure 12).

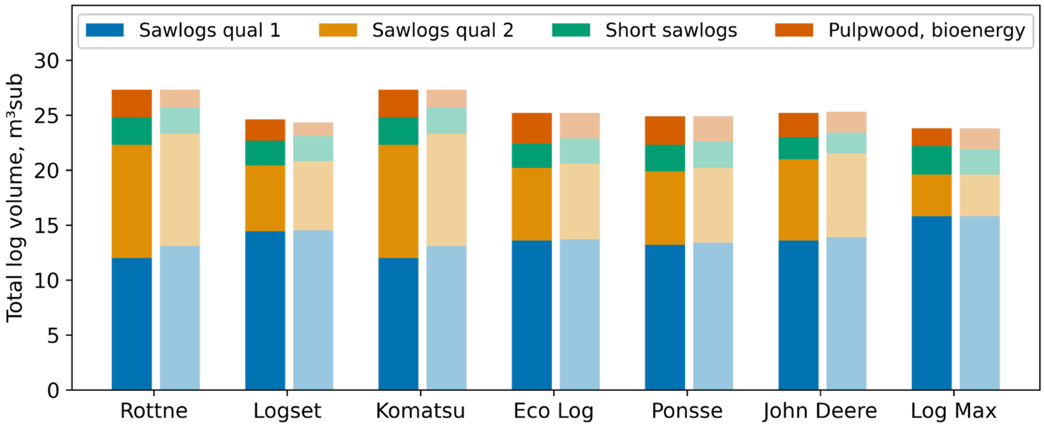


Figure 13. Total under-bark log volume by assortment according to the control measurements from the value bucking of 30 spruce stems (left bars) and according to Aptupp's bucking simulation of the same stems (right bars).

Figure 14 presents the average bucking degrees from the current and previous wood value trials. When comparing with previous results, it should be taken into consideration that the bucking degree can be affected by the product instructions used. In particular, the valuation of assortments relative to one another can make comparisons difficult, since in the wood value trials, this valuation has followed the market price, which varies over time.

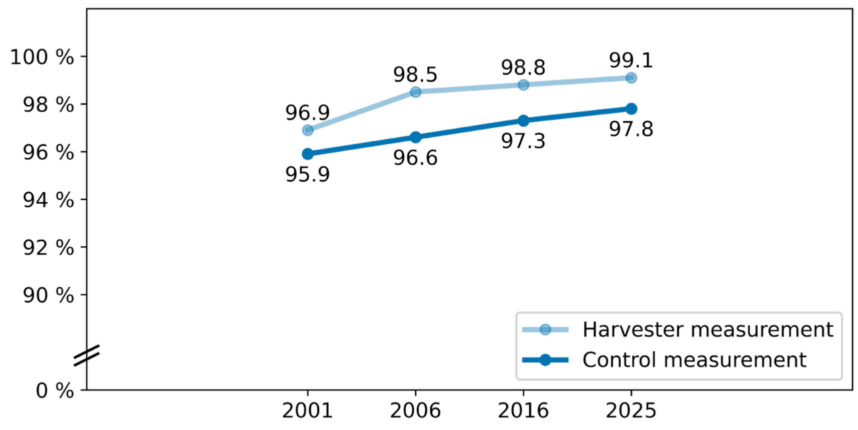


Figure 14. Bucking degrees (average over all machine systems) from the current and previous wood value trials. Note the broken y-axis.

Table 12 shows which method is used by the bucking computers to make a stem profile prediction. All bucking computers except Logset's use so-called adaptive stem prediction, which means that the taper of previously harvested trees is utilized (i.e., the prediction adapts to the forest). Adaptive stem predictions are expected to be more accurate, as is a stem prediction with a high update frequency.

Table 12. Method used for the stem prediction function in the bucking computer, according to information provided by the respective machine manufacturers.

	Rottne Eco Log (Dasa)	Ponsse	John Deere	Komatsu	Log Max	Logset
Method for stem taper prognosis	Adaptive	Adaptive	Adaptive	Adaptive	Adaptive	Not adaptive
Length of prognosis	Min. 20 m	Whole stem	Whole stem	Whole stem	Whole stem	12 m
Frequency of prognosis updates	6 Hz	10 Hz	When measurement and prognosis deviates	When measurement and prognosis deviates and for each log cut	10 Hz	When measurement and prognosis deviates

Bucking quality – Distribution bucking

Figure 15 presents distribution degrees for spruce sawlogs achieved with the harvester after distribution bucking of 500 sawlogs, together with a reference value. The distribution degree measures how closely the resulting distribution of log lengths corresponds to the desired length distribution, where a value of 100 indicates an exact match. The reference value is the distribution degree achieved with Aptan in a bucking simulation of the same stems. When evaluating and comparing machine systems, it is the distribution degree relative to the reference value that is of interest, since what can be achieved is partly determined by stand characteristics. In general, higher distribution degrees can be achieved in larger-diameter stands. Figure 16 presents the achieved and desired length distributions.

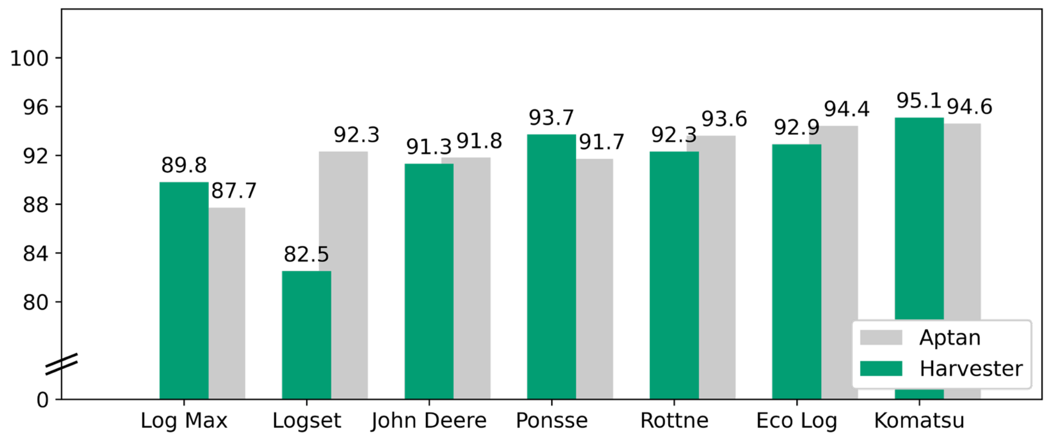


Figure 15. Distribution degrees achieved by harvesters during the distribution bucking of 500 sawlogs and, for reference, the distribution degrees achieved by the Aptan bucking simulator when simulating the same stems. When comparing machine systems, it is the difference to the reference value that is of interest, since the achievable outcome is partly determined by the characteristics of the specific forest being harvested. Note the broken y-axis.

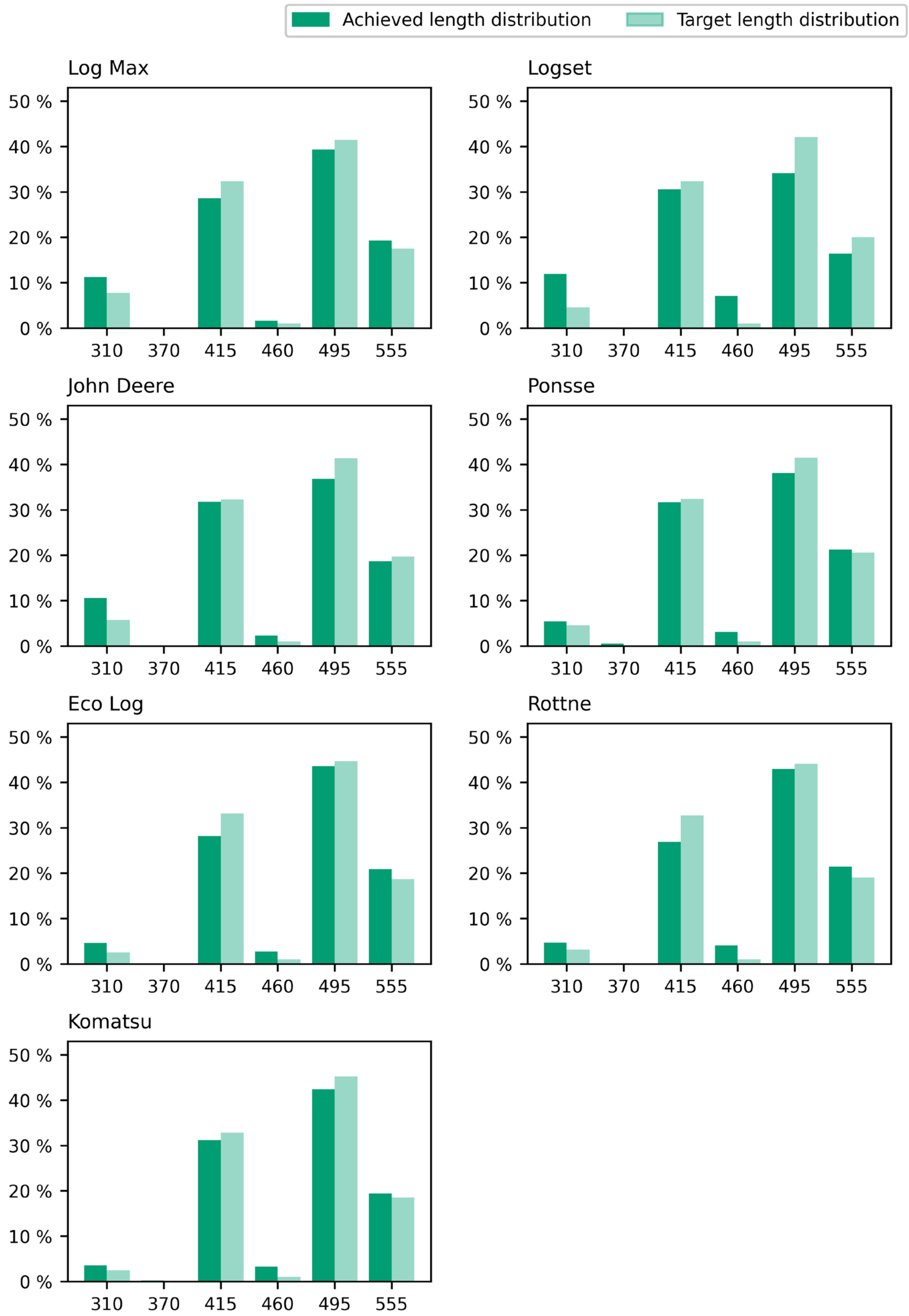


Figure 16. Achieved and target volume proportions (y-axis) by length class for spruce sawlogs (x-axis, cm) during the distribution bucking of 500 sawlogs.

Table 13 presents other key figures from the distribution bucking, including mean stem volume. The stand with, by far, smallest mean stem value was harvested by Log Max, which explains why Log Max achieved a lower distribution degree than the other systems (in line with the reference value for Log Max' stems). The table also shows the sawlog proportion (proportion of sawlogs of total harvested volume). When using distribution bucking to promote a specific length distribution, it is desirable that the sawlog proportion is not affected more than necessary. Again, it is the sawlog proportion relative to a reference value that is of interest. The reference value is the sawlog proportion achieved with Aptan.

The overall results are that both distribution degrees and sawlog proportions are at a level comparable to the reference value for all machine systems except Logset, whose distribution degree deviates from the reference value. The indication is that Logset's distribution bucking optimization can be improved. For the other machine systems, the distribution bucking performs well and works as expected.

The proportion of manual cuts of sawlogs during distribution bucking, also shown in Table 13, is historically low for a wood value trial. In general, fewer manual cuts result in better length distribution. Swedish forestry has worked actively to reduce manual cuts and thereby increase the distribution degree (and also the bucking degree). This ambition is reflected in the results from the current tests.

Table 13. Results of the distribution bucking of 500 sawlogs. Sawlogs refer only to normal sawlogs and do not include short sawlogs.

	Log Max	Logset	John Deere	Ponsse	Rottne	Eco Log	Komatsu
Number of harvested stems (pcs)	435	208	283	211	173	161	165
Mean stem volume (m^3sub)	0,361	0,658	0,504	0,669	0,885	1,007	0,998
No of sawlogs (pcs)	501	505	509	505	500	501	510
Proportion of manual cuts (%)	0,0	3,6	0,2	0,0	0,2	0,2	0,4
Proportion of sawlogs (%)	58,6	78,3	70,8	79,8	85,8	88,1	89,6
Proportion of sawlogs, difference to Aptan (%)	-1,4	1,6	-2,0	-1,2	0,6	0,1	0,7
Degree of length distribution (%)	89,8	82,5	91,3	93,7	92,3	92,9	95,1
Degree of length distribution, difference to Aptan (%)	2,1	-9,8	-0,5	2,0	-1,3	-1,5	0,5

Bucking quality – Handling of tops

Good handling of tops has only a marginal effect on the bucking degree. This is because the volume of top logs is relatively small and, in addition, has a relatively low price (normally pulpwood price). At the same time, there is an ambition in Swedish forestry to maximize the utilization of the stem volume by ensuring that the final log is cut at as small a diameter as possible. This has been facilitated by the bucking function for minimum-diameter search (TopLogFreeBuck).

According to StanForD 2010, the intention of minimum-diameter search is that the final cut on a stem should automatically be made at the smallest permitted diameter, or at the longest permitted length for the current product. The final cut should therefore not be controlled by what would be optimal according to value or distribution bucking. An important aspect is also that previous cuts should not be affected.

Figure 17 shows the length and diameters of all pulpwood logs that were cut during the test of distribution bucking. With TopLogFreeBuck, automatic final cuts are expected to occur in the smallest diameter class 50 mm (the 30 mm diameter class was permitted only for manual cuts), whereas larger automatic final cuts are expected to have been made at the longest permitted log length 560 cm. Other cuts should, according to the product instructions used, have been subjected to distribution bucking towards the desired length distribution, which during the test prioritized the lengths 420, 450 and 480 cm. This means that automatic final cuts are expected to appear in the blue, L-shaped area in the graphs, whereas other cuts are expected to be concentrated in the green area.

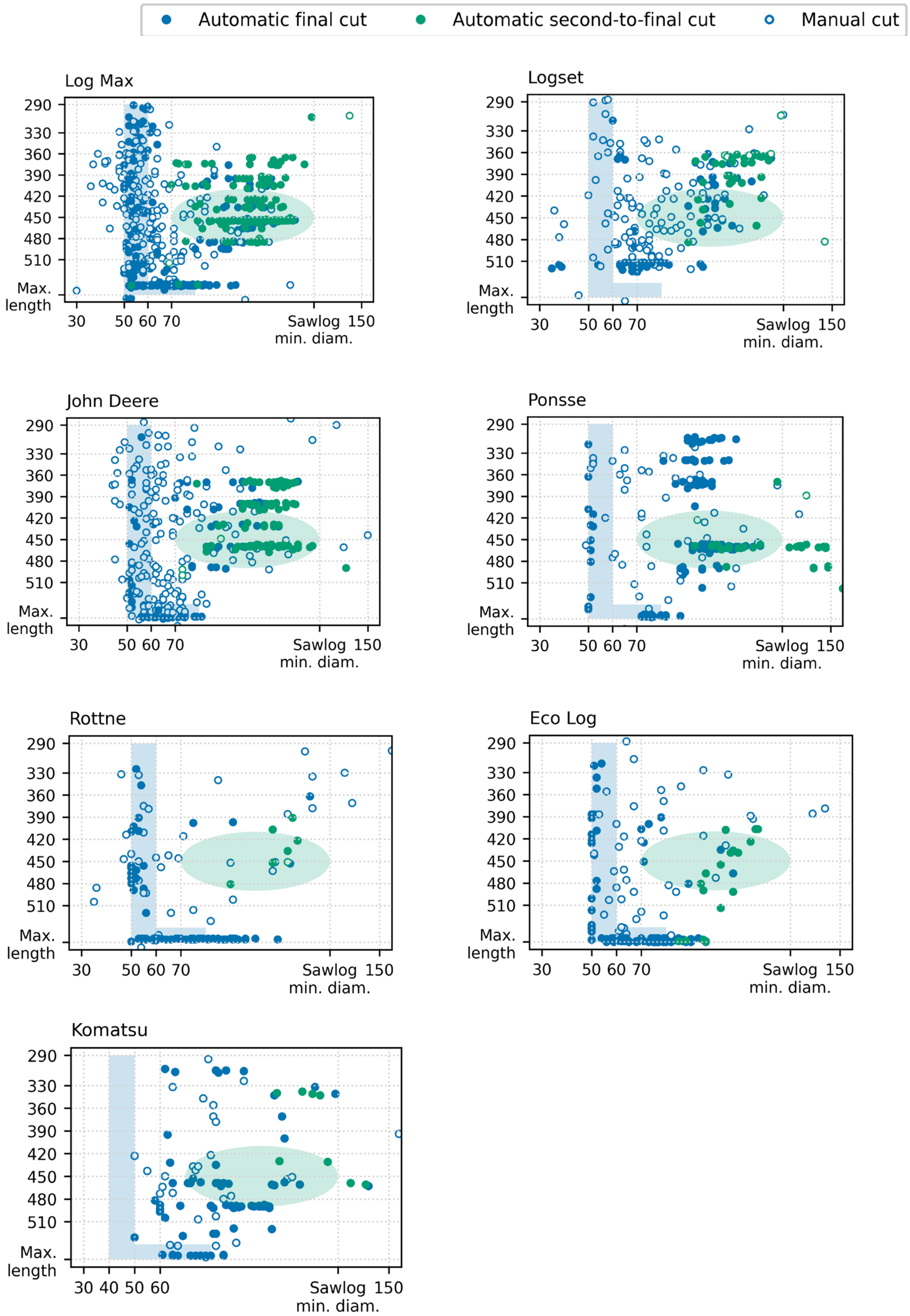


Figure 17. Log dimensions of pulpwood harvested during the distribution bucking test. Markings on the x- and y-axes indicate diameter (mm) and length (cm) classes*, as well as the smallest allowed diameter for short sawlogs (130 mm) and the maximum permitted length (560 cm). TopLogFreeBuck is expected to result in automatic final cuts in the blue L-shaped area, whereas distribution bucking is expected to result in second-to-final cuts primarily in the green area.

*For Komatsu, diameter classes differed slightly from those used for the other systems. This is not considered to have affected the results.

For all machine systems that support TopLogFreeBuck (all except Logset), the graphs confirm that the function works as expected. However, there are mainly automatic final cuts at the longest permitted length (the horizontal part of the L-shaped area). For Log Max, John Deere, Ponsse, Rottne and Eco Log, there are some automatic final cuts in the smallest diameter class (the vertical part of the L-shaped area), but for Komatsu, there are no final cuts in the smallest diameter class. However, Komatsu has shown in previous tests that TopLogFreeBuck works well in their control system (Nordström et al. 2018). It is worth noting that for Log Max and John Deere, the manual cuts follow the expected pattern for automatic cuts resulting from TopLogFreeBuck.

Table 14 provides key figures for the handling of tops. With regard to maximizing the utilization of the stem volume by aiming for final cuts with smallest possible top diameters, Rottne performs best. For Rottne, 37.1 percent of automatic final cuts are smaller than 60 mm in top diameter, followed by Log Max and Eco Log with around 30 percent; all three with a mean top diameter of around 70 mm. For Ponsse and Komatsu in particular, a large number of logs with diameters expected for a second-to-final cut (around 100 mm) have been registered as the final log, resulting in high mean values for top diameter. It cannot be ruled out that this is partly due to external circumstances, such as top breakage.

Table 14 also gives the distribution degree for pulpwood logs in the 70 mm diameter class (both automatically and manually cut, but excluding logs around the longest permitted length). Ponsse performs best, with a distribution degree of 82.3, followed by Log Max with a distribution degree of 74.8. Rottne and Eco Log have low distribution degrees, which is probably an effect of a very small dataset for distribution bucking of pulpwood (only 19 and 38 pulpwood logs, respectively) – a consequence of the forest harvested by these machine systems with a larger mean stem volume.

Both minimum-diameter search and distribution bucking of pulpwood are improved by an accurate prediction of taper in the tops. The strongly varying tree sizes (see mean stem volume in Table 13) may have created different conditions for the machine systems to make an accurate stem profile prediction. In general, large-diameter trees have more rapid and therefore more difficult-to-capture taper in the top than small-diameter stems. In addition, larger trees more often have larger branches in the crown, which can impair stem holding and diameter measurement. During the test, the part of the stand with largest trees was harvested by Rottne, Eco Log and Komatsu, whereas Log Max harvested by far the smallest-diameter part of the stand.

In summary, all machine systems have potential for improvement regarding handling of tops. One possible objective for forestry is that both the mean and median values for top diameters at final cuts should be below 60 mm. Achieving this goal will require both improved logic and improved length and diameter measurement. The results of the tests motivate continued attention to how the tops are handled by harvesters.

Table 14. Results of top-end handling during the distribution bucking of 500 sawlogs.

	Log Max	Logset	John Deere	Ponsse	Rottne	Eco Log	Komatsu
No. of harvested pulp wood logs* (pcs)	574	221	357	219	141	157	115
of which were manually cut (%)	27,8	59,7	51,3	23,0	32,1	28,8	25,7
No. of automatically cut last pulp wood logs* (pcs)	252	67	81	136	89	94	76
Of which smaller diameter than 60 mm (%)	32,9	6,0	21,0	9,6	37,1	29,8	2,6
Top diameter for automatically cut last pulp wood logs*, average (mm)	68,1	78,5	70,9	88,3	70,6	70,2	82,4
No. of logs in diameter class 70 mm** (pcs)	254	135	162	131	19	38	78
Distribution degree for logs in diameter class 70 mm**	74,8	38,4	59,0	82,3	35,9	44,7	60,7

*Also bioenergy.

**Only spruce pulpwood. Only logs shorter than 520 cm. Both automatically and manually cut logs.

Possibility of updating control settings

Table 15 presents the machine systems' ability to read and update bucking instructions during ongoing production. The possibility of easily updating the bucking instruction was one of the cornerstones in the development of StanForD 2010, since this had only been possible through a complex procedure in the older version of StanForD.

The need to update the object instruction (oin) concerns the ability to change the products being bucked during harvesting on an object. One example may be when the total sawlog volume harvested for a particular sawmill exceeds demand, so that sawlogs should instead be harvested for another sawmill. The need to update a product instruction (pin) arises when changes occur in the market demand for a product, for example its length distribution. The possibility of updating during ongoing harvesting enables such changes to take effect more rapidly. Regarding the tree-species instruction (spi), the need for easy updating has so far been limited. Updates have rarely or never been made after an spi file has been loaded during the machine's initial start-up. However, as the use of stem codes has now gained momentum, the need to be able to update the tree-species instruction easily is also increasing.

Table 15. Possibility to read and update bucking instructions before and during production. In the table whether the functionality is supported or works according to expectation (Ok) or if its not supported (–).

	Rottne, Eco Log (Dasa)	Ponsse	John Deere	Komatsu	Log Max	Logset
Read oin, pin, spi	Ok	Ok	Ok	Ok	Ok	Ok
Start object with env-package with oin, pin, spi	Ok	Ok	Ok	Ok	Ok	Ok
Start object with only oin (pin and spi read from database)	Ok	Ok	Ok	Ok	Ok	Ok
Update pin during production	Ok	Ok	Ok	Ok	Ok	Ok
Update oin during production	Ok	Ok*	Ok*	Ok	Ok	–
Update spi during production	Ok	Ok*	Ok*	Ok	Ok	–
Keep quality setting after updating pin	–	Ok	Ok	Ok	Ok	–
Keep color setting after updating pin	Ok	Ok	Ok	Ok	Ok	–
modificationRestricted implemented	Ok	Ok	Ok	Ok	Ok	Ok

*Not functioning during field tests, but the function was subsequently confirmed in a simulated environment and/or otherwise certified by the machine manufacturer.

For all machine systems except Logset, it was possible to update pin, oin and spi during ongoing production. For Logset, it was possible to update pin, but updates of oin and spi would require starting a new object. However, several machine systems would need to make it easier for users to put an updated spi file into use. The user interfaces are not perceived as adapted for easy updating of spi in the same way as for pin and oin.

Study 3: Other core functions in StanForD 2010

Objective

The objective of the study was to evaluate and map how harvester computers handle several core functions in the standard for communication with forest machines, StanForD 2010, that were not directly tested in Study 2.

Materials and methods

Questionnaire

In addition to the functions tested in the field, all manufacturers received a questionnaire with supplementary questions regarding functionality in their systems. After these questionnaires had been answered, the responsible staff at Skogforsk reviewed the responses first individually and then together with each manufacturer's working group for the tests, to ensure that questions and responses were interpreted consistently. The responses were then compiled in the tables included in the report, and comments were added where needed for clarification.

Results and discussion

StanForD version 4.1

Three different harvesters with support for version 4.1 participated in the test: Rottne, Eco Log and John Deere. Most control systems plan to introduce support for 4.1 during 2026, except Logset and Ponsse, which plan to do so in 2027. Dasa will support all Forester systems, John Deere the G and H series, Ponsse systems manufactured after 2022 (5G and newer 4G), Log Max Logmate systems manufactured after 2017 (510), and Komatsu MaxiXT, while Logset has not made a decision on the matter (Table 2).

Production reporting

Production can be stored in hpr format by all systems. In Table 16, a summary of possible production reporting in hpr is presented. All systems can also include the diameter vector, where diameter is reported per 10 cm and represents the smallest recorded value. In comparison between the reported log volume and a volume calculated from the diameter vector, the systematic error never exceeded +/-0,5 percent.

All systems had implemented the ability to register cutting reason (CuttingReason). Dasa, John Deere, Komatsu and Logset have implemented a list of cutting reasons, whereas Ponsse and Log Max distinguish only between manual and automatic cuts.

Multi-tree felling and multi-tree processing can be registered in all systems. Registration of felled stems requires activation in all systems except Log Max. Most systems could also register single-tree felling; however, Logset registered single tree felled stems as multi-tree felled, with one stem per bunch.

All systems except Logset can register the element for bioenergy adaptation per stem.

All systems can register stem codes, but during the practical tests Log Max and Logset did not report stem codes. Many of the systems also support the “sticky” stem-code function. A sticky stem-code function means that the same stem code can be registered on several consecutive stems without a new button press. Sticky stem codes can, among other things, facilitate the operator’s work when harvesting in, for example, storm-damaged forest. Komatsu did not have this function during the test but has subsequently implemented it in its system, and the function will be available from 1 June 2026. Log Max also did not support this function during the test but implemented it during spring 2026 for practical testing, and the function will be included in all updates from autumn 2026 onwards. Logset does not support the “sticky” stem-code function.

Table 16. Summary of production reporting in hpr.

	Rottne, Eco Log (Dasa)	Ponsse	John Deere	Komatsu	Log Max	Logset
Production stored in hpr	Yes	Yes	Yes	Yes	Yes	Yes
Hpr can be generated automatically (e.g. with certain time interval, shift change, at end of object)	Yes	Yes	Yes	Yes	Yes	No
Diameter vector can be registered in hpr	Yes	Yes	Yes	Yes	Yes	Yes
Manual cut registered in hpr	Yes	Yes*	Yes*	Yes	Yes*	Yes
MultiTreeProcessing registered in hpr	Yes	Yes	Yes	Yes	Yes	Yes
MultiTreeFelling registered in hpr	Yes	Yes	Yes	Yes	Yes	Yes
SingleTreeFelling registered in hpr	Yes	Yes	Yes	Yes	Yes	No*
Special machine setting register felled stems?	Yes	Yes	Yes	Yes	No	Yes
BioEnergyAdaption can be registered	Yes	Yes	Yes	Yes	Yes	No
StemCode (e.g. High stump, culture stump) registered in hpr	Yes	Yes	Yes	Yes	Yes*	Yes*
Can the same stem code be registered on multiple stems in a row without new button press (”sticky” stem code)?	Yes	Yes	Yes	Yes*	Yes*	No

*See comments in the running text.

Only Log Max supports registration of reversing during stem feeding (Table 17). Logging of reversing events may be useful in quality follow-up, since length measurement can be expected to be adversely affected by reversing.

All systems except John Deere support registration of stump treatment per stem. This registration enables large-scale follow-up of stump treatment at tree level. In the Swedish market, stump treatment refers to root-rot treatment of the stump, but in other markets it may also include other types of treatment.

All systems support registration of whether a top saw has been used, but since top sawing does not occur in the Swedish market, this was not tested in practice in the present test.

All systems except Ponsse and Logset support registration of whether automation for reversing to the butt cut has been used. Automatic reversing to the butt cut is used when length measurement needs to be reset for a log.

Table 17. Support for new stem and log parameters in hpr.

	Rottne, Eco Log (Dasa)	Ponsse	John Deere	Komatsu	Log Max	Logset
Supports element Reversing (registering of revered feeding of stem)?	No	No	No	No	Yes	No
Supports element StumpTreatment (the use of stump treatment)?	Yes	Yes	No	Yes	Yes	Yes
Supports element TopSawing (the use of a top saw)?	Yes	Yes	Yes	Yes	Yes	Yes
Supports element FindButtEnd (automatic reversed feed to the nearest butt end cut)?	Yes	No	Yes	Yes	Yes	No

All manufacturers can report a time stamp per stem, but these are registered in different ways (Table 18). The most common approach is to register HarvestDate when the harvester head is tilted up after processing a stem, followed by registration when the harvester head opens after the stem has been processed. Komatsu records HarvestDate at the fell-cut of the stem, and Logset at the cut of the first log. For tree-level analyses involving different machines, we recommend paying attention to this variation.

The stem coordinate is often registered at a different point in time than HarvestDate. Dasa's system in Rottne registers it at the fell-cut, and Dasa's system in Eco Log at "reset stem". We interpret this to mean that the stem coordinate and date (HarvestDate) may be registered differently depending on how the control system is implemented. Ponsse and Komatsu register it at the fell-cut. John Deere can record the position either at the felling cut or when the harvester head opens; this is a setting, but they have stated that all their machines on the Swedish market register it at the felling cut. Logset registers the position at the felling cut if they register the attachment center coordinate (Logset did not show examples of having implemented this during the test), and at the first log cut if it is the base machine's position. In the test, Skogforsk did not validate the information in this paragraph; it is based on the manufacturers' own information.

All coordinates in the standard can carry a time stamp (CoordinateDate). It was noted that, for many of the systems, this time differs from the time registered in HarvestDate. The reason appears to be that Dasa and Ponsse store the most recent relevant coordinate generated by the GNSS receiver. If the machine is stationary, this may mean that the coordinate has not been updated and that CoordinateDate therefore occurs several minutes before HarvestDate. We therefore observe that several trees may have the same CoordinateDate if the machine has remained completely stationary. This issue is probably related to the fact that, in some systems, coordinates are filtered so that they are updated only during movement or at a certain time interval.

Only Komatsu can report the log position and the time of the log cut. In the test, this information was stored using an Extension element, that is, not in the standard elements because these had not been introduced in version 3.6.

According to the standard, boom positioning (BoomPositioning) can be registered at felling or at the last cut of the stem (BoomPositioningCategory). This means that the boom angle, the distance from the machine to the boom tip and, where applicable, the machine's compass bearing is reported. Boom positioning linked to each stem can be stored in most of the tested systems, but not by Log Max or Logset. Those that have implemented boom positioning have done so for the time of felling; in addition, Komatsu, Ponsse and Dasa have also implemented extended boom length at the same point in time. Only Dasa and John Deere have also implemented boom positioning at the last cut. This means that they can register boom angle and extended boom length at both felling and the last cut. Registering boom positioning also at the last cut is positive from a user perspective. It makes it possible to distinguish strip roads from so-called winding extraction routes, which is important when using Automated thinning follow-up. One peculiarity was noted in Dasa's system. The reported values for extended boom length were maximum values for extended boom length that should not be used, because the harvester lacked the sensor needed to calculate extended boom length. John Deere during the test reported only the value 1000 for extended boom length. It is likely that it also lacked the correct sensor.

All systems except Logset can report tracking data, in addition to the other coordinates reported. However, John Deere's system reports time stamps for the tracking coordinates only if they are reported in mom and not in hpr.

Ponsse, John Deere and Komatsu can report coordinates with high GNSS precision (RTK correction). As standard for these three systems, as well as for Dasa, the machine is always delivered with an installed GNSS splitter. GNSS splitter means that the positioning system can be used simultaneously by more than one system in the machine. Note that the RTK correction did not function correctly for Ponsse during the test. The reason for this is unknown.

Table 18. Production reports of positioning and time in hpr.

	Rottne, Eco Log (Dasa)	Ponsse	John Deere	Komatsu	Log Max	Logset
Timestamp when harvesting a stem (HarvestDate)	Yes	Yes	Yes	Yes	Yes	Yes
HarvestDate registered at?	Tilt up	Tilt up/ Head open	Head open	Felling cut	Tilt up	First log
Coordinates at felling, machine position	Yes	Yes	Yes	Yes	Yes	Yes
Coordinates at felling, stem position	No	Yes	Yes	Yes	No	No
Coordinates at log cut, log position	No	No	No	Yes	No	No
Time for log coordinate registered at?	-	-	-	Log cut	-	-
Boom positioning when felling stem?	Yes*	Yes	Yes	Yes	No	No
Boom positioning at the last cut of a stem?	Yes*	No	Yes	No	No	No
Boom extension	Yes*	Yes	Yes*	Yes	No	No
Track coordinates in hpr?	Yes	Yes	Yes	Yes	Yes	No
Track coordinates with time in hpr?	Yes	Yes	No*	Yes	Yes	No
GNSS with high precision (RTK-correction)?	No	Yes	Yes	Yes	No	No
GNSS-splitter as standard?	Yes	Yes	Yes	Yes	No	No

*See comments in the running text.

The handling and registration of key identities generally worked very well (Table 19). For Log Max, the attribute ContractCategory, which is located under the element ContractNo, and the element LoggingForm were missing. For Logset, somewhat more extensive deficiencies were noted:

- the attribute ContractCategory was missing,
- the element RealEstateIDObject was missing,
- in the element ForestOwner only the surname (LastName) was reported,
- in the element LoggingOrganization only BusinessName and BusinessID were reported,
- the element ProductBuyer was entirely missing.

Table 19. Summary of identities in production files according to StanForD 2010.

	Rottne, Eco Log (Dasa)	Ponsse	John Deere	Komatsu	Log Max	Logset
ContractNo	Yes	Yes	Yes	Yes	Yes*	Yes*
RealEstateIDObject	Yes	Yes	Yes	Yes	Yes	No
LoggingForm	Yes	Yes	Yes	Yes	No	Yes
ForestOwner, LoggingOrganization	Yes	Yes	Yes	Yes	Yes	Yes*
ProductInfo	Yes	Yes	Yes	Yes	Yes	Yes
ProductVersion	Yes	Yes	Yes	Yes	Yes	Yes
ProductDestination.BusinessID	Yes	Yes	Yes	Yes	Yes	Yes
ProductBuyer.BusinessID	Yes	Yes	Yes	Yes	Yes	No

*See comments in the running text.

Multi-tree handling functions well, although Logset's control system has some development potential (Table 20). Logset does not report multi-tree felled volumes, single-felled trees are registered as multi-tree felled, and the unit "m^3sob/sub" is used instead of "m^3sub/sob Estimated" for multi-tree processing. Only top diameter over bark is registered for these multi-tree processed logs. In the case of Logset, all multi-tree processed logs were registered with the product "Unclassified" and not, for example, pulpwood. It is therefore unknown whether logs can be registered as, for example, pulpwood during multi-tree processing.

Table 20. Details regarding registrations of multitree stems.

	Rottne, Eco Log (Dasa)	Ponsse	John Deere	Komatsu	Log Max	Logset
Multi tree felled volumes	Yes	Yes	Yes	Yes	Yes	No
Single tree felled volumes	Yes	Yes	Yes	Yes	Yes	No
Multi tree processed volumes (estimated)	Yes	Yes	Yes	Yes	Yes	Yes
Product registered per log (Multitree processed)	Yes	Yes	Yes	Yes	Yes	?
Length and top diameter (ob and ub) per log	Yes	Yes	Yes	Yes	Yes	Yes*

*See comments in the running text.

Quality assurance of machine measurement

Functionality for control and calibration has been implemented to a large extent in the systems of all manufacturers, and the HQC message can be generated in all systems (Table 21). Random selection of stems can be performed based on stem frequency (number of stems), time, or volume. All systems are capable of randomly selecting control stems based on time; however, Logset cannot perform random selection based on either the number of stems or volume. Log Max and John Deere cannot randomly select stems based on volume. It should be noted that random selection based on time and volume was not tested in practice, and it is known that these randomization algorithms may differ substantially among systems.

All manufacturers support the use of Haglöf and Masser digital calipers. In addition, Ponsse also supports its own caliper, Caliper 3_3, which was the caliper used when calibrating the harvester for the test. For the control measurements, the Haglöf DpII+ caliper was used throughout.

The statement that accepted but unmeasured stems can be sent in hqc to Biometria refers to what happens if a stem is sent to the caliper, but the caliper is then emptied before any hqc has been sent to the machine. This is one way of making randomly selected stems disappear entirely. John Deere and Log Max lack this function.

Table 21. Brief overview of implemented functionality regarding control and calibration.

	Rottne, Eco Log (Dasa)	Ponsse	John Deere	Komatsu	Log Max	Logset
hqc implemented	Yes	Yes	Yes	Yes	Yes	Yes
Random selection based on frequency (number of stems)	Yes	Yes	Yes	Yes	Yes	No
Random selection based on time	Yes	Yes	Yes	Yes	Yes	Yes
Random selection based on volume	Yes	Yes	No	Yes	No	No
Last five random selection settings registers per tree species in hqc	Yes	Yes	Latest	Latest	Yes	Latest
Rejected stems are stored as hqc	Yes	Yes	Yes	Yes	Yes	Yes
Accepted but not measured stems (only M1-measurement) can be sent in hqc to Biometria	Yes	Yes	No	Yes	No	Yes

Operational monitoring

All systems can generate the mom format for reporting operational-monitoring data (Table 22). In all cases, a comparison was made between production data in hpr and mom, which did not indicate any differences in stem count or total volume.

Because Dasa's control system supports version 4.1, it has also been able to use the hard-coded down time reason "ControllerDefault", which means that the operator can choose not to manually register specific down time reasons at all.

Log Max can only report production automatically by time interval.

Tracking data with time stamps can be stored in all mom files except in Eco Log, Rottne and Logset. However, it should be clarified that tracking can be saved in the mom file from Rottne and Eco Log forwarders. The parameter “DrivenDistance” was missing from the mom files from Rottne and Eco Log, but according to Dasa it can be activated.

Table 22. Description of functionality connected to operational monitoring.

	Rottne, Eco Log (Dasa)	Ponsse	John Deere	Komatsu	Log Max	Logset
Generation of mom per object	Yes	Yes	Yes	Yes	Yes	Yes
Type of time registration (I=individual, C=combined)	I	I	I	C	I	I
Is both partial- and total reporting of hpr possible?	Yes	Yes	Yes	Yes	Yes	Yes
Can production reports be generated automatically per hour or shift?	Yes	Yes	Yes	Yes	Yes*	No
Can production data and monitoring data be reported automatically at different times?	Yes	Yes	Yes	No	Yes	No
Tracking data with time stamps	No	Yes	Yes	Yes	Yes	Yes

*See comments in the running text.

Geographic map instruction

The StanForD standard includes a format that can be used to communicate geographic information to the forest machine’s GIS application (ogi). Among the test files there was one such instruction. However, at the time of testing, no machine manufacturer had implemented support for this format, and it could therefore not be tested in practice.

Study 4: Cutting time and chain speed

Objective

The objective of this study was to compare the cutting time of the machine systems and to verify that the machines were configured so that chain speed did not exceed the maximum permitted limit.

Materials and methods

Chain speed is subject to a regulated maximum because excessive speed increases the risk of chain shot. Since chain speed also affects cutting time, all machine systems were checked for compliance before the cutting-time measurements began. All machine systems tested were fitted with brand-new chains of the same model, Carlton B8HC, to eliminate the effect of different chain models on the results. Chain speed was confirmed to remain below the permitted maximum: 40 m/s during the cut itself, and 42 m/s at the start and end of the cut, when the saw chain first and last contacts the log. The higher limit at the start and end of the cut reflects the fact that the overshoot which often occurs at these points constitutes only a very limited part of the overall cutting sequence.

To verify chain speed, saw-motor rpm was recorded for all machine systems while cutting a large-diameter spruce log (approximately 40 cm in diameter). Measurements were made using an incremental rotary encoder mounted on the saw box and connected via a flexible coupling to the chain sprocket hub (Figure 18). The sensor produced one pulse per revolution, corresponding to a resolution of approximately 110–150 Hz at a chain speed of 40 m/s, depending on sprocket size, which ranged from 13 to 18 teeth across the different harvester heads tested. Pulse timestamps were recorded using an Arduino Nano Every microcontroller board, and the interval between pulses was then converted into instantaneous rpm. Rotational speed (RPM, revolutions/minute) was converted to chain speed (v, m/s) using the following formula:

$$v = RPM \times 0.00034 \times n$$

where n is the number of teeth on the drive sprocket and 0.00034 is the pitch factor for the chain used (Oregon, 2012). A ten-observation rolling average was then applied to reduce the influence of any artefacts or momentary spikes and to instead highlight the overall trend.

Figure 18. Rotary encoder connected to the sprocket hub for measuring the saw motor speed. The pulses and their timestamps were logged locally and streamed via Bluetooth to a mobile phone, which also controlled the start and stop times for data collection. Photo: Björn Hannrup, Skogforsk.

Cutting-time measurements were made using video recordings, following a methodology previously developed by Skogforsk (Skogforsk, 1999). The cutting sequence was filmed with a GoPro Hero 10 camera (Figure 19). In this study, cutting time was defined as the time from when the chain first entered the bark until the disc was fully separated from the log. Cutting time was determined by counting the number of frames between these two events in the footage. Filming was carried out at a frame rate of 240 frames per second, meaning the interval between two frames was 4.2 milliseconds.

Figure 19. Camera used to record the cutting process. Photo: Astrid Bygge, Skogforsk.

Using the same video recordings, the duration of the first and second halves of each cut was also determined. This was done by identifying the frame in which the cutting front passed through the geometric center of the disc in question (Figure 20), which marked the transition from the first to the second half of the cut.

During the cutting-time measurements, discs were cut from six spruce logs with diameters ranging from 20 to 40 cm (Figure 21). The logs were selected to represent a broad diameter range, so that the general relationship between cutting time and cutting area could be established for each machine system. Measurements were recorded for two cuts per log per machine system, resulting in a total of 12 cuts per machine system. After cutting, disc diameter was determined using cross-calipering. An initial review of the data led to the exclusion of four cuts from discs where cutting time was substantially elevated due to wood with large or numerous knots. These cuts were made by Rottne, Ecolog, Komatsu and Ponsse, resulting in 11 observations instead of 12 for those machine systems.

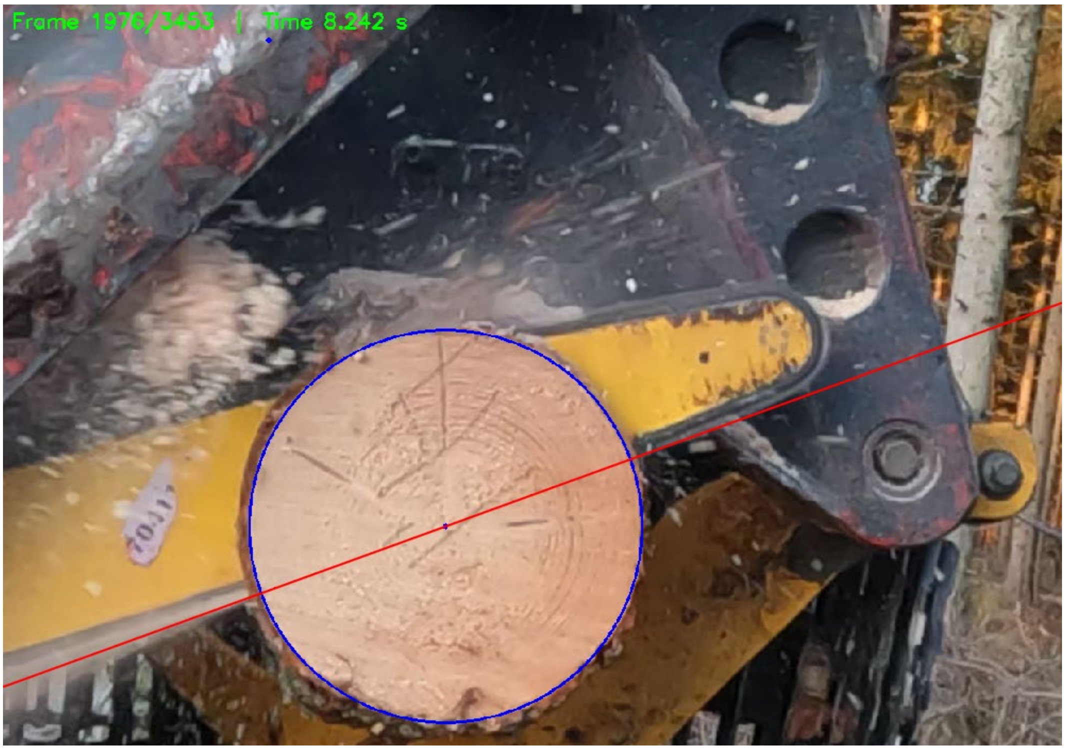


Figure 20. Illustration of the method used to identify when half of the cut had been completed. The line separating the two halves passes through the geometric center of the disc rather than the pith. Photo: Mats Richardson, Skogforsk.

Figure 21. The six logs used for measuring cutting time. photo: Björn Hannrup, Skogforsk.

Results and discussion

Chain speed

Figure 22 shows chain speed during the cutting sequence for the seven machine systems. After verification, all machine systems had a chain speed below 40 m/s during the cut itself. An initial peak followed by a decrease in chain speed can be observed for all machine systems except Eco Log, which instead shows a longer and more gradual increase in chain speed. For Log Max, the cut was initiated with a relatively low chain speed. The initial peak is therefore lower than the chain speed during the remainder of the cut, but can still be observed. A corresponding peak at the end of the cut is visible to varying degrees for John Deere, Komatsu, Log Max, and Rottne, occurring when resistance from the log disappears.

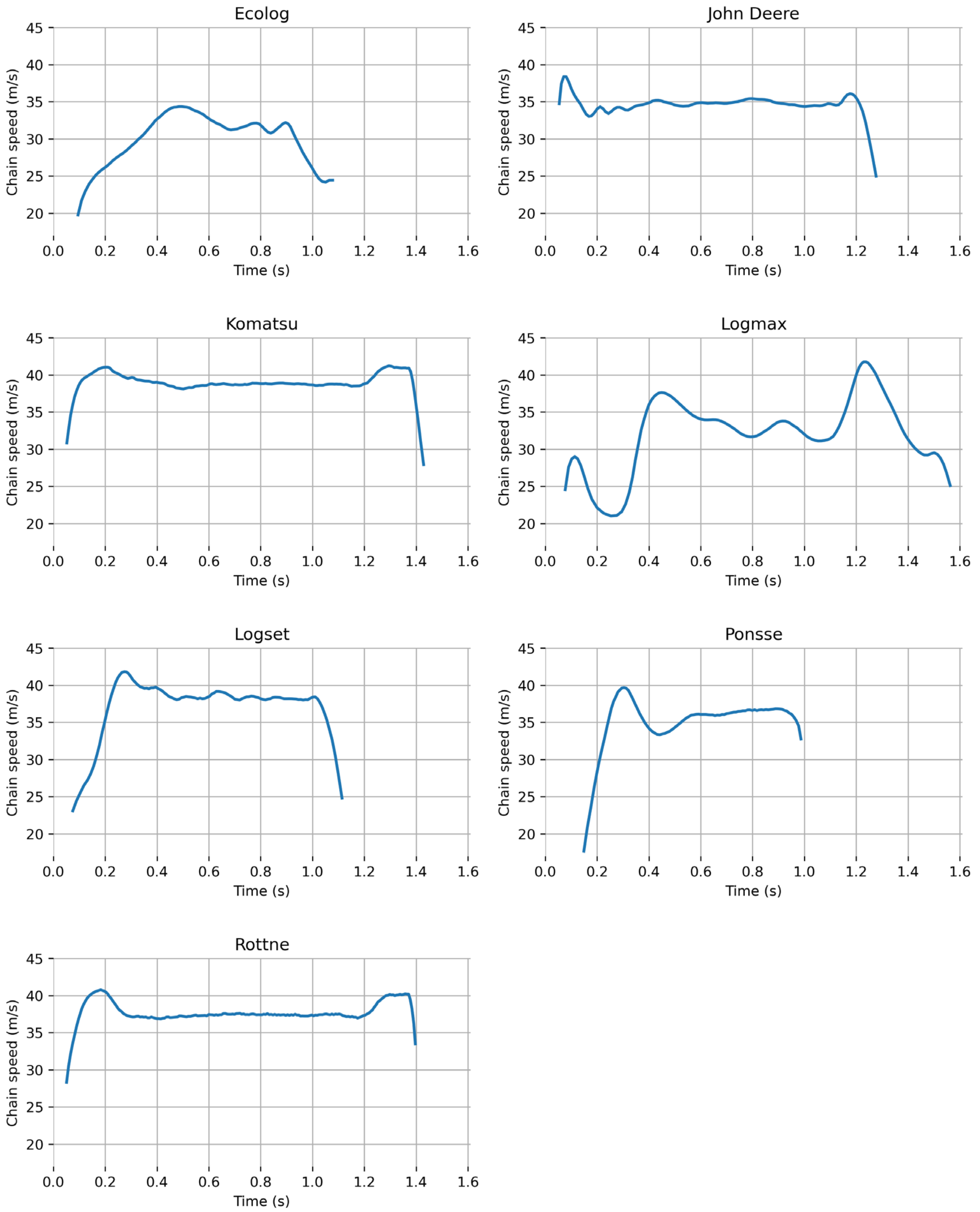


Figure 22. The machine systems' chain speed when cutting a large-diameter spruce log. Note that the diameters of the logs used varied slightly, and the cutting times were not adjusted to account for these differences.

Table 23 presents information on the different saw systems the machine systems were equipped with during the trial. Control of saw-motor rpm and bar-feed pressure also differed between the systems. Komatsu and Rottne both used the F11-iP saw motor from Parker Hannifin, which has integrated hydraulic control of the saw motor and bar feed. The similarity in their chain-speed curves reflects this. Log Max and Logset controlled rpm via a hydraulic compensator and bar feed via a proportional valve. John Deere and Eco Log also used this type of control, but supplemented it with software-based solutions. Since the last wood value trial, John Deere has implemented an adaptive function with feedback from the built-in rpm sensor, intended to help counteract momentary chain speed spikes. Eco Log used a patented method to keep saw-motor hydraulic pressure, and thereby rpm, at a steady level, by adjusting bar-feed pressure based on feedback from a pressure sensor located between the pump and the saw motor. Ponsse also had an in-house adaptive solution, which regulated bar-feed pressure in steps based on log diameter and bar progression through the cut. In addition to John Deere, Eco Log and Komatsu also had built-in rpm sensors in their saw motors, but used these to calibrate chain speed rather than control it during the cut. For these manufacturers, chain-speed verification was quick, and any adjustments made were only fine-tuning. The machine systems that lacked a built-in rpm sensor, and instead calibrated using air cuts without a chain mounted, initially had an excessively high chain speed and had to adjust it downward.

Table 13. Saw motor model and size, number of teeth on the drive sprocket, and whether built-in rpm measurement was used, for the machine systems evaluated.

Machine system	Saw motor	Size (cm^3)	Drive sprocket teeth	Built-in rpm measurement
Eco Log	Bucher QXM42-032	32	17	Yes
John Deere	Bucher	32	18	Yes
Komatsu	Parker F11-019 IP	19	14	Yes
Log Max	Parker F12-030	30	18	No
Logset	Bucher QXM42-032	32	17	No
Ponsse	Parker F12-030	30	16	No
Rottne	Parker F11-019 IP	19	13	No

Cutting time

The regression lines and corresponding equations for the relationship between cutting area and total cutting time are presented in Figure 23 and Table 24. Rottne had the shortest measured cutting time, and Eco Log the longest — on average 19 percent longer than Rottne. The relative difference in time is greatest for logs with smaller diameters, and decreases as diameter increases, except for Komatsu and Rottne which remain faster even at larger diameters. Cutting-time measurements for Eco Log, Rottne, and Komatsu were carried out under sub-zero weather conditions; see Figure 2.

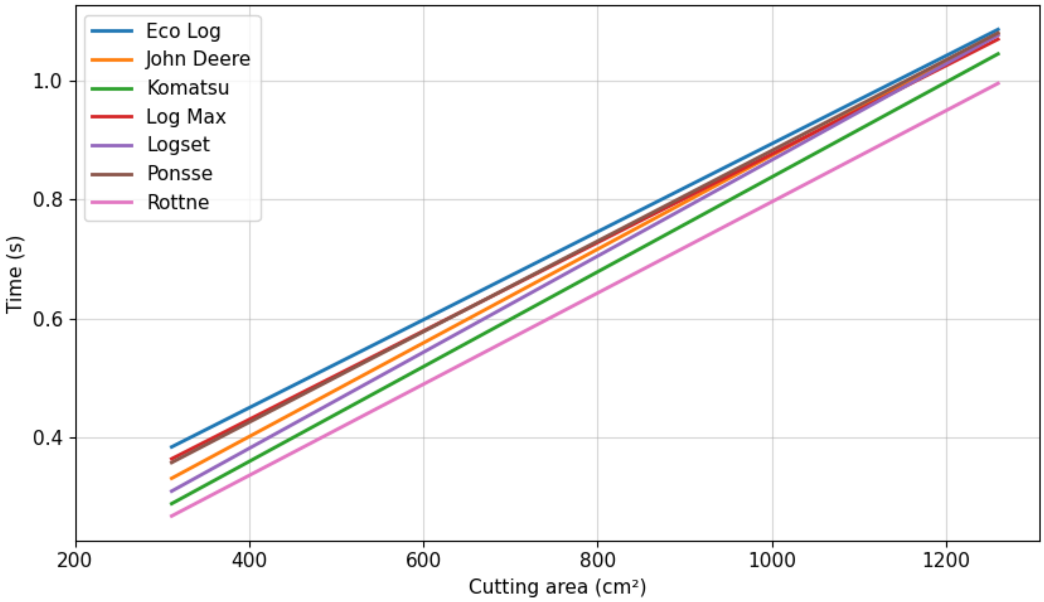


Figure 23. The relationship between cutting area and cutting time for the evaluated machine systems. A log with a cross-sectional area (cutting area) of 400 cm² has a diameter of approximately 23 cm, and a cutting area of 1200 cm² corresponds to a diameter of approximately 39 cm

Table 24. Equations for the modeled linear relationship between cutting area A and cutting time t, and the models' explanatory power (R^2) for the evaluated machine systems.

Machine	Regression equation *	R^2
Eco Log	t = 0.1528 + 0.00074 x A	0.963
John Deere	t = 0.085 + 0.00079 x A	0.970
Komatsu	t = 0.0394 + 0.0008 x A	0.961
Log Max	t = 0.1316 + 0.00075 x A	0.988
Logset	t = 0.0571 + 0.00081 x A	0.969
Ponsse	t = 0.1198 + 0.00076 x A	0.997
Rottne	t = 0.0281 + 0.00077 x A	0.991

*Units for cutting time and cutting area are seconds and cm^2, respectively.

Trends in cutting time over the years

Figure 24 presents the average cutting time for the machine systems that participated in this year's trial, along with the corresponding averages from the wood value trials conducted in 2001 and 2016. The results indicate that cutting time has not changed markedly since 2016, in contrast to the average 10 percent reduction in cutting time observed between 2001 and 2016. (Nordström et al. 2018).

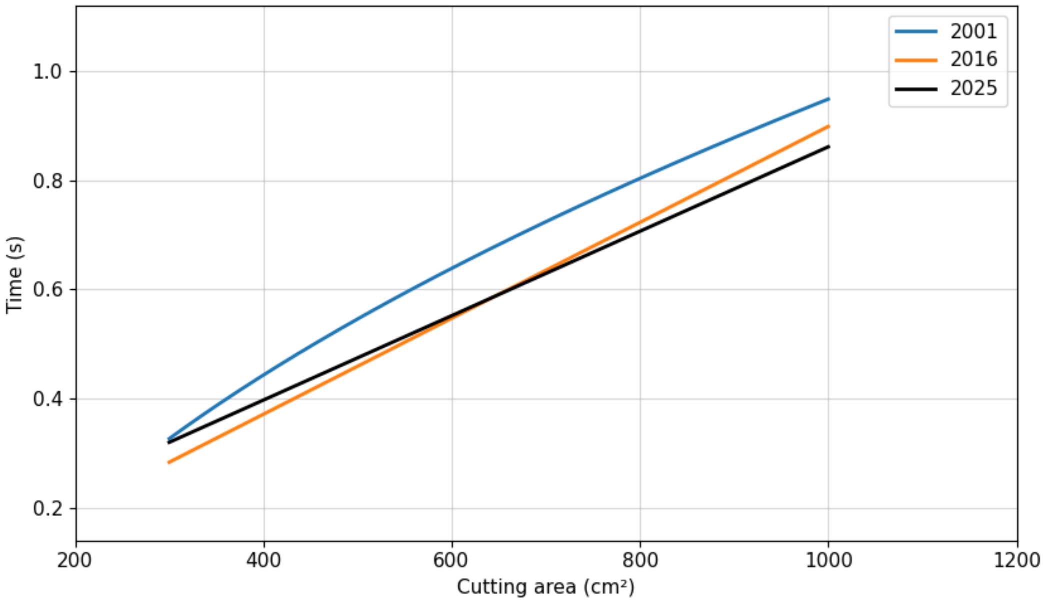


Figure 14. Relationships between cutting area and cutting time for the wood value trials of 2001, 2016, and 2026.

Relationship between cutting time and the occurrence of bucking splits

Bucking splits occur during the final third of the cut, primarily when cutting large-diameter logs (Helgesson, 1997). To reduce the risk of bucking splits, a high cutting speed is important, especially during the latter part of the cut. Figure 25 shows the duration of the first and second half of the cut for the seven machine systems examined. The largest difference in time between the first and second halves was found for Ponsse and Eco Log. For Ponsse, this may be due to the stepwise control used, which can be adjusted depending on the bar's position in the cut. However, some of the footage from the cutting-time measurements showed that Ponsse's saw chain slowed notably on first contact with the log, which could also explain the longer time required for the first half of the cut. After the trial was completed, Eco Log reported that they had been running a setting in which bar-feed pressure was updated at a frequency of 10 ms instead of the standard 2 ms, which, according to the manufacturer, may have contributed to a slower first half of the cut. John Deere, Komatsu, and Rottne had similar durations for the first and second halves of the cut. Of all the machine systems examined, only Logset's second half of the cut took longer than their first half. In a comment provided after the trial, the manufacturer identified an excessively high bar-feed pressure setting as a possible cause, resulting in insufficient chip evacuation and a longer cutting time during the second half.

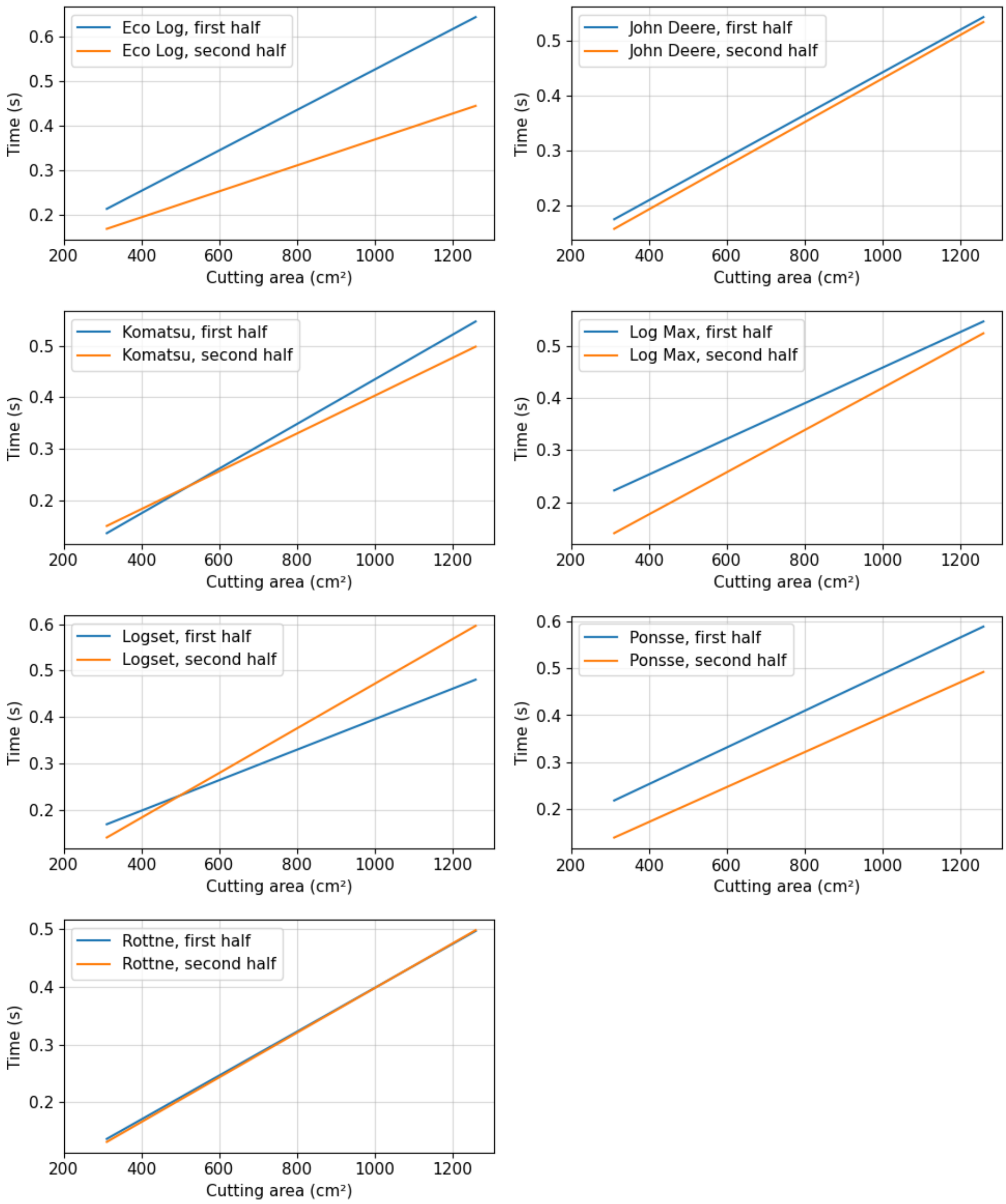


Figure 25. Relationship between cutting area and cutting time for the first and second halves of the cut, respectively, for the evaluated machine systems.

Study 5: Harvesting damage

Aim

The aim of the study was to compare the machine systems with respect to bucking splits, bark damage and feed roller spike damage, and to compare the current systems with previous tests.

Material and methods

This section presents the measurement and analysis methods for bucking splits, feed roller spike damage and bark damage.

Bucking splits

Bucking splits are caused by the bending moment generated by the freely suspended log during the cutting operation. Measurements of bucking splits were carried out on the same 30 stems that were used to evaluate the harvesters' dimensional measurement. All cutting was performed *without support, with the processed log freely suspended*. This is essential for enabling comparisons between the machine systems.

Measurements of bucking splits were made on all sawlog products down to a top diameter of 14 cm, from a total of 30 spruce stems per machine system. Both log ends were measured, except for butt logs, which were measured only at the top end. Splits in the butt end of butt logs were not measured, since they appear during felling and are strongly operator dependent. No measurements were made on log ends where rot was present.

Measurements of bucking splits were made using the so-called disc method (Helgesson 1997, p. 20), as follows:

1. The path of the length-measuring wheel was identified, and a thin groove was cut with a chainsaw along the path.
2. Wood discs approximately four centimetres thick were cut from the log end (Figure 26) and then tapped against the log end to determine whether they split where a bucking split was expected. Using the groove cut along the path of the length-measuring wheel as a guide, it was ensured that any potential splits had the expected direction (as a chord across the annual rings, approximately perpendicular to the path of the length-measuring wheel) and position (the lower third of the diameter).
3. Discs continued to be cut until the final disc no longer showed a bucking split when tapped.

Figure 262. Bucking splits appear in the lower third of the cut. The butt end of the tree is to the left. The harvester head has processed the causing log, and the bucking split is generally longest in the held log. Illustration by Mats Richardson, Skogforsk.

Bucking splits are characterised by fibres being torn in a jagged pattern across the annual rings. For log ends with bucking splits, the following were recorded: *i)* number of discs with splits, *ii)* the summed thickness of the discs, and *iii)* the distance from the log pith to the bucking split.

Figure 27. The disc method of measuring bucking splits. The wood discs are cut from the same log end, and the lenght of the bucking split can be estimated by summing the thickness of the discs. Photo: Björn Hannrup, Skogforsk.

The proportion of log ends with bucking splits were calculated, as well as the length of the bucking splits. The split length was calculated as the summed thickness of the discs plus the width of the saw kerf (8 mm) (Figure 27). Also, the position of the bucking splits in the cross-section was calculated, expressed as the proportion of the log diameter that remained to be cut when the bucking split formed. Log diameter and length have an effect on the occurrence of bucking splits. To test whether the differences in the measured split variables (proportion, position and length) among the machine systems were statistically significant, while accounting for existing differences in log dimensions, an analysis of variance was performed. Log length and diameter were then used as covariates to compensate for differences in log dimensions between machine systems. The log dimensions used were those of the causing log, that is, the processed log that was freely suspended during cutting. The following model was fitted:

$$y = m + v + e$$

where y is the end-split variable analysed in the affected log, m is the machine system, v is the volume of the causing log and e is the random error. Since the harvester computer controls log length according to diameter, the total volume of the causal log was used as the explanatory variable. In the analysis, least-squares means were calculated for the machine systems, that is, the mean end-split value for the machine systems after compensation for differences in log dimensions. In addition, the effects of the different parameters were tested for significance.

Feed roller spike damage

Feed roller spike damage occurs when the spikes on the feed rollers penetrate the wood during stem feeding. Measurements of feed roller spike damage were made at the top end of all sawlogs down to a top diameter of 14 cm, from a total of 30 spruce stems per machine system. The measurements were carried out in parallel with the bucking split measurements using the so-called axe method. For the first disc cut from the top end of the logs, a segment of wood was cut loose with a knife or axe from an area of the log where the outer feed rollers had been in contact. The wood segment was split in the fibre direction and the depth to the innermost torn wood fibre was measured with callipers (Figure 28). The measurements were restricted to damage caused by the feed rollers during normal forward feeding of the stem. Damage that occurred during slipping or reverse feeding of the stem was not measured.

Figure 3. The feed roller spike damage was measured with callipers.

Bark damage

Bark damage is caused by delimbing knives and feed rollers as the stem is fed through the harvester head. Measurements of bark damage were made at the top end of all logs, including pulpwood logs, from a total of 30 spruce stems per machine system. During measurement, a measuring tape was placed around the circumference of the log surface, starting at the groove cut at the path of the measuring-wheel from the bucking split measurements. For each bark-damage occurrence, the distance from the start and end points of the damage on the log surface was recorded (Figure 29). Length was measured to the nearest half centimetre. Two damage-depth classes were used: partial damage, that is, damage where the bark was affected but did not extend as deep as the wood surface, and full damage, where the damage was deep enough to expose the wood (Figure 25). For each log, the proportion of damaged bark, expressed as a proportion of circumference, was calculated separately for the two damage-depth classes. Corresponding values per machine system were calculated as the arithmetic mean of the log-level values.

Figure 29. Illustration of the definition of bark stripping and how it was measured in practice. Bark stripping was assessed in two classes: exposed wood and inner bark remaining.

Results and discussion

Bucking splits

The mean diameter and length of the logs included were similar among the different machine systems (see Table 34, Table 35 and Table 36 in Appendix 5). Log length and diameter affect the bending moment exerted by the fed-out log, and in the analyses of the end-split parameters (proportion of splits, split length and split position), we compensated for the differences in log dimensions that nevertheless existed among the machine systems.

In total, 48 percent of the logs had bucking splits at the butt end, and 23 percent of the logs had splits at the top end (Figure 30). There was variation among the machine systems, and John Deere and Log Max had the lowest total proportion of bucking splits. Differences among machine systems were tested using statistical modelling, which showed significant results. The proportion of splits in 2025 is very similar to that in 2016, when the total proportion was 48 percent splits at butt ends and 17 percent splits at top ends.

There were differences in mean split length (Table 25). Mean split length was consistently shorter at the top end of the log than at the butt end. For all machine systems, the proportion of splits longer than 50 mm is also reported. Both the mean split length and the proportion of splits exceeding 50 mm represent an improvement compared with the 2016 test. At that time, the mean length was 93 mm at the butt end (71 percent over 50 mm) and 71 mm at the top end (80 percent over 50 mm). This means that the 2025 results show bucking splits that are almost 2 cm shorter at both ends of the log than in the previous test.

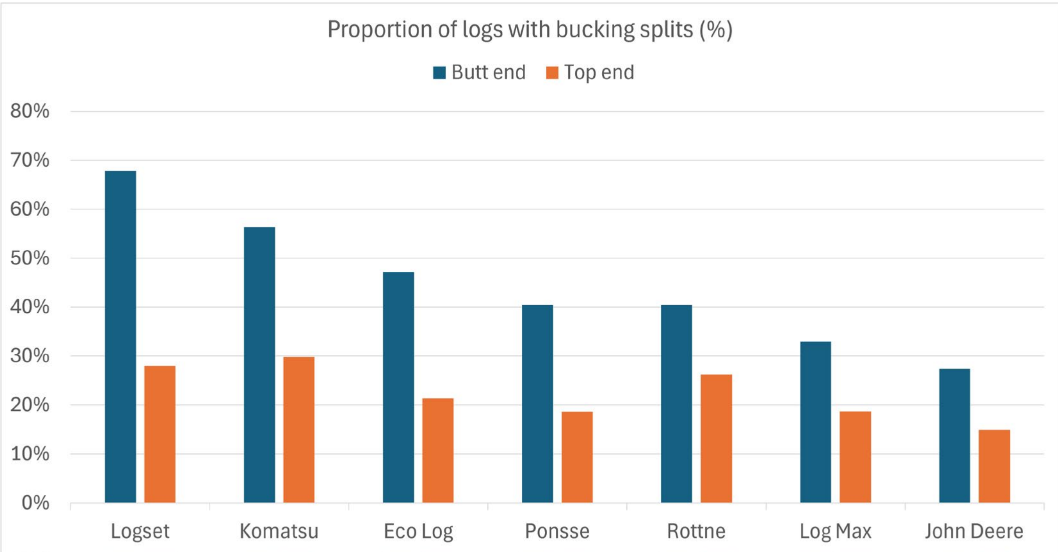


Figure 30. Proportion of logs with bucking splits in each log end. The bars are ordered by descending proportion of bucking splits at the butt end.

Table 35. Average bucking split length (mm) at the butt and top end of the affected logs for the evaluated machine systems. The proportion of splits longer than 50 mm is also reported for each log end. The order of the machine systems follows Figure 30 above.

Machine	**Bucking splits in butt end**		**Bucking splits in top end**	
	Mean length (mm)	Splits over 50 mm (%)	Mean length (mm)	Splits over 50 mm (%)
Logset	82	54	52	43
Komatsu	64	45	48	36
Eco Log	61	29	51	24
Ponsse	90	82	71	78
Rottne	64	56	53	52
Log Max	59	39	46	32
John Deere	51	26	53	30
Mean	**67**	**47**	**53**	**42**

The distribution of bucking splits was not uniform across the cuts within the same stem. The first cut, between the top end of the first log and the butt end of the second log, generated the most splits. The highest proportion of bucking splits occurred at the butt end of the second log (58 percent), and many of the first cuts also generated splits at the top of the butt log. The proportion of bucking splits decreased higher up in the stem, but bucking splits also occurred in short-log products.

Table 26 presents the position of bucking splits in the log cross-sections for the seven machine systems (see the illustration of the reported measure in Figure 31). On average across all machine systems, bucking splits formed when 27 percent of the log diameter remained to be cut, which is consistent with results from previous studies (Hannrup & Jönsson 2010). Similarity among the machines was tested statistically, and no differences were found. In the 2016 wood value trial, bucking splits were on average found when 24 percent of the log remained. This means that the average split was located slightly higher in the 2025 test.

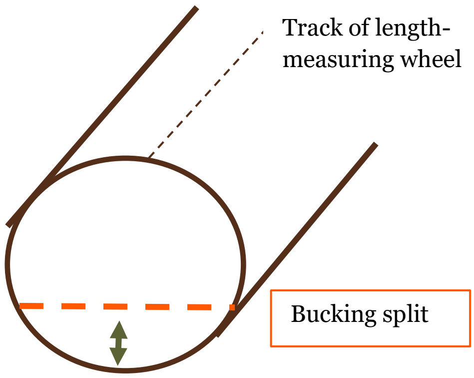
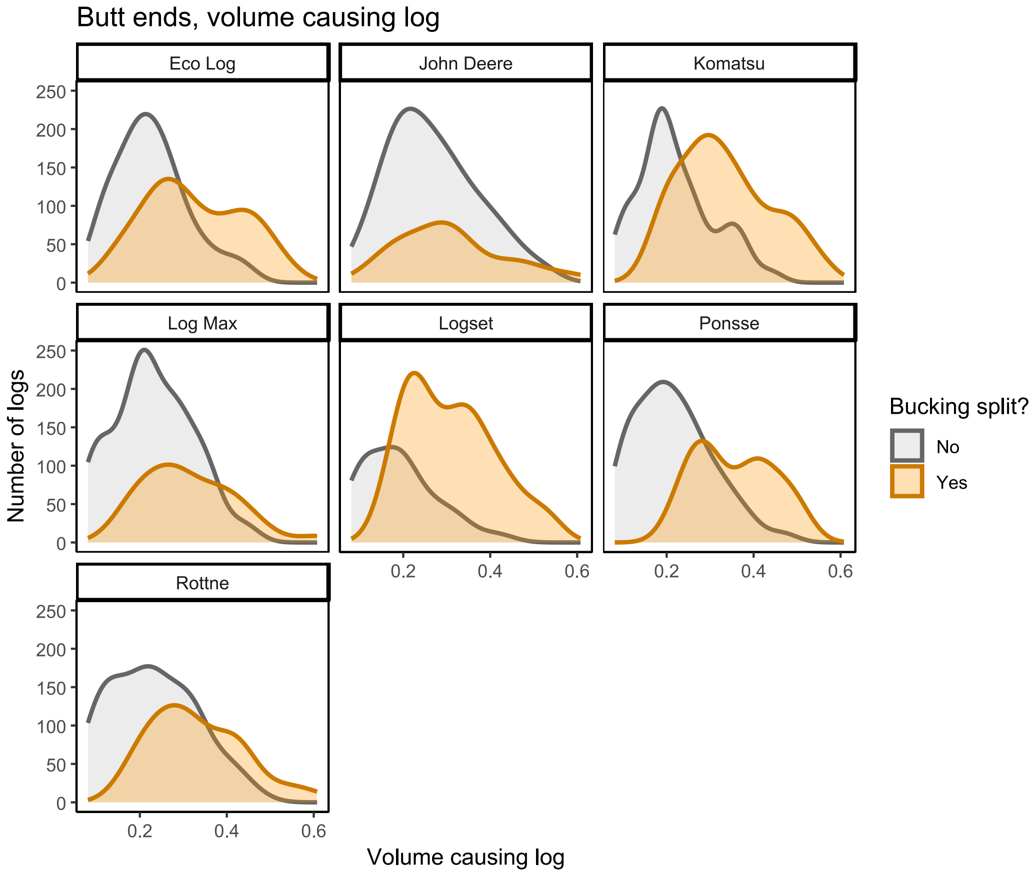


Figure 31. Illustration of the position of bucking splits in the log cross section. The arrow indicates how much of the diameter that remained to cut when the bucking split formed.

Table 46. Average bucking split location, in percent of remaining log diameter. A higher number means that a larger proportion of the log remains to cut.

Machine	Proportion of diameter remaining to cut (%)
Logset	27
Komatsu	24
Eco Log	28
Ponsse	27
Rottne	26
Log Max	28
John Deere	30
Mean	**27**

Figure 32 on the next page illustrates the occurrence of bucking splits for different volumes of the causing log. The causing log was the log that was freely suspended during cutting and that caused to the bucking split, either at its own top end or at the butt end of the next log (As previously illustrated in Figure 26).



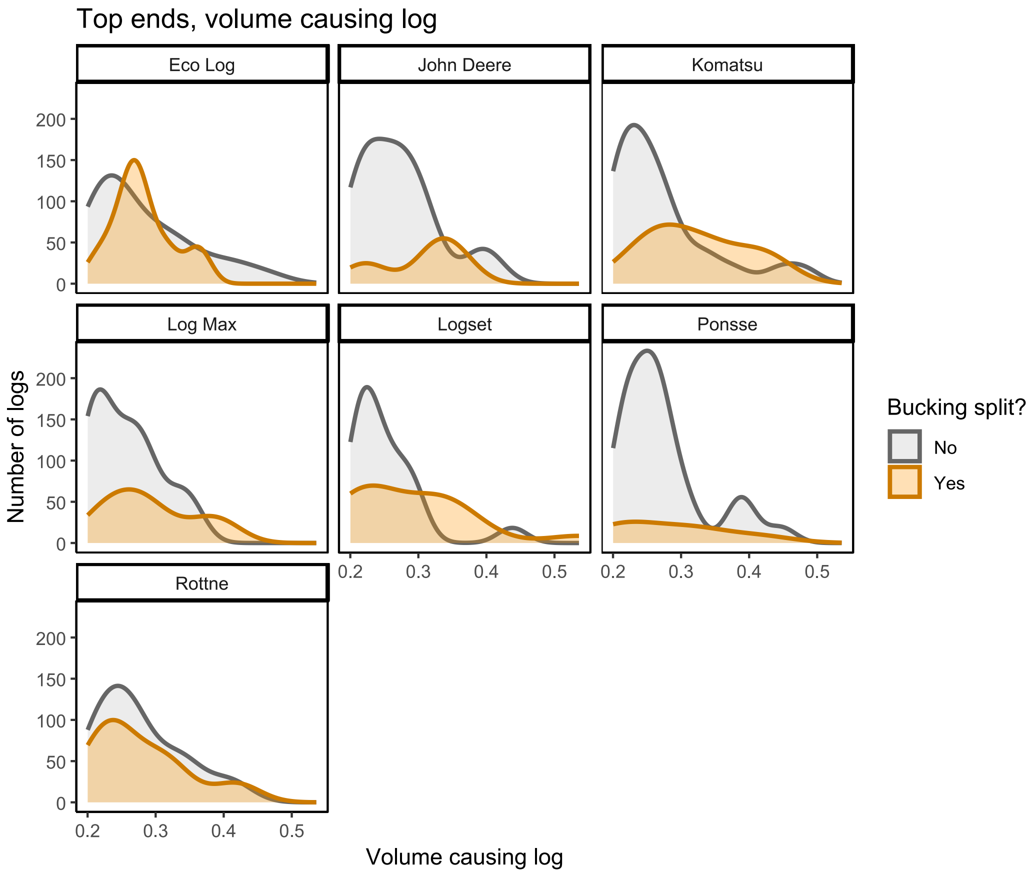


Figure 32. Occurrence of bucking splits at the butt and top ends of logs for different volumes of the causing log (m³sub). For the top ends, logs with volumes below 0.2 m³sub have been excluded for readability.

Development of bucking-split occurrence over time

Compared with results from previous wood value trials, there is no indication that the proportion of bucking splits when cutting freely suspended logs with new harvesters has decreased over time. Rather, it has increased at the top ends. However, the mean split length has decreased since the previous test in 2016 (Figure 33 and 34).

The level of bucking split occurrence that can be expected in forestry in the near future is equivalent to the level observed today. It should be emphasised, however, that the levels measured in this study relate to cutting freely suspended logs. During production harvesting, operators use support during cutting to varying degrees, which reduces the risk of bucking splits.

Based on the discussion above, we draw the following conclusions:

- The proportion of bucking splits has not decreased over time; however, the mean split length has decreased by approximately two centimeters per end since the previous test. Technological development affects the results, which is why it is important to continue developing new technology to achieve the goal of split-free cutting.
- The highest number of bucking splits occurred when the causal log had a large volume. All logs were cut while freely suspended; therefore, extra caution should be exercised when harvesting in stands with large-diameter trees.

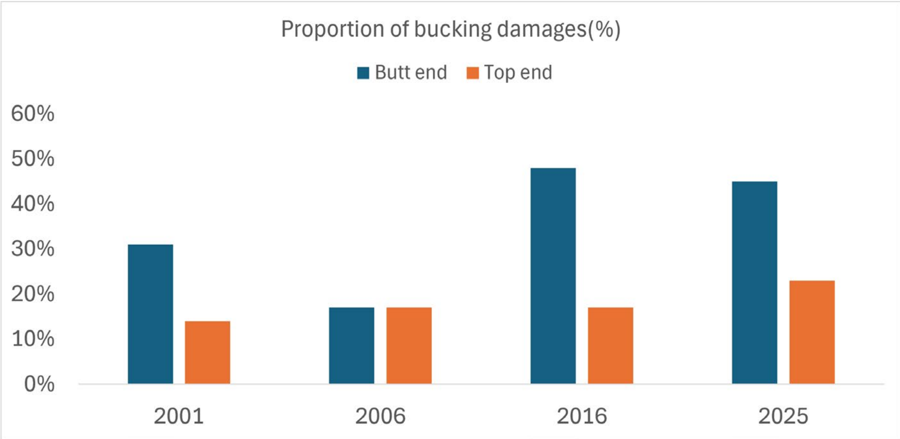


Figure 33. Proportion of bucking splits over the wood value trials.

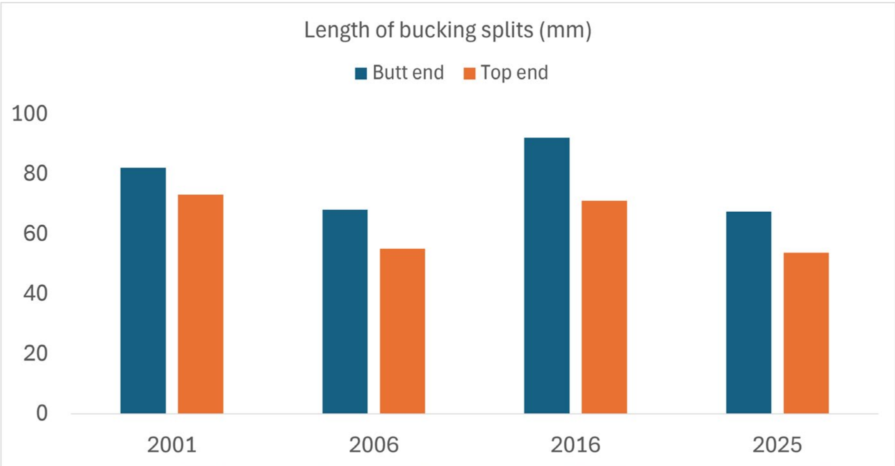


Figure 34. Average length of bucking splits over the wood value trials.

Feed roller spike damage

The mean penetration depth of the feed roller spikes for the studied machine systems was 4.8 mm (Table 27), which was approximately the same level as in the 2016 wood value trial (4.6 mm).

Table 57. Mean depth, deviations, and number of observations for measured feedroller spike damage of the seven machine systems.

Machine	Mean spike depth (mm)	Std.dev. (mm)	Min (mm)	Max (mm)	N
Logset	6,8	2,3	2	13	116
Ponsse	5,2	1,6	2	10	112
Log Max	5,0	1,8	1	10	116
Eco Log	4,7	1,8	1	8	113
John Deere	4,2	1,4	1	7	114
Komatsu	4,1	1,1	1	7	124
Rottne	3,2	1,0	1	6	114
Mean	**4,8**	**1,9**	**1**	**13**	**809**

Feed roller spike damage in Swedish timber-measurement regulations

According to the national Swedish instruction used for payment measurement of sawlogs (Biometria 2026), sawlogs are classified with respect to feed roller spike damage if so agreed. In the classification, a log is considered to have feed roller spike damage if the penetration depth in the wood exceeds 7 mm. If the proportion of logs with feed roller spike damage exceeds 5 percent, the delivery is classified as having feed roller spike damage.

Figure 35 shows the proportion of logs with penetration depths from the feed roller spikes above and below 7 mm, respectively. For three of the machine systems (John Deere, Komatsu and Rottne), no spike penetration depths above 7 mm were measured. For four of the machine systems (Eco Log, Log Max, Ponsse and Logset), the proportion of logs with penetration depths above 7 mm was 10, 12, 15 and 42 percent, respectively. That is above the threshold at which timber deliveries are to be regarded as having feed roller spike damage and assigned a reduced value.

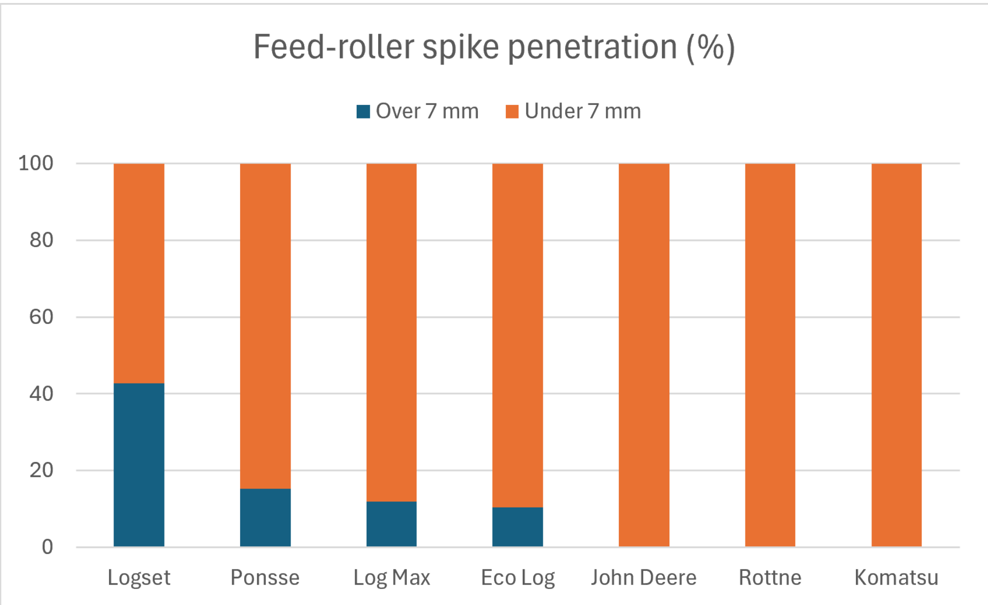


Figure 35. Proportion of logs (%) with feed roller spike penetration depth above and below the threshold value of 7 mm. Three machines had no recorded spike depths over 7 mm.

Development of feed roller spike damage occurrence over time

In the 2001 wood value trial, the tested machine systems mainly used rubber wheels fitted with chains, and no deep feed roller spike damage was recorded (Figure 36). In 2006, all production machines were equipped with steel rollers. At that time, an average of 3 percent of the logs had deep feed roller spike damage, and all tested machine systems met the threshold of a maximum of 5 percent deep damage. In the 2016 test, the proportion of deep damage averaged across all four participating machine systems, all of which used steel rollers, had increased to 11.5 percent. The same proportion was observed in this year's test with seven participating machine systems. All used steel rollers. If Logset, which had a significantly higher proportion of deep feed roller spike damage than the others, is excluded from the analysis, the mean decreases from 11.5 to 6.3 percent deep feed roller spike damage.

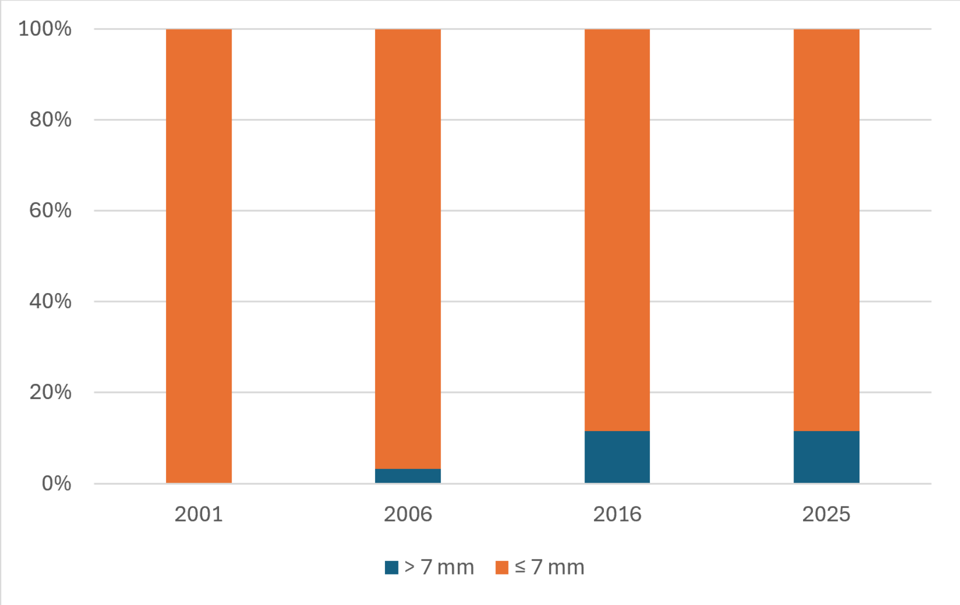


Figure 36. Feed roller spike damage over the wood value trials. Proportion of penetration depths over the threshold value 7 mm (%).

Based on the data presented above, we draw the following conclusions:

- If these levels of feed roller spike damage can be considered representative of those obtained during normal production, this means that a substantial proportion of today's produced timber has feed roller spike damage at a level where, according to the timber-measurement regulations, it should be regarded as spike-damaged and therefore assigned a reduced value.
- Three of the machine systems in this year's test used steel rollers and had no feed roller spike damage. It should therefore be possible, within the framework of current technology, to achieve acceptable levels of feed roller spike damage. Achieving this will require increased focus on the issue in day-to-day operations.

Bark peeling damage

Figure 37 shows bark peeling damage divided into the two damage-depth classes. For four of the machine systems (Komatsu, Rottne, Logset and Log Max), the total proportion of damaged bark was below ten percent. For three of the machine systems (Eco Log, John Deere and Ponsse), the corresponding damage level was higher. On average, 4.3 percent of the log circumference was peeled down to exposed wood and 6.2 percent down to the inner bark. The highest amount of damage affecting wood was found for Eco Log. In the test, their feed rollers cut through the inner bark and exposed the underlying wood, which is why this was classified as bark damage. For the remaining machine systems, the bark damage was assessed as peeling from the delimbing knives.

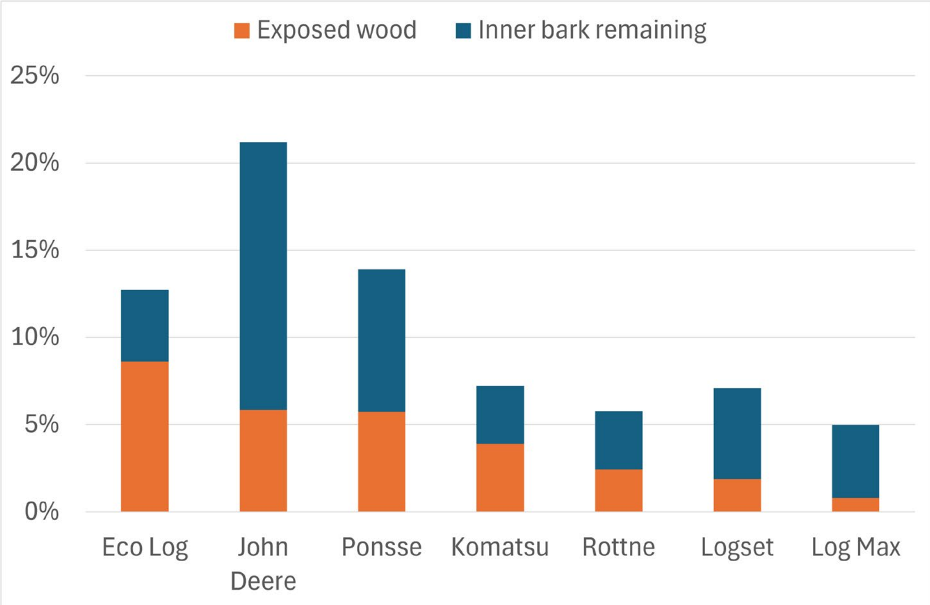
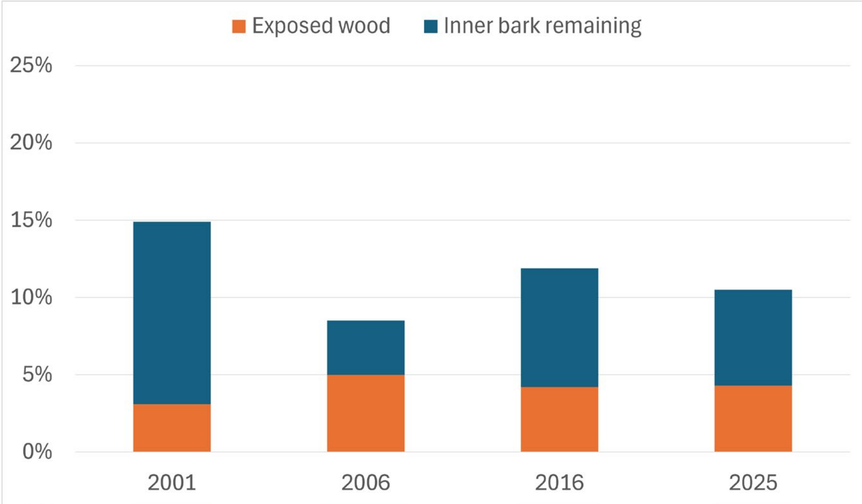


Figure 37. Percentage of bark removed from the log circumference (%), divided into two damage classes: exposed wood (complete bark removal exposing the wood surface) and inner bark remaining (partial bark removal down to the inner bark); bars are ordered by decreasing proportion of exposed wood.

Previous studies have shown that an increasing amount of bark peeling resulted in lower precision in diameter measurement (Möller et al. 2008). Neither in the 2016 test nor in the 2025 test was such a relationship present. The three machine systems (Eco Log, John Deere and Ponsse) with the greatest amount of bark damage performed well in both diameter and length measurement. One explanation may be that the bark damage in the harvester heads mainly originated from feed rollers and lower delimbing knives, and therefore did not affect diameter measurement, which was performed using the upper delimbing knives. Compared with previous wood value trials, there was no clear trend in the development of bark damage (Figure 38).

The economic impact of bark damage (see examples of bark damage in Figure 39 on next page) is an increased risk of blue-stain attack on the timber and a reduced fuel value of the bark because of the reduced amount of available bark. The energy value of the abraded bark was calculated to average 3 SEK per m^{3}ob of harvested timber. This is approximately twice the level in the 2016 test, explained by the fuel price being approximately twice as high in 2025. See Appendix 6 for price assumptions and calculations.



Figur 38. Average bark damage over the wood value trials.

In summary, our results indicate that there is potential to increase timber value by keeping bark damage low and reducing staining. Achieving this will probably require some form of standardised monitoring in combination with established tolerance levels for bark damage. Based on data from this and previous wood value trials, we propose that a maximum of 10 percent total bark damage can be used as a preliminary tolerance level for bark damage during most of the year.

Figure 39. Two images illustrate three types of bark damage. The left image shows a high level of bark damage caused by the delimbing knives, however most of the inner bark remains intact. The right image shows two types of damage side by side. The completely peeled section illustrates bark damage that has exposed wood. The cuts above it shows feed roller penetration that has also exposed wood. This type of feed roller damage was observed only on Eco Log stems. Although the feed roller penetration appears severe in the image, most penetration depths were no greater than 7 mm. For further details, see previous section on feed roller spike damage.

Study 6: Positioning

Aim

The aim of this study was to evaluate the harvesters' support for, and ability to, correctly specify positions for harvested logs and processed stems. Functionality for positioning logs and stems is relatively new for harvesters, and this test has been added since the most recent wood value trial in 2016. An additional aim of this study was therefore to provide an overview of how positioning functionality has been implemented across the industry.

Material and methods

Two types of harvester positioning were evaluated in this study:

- Stem positioning.
- Log positioning.

Evaluation of stem positioning was carried out on the 30 selected Norway spruce stems harvested during the value-optimized bucking test. Evaluation of log positions was carried out on the first two logs from each of the ten Scots pine stems harvested during the value-optimized bucking test. The stem positions were control-measured using a point at the center of the stump after harvesting. The logs from the harvested pine stems were control measured at the butt and top ends, after which the center was calculated as the midpoint between these. All control measurements were performed using a GNSS receiver with RTK, with position correction from SWEPOS, and only positions with "Fix" precision were accepted, giving an indicated accuracy of approximately 2 cm.

The evaluations were carried out on systems that had a standard implementation of one or both functions, where the results were written to the harvester's hpr file.

Stem positioning was analyzed by comparing the control measured coordinates with the coordinates reported in the harvesters' hpr files. The comparisons were made after projecting the coordinates to SWEREF99 TM (EPSG:3006). The following parameters were analyzed:

- The mean deviation between the control measurements and the harvester measurements, calculated as the mean distance between each control point and the corresponding point reported by the harvester. Because this measure describes distance, all values are positive.
- The dispersion of the differences between the control measurements and the harvester measurements. This dispersion is reported as the standard deviations in the two principal directions generated by the dispersion of points in x and y, together with the combined standard deviation calculated as their norm.

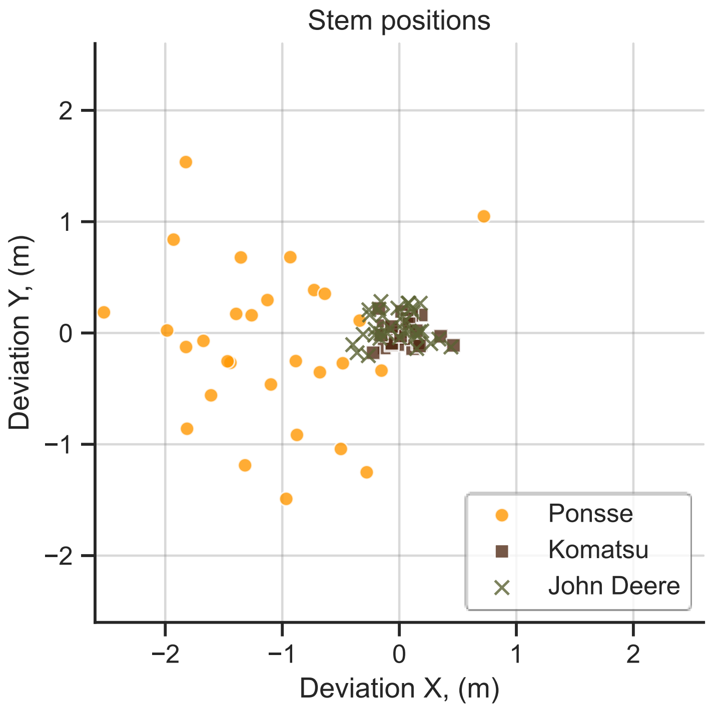
Log positions are reported in the harvesters' hpr files as their respective center points. These points were compared with the calculated center points from the control measurements. As for stem positioning, the coordinates were compared after projection to SWEREF99 TM (EPSG:3006). For log positioning, the following parameters were analyzed:

- The mean deviation between the control measurements and the harvester measurements for the log center points, calculated as the mean distance between these points, as for stem positioning.
- The dispersion of the differences between the control measurement and the harvester measurements, expressed as the standard deviation in the principal directions and as the combined standard deviation calculated as their norm, as for stem positioning.
- The mean deviation in log direction between the control measurements and the harvester measurements.
- The standard deviation of the differences in log direction between the control measurements and the harvester measurements.

Results and discussion

Stem positioning

Support for stem positioning was implemented only by Ponsse, John Deere and Komatsu. The results for stem positioning are shown in figure 40, which shows the differences between the control measurements and the position registered by the harvester.



Figur 40. Deviation between control measurements and the harvester stem positions.

Positioning generally works well, although John Deere and Komatsu achieved better results than Ponsse. A major reason for this was that Ponsse did not use precise positioning via RTK. They support this, but the functionality was not available during the test and has therefore not been evaluated. Instead, Ponsse's results describe a typical case in which a standard GNSS receiver was used for stem positioning, which clearly reduces resolution compared with cases using positioning via RTK. Values for the mean deviation, that is, the average distance between the reference measurements and the harvester measurements, and the standard deviation for these three manufacturers are shown in Table 28. The standard deviations are reported for the two principal directions spanned in the x- and y-plane, but they do not represent the geographical x and y directions, because these have no particular significance for the measurements. Instead, the directions of greatest dispersion and the direction orthogonal to this are reported as 1 and 2, respectively. The total standard deviation is also reported as the norm of these. For Komatsu, one measurement point was excluded because it showed a deviation of approximately 3 meters from its reference measurement. Because this is an extreme deviation relative to all other measurements, it most likely originated from an erroneous control measurement and was therefore excluded.

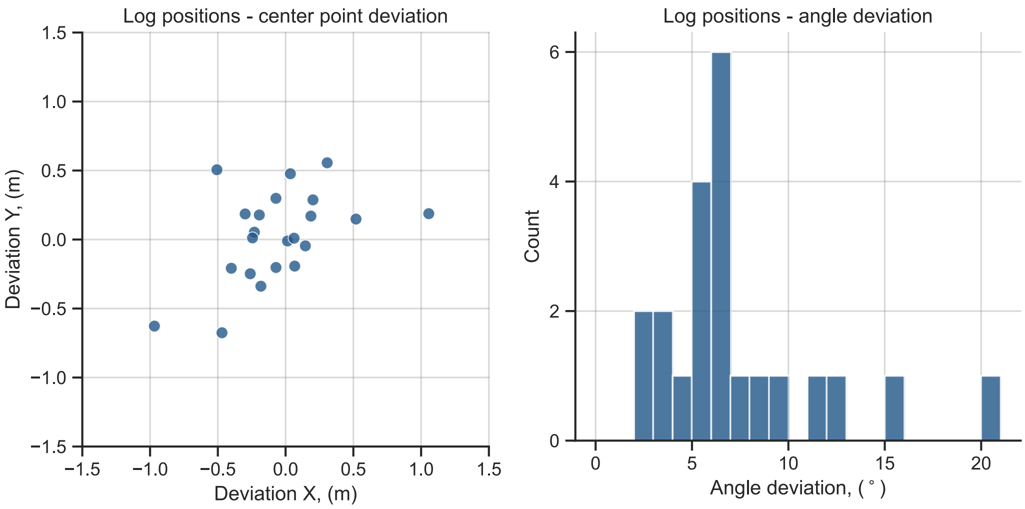
Table 68. Results from stem positioning. Average error, standard deviation in the first and second principal direction along with the combined standard deviation.

	Ponsse	John Deere	Komatsu
Average error (m)	1,38	0,23	0,16
Standard deviation 1 (m)	0,73	0,21	0,15
Standard deviation 2 (m)	0,66	0,14	0,11
Standard deviation combined (m)	0,98	0,25	0,19

Positioning with a precision of 2.5 dm or less, as demonstrated by John Deere and Komatsu, is very good. The fundamental objective of stem positioning should be to enable each individual tree to be clearly distinguished, and with this level of precision this is possible. This will enable interesting new applications, and all manufacturers should work to implement stem positioning.

Log positioning

In this test, only Komatsu had implemented log positioning. Unlike a standing stem, a log has not only a center coordinate but also a direction. Komatsu reports both in its hpr files, and Figure 41 shows the results relative to the control measurements performed. For the center positions, deviations in the x and y directions are shown, and for the angular deviations, a histogram of angular deviations is shown.



Figur 41. Log positioning, center coordinate deviation to the left, histogram of angle deviations to the right.

For log positioning, the center coordinate of the log is calculated using the position of the harvester head together with an estimate of the head angle and the log length. This adds further steps to the calculation chain compared with stem positioning. Errors in the angle estimate will also amplify any deviations in the position of the harvester head. Another factor is that logs can roll on the ground after they have been cut, which is also a source of error. For this reason, log positioning should be expected to perform less well than stem positioning. Table 29 summarizes the results, reporting the mean deviation and standard deviations in the principal directions, analogous to those reported for stem positioning, as well as the mean error and standard deviation for the angular deviations.

Table 29. Average positional error and standard deviation for the center coordinates of the logs and average error and standard deviation for the log angles.

	Komatsu
Average error (m)	0,42
Standard deviation 1 (m)	0,45
Standard deviation 2 (m)	0,26
Standard deviation combined (m)	0,52
Average angle error, (grader)	7,41
Standard deviation angle (grader)	4,19

The results show that log positioning works well. The fact that the deviations are larger than for stem positioning is expected, given the additional complications involved in the calculation. As for stem positioning, the objective should be to enable individual logs to be clearly identified, but the conditions for doing so make this more difficult to achieve than the corresponding functionality for stems. Cut logs can often lie very close to one another, creating a much more challenging situation for identifying individual logs compared with growing stems. Nevertheless, the results show that positioning performs well enough that the majority of logs would roughly be found within an open forwarder grapple. This is a very good result given how new this technology is. Like stem positioning, log positioning will most likely lead to many new applications, and all manufacturers should implement it.

References

Agresti, A. 2002. Categorical Data Analysis. John Wiley & Sons.

Arlinger, J., Nordström, M. & Möller, J. J. 2021. StanForD 2010 – Modern kommunikation med skogsmaskiner. Arbetsrapport 784-2021. Skogforsk.

Biometria, 2026. Kvalitetsbestämning av sågtimmer av tall och gran. Nationella bestämmelser för virkesmätning.

Biometria, 2026. Kvalitetssäkrad mätning med skördare.

Brown, M. & Forsythe, A. 1974. Robust Tests for the Equality of Variances. Journal of the American Statistical Association, pp. 364–367.

Efron, B. 1987. Better Bootstrap Confidence Intervals. Journal of the American Statistical Association, pp. 171–185.

Engberg Sundström, L., Ene, L., Möller, J. J. & Arlinger, J. 2025. Automatgenererade styrprislistor för skördare. Skogforsk.

Hannrup, B. &. Jönsson. P. 2010. Utvärdering av sågmotorn F11-iP med avseende på förekomsten av kapsprickor – en jämförande studie. Arbetsrapport nr. 708. Skogforsk, 21 s.

Hannrup, B. 2004. Funktioner för skattning av barkens tjocklek hos tall och gran vid avverkning med skördare. Arbetsrapport 575-2004. Skogforsk.

Hannrup, B., m.fl. 2020. Utveckling av ny barkfunktion och utvärdering av mätprecision för björk i södra och mellersta Sverige. Arbetsrapport 1035-2020. Skogforsk.

Hannrup, B., m.fl.. 2022. Utveckling av rikstäckande barkfunktion för björk för användning i skördare. Arbetsrapport 1122-2022. Skogforsk.

Hannrup, B., Nordström, M., Arlinger, J. & Carlsson, F. 2023. Förbättrat uppföljningsverktyg för diametermätning i skördare – erfarenheter från praktiska tester. Arbetsrapport 1152-2023. Skogforsk.

Hannrup, B., Nordström, M., Arlinger, J. & Andersson, M. 2020. Nya uppföljningsverktyg för förbättrad diametermätning i skördare. Arbetsrapport 1055-2020. Skogforsk.

Helgesson, T. 1997. Förekomst av kapsprickor hos sågtimmer upparbetat med skördare. Trätek Rapport nr. 9712100.

Holm, S. 1979. A Simple Sequentially Rejective Multiple Test Procedure. Scandinavian Journal of Statistics, pp. 65–70.

Möller, J. J., Arlinger, J., Hannrup, B. & Jönsson, P. 2008. Virkesvärdestest 2006. Redogörelse 5-2008. Skogforsk.

Möller, J. J., Arlinger, J. & Nordström, M. 2013. Test av StanForD 2010 – Implementation i skördare. Arbetsrapport 798–2013. Skogforsk.

Möller, J. J., Sondell, J. & Arlinger, J. 2002. Virkesvärdestest 2001 – Apteringsfrågor. Redogörelse 7-2002. Skogforsk.

Nordström, M., m.fl. 2018. Virkesvärdestest 2016. Skogforsk.

,Oregon. 2012. Saw Chain Information. In: Mechanical Timber Harvesting Handbook.

Skogforsk, 1999. Gör din egen film om kapsprickor. Skogforsk Nytt nr 1.

Skogforsk. Timan 5.0 – verktyg för virkesanalyser. [Online]
Available at: https://www.skogforsk.se/rad--stod/beslutsstod--verktyg/timan-5.0
[Accessed 2026].

Skogforsk. Verktyg för analys av skördardata – hprStamhållning. [Online]
Available at: https://www.skogforsk.se/rad--stod/beslutsstod--verktyg/verktyg-for-analys-av-skordardata2/
[Accessed 2026].

Sondell, J. & von Essen, I. 1996. Apteringsdatortest 1995 – studier av sex apterings-system. Redogörelse 4-1996. Skogforsk.

StanForD, Skogforsk. StanForD - Default species group instructions. [Online]
Available at: https://www.skogforsk.se/english/projects/stanford/
[Accessed 2026].

Wilson, E. 1927. Probable Inference, the Law of Succession, and Statistical Inference. Journal of American Statistical Association, pp. 209–212.

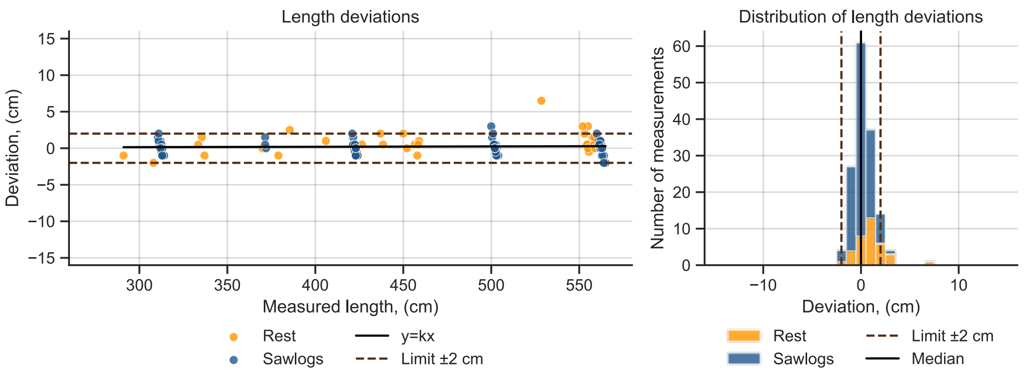
Appendix 1

This appendix contains supplementary information for Study 1. It includes overview figures of all length and diameter measurements, results from hypothesis testing of differences among manufacturers, and information on standard deviations for diameter measurements corrected for calibration.

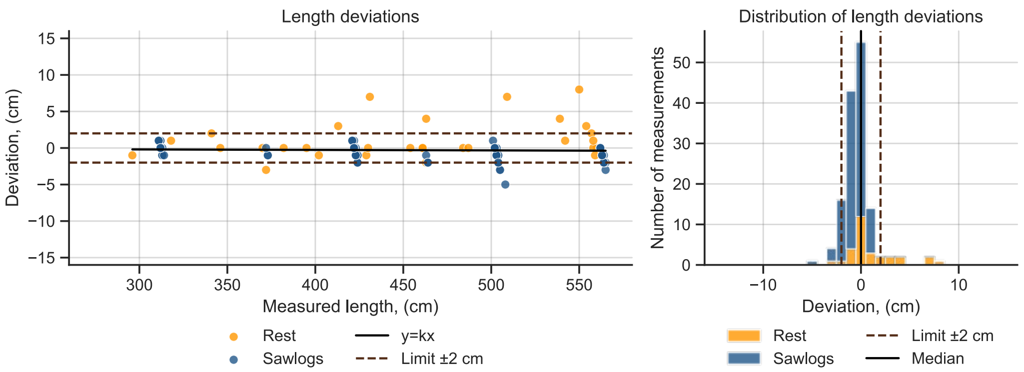
Length measurements

All length measurements for all manufacturers are shown here. The results are divided into sawlog products and other products. Each figure shows the length deviation between the harvester measurements and the control measurements on the left as a function of measured length, together with a linear calibration curve without offset and the threshold values ±2 cm. On the right, a histogram of the same deviations is shown with the median value and the same threshold values indicated.

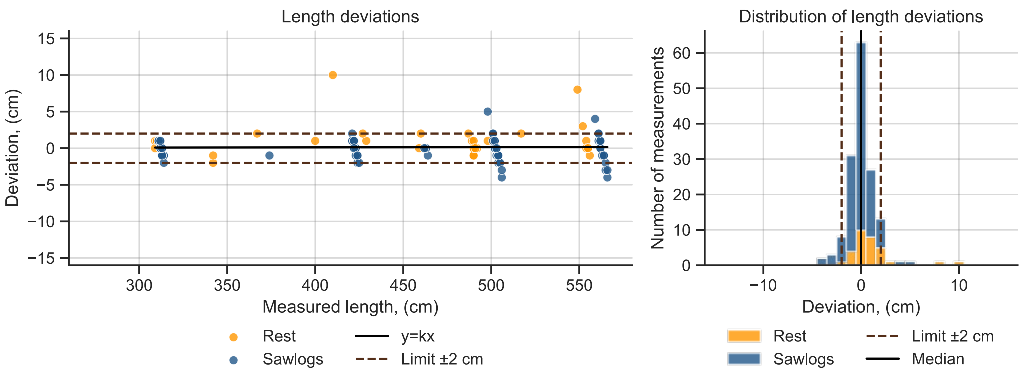
Eco Log



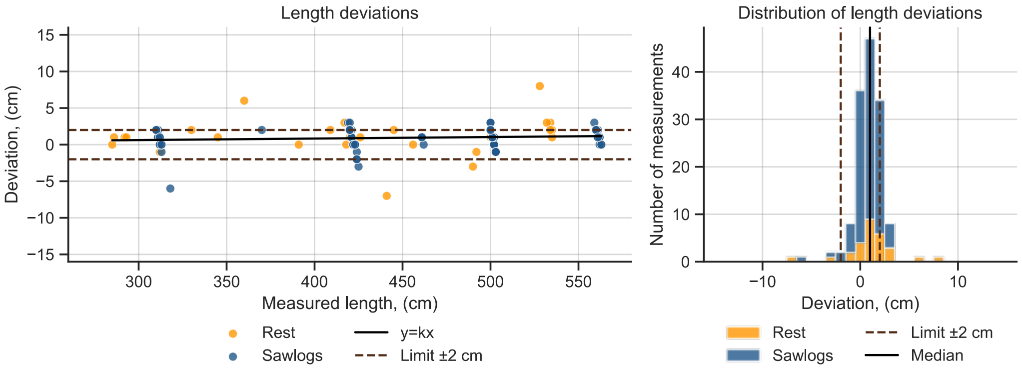
John Deere



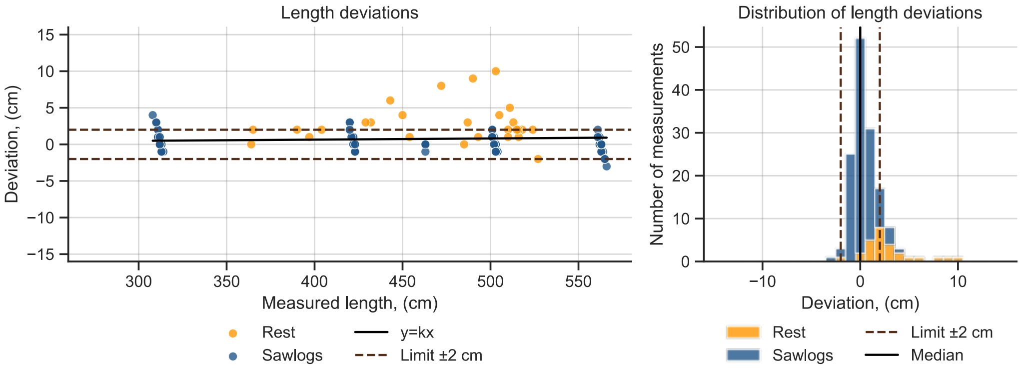
Komatsu



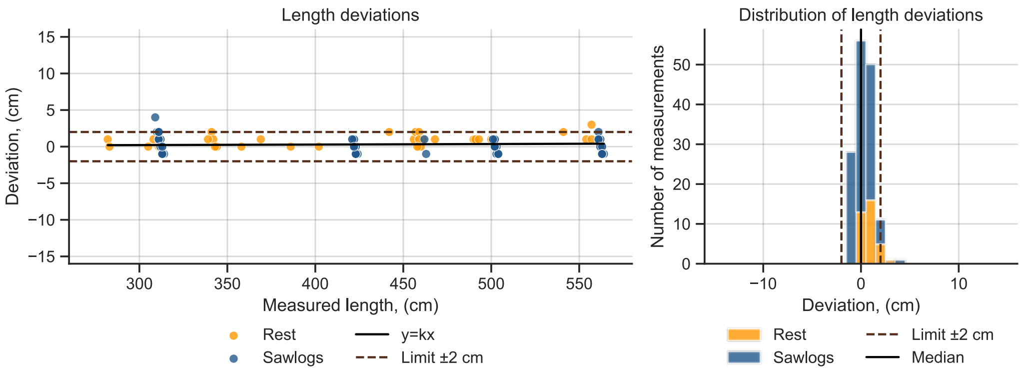
Log Max



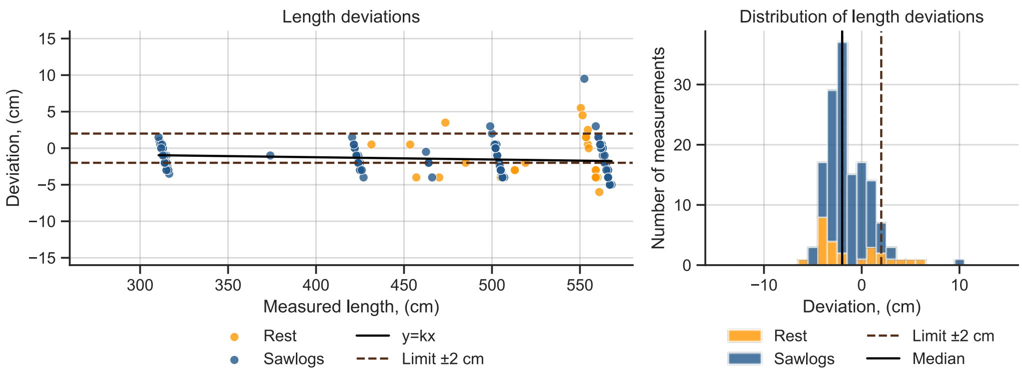
Logset



Ponsse



Rottne



Hypothesis testing for length measurements

Below are the results from hypothesis testing of differences in standard deviation among all manufacturers and differences in the proportion within ±2 cm. For the standard deviations, the evaluation was carried out using pairwise Brown-Forsythe tests to compare variance among all manufacturers (Brown & Forsythe 1974). The reason for using Brown-Forsythe was that this test is more robust for non-normal distributions. To correct for the large number of subtests, all manufacturers compared with each other, that is, 21, a Holm correction (Holm 1979) was used to avoid overestimating differences among manufacturers. The Holm correction sorts all p-values from lowest to highest and then adjusts each value by multiplying it by m-i, where m is the number of subtests performed (21) and i is an index that is 0 for the first p-value and then increases by 1 for each subsequent p-value. For hypothesis testing of the proportion within ±2 cm, a standard Z-test was used (Agresti 2002), and in this case too a Holm correction was used to correct for the number of tests.

The tests below were performed on all logs from the sawlog product. The numbers in the image matrices indicate corrected p-values, where a value below a given tolerance level indicates significance (usually 0.05). This means that the differences shown in the bar charts among manufacturers are significant if the p-value for the corresponding manufacturer combination is below 0.05. The confidence intervals in the bar charts were estimated using bootstrapping and show the 95% interval. The method is a resampling method that involves drawing N randomly selected values with replacement from the collected measurements, where N corresponds to the number of measurements in the original data. For the new dataset, the parameter of interest, here the standard deviation, is then calculated. This is then repeated a large number of times; here it was done 9999 times. This produces a distribution of standard deviations from which a confidence interval can then be extracted. The BCa variant of this method makes it more robust by correcting for systematic errors in the estimate and handling skewness in the underlying distribution (Efron 1987). The confidence intervals for the proportion within the threshold values ±2 cm also indicate a 95 percent interval and were calculated using Wilson's method (Wilson 1927). Because each test can only produce one of two outcomes (inside or outside the interval), the standard deviation and confidence interval can be calculated solely from the proportion of tests performed and the proportion within the threshold values. Wilson's method is used here instead of Wald's method because the probability of a successful test is relatively close to 100 percent and is therefore more suitable.

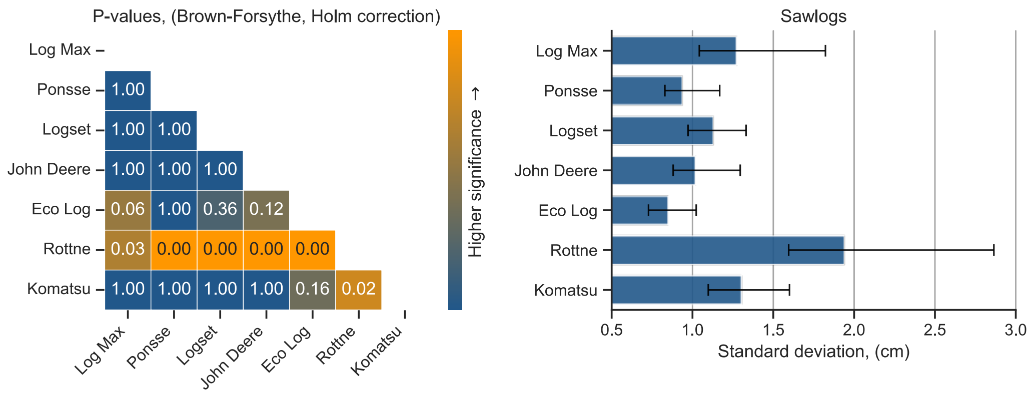


Figure 42. Hypothesis testing of differences in variance between all manufacturers based on a Brown-Forsyth test with Holm correction. P-values to the left, standard deviations to the right along with 95% CI.

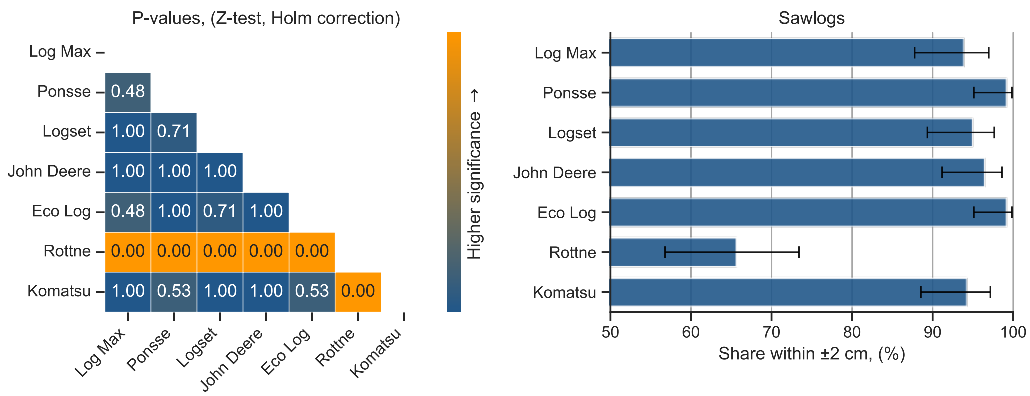
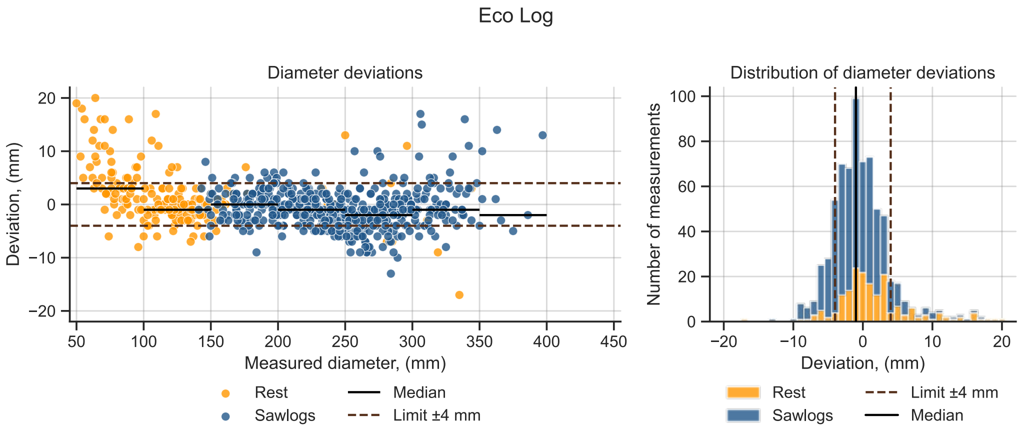
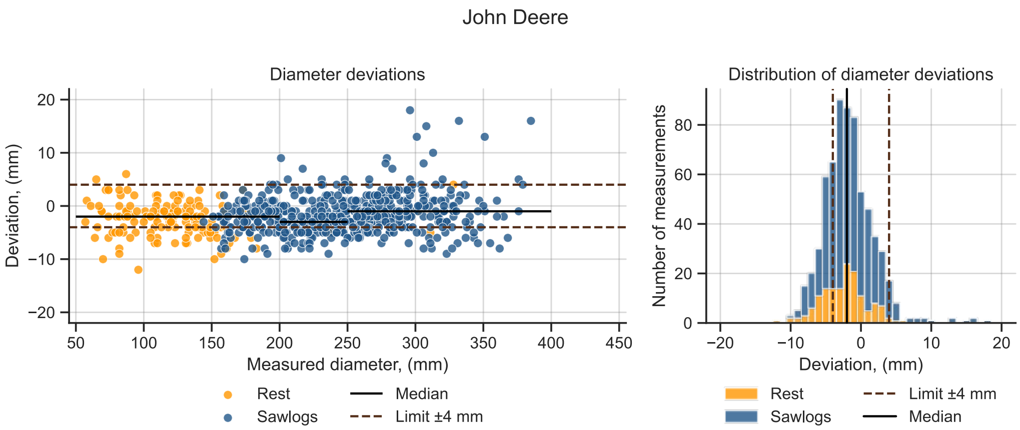


Figure 43. Hypothesis testing of differences in the share of measurements within ±2 cm between all manufacturers based on a Z-test with Holm correction. P-values to the left actual values to the right along with 95% CI.

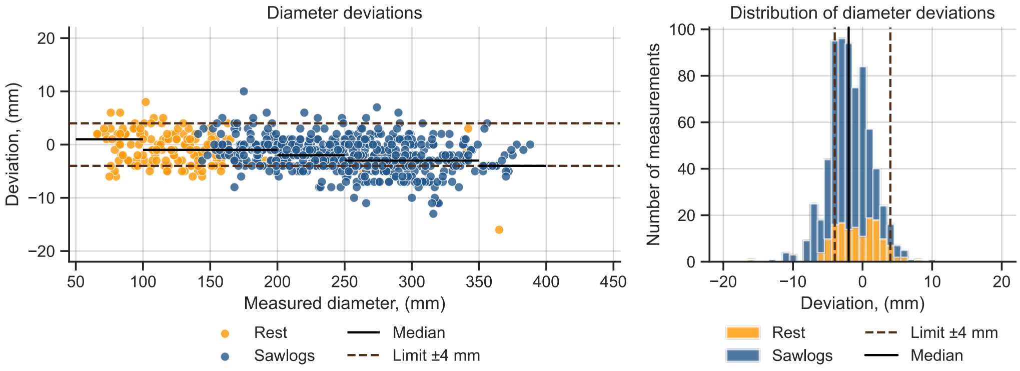
Diameter measurements

All diameter measurements for all manufacturers are shown here. The results are divided into sawlog products and other products. The deviations between the harvester measurements and the control measurements are shown on the left as a function of measured diameter, together with median values for each 50 cm interval and the threshold values ±4 mm. On the right, a histogram of the same deviations is shown together with the median value and the same threshold values.

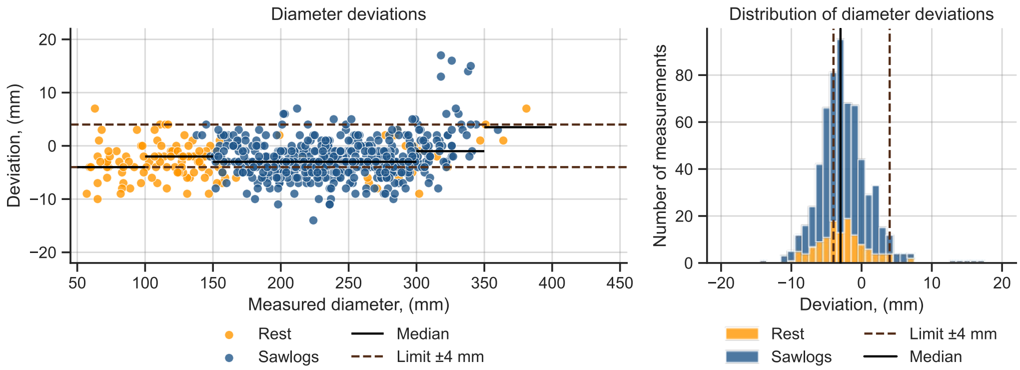




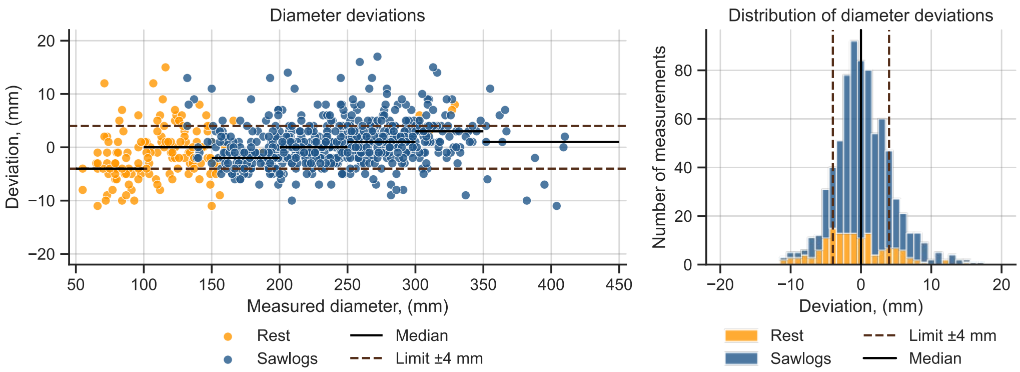
Komatsu



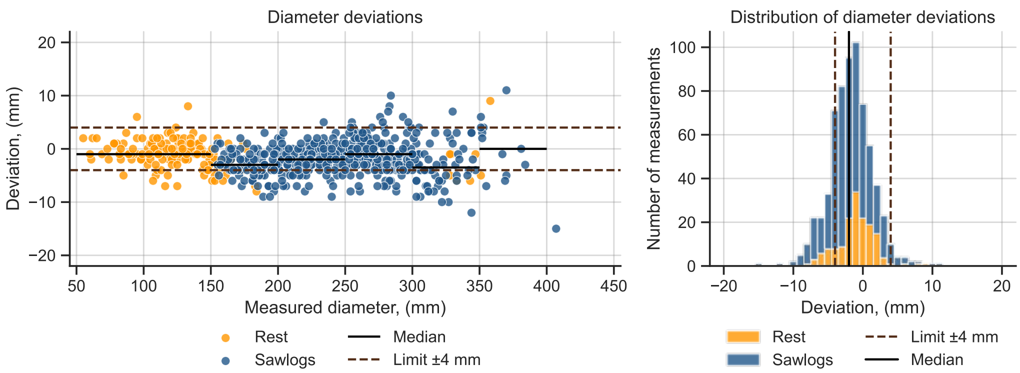
Log Max

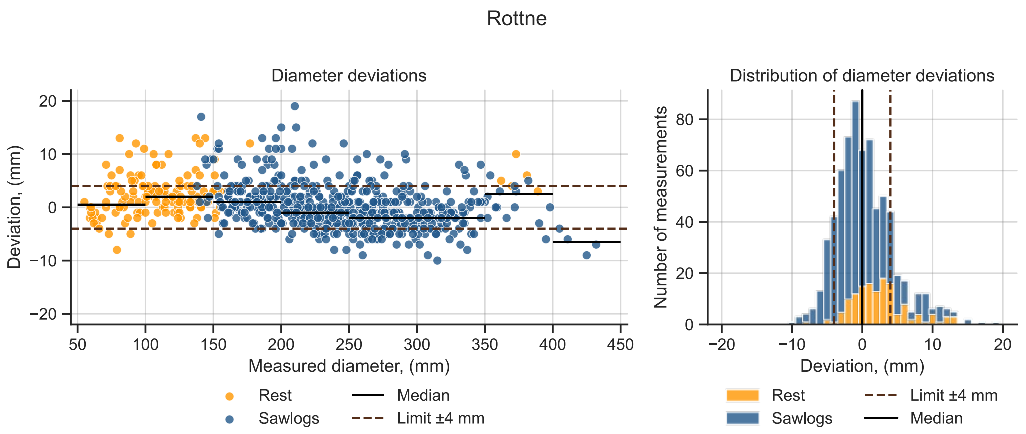


Logset



Ponsse





Hypothesis testing for diameter measurements

Here, the results from hypothesis testing for the diameter measurements are shown for the proportion within ±4 mm and the variance in the measurements. The results refer to the sawlog product. The procedure follows that used for the length measurements, where a more detailed description of the methods is provided.

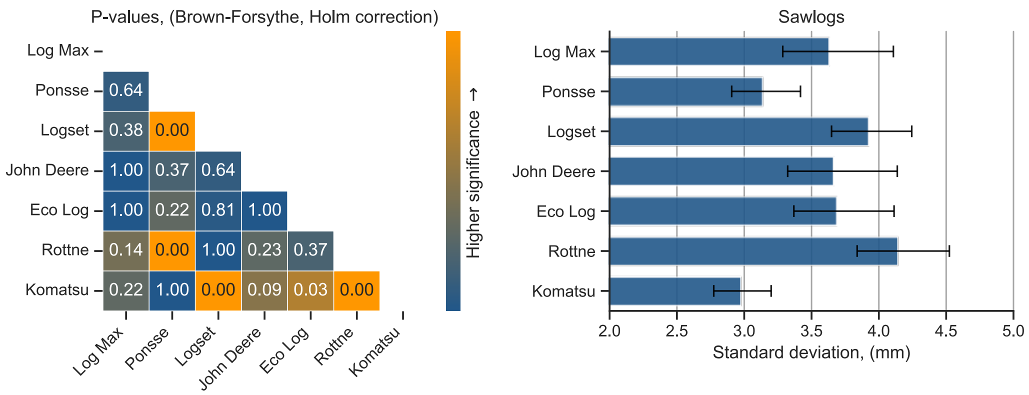


Figure 44. Hypothesis testing of differences in variance between all manufacturers based on a Brown-Forsyth test with Holm correction. P-values to the left, standard deviations to the right along with 95% CI.

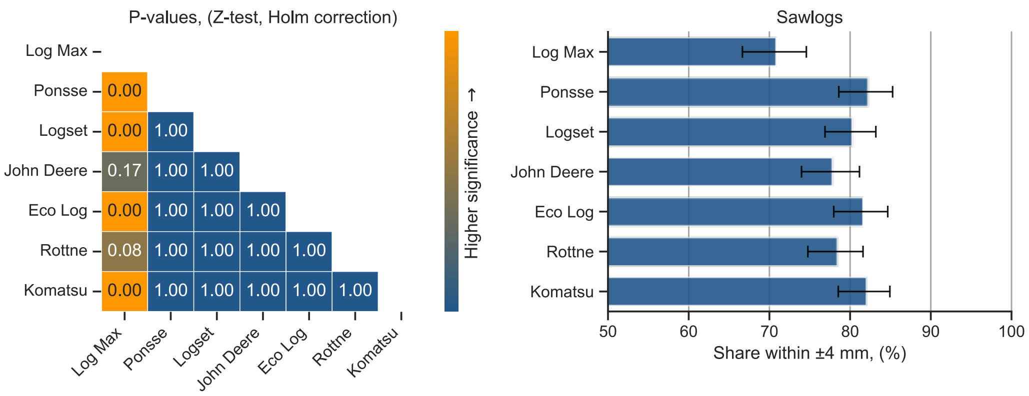


Figure 45. Hypothesis testing of differences in the share of measurements within ±4 mm between all manufacturers based on a Z-test with Holm correction. P-values to the left actual values to the right along with 95% CI.

Corrected standard deviations for diameter measurements

Standard deviations for all manufacturers after correction of mean values within diameter classes. This shows the standard deviation for the machines without the effect of calibration. Effects of calibration may still remain if the original calibration was not performed at even intervals of 50 cm or multiples thereof. For the sawlog product, the differences are relatively consistent across all manufacturers. At the margin, John Deere is affected slightly less and Rottne slightly more in relation to the standard deviations for the machines as they were configured during the test. The average difference for all products is 0.23 mm, and for the sawlog products it is 0.18 mm.

Table 307. Standard deviations for the differences in diameter measurements between control measurements and harvesters. The results show all products, sawlog products and both combined. Not calibrated show the results without correction across the entire dataset while calibrated show the results across the entire dataset after removing the bias in each diameter class to remove the artificial contribution to the standard deviation otherwise present.

	Not calibrated		Calibrated		Difference	
Log Max	All	Sawlogs	All	Sawlogs	All	Sawlogs
Average (mm)	-2,48	-2,41	0,00	0,00	-	-
Standard deviation (mm)	3,58	3,63	3,38	3,39	0,20	0,24
Ponsse	All	Sawlogs	All	Sawlogs	All	Sawlogs
Average (mm)	-1,67	-1,88	0,00	0,00	-	-
Standard deviation (mm)	3,06	3,13	2,84	2,94	0,21	0,19
Logset	All	Sawlogs	All	Sawlogs	All	Sawlogs
Average (mm)	0,39	0,71	0,00	0,00	-	-
Standard deviation (mm)	4,16	3,92	3,89	3,75	0,27	0,17
John Deere	All	Sawlogs	All	Sawlogs	All	Sawlogs
Average (mm)	-1,73	-1,53	0,00	0,00	-	-
Standard deviation (mm)	3,59	3,66	3,50	3,58	0,09	0,08
Eco Log	All	Sawlogs	All	Sawlogs	All	Sawlogs
Average (mm)	-0,22	-0,92	0,00	0,00	-	-
Standard deviation (mm)	4,41	3,69	3,93	3,47	0,48	0,22
Rottne	All	Sawlogs	All	Sawlogs	All	Sawlogs
Average (mm)	0,48	-0,02	0,00	0,00	-	-
Standard deviation (mm)	4,22	4,14	3,86	3,83	0,35	0,31
Komatsu	All	Sawlogs	All	Sawlogs	All	Sawlogs
Average (mm)	-1,78	-2,06	0,00	0,00	-	-
Standard deviation (mm)	3,08	2,97	2,90	2,83	0,18	0,14

Historical results

Table 31 shows the historical results from previous wood value trials. The table refers to the sawlog products and shows the proportion within the respective tolerances for the length and diameter measurements, as well as the standard deviations.

Table 81. Historical results for the share of measurements within tolerances and the standard deviations for both length and diameter measurements. All values are for the sawlog products.

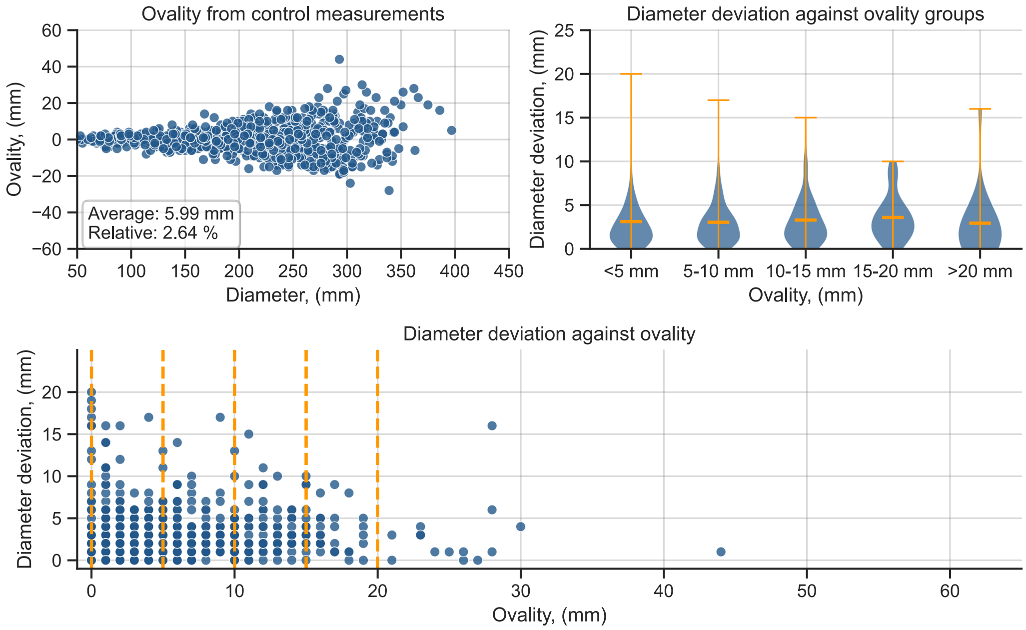
Year	2001	2006	2016	2025
Length within ±2 cm (%)	77,0	84,0	89,3	91,6
Length standard deviation (cm)	3,10	2,20	1,74	1,44
Diameter within ±4 mm (%)	63,8	68,0	78,6	79,1
Diameter standard deviation (mm)	5,00	4,50	4,12	3,78

If the 2025 values are corrected by excluding Rottne because of their calibration problems, the values for the length measurements are 96.2 percent within ±2 cm and a standard deviation of 1.18 cm.

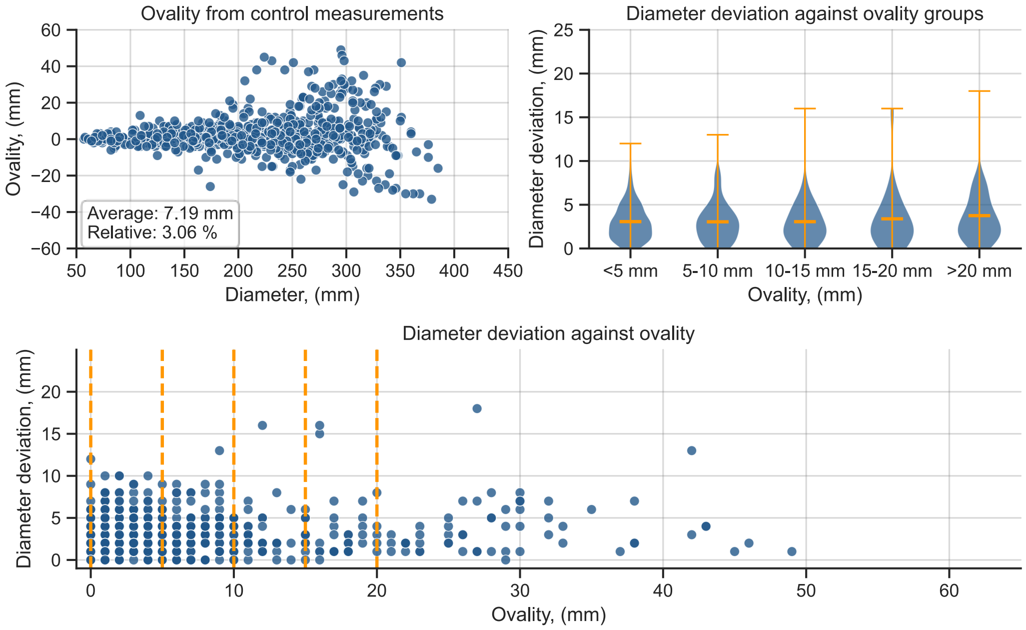
Ovality

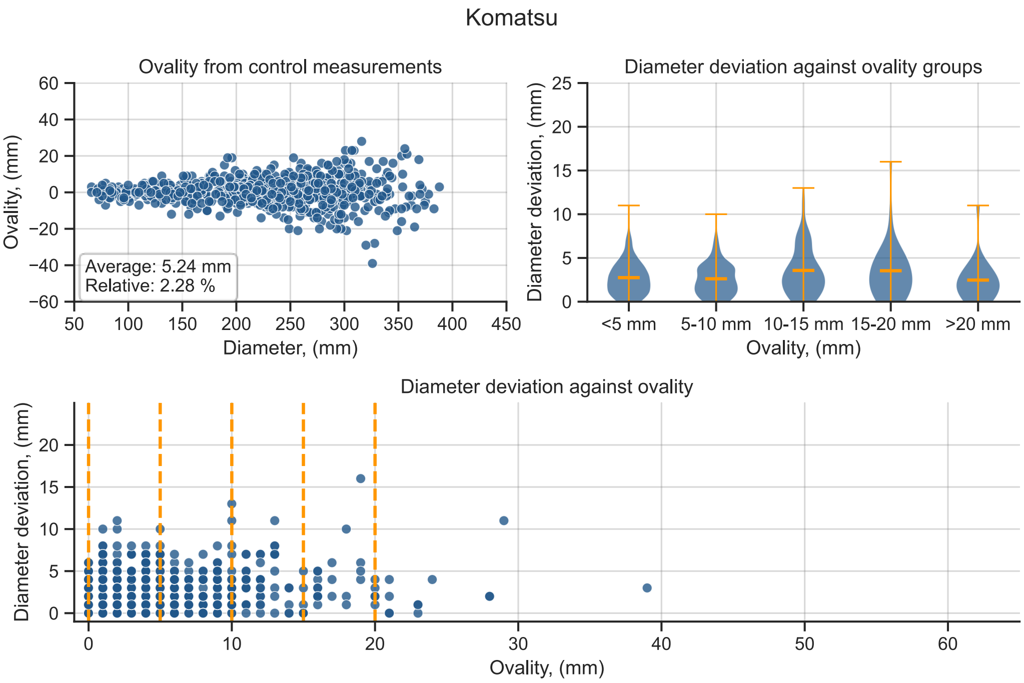
Below, the ovality from all diameter measurements is shown, estimated as the difference between the two cross-callipered diameters from the control measurements for all manufacturers. The upper-left panel shows the estimated ovality in relation to the measured diameter. The mean absolute ovality and the mean relative ovality are also indicated. The upper-right panel shows how the diameter deviations vary depending on the estimated ovality, where ovality has been grouped into 5 mm sections to make it more balanced and robust. Below these, all ovality estimates are shown against the diameter deviations, with the group intervals indicated to facilitate matching with the upper-right figure. Based on the control measurements performed during this test, no clear relationship between increased ovality and poorer measurement performance can be identified for any manufacturer.

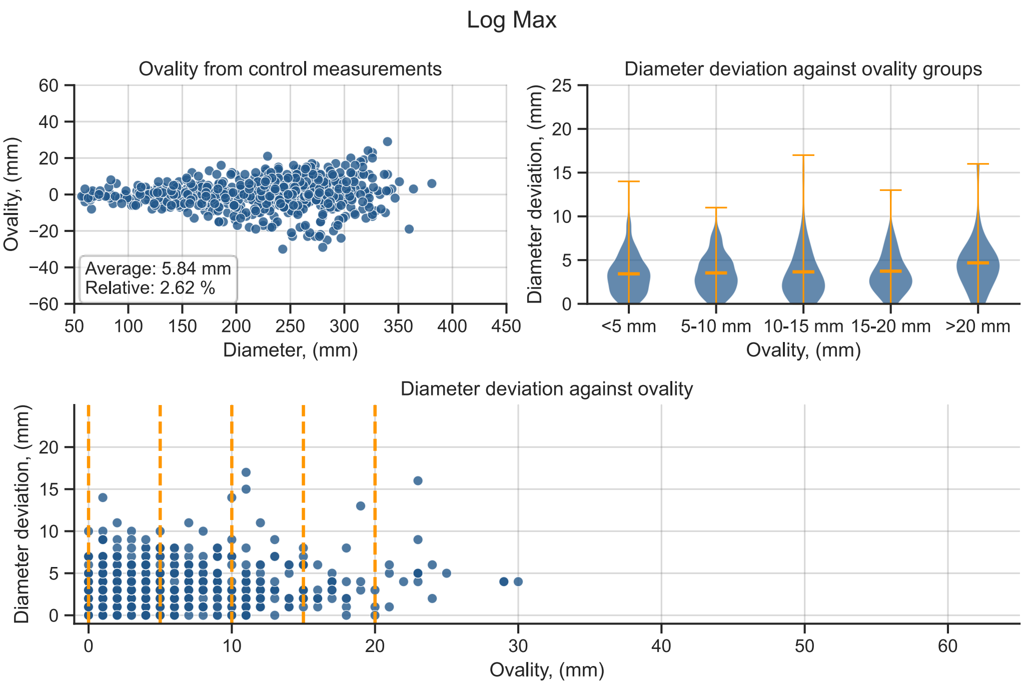
Eco Log



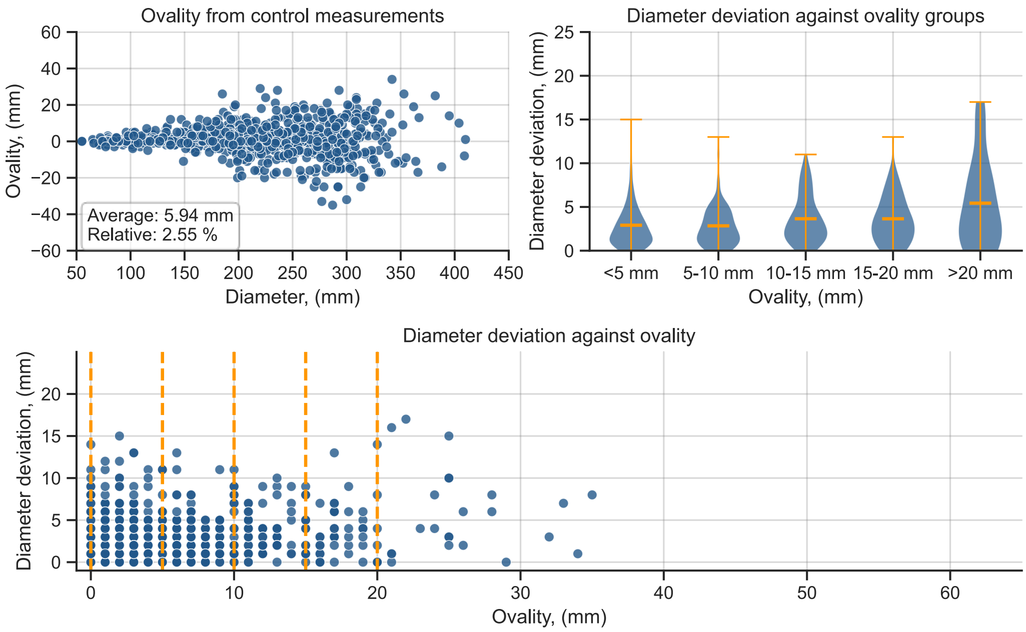
John Deere



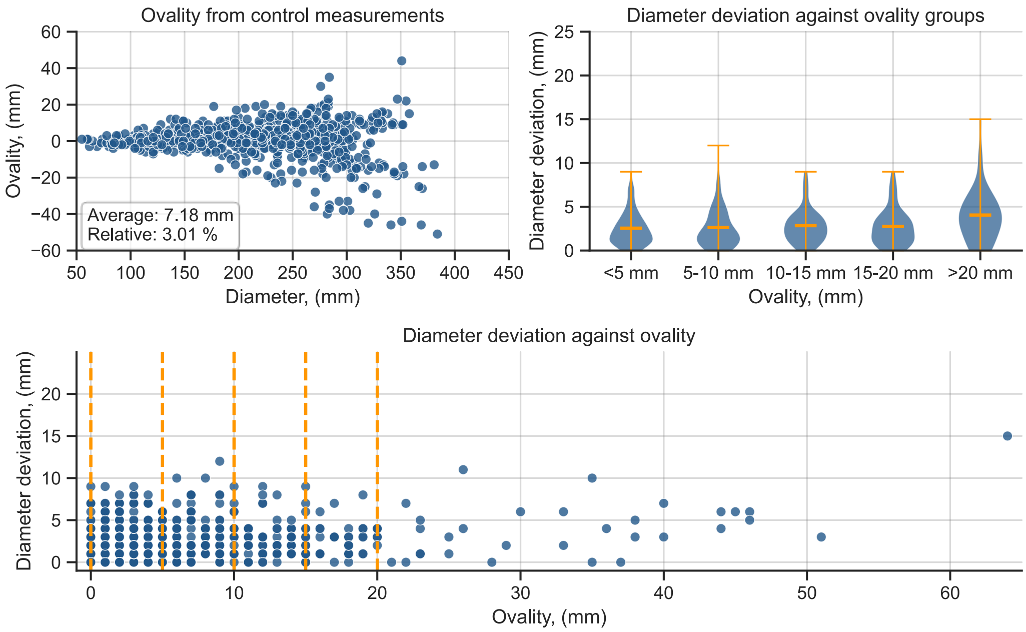

Komatsu
Ovality from control measurements
Ovality, (mm)
Diameter, (mm)
Average: 5.24 mm
Relative: 2.28 %
Diameter deviation against ovality groups
Diameter deviation, (mm)
<5 mm
5-10 mm
10-15 mm
15-20 mm
>20 mm
Ovality, (mm)
Diameter deviation against ovality
Diameter deviation, (mm)
Ovality, (mm)

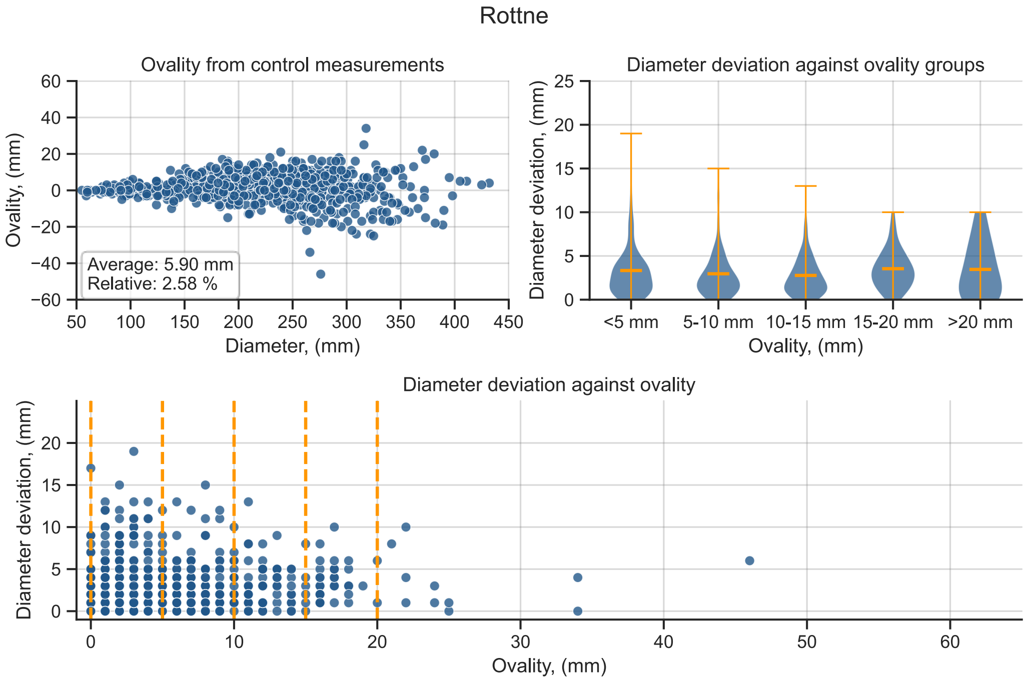

Log Max
Ovality from control measurements
Ovality, (mm)
Diameter, (mm)
Average: 5.84 mm
Relative: 2.62 %
Diameter deviation against ovality groups
Diameter deviation, (mm)
<5 mm
5-10 mm
10-15 mm
15-20 mm
>20 mm
Ovality, (mm)
Diameter deviation against ovality
Diameter deviation, (mm)
Ovality, (mm)

Logset



Ponsse





Rottne
Ovality from control measurements
Ovality, (mm)
Diameter, (mm)
Average: 5.90 mm
Relative: 2.58 %
Diameter deviation against ovality groups
Diameter deviation, (mm)
<5 mm
5-10 mm
10-15 mm
15-20 mm
>20 mm
Ovality, (mm)
Diameter deviation against ovality
Diameter deviation, (mm)
Ovality, (mm)

Appendix 2

Product matrices used during the trial

Sawlogs for value optimized bucking

Price matrix (top) and distribution matrix (bottom), including length classes (cm) and diameter classes (mm), for spruce sawlogs class 1 used for value optimized bucking. Classes marked in blue were permitted only for manual cuts. Classes marked in red were completely prohibited. Prices are given in SEK/m³top (ub) and distributions as proportions of volume (by diameter class). The price matrix was designed using Skogforsk's Autopris tool, based on the distribution matrix; thus, the distribution matrix was not used for distribution bucking. The matrices for spruce sawlogs class 2 had the same structure, but the price matrix was reduced by 150 SEK in each cell.

L\D	180	190	200	220	230	240	260	280	300	320	340	370	400
310	1071	1124	1131	550	550	550	550	550	550	550	550	550	550
370	1071	1124	1137	1179	1224	1243	1248	1261	1273	1276	1257	995	1132
420	1304	1326	1338	1346	1402	1403	1433	1452	1454	1472	1443	1204	1275
460	1247	1242	1330	1332	1385	1398	1426	1433	1444	1451	1430	1189	1258
500	1382	1369	1396	1414	1443	1472	1498	1505	1503	1496	1467	1254	1293
560	1259	1397	1447	1458	1461	1498	1528	1520	1524	1499	1478	1100	1100

L\D	180	190	200	220	230	240	260	280	300	320	340	370	400
310	20	20	10	0	0	0	0	0	0	0	0	0	0
370	3	3	3	3	3	3	3	3	3	3	3	3	3
420	30	30	30	40	40	25	25	25	25	40	40	40	40
460	3	2	2	2	2	2	2	2	2	2	2	2	2
500	34	25	30	30	30	40	40	40	40	35	35	50	50
560	10	20	25	25	25	30	30	30	30	20	20	5	5

Sawlogs for distribution bucking

Price matrix (top) and distribution matrix (bottom), including length classes (cm) and diameter classes (mm), for spruce sawlogs classes 1–2 used for distribution bucking. Classes marked in red were completely prohibited. Prices are given in SEK/m³sub and distributions as proportions of volume (by diameter class).

L\D	180	190	200	220	230	240	260	280	300	320	340	370	400
310	1000	1000	1000	0	0	0	0	0	0	0	0	0	0
370	850	850	850	850	850	850	850	850	850	850	850	850	850
415	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
460	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
495	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
555	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

L\D	180	190	200	220	230	240	260	280	300	320	340	370	400
310	20	15	5	0	0	0	0	0	0	0	0	0	0

370	0	0	0	0	0	0	0	0	0	0	0	0	0
415	35	30	30	35	31	31	31	35	35	35	35	31	31
460	1	1	1	1	1	1	1	1	1	1	1	1	1
495	43	34	44	44	38	38	38	49	49	49	49	67	67
555	1	20	20	20	30	30	30	15	15	15	15	1	1

Short sawlogs

Price matrix, including length classes (cm) and diameter classes (mm), for short sawlogs. Prices are given in SEK/m^3sub.

L\D	130	140	150	160	170	180	190
310	680	680	680	680	680	830	830

Pulpwood

Price matrix (left) and distribution matrix (right), including length classes (cm) and diameter classes (mm), for spruce pulpwood. The matrices were designed in accordance with the recommendation for designing pulpwood matrices provided in Appendix 5b, Nordström et al. 2018. Classes marked in blue were allowed only for manual cuts. Classes marked in yellow were allowed only for value optimized bucking. Prices are given in SEK/m^3sub and distributions as proportions of volume (by diameter class). The matrices for coniferous pulpwood had the same structure but were assigned a slightly lower price in all cells.

L\D	30	50	60	70	150
290	30	60	110	600	600
330	30	60	110	600	600
360	30	60	110	600	600
390	30	60	110	600	600
420	30	60	110	600	600
450	30	60	110	600	600
480	30	60	110	600	600
510	30	60	110	600	600

L\D	30	50	60	70	150
290	0	0	0	0	0
330	0	0	0	0	0
360	0	0	0	0	0
390	0	0	0	0	0
420	0	0	15	15	0
450	0	0	70	70	0
480	0	0	15	15	0
510	0	0	0	0	0

Appendix 3

Stem profiles and pulpwood lengths when calculating bucking degree

When bucking performance is monitored using Aptupp, the registration of the stem profile (diameter vectors in hpr and hqc) affects the resulting bucking degree. If the stem profile contains diameter values only up to the final cut, a higher bucking degree is obtained than when diameter values beyond the final cut are included (ideally up to the smallest permitted diameter). This is because a stem profile ending at the final cut indirectly forces Aptupp's bucking simulation to place the final cut at the same stem height as the harvester, whereas, in theory, it may have been possible to make the final cut higher up the stem and thereby achieve a higher timber value.

The registration of the harvester-measured stem profile (hpr or hqc-M1) varies among machine systems: in some systems, the stem profile is recorded only up to the final cut, whereas in others the registration continues as far as the harvester head feeds the stem before the top is released. This should be taken into account during follow-up based on the harvester-measured stem profile.

For follow-up based on the control-measured stem profile (hqc-M2), the entire merchantable portion of the tree should be recorded during control measurement, which often means that the unused top also needs to be measured. During the Wood Value Trials, the length of the tops was measured from the final cut (the butt end of the top) up to a diameter of 50 mm. A problem arises, however, if the stem has a broken top. How far should values then be collected?

In accordance with previous Wood Value Trials, the rules below were applied.

Stem profile from harvester measurement

Only the stem profile up to the final cut was used, and any additional diameter values were removed. However, this indirectly forces Aptupp's bucking simulation toward a bucking pattern similar to that of the harvester. To make the bucking simulation more independent of the harvester's bucking, 100 cm pulpwood pieces were permitted in diameter classes smaller than the smallest diameter class for sawlogs and short sawlogs.

Stem profile from control measurement

The stem profile from manual control measurement (hqc-M2) contains diameter values up to the final cut. This stem profile was supplemented with data from the separate measurement of top lengths up to a diameter of 50 mm.

Stem profile from control measurement in cases of top breakage

The stem profile from manual control measurement contains diameter values up to the broken top. In cases of broken tops, the length of the top is missing, which results in a stem profile ending at the final cut and indirectly forces the bucking simulation toward a bucking pattern similar to that of the harvester. Therefore, as in the follow-up based on stem profiles from harvester measurement, 100 cm pulpwood pieces were permitted in diameter classes smaller than the smallest diameter class for sawlogs and short sawlogs.

Stems with broken tops with a final-cut diameter larger than the minimum sawlog dimensions were not included among the 30 spruce stems in the main trial.

Appendix 4

Support for other bucking settings

Table 32. Bucking logic and pin and spi settings.

	Dasa	Ponsse	John Deere	Komatsu	Log Max	Logset
Max no. of tree species	10	12	16	No limit	16	10
Max no. of products per species	No limit	16	No limit	No limit	No limit	No limit
Max no. of diameter classes per matrix/total	No limit	No limit	No limit	No limit	No limit	No limit
Max no. of length classes per matrix/total	No limit	No limit	No limit	No limit	No limit	No limit
Max no. of qualities	No limit	16	No limit	No limit	No limit	No limit
Pulpwood requirement	No	No	No	No	No	No
ButtLogMAXStartHeight	No	Yes (defaults to 150 cm)	No	No	No	No
Length margin	Yes	Yes	Yes	Yes	Yes	Yes

Table 339. Distribution bucking logic.

	Dasa	Ponsse	John Deere	Komatsu	Log max	Logset
Distribution model	Near-optimal	Near-optimal*	Near-optimal	Near-optimal	Near-optimal	Unknown
Calculation model for value deviation	Max value of 1st log	Max value of 1st log	Max value of 1st log	Max value of 1st log	Max value of 1st log	Unknown
Selection of log to be cut	Greatest deficit	Greatest deficit	Greatest deficit	Greatest deficit	Greatest deficit	Unknown
New object using old log tally in distribution bucking	No	Yes	Yes	Yes	Yes	Unknown
Use distribution bucking based on “volume” and “no. of logs” at the same object	Yes	Yes	No	Yes	Yes	-
Warning when cutting unclassified log	No	Enter + forced cut	Special command	Special command	No	Yes

*Ponsse also supports the “adaptive price list” method.

Appendix 5

Log dimensions

Each harvester bucked 30 Norway spruce stems. For the larger spruces, the bucking gave five different sawlogs per stem. Sawlogs and small-diameter sawlogs ("kubb") were evaluated, but not pulpwood. Below, the number of sawlogs per manufacturer and the corresponding dimensions are presented. For example, up to the third log, all manufacturers had approximately the same number of logs. More importantly, the top diameters are relatively uniform.

Table 34. Number of logs per log number and total sawlog amount for each of the machine systems.

Machine	Number of sawlogs per log number (N)					Total sawlogs (N)
	1	2	3	4	5	
Eco Log	30	30	29	26	2	**117**
John Deere	30	30	30	21	3	**114**
Komatsu	30	30	30	29	5	**124**
Log Max	30	30	30	24	4	**118**
Logset	30	30	30	27	1	**118**
Ponsse	30	30	30	23	0	**113**
Rottne	29	29	29	26	5	**118**

Table 35. Average top diameter (mm) per log number and in total for the machine systems.

Machine	Top diameter per log number (mm)					Mean (mm)
	1	2	3	4	5	
Eco Log	277	242	204	164	150	**215**
John Deere	279	242	200	169	150	**217**
Komatsu	287	254	210	172	158	**220**
Log Max	273	240	200	167	152	**212**
Logset	282	246	201	164	141	**216**
Ponsse	277	242	202	168		**217**
Rottne	277	244	205	170	164	**215**

Table 36. Average length (cm) per log number and in total for the machine systems.

Machine	Length per log number (cm)					Mean (cm)
	1	2	3	4	5	
Eco Log	461	492	438	325	312	**426**
John Deere	483	488	411	337	312	**427**
Komatsu	496	492	466	327	312	**433**
Log Max	485	480	415	317	313	**417**
Logset	491	474	413	316	312	**416**
Ponsse	499	483	387	317		**417**
Rottne	517	500	414	332	334	**428**

Appendix 6

Energy value of peeled bark

The price of bark was assumed based on the Swedish Energy Agency's quarterly statistics for wood fuel, peat and waste prices (2026). In the calculations, we used the price for the product "Biprodukter vid leverans till Värmeverk"(By-products to heating plant). We used the average price for the period 2020–2025, which amounted to 225 SEK/MWh. The price of "Biprodukter och andra trädbränslen" (Byproducts and other wood fuels) has generally increased sharply since 2022.

The following conversion factors and assumptions were used in the calculations:

- Assumed energy content: 0,65 MWh/m^3 loose (bulk cubic metre), corresponding to 1,54 m^3 loose/MWh
- Conversion: 2,5 m^3 loose/m^3sub (solid under bark) corresponds to 0,62 m^3sub/MWh, corresponding to 1,6 MWh/m^3sob (solid on bark)
- Energy value of bark: 1,6 MWh/m^3sob * 225 SEK/MWh = 360 SEK/m^3sob
- Assumed bark proportion: 12 % bark per m^3sob of timber
- Total bark value per m^3sob of timber: 0,12 * 360 = 43,2 SEK/m^3sob

Thus, the energy value for each percentage point of bark that is abraded, expressed as the value per m^3sob of timber, is 43,2 * 0,01 = 0,43 SEK

On average across all harvesters, the proportion of abraded bark relative to the total bark volume was 7 percent. The energy value of the abraded bark therefore averaged 7 * 0,43 = 3 SEK per m^3sob of harvested timber across all harvesters. The proportion of peeled off bark relative to the total bark volume for each harvester is presented in the table below.

Machine	**Total proportion of damaged bark volume (%)**
John Deere	14
Eco Log	11
Ponsse	10
Komatsu	6
Logset	4
Rottne	4
Log Max	3
Mean	**7**

Reference: Energimyndigheten 2026. Trädbränsle-, torv- och avfallspriser (Accessed 2026-04-07).