PO Box 1127
Rotorua 3040
Ph: + 64 7 921 1883
Fax: + 64 7 921 1020
Email: forestgrowersresearch@fgr.nz
Web: www.fgr.nz

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Benchmarking 2019 data and longer-term productivity and cost analyses

Authors:
Rien Visser[1] and Francis Obi[2]

Research Provider:
School of Forestry,
University of Canterbury

[1]Rien Visser is Associate Professor at School of Forestry, University of Canterbury

[2]Francis Obi is a lecturer at the Agricultural & Bioresources, University of Nigeria, Nsukka, Nigeria.

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EXECUTIVE SUMMARY

The drivers of productivity and cost of logging operations are important as productivity is a major determinant of the logging rate and the cost of logging operations directly affects the bottom line of both forest management companies and independent harvesting contractors. Understanding the drivers of logging cost and productivity is also important in considering alternative harvest systems as forest stand and terrain conditions change. Benchmarking harvesting cost and productivity across different conditions is one way for forest management companies and contractors to understand these drivers. Forest Growers Research Ltd has been operating a benchmarking system, managed by the School of Forestry, University of Canterbury, for 12 years with a total of 1652 unique harvest area entries contributed from 2008 to 2019.

The benchmarking database records standardised parameters relating to forest stand details, terrain details, and harvesting crew information on actual and completed logging operations by harvest area. This information includes tree size (tonnes), stand volume (tonnes/ha) and harvest area (ha), extraction distance (m), average slope (%), machine and labour usage, system productivity and actual logging rate.

This report is in two parts: the first part reports on results of the 2019 benchmarking data and trends; and part two analyses the whole database. Part one reports the results of 163 harvest area entries harvested in 2019. Part two of this report is a detailed evaluation of the 1600 unique entries received over the past 12 years (2008-2019). It analyses the key factors that influence productivity and logging rates and provides a series of regression equations that help improve our understanding of terrain and stand influences.

The overall average logging rate for ground-based operations increased to $28.70/tonne, which is up $0.35 compared to 2018 data. The ground-based logging rates ranged from $18/tonne for a mechanised grapple skidder operation, through to $50/tonne for a manual felling/skidder combination working in a difficult setting. For cable logging the average logging rate was $42.20/tonne, which was a $0.95 increase from the previous year. The lowest rate in the 2019 sample was for a swing yarder in a mechanised felling two-staging operation at $24/tonne, through to a high of $58/tonne for a manual felling tower yarder operation with poor deflection.

In cable logging operations the level of mechanised felling has continued to increase, now up to 40% of steep terrain operations. An additional 40 entries were received where the operation was supported by winch-assist, with all but six for yarder operations (the balance was in ground-based operations). While early indications were that winch-assist added a cost that was not recovered through increased productivity, in 2018 data that trend reversed with an average logging rate lower by $1.25/tonne. That change has been confirmed this year with the logging rate lower by $2.00/tonne for the 2019 data while also seeing an increase in productivity of 2 tonnes/hour in productivity. This reflects the industry becoming more confident and experienced with implementation of winch-assist.

With logging rates adjusted to 2019 values using the Producer Price Index, the mean harvesting contract rate was NZD $34.24/tonne, but it varied significantly between harvest methods. Harvesting contract rates for cable-based operations, being more labour intensive and lower productivity, were significantly higher than ground-based operations at $40.30/tonne and $27.90/tonne, respectively. The study highlighted differences in rates across the years, forest regions and seasons of harvest.

INTRODUCTION

The cost of logging operations has always been of great interest to both forest management companies and independent harvesting contractors. Logging cost directly affects the profitability of forest management companies, and the contract rate is vital to harvesting contractors for sustaining a financially viable business (Cubbage *et al.,* 1988). Logging rate is a "payment for services, whereby the service provided by the logging contractor to the forestry company is the conversion of standing trees into a number of specific log products" (Visser, 2010). Understanding the drivers that impact logging costs is important when considering harvest system alternatives as stand and terrain conditions change. Irrespective of the motivation to better understand harvesting cost and productivity, the true cost of operations can be challenging to reliably predict (Bell *et al.* 2017).

Although a number of studies over the years have provided good information on logging costs, these studies are often based on either specific conditions (case studies) or theoretical calculations using standard costing methodologies, rather than on empirical evidence of actual logging rates agreed between forest management companies and independent logging contractors on real contracts (Cubbage *et al.,* 1988; Hånell *et al.,* 2000; Kelly *et al.,* 2017). Very few reference studies are available for actual logging contract rates (Spinelli *et al.,* 2017). This is primarily because it takes substantial long-term effort to gather sufficient actual information to make realistic generalisations about the logging industry (Baker *et al.,* 2014). In addition, contracted logging rates are influenced by a number of factors including technical and non-technical factors associated with machine use, the operating environment, competition between contractors, and the market demand and supply of logging services (Spinelli *et al.,* 2015; Visser, 2010).

Logging rates derived using previously published studies are useful for comparing harvest systems, including developing and validating models (Baker *et al.,* 2014; Hartsough *et al.,* 2001). As such, theoretical predictions offer information to forest management companies when attempting to manage their logging rate, particularly in generalising harvest cost trends for the industry. Time and motion studies can be combined with advanced simulations to develop system models capable of combining forest stand, terrain and system data to produce reliable cost figures (McDonagh *et al.,* 2004). However, harvesting rates are composed of both technical and non-technical factors (Spinelli *et al.,* 2015; Obi and Visser 2018), and this reflects only one component of harvesting cost, not the actual rate. This makes it difficult to realistically predict and manage logging cost for practical purposes.

Direct collection of data from forest harvesting contractors provides an appropriate method of obtaining actual cost data for the logging industry and, over the long term provides potential to compare trends (Baker and Greene, 2008). The University of Canterbury, New Zealand currently manages an existing benchmarking database on behalf of Forest Growers Research Ltd. The database records standardised parameters by harvest area relating to actual and completed logging operations, including forest stand details, terrain details, and harvesting crew information. The database provides detailed information including tree size (tonnes), stand volume (tonnes/ha) and harvest area (ha), extraction distance (m), average slope (%), machine and labour usage, system productivity and actual logging rate.

Earlier publications have described the system and parameters recorded, along with results of harvest system descriptions, regional variation, parameter averages for cable and ground-based operations, and productivity and cost functions (Visser, 2009; Visser, 2011). Annual summary statistics have been presented in subsequent reports, with specific evaluations such as early analyses of the drivers of logging rate and productivity for grapple skidder, tower yarder and swing yarder systems (Visser, 2012; Visser, 2015; Visser, 2017) and changes in levels of mechanisation (Visser, 2014; Visser, 2016; Visser, 2018), and the adoption of winch-assist harvesting (Visser, 2018; Visser, 2019). One report summarised the trends over ten years of ground-based harvesting and cable yarding data (Visser, 2019).

The FGR Benchmarking system has demonstrated that many benefits can be gained from the systematic and continual sampling of productivity and logging rates in New Zealand. However, future opportunities include gaining knowledge of harvest contract rates between countries, given that modern industries are influenced by, and benefit from, the global wood market and the movement of contractors and their businesses from one country to another. Specific examples where this might be especially useful include significant changes in local market conditions due to catastrophic occurrences (such as forest fires, or widespread insect attack) in which case the knowledge of harvesting contract rates across borders becomes important to harvesting service providers (Spinelli *et al.,* 2017). The frequency of catastrophic damage in forests is projected to increase in the near future due to increasing climate change effect and wider silvicultural options (Dale *et al.,* 2001). Another situation could be in a case of demographic and forest resource differences as in the case of Italian and French logging companies and their forest resource differences (Spinelli *et al.,* 2017).

PART 1: 2019 BENCHMARKING DATA

For 2019 harvesting data, a total of 163 entries were received from 11 different companies, whereby six companies provided data that spanned two or more regions. Ground-based harvesting comprised 91 harvest area entries, and the remaining 72 entries were for cable logging. Most of the entries (95%) were from clearfell operations, with eight entries (5%) from road lining operations. There were no entries from thinning operations in the 2019 sample.

Average results for all data submitted in 2019 showed:

- The average harvest area was characterised as 12.4 hectares in area, with stand volume of 7,540 tonnes, or 608 tonnes/ha and average piece size of 1.98 tonnes, on a 27% slope.
- Regarding crew characteristics, 6.7 workers operated 5.4 machines, working 8.7 hours per day, extracting over a distance of 220 metres, producing 8.8 log sorts in 28 working days per landing.
- Over three-quarters of operations (78%) used a primary landing for processing, 10% of operations processed at the stump (cut-to-length harvester-forwarder crews), and 6% of operations used a secondary landing, and 6% processed at a log yard or central processing yard. In total, 17% of operations were two-staged with an average two-staging distance of 420m.
- In terms of harvesting difficulty, 38% of operations were rated by company staff as 'Easy', 48% were rated 'Medium' difficulty, and 14% were rated as 'Hard'. The difficulty factor attempts to rate the site for factors not covered by the standard terrain and stand factors.
- Mechanised felling was used in 132 of the operations (81%), and 158 operations (97%) used mechanised processing. Around 25% of operations were supported by winch assist (40 entries), and all but six winch-assist machines were in cable logging operations.
- The average logging rate was $34.40 per tonne and hourly productivity was 33.5 tonnes per scheduled machine hour (SMH).

Ground-based Harvesting

Ground-based systems comprised 91 entries (55.8% of total operations in 2019). Grapple skidder continued to be the dominant system with 56 entries (61% of ground-based operations). Forwarders have also become more common over the last few years, now comprising 20% of operations. Only 5 entries of shovel-logging operations were received (3%), and tractor/arch operations were down to just 1% (2 operations).

The overall average ground-based logging rate increased to $28.70/tonne, which is up only $0.35/t on 2018 data, the lowest increase in rate in the last four years. Of the 91 ground-based entries, six had logging rates between $18.00-$19.00/tonne – all associated with highly mechanised grapple skidder crews (from 3 different regions). At the higher end of the logging cost scale, nine entries were over $40.00/tonne, coming from seven different regions – but only one of these was identified as "difficult" with a long uphill pull and shovel logging. The common denominator of the high logging rates was the relatively steep slopes on which they were working, resulting in productivity rates that were less than half the overall average (16 tonnes/hour vs 34 tonnes/hour). In terms of ground-based operations that were categorised as "hard", the reasons included: cliff hazards; powerlines; farm with big leaning trees; short steep slopes; and swampy gullies.

Table 1 shows the trends in average parameters over the 11-year period from 2008-2019.

Table 1: Summary of ground-based data over time (total n=827)

Attribute	2009*	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Scheduled Hours/day	8.3	8.4	8.4	8.5	8.4	8.5	8.4	8.4	8.3	8.2	8.8
Piece Size (t)	1.9	2.3	1.8	1.8	1.8	2.2	2.3	1.9	2.1	1.7	1.9
Extraction Dist. (m)	200	210	219	193	194	214	234	209	246	255	230
Slope (%)	14	15	18	21	17	13	14	16.3	14.9	18.5	15.6
# Machines	3.5	3.7	4.3	4.3	4.1	4.9	5.6	4.4	4.9	4.5	4.7
# Workers	7.2	8.4	7.6	6.4	6.6	6.8	6.7	6.9	6.7	5.9	5.7
# Log Sorts	10.1	12.0	10.1	11.4	11.1	11.3	9.8	10.6	12.1	10.9	9.5
Harvest Area (ha)	12.5	15.0	13.4	15.1	9.5	14.4	9.8	14.1	13.1	14.2	12.1
Stand Vol. (t/ha)	478	526	478	535	518	571	597	545	575	543	590
Productivity (t/hour)	33.5	28.8	28.3	28.1	27.7	34.9	36.8	31.7	34.6	34.1	34.4
Logging Rate ($/t)	20.90	24.10	24.40	25.30	26.90	24.30	23.60	24.20	26.80	28.35	28.70

**Note: the limited 2008 data has been aggregated with 2009 data.*

The proportion of ground-based operations using mechanised felling was a record high at 93%, and 98% of ground-based log processing was mechanised.

Using a 3-year running average, significant trends over the last 10-year period (2010-2019) can be identified (Figure 1). One clear trend is the decline in number of workers per crew, with the average reducing by 30% in this time. Consistent with other industries such as mining and oil exploration, mechanisation can initially increases worker requirements, but as the efficiencies of mechanisation a realised there is a reduction in worker input. As such, the ‘hump’ visible in years 4 to 8 reflect the period where mechanisation, expressed as workers/machine ratio, changed from 1.8 down to 1.3.

The sudden change towards higher level of mechanisation, especially felling and processing, created a 15% jump in level of crew productivity, by that increase has flattened the last 5 years. Combining the two, the level of worker productivity has increased because there are fewer workers per crew – from 2.9 t/pp/hr in the first few years up to 4.9 t/pp/hr.

Average extraction distance has also trended up the last 7 years, perhaps with improved equipment, and especially pre-bunching with mechanised felling systems, allowing crews to maintain efficiency at longer distances. Average stand volume has increased by about 10% over the 10-year period, and this may simply reflect the silvicultural regime change many companies made in the 1990’s to move from pruned to more industrial grade regimes. While logging rate decreased during this period of highest level of mechanisation change, overall we have seen a steady increase.

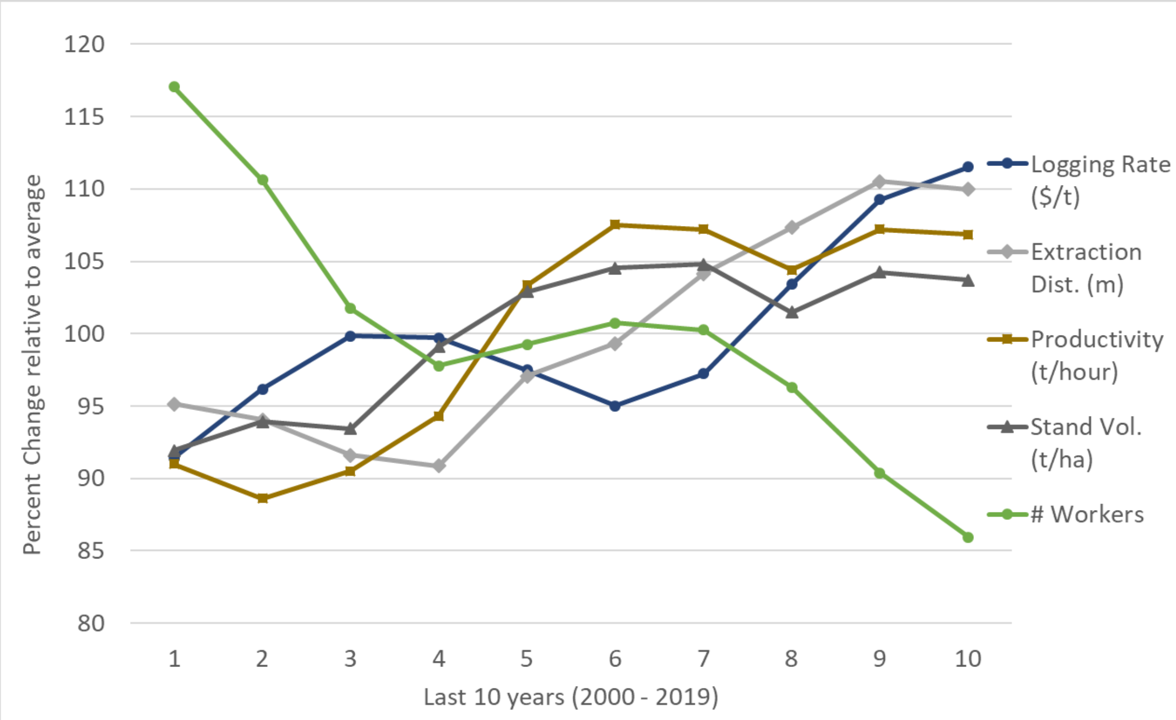

Figure 1: Significant trends in ground-based logging over the last 10 years (percentage change from average).

Cable Yarding

There were 72 yarder entries, broken down as 38 swing yarder and 34 tower haulers (representing 23 and 21% of the total entries respectively). Of the 34 tower hauler entries, only six were classed as 'Large', which is 90ft or taller. The 70ft yarders were by far the most common, with 20 of the 34 towers being that height.

Table 2: Ten years of cable yarding data (total n=825)

Attribute	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Scheduled Hours/day	8.5	8.7	8.5	8.7	8.6	8.9	8.8	8.4	8.6	8.5	8.6
Piece Size (t)	2.2	2.3	2.0	1.8	2.2	2.2	2.6	2.1	2.2	1.9	2.1
Extraction Dist. (m)	212	193	216	189	190	222	220	212	243	233	206
Slope (%)	47	48	38	39	50	48	49	41	42	44	42
No. of Machines	3.9	4.1	4.8	4.4	4.4	4.9	5.0	4.8	5.3	5.8	6.1
No. of Workers	9.7	8.8	7.8	8.5	8.9	8.9	8.2	7.6	7.9	7.6	7.9
No. of Log Sorts	10.2	10.9	9.6	11.3	10.1	9.7	9.1	10.1	10.9	9.9	8.1
Harvest Area (ha)	12.2	14.9	14.7	13.8	9.5	12.9	11.6	13.4	13.8	14.1	13.8
Stand Vol. (t/ha)	514	505	487	528	502	531	561	545	615	570	605
Productivity (t/hour)	22.2	24.9	26.2	23.5	23.4	26.2	26.8	29.4	28.6	27.4	31.1
Logging Rate ($/tonne)	32.20	32.80	31.50	35.10	35.90	36.60	37.50	37.30	39.40	41.25	42.20

**Note: the limited 2008 data has been aggregated with 2009 data.*

The average logging rates for cable logging increased to $42.20/tonne, which is a $0.95 increase from 2018 (+2.3%). The logging rates ranged from $23/tonne as the lowest ($27/tonne at the 10th percentile), up to $58/tonne maximum ($49.50/tonne at the 90th percentile).

Mechanisation of felling was 33%, which is the same as the average over the last three years (40%, 35% and 28%, for 2018, 2017 and 2016 respectively). Of all the hauler entries there was only two for manual processing (or 3% of operations), similar to last year.

There was a considerable jump in average productivity, from an average of 28.5 tonnes per scheduled machine hour from the previous three years to 31.1 tonnes/hour (+8%). Several operating parameters moved favourably to support the higher productivity, including more machines, shorter extraction distance, fewer log sorts and higher stand volume.

Similar to ground-based operations, a number of parameters have changed significantly over the 10-year period, using a rolling three-year average to eliminate year on year variation that is more attributable to the changing nature of companies submitting data (Figure 2).

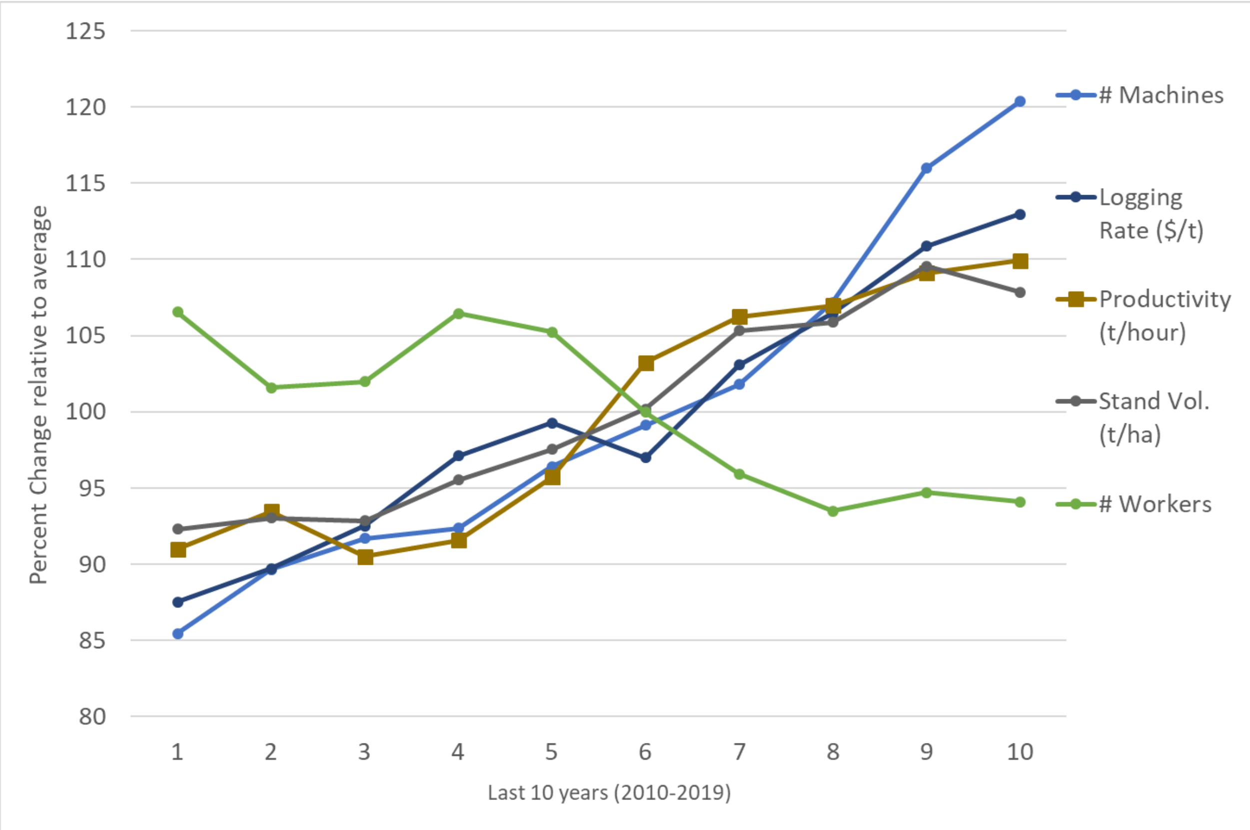

Figure 2: Significant trends in cable yarding over the last 10 years (percentage change from average)

The most substantial increase has been the number of machines, which has increased by 34% from 2009-2011 to 2017-2019. This can readily be explained not only by the higher level of mechanisation, but also the adoption of winch assisted felling that typically adds two machines to a manual felling system (the winch assist unit plus the felling machine). Conversely, the number of workers per crew has decreased over the same period, but only by about 11% from 2009-2011 to 2017-2019. Productivity has increased by 19%, but interestingly the average stand volume has also increased by 19%. Despite these improvements, logging rate has also climbed steadily over the ten year period.

Breaking the data down by type of yarder (towers versus swing yarders), there is a $6.20/tonne difference ($45.50/tonne for towers versus $39.25/tonne for swing yarders), mainly driven by the difference in productivity (26.2t/hr versus 35.6 t/hr). This in turn is driven by stand parameters such as extraction distance being favourable for swing yarders (184m versus 230m) and piece size (2.1 versus 2.0), although average stand volume was the same.

Winch Assist Harvesting

Winch-assist harvesting is transforming operations on steep slopes. By mid-2019 there were more than 110 operations working in New Zealand. In the 2019 Benchmarking data, 50% of all yarder operations used winch-assist (defined in the Benchmarking database as being used in 20% or more of any harvest area). This is an increase on the 41% of operations reported in the 2018 data. Despite working on steeper slopes (35.8% slope versus 30.6%), average productivity was higher (32.3 tonnes/hour versus 30.5 tonnes/hour) and the logging rate was $2.00/tonne lower ($43.20/tonne versus $41.20/tonne). These data confirm the trends already established last year without statistical significance.

PART 2: ANALYSIS OF THE DRIVERS OF LOGGING RATES

The study comprised 1,599 actual and completed harvest areas operating in all forest regions of New Zealand, with an approximately even split between ground-based and cable harvesting operations. Data from the 1,599 logging operations represent a total of about 68,336 harvest days and 576,392 work hours for a total log harvest of 17.1 million tonnes.

The harvest operations varied in terms of harvest method, crew size, equipment mix, and system productivity, across all forest regions in New Zealand.

The logging contract rates were from a 11-year period, dating back to 2008, so all the rates were adjusted to 2019 figures using the Producer Price Index as reported by New Zealand's official data agency, Statistics New Zealand (https://www.stats.govt.nz/). The mean logging contract rate for the entire study period (2008 – 2019) was $34.24 per tonne amounting to a mean contract value of about NZD $311,300 per contracted harvest operation (Table 3).

Table 3. Summary statistics of completed logging contracts in New Zealand (2008 – 2019)

Logging Parameters (n=1585)	**Mean**	**SD**	**5th Percentile**	**95th Percentile**
Number of machines	4.8	1.5	3.0	7.5
Number of workers	7.5	2.2	4.0	11.0
Work hours per day (hours)	8.5	0.6	8.0	9.0
Number of harvest days per landing	27.6	25.5	6.3	75.0
Harvest area per landing (hectares)	12.5	12.3	2.3	34.2
Piece size (tonnes)	2.0	0.7	1.0	3.2
Extraction distance (m)	215	80.2	110	358
Terrain slope (%)	31.0	20.9	3.0	70.0
Number of log sorts	10.3	3.4	4.0	16.0
Stand Volume (tonnes/ha)	546.3	163.7	290.7	795.8
Logging contract rate ($/tonne)	34.24	9.20	20.10	49.00
Logging contract value per landing ($)	311,300	331,700	52,300	922,900
System productivity (t/hour)	29.6	12.7	12.7	54.5

The stands were predominantly radiata pine (about 98% of the forest stands) while the rest were Douglas fir, and Eucalyptus. Mean stand volume was 546 tonnes/ha, and the mean harvest area size per landing was 12.5 hectares. Other summary stand data for all harvesting operations included piece size (2.0 tonnes) and terrain slope (31%).

For all harvesting operations combined, manual felling using chainsaws was used in about 58% of the contracted logging operations, while the rest utilised mechanised felling (42%). Log extraction methods included forwarder, cable skidder, shovel, tractor/arch, grapple skidder, hauler, and swing yarder. Grapple skidder was the most common method of extraction as it accounted for 33% of all extraction methods used.

Independent logging contractors utilized an average of 5 machines and 8 workers per contract operation giving a mean mechanization index of 0.6. Mechanization index is defined as the ratio of machines per crew to number of workers per crew. The average scheduled machine hours (SMH) per day was 8.5 hours. The extraction distance ranged from 110m to 358 m (5th and 95th percentile range) with a mean value of 215 m. The average number of log sorts cut was 10, and average system productivity was 29.6 tonnes/SMH.

The mean harvest contract rate varied significantly between harvest methods (Table 4). Harvest contract rates for cable-based operations, being more laborious and less productive, were significantly higher than ground-based operations at NZD $40.30/t and NZD $27.90/t, respectively.

Table 4. Comparison of ground and cable-based harvesting in New Zealand (2008 - 2019)

Parameter	**Harvesting Method (Mean ± SD)**	
	Ground-based	**Cable-based**
Mechanization index	0.8 ± 0.3[a]	0.6 ± 0.3[b]
Number of harvest days per landing	26.0 ± 24.9[a]	29.3 ± 25.1[b]
Harvest area per landing (hectares)	12.4 ± 12.8[a]	12.5 ± 11.7[a]
Average piece size (tonnes)	1.9 ± 0.8[a]	2.1 ± 0.6[b]
Stand volume (tonnes/ha)	549 ± 161[a]	530 ± 152[a]
Average extraction distance (metres)	221 ± 86[a]	209 ± 74[b]
Average terrain slope (%)	16.0 ± 11.5[a]	45.0 ± 17.8[b]
Number of log sorts	10.9 ± 3.5[a]	9.9 ± 3.0[b]
System productivity (tonnes/SMH)	32.7 ± 15.5[a]	27.0 ± 8.1[b]
Logging contract rate ($/tonne)	27.90 ± 7.0[a]	40.30 ± 6.6[b]
Logging contract value per landing ($)	160,270± 202,250 [a]	231,460 ± 216,610[b]

Means in the same row that do not share a letter are significantly different (p<0.05).
Ground-based (*N* = 780); Cable-based (*N* = 819); SD = Standard deviation

Various technical parameters associated with contracted logging operations for ground- and cable-based logging operations were compared using the Tukey method. The parameters included: mechanization index, harvest days, number of landings per harvest area, harvest area size, piece size, stand volume, extraction distance, terrain slope, number of log sorts produced, system productivity, logging rate, and contract value per landing.

The study highlighted significant differences (p<0.05) between ground-based and cable logging systems. All the means compared between ground-based and cable logging showed significant differences (p<0.05) except for harvest area size per landing and stand volume per hectare. Ground-based operations were characterised by significantly higher (p<0.05) mean mechanization index, number of landings per harvest area, longer extraction distance, more log sorts and higher system productivity/SMH. Spinelli *et al.* (2017) reported similar significant differences between ground-based and cable logging operations in the Alpine regions of France and Italy.

Cable logging operations were characterised by significantly higher (p<0.05) mean number of harvest days per landing (related to productivity), larger piece size, steeper terrain slope, and higher logging contract rates. Due to the challenges and difficulties associated with steep terrain harvesting, it is unsurprising to observe significantly lower system productivity. This results in significantly higher mean logging contract rates for cable-based operations ($40.30/tonne) as opposed to ground-based operations ($27.90/tonne). Spinelli *et al.* (2017) reported a similar trend for ground- and cable-based logging systems in terms of logging contract rate.

Spinelli *et al*. (2015) added that the challenging operating environment associated with cable logging makes it less profitable compared to ground-based logging. In contrast, easier to operate terrain allows for the deployment of modern ground-based logging equipment with a significant positive effect on cost reduction and improved system efficiency (Obi and Visser, 2017; Obi and Visser, 2018; Spinelli *et al.,* 2017).

Trends in logging contract rates

Yearly trend

Yearly trend of logging contract rate in New Zealand is presented in Figure 3. The figure also shows a linear trend line of increasing yearly average logging contract rate over the study period. The yearly average contract rate increased from $31.12/tonne in 2008 to $35.20/tonne in 2019. This reflects an average annual increase of 1.1% in logging contract rate in New Zealand.

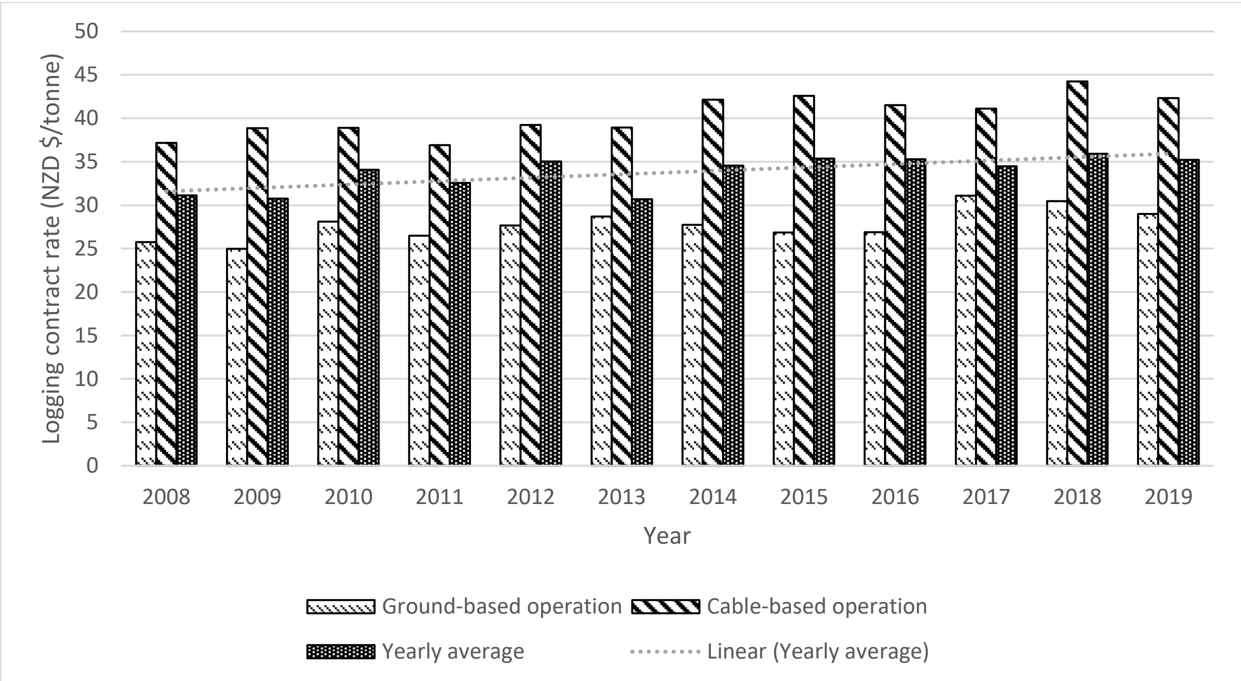

Figure 3. Yearly trend in logging contract rate in New Zealand (rates adjusted to 2019 values using CPI)

With respect to ground-based logging systems, the mean annual contract rate was significantly lower ($p<0.05$) than the mean annual rate for cable logging systems, by margins of over $12.00/tonne since 2014. This is consistent with the earlier result presented in Table 4.

Regional trends

There are nine regions defined in New Zealand forestry (Forest Owners Association, 2019). The spread of contracted logging operations across the forest regions was recorded in the database was as follows:

- Northland – 19%
- Central North Island – 16%
- East Coast – 23%
- Hawke's Bay – 7%
- Southern North Island – 9%
- Nelson/Marlborough – 1%

- Canterbury – 9%
- West Coast – 2%
- Otago/Southland – 14%

Based on the significant difference in logging rate and system productivity between ground-based and cable logging systems, these datasets were evaluated separately to achieve a more meaningful relationship with the stand and terrain parameters.

Comparing forest regions in New Zealand, the mean logging contract rate recorded for ground-based logging operations varied greatly (Figure 4). The East Coast region (ECT) recorded the highest mean contract rate for ground-based logging of $34.83/tonne while the lowest regional rates for ground-based logging ($23.19/tonne) were recorded in Central North Island (CNI). The mean logging rate for ground-based logging recorded in Central North Island was well below the national average rate of $27.90/tonne. The low rate for Central North Island ground-based logging is linked to the relatively high percentage of logging operations in easy operating environment (62%) compared to other regions.

West Coast (WEC) recorded the highest mean rate for cable logging ($46.50/tonne) and the lowest regional rates for cable logging (NZD $33.39/tonne) were recorded in Otago/Southland (OSL). The mean logging rate for cable logging recorded in Otago/Southland was well below the national average rate of $40.30/tonne. The low cable logging rate in Otago/Southland region could be attributed to the relatively low percentage of operations in difficult environment (7%) compared to other regions.

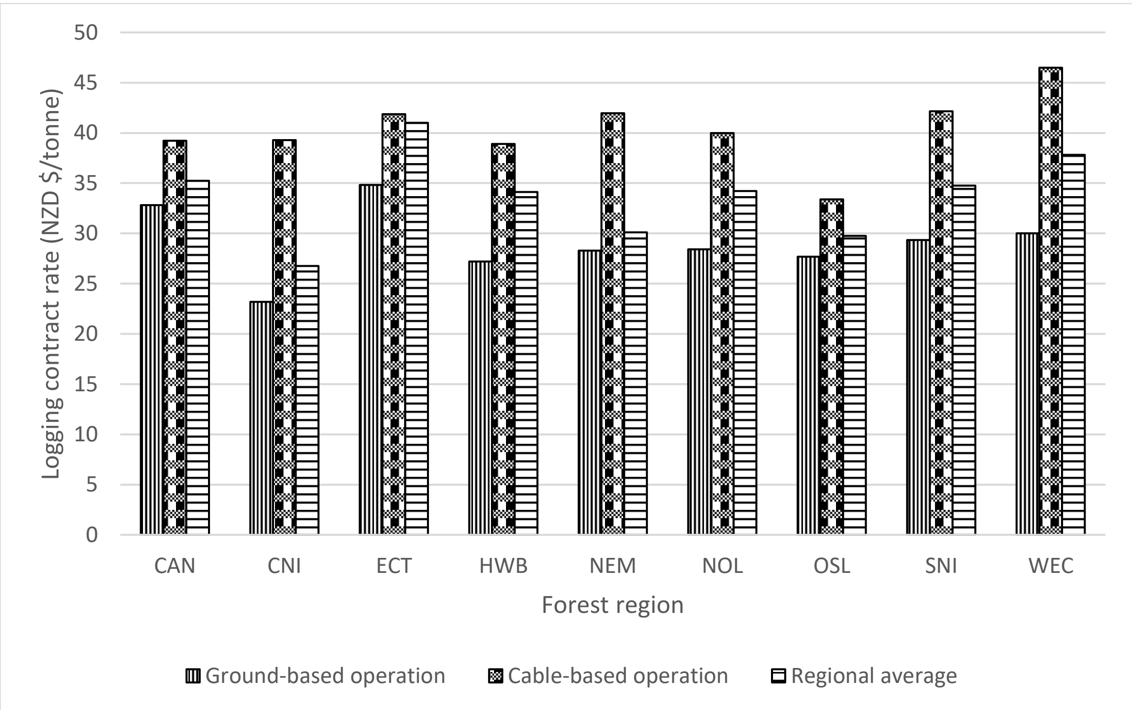

Figure 4. Logging rates across New Zealand forest regions for the period 2008 - 2019

(CAN – Canterbury (*N* = 137); CNI – Central North Island (*N* = 249); ECT – East Coast (*N* = 382); HWB – Hawke's Bay (*N* = 105); NEM – Nelson/Marlborough (*N* = 15); NOL – Northland (*N* = 311); OSL – Otago/Southland (*N* = 218); SNI – South North Island (*N* = 144); WEC – West Coast (*N* = 38).

The comparison of regional average logging contract rates (Table 5) shows that the mean rate for East Coast is significantly higher (p<0.05) than the mean rate for all forest regions ($34.24/tonne) as shown in Table 4. This is due to the high representation of East Coast in the dataset and the heavy weighting towards cable logging in this region.

The statistical comparison shows that while the mean regional rate was lowest for Central North Island ($26.75/tonne), this value is not significantly different (p>0.05) from the regional average rate of $30.11/tonne recorded for Nelson/Marlborough (NEM). The mean regional rates for Central North Island, Hawke's Bay (HWB), Nelson/Marlborough and Otago/Southland were all below the national average logging rate of $34.24/tonne.

Table 5. Comparison of regional average logging contract rate in New Zealand

Forest region	N	Regional average contract rate (NZD $/tonne)
East Coast (ECT)	382	41.00^{a}
West Coast (WEC)	38	37.83^{b}
Canterbury (CAN)	137	35.24^{b,c}
South North Island	144	34.77^{c}
Northland (NOL)	311	34.23^{c}
Hawke's Bay (HWB)	105	34.11^{c,d}
Nelson/Marlborough (NEM)	15	30.11^{d,e,f}
Otago/Southland (OSL)	218	29.75^{e}
Central North Island (CNI)	249	26.75^{f}

Means with different superscript letters are significantly different (p<0.05)

The differences observed in the logging rate among the regions could be an indication of distinct harvesting practices adopted due to differences in stand and terrain conditions. In addition, differences in labour availability, cost, and market competition for contractors could affect logging contract rates. In comparing the logging rate between Italy and France, Spinelli *et al.* (2017) observed that differences in technological competence, as well as differences in labour cost and fuel price were some of the underlying factors responsible for logging rate differences. Within countries, while landscapes and culture may be common, local differences could be encountered in market competition, labour cost, among other economic components (Spinelli *et al.,* 2015). It is therefore possible for forest harvesting contractors and forest managers to investigate bordering regions for better rates where associated logistic conditions and costs are more favourable.

Seasonal rates

Figure 5 shows the average seasonal contract rates in New Zealand as well as the mean rates for ground-based and cable logging operations for each season. While cable logging rates showed no difference, ground-based logging rates declined significantly (p<0.05) from $28.98/tonne in spring to $26.82/tonne in winter. This could be related to more competition for harvest blocks in the winter.

The seasonal average logging contract rates were compared using the Tukey method. The result showed that the seasonal averages in spring, summer and winter were not significantly different from one another (p>0.05). However, the mean seasonal rate in autumn, $32.83/tonne, was significantly lower compared to all other seasonal average rates (P<0.05). This was also reflected in the logging rate in autumn for cable-based operations, which had the lowest mean rate of $38.83/tonne, significantly lower (p<0.05) than the cable logging rates in summer, winter and spring seasons.

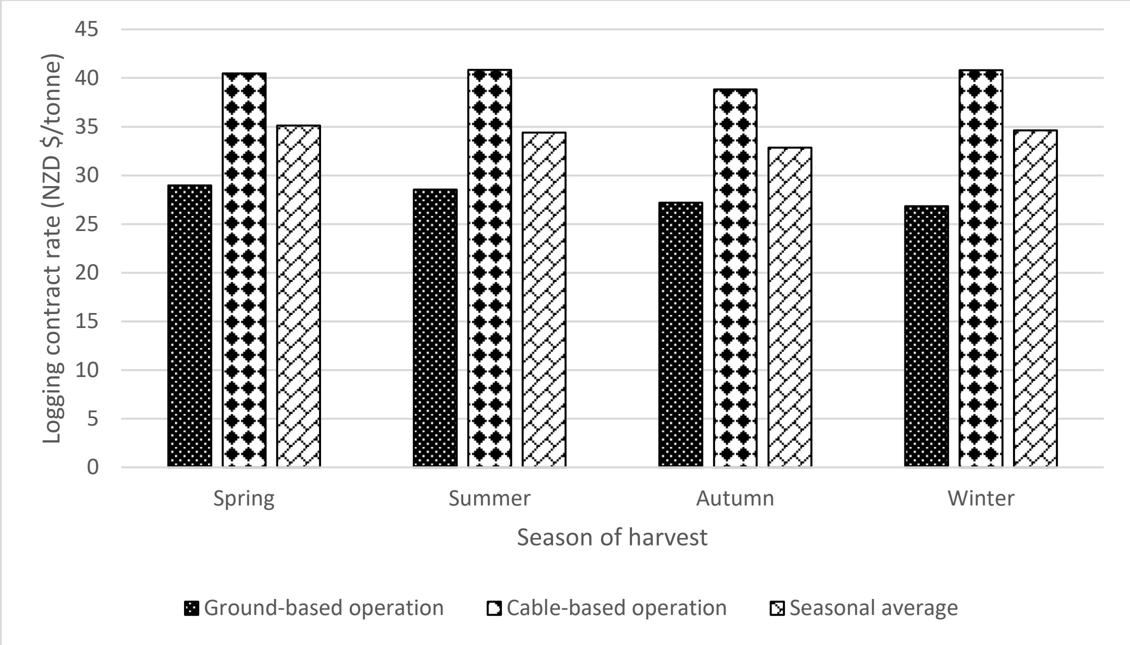

Figure 5. Mean logging contract rate in different harvesting seasons in New Zealand (2008 – 2019)

(Spring – September to November (*N* = 419); Summer – December to February (*N* = 385); Autumn – March to May (*N* = 388); Winter – June to August (*N* = 388)

The trend observed between lower ground-based rates and higher cable logging rates over the study period (Figure 3), and across New Zealand forest regions (Figure 4) was sustained for each of the harvest seasons (spring, summer, autumn, and winter). The mean logging contract rates for ground-based operations were significantly lower than the mean rates for cable logging operations ($p<0.05$). Different environmental challenges posed by the various seasons could potentially influence both system productivity and logging rates (Ghaffariyan *et al.,* 2013).

For cable logging, mean system productivity across the seasons ranged from 25.5 tonnes/SMH in the summer to 27.7 tonnes/SMH in spring being the highest mean system productivity. Autumn and winter had a mean system productivity of 26.5 tonnes/SMH and 27.0 tonnes/SMH, respectively. For ground-based logging, autumn and winter both shared the highest mean system productivity of 34.3 tonnes/SMH, while spring and summer were 32.8 and 31.5 tonnes/SMH respectively. It is unclear as to the specific seasonal conditions that affect system productivity in New Zealand.

Regression Analysis

To understand the relationship between logging rate for ground-based and cable logging systems, their system productivity, and some logging parameters, regression analyses were carried out. The regression models showed a strong relationship between logging contract rate, system productivity and some technical parameters.

Relationship between logging rate and operational parameters

Regression analyses specific to ground-based and cable-based logging rate are presented in Tables 6 and 7, respectively. The separate regression equations were estimated to see if the logging rate for different harvesting methods are influenced differently by stand, terrain, and system parameters available in the FGR database.

For the ground-based operations, the parameters in the regression analysis accounted for about 43% of the variation in the logging rate (Table 6; $Equation\ 1:\ \ LoggingRate_{GB}$). The influence of harvest days, harvest area size, piece size, terrain slope and stand volume were all significant ($p<0.05$), however, their direction of influence differed. As expected, piece size, harvest area size, and stand volume all had a decreasing effect on ground-based logging contract rate. This is in line with an earlier study that suggested that such increases tend to increase productivity and decrease cost (Spinelli *et al.*, 2015). An increase in terrain slope and harvest days (related to productivity) both had an increasing effect on the ground-based logging rate.

While forest region had an overall significant influence on ground-based logging contract rate, not all regions significantly influenced the logging rate. Central North Island, Nelson/Marlborough, Northland, and Otago/Southland regions all significantly influenced ground-based logging rate ($p<0.05$) in the negative direction. The effects of other forest regions were insignificant ($p>0.05$).

Table 6. Ground-based logging contract rate regression results (N = 706)

Parameters	**Coefficient**	**Std. Error**	**P Value**
Constant	37.53	0.98	0.000
Number of harvest days per landing (A)	0.087	0.013	0.000
Harvest area size, hectares (B)	-0.214	0.025	0.000
Average piece size, tonnes (C)	-2.19	0.356	0.000
Average slope, % (D)	0.165	0.020	0.000
Stand Volume, tonnes/ha (E)	-0.009	0.002	0.000
Forest region			
Central North Island (F)	-4.95	0.858	0.000
East Coast (G)	1.87	1.060	0.079
Hawke’s Bay (H)	-1.84	1.120	0.101
Nelson/Marlborough (I)	-4.62	1.630	0.005
Northland (J)	-3.59	0.765	0.000
Otago/Southland (K)	-4.89	0.783	0.000
South North Island (L)	-1.44	0.949	0.129
West Coast (M)	-0.08	1.420	0.953

Forest region = 0, if Canterbury; Central North Island = 1, otherwise 0; East Coast =1, otherwise 0; Hawke’s Bay = 1 otherwise 0; Nelson/Marlborough = 1 otherwise 0; Northland = 1, otherwise 0; Otago/Southland =1, otherwise 0; South North Island = 1 otherwise 0; West Coast = 1 otherwise 0.

$$Equation\ 1:\ \ LoggingRate_{GB} = 37.534 + 0.087A - 0.214B - 2.19C + 0.165D - 0.009E - 4.948F + 1.87G - 1.84H - 4.62I - 3.591J - 4.888K - 1.441L - 0.080M$$

(R^2=0.43)

The regression analysis for cable-based logging contract rates is given in Table 7 (Equation 2: $LoggingRate_{CB}$). The parameters in the regression model accounted for about 32% of the variation in cable logging contract rate. All the parameters presented significantly influenced the cable logging contract rate ($p<0.05$). Not all forest regions had a significant effect on the rate ($p>0.05$). Central North Island, Hawke's Bay, Nelson/Marlborough, and Northland regions had no significant effect on the contract rate.

Table 7. Cable-based logging contract rate regression results (N = 772)

Parameters	Coefficient	Std. Error	P-Value
Constant	37.54	1.730	0.000
Number of harvest days/Landing (A)	0.082	0.017	0.000
Mechanization index (B)	4.35	0.872	0.000
Harvest area size/Landing, hectares (C)	-0.21	0.036	0.000
Average piece size, tonnes (D)	-2.53	0.401	0.000
Average extraction distance, meters (E)	0.010	0.003	0.000
Average slope, % (F)	0.055	0.014	0.000
Stand Volume, tonnes/ha (G)	-0.005	0.002	0.003
Season of Harvest			
Spring, Winter (H)	1.853	0.560	0.001
Summer (I)	1.535	0.592	0.010
Forest Region			
Central North Island (J)	1.770	1.120	0.112
East Coast (K)	4.373	0.917	0.000
Hawke's Bay (L)	2.170	1.120	0.053
Nelson/Marlborough (M)	0.630	3.940	0.874
Northland (N)	1.401	0.934	0.134
Otago/Southland (P)	-5.970	1.010	0.000
South North Island (Q)	3.700	1.140	0.001
West Coast (R)	10.360	1.610	0.000

Season of harvest = 0 if Autumn; Spring = 1, otherwise 0; Summer = 1, otherwise 0; Winter = 1, otherwise 0; Harvest type = 0 if clearfell otherwise 1; Forest region = 0 if Canterbury; Central North Island = 1, otherwise 0; East Coast =1, otherwise 0; Hawke's Bay = 1 otherwise 0; Nelson/Marlborough = 1 otherwise 0; Northland = 1, otherwise 0; Otago/Southland =1, otherwise 0; South North Island = 1 otherwise 0; West Coast = 1 otherwise 0.

Equation 2: $LoggingRate_{CB} = 37.54 + 0.082A + 4.353B - 0.207C - 2.527D + 0.01E + 0.055F - 0.005G + 1.876H + 1.535I + 1.77J + 4.373K + 2.17L + 0.63M + 1.401N - 5.97P + 3.7Q$ *(R^2=0.32)*

It is interesting that harvest seasons positively influenced the logging rate with spring having the largest size effect. The regression result suggests that the more mechanized a cable logging operation is, the higher its positive influence on logging rate. Similar to ground-based operations, the effect of stand volume is significant in cable logging contract rate ($p<0.05$), however the size effect is minimal. Other parameters including harvest days per landing, extraction distance and terrain slope all positively influenced cable logging contract rate. The positive effect of extraction distance on cable-based logging rate has also been reported in the Alpine region (Spinelli *et al.,* 2015). As expected, average terrain slope significantly influenced cable logging contract rate.

Unexplained variability in logging rate reflected in the regression coefficient of the models could be considered to derive partly from other technical parameters and non-technical parameters such as contractors' negotiation ability, local competition among competitors, and general market dynamics within the sector (Spinelli *et al.,* 2017; Visser, 2010). Other technical factors not included in this study include silvicultural practices which is known to greatly affect cable logging cost and productivity (Hartley and Han, 2007).

Relationship between system productivity and operational parameters

Regression analyses were carried out to understand the relation between system productivity and stand, terrain, and logging crew parameters. Table 8 presents the regression results for ground–based system productivity.

Table 8. Ground-based logging system productivity regression results (N = 706)

Variable	Coefficient	Std. Error	P Value
Constant	0.850	1.950	0.662
Number of harvest days/Landing (A)	-0.443	0.025	0.000
Harvest area size/Landing, hectares (B)	0.935	0.048	0.000
Number of landings (C)	0.886	0.185	0.000
Number of log sorts (D)	0.412	0.126	0.001
Stand Volume, tonnes/ha (E)	0.033	0.003	0.000
Harvest type			
Road line (F)	-4.350	1.470	0.003
Felling Method			
Mechanised (G)	5.870	0.926	0.000
Forest region			
Central North Island (H)	6.820	1.500	0.000
East Coast (I)	4.960	2.030	0.015
Hawke's Bay (J)	1.130	2.090	0.589
Nelson/Marlborough (K)	4.310	3.030	0.156
Northland (L)	0.880	1.450	0.543
Otago/Southland (M)	4.880	1.440	0.001
South North Island (N)	3.390	1.740	0.051
West Coast (O)	-4.190	2.600	0.107

Harvest type = 0 if clearfell, otherwise = 1; Felling method = 0 if manual otherwise = 1; Forest region = 0, if Canterbury; Central North Island = 1, otherwise 0; East Coast =1, otherwise 0; Hawke's Bay = 1 otherwise 0; Nelson/Marlborough = 1 otherwise 0; Northland = 1, otherwise 0; Otago/Southland =1, otherwise 0; South North Island = 1 otherwise 0; West Coast = 1 otherwise 0; SP_{GB} *= Ground-based logging contract rate.*

Equation 3: $SysProd_{GB} = 0.85 - 0.443A + 0.935B + 0.886C + 0.412D + 0.033E - 4.35F + 5.87G + 6.82H + 4.96I + 1.13J + 4.31K + 0.88L + 4.88M + 3.39N - 4.19O$ *(R^2 = 0.59)*

The parameters presented in Equation 3 indicate a positive effect on ground-based system productivity including harvest days, harvest area size, number of landings, log sorts, stand volume, felling method, and forest regions (except West Coast). Dramm (2002) noted that larger landing size offers greater flexibility in accommodating wood inflows and log sorts, thus capable of increasing productivity and cost effectiveness of the system.

Some of the forest regions do not significantly affect system productivity for ground-based logging ($p>0.05$) and they include Hawke's bay, Nelson/Marlborough, Northland, South North Island, and West Coast. The parameters in the regression model for ground-based system productivity accounted for 59% of the variation in ground-based logging system productivity.

The regression equation to model cable logging system productivity indicates that harvest days, harvest area size, piece size, terrain slope, stand volume, felling and extraction methods, log processing type, two-staging and forest region are all significant ($p<0.05$) influences on system productivity (Table 9).

Equation 4: $SysProd_{CB} = 9.68 - 0.252A + 0.586B + 2.297C - 0.052D + 0.023E + 3.445F + 2.471G + 1.586H - 1.308I - 0.15J - 0.80K - 2.57L - 4.43M - 2.04N + 2.90O - 1.52P + 4.69Q$ *(R^2 = 0.47)*

Equation 4 shows these parameters accounted for 47% of the variability in cable logging system productivity. While forest region has an overall significant effect on system productivity for cable logging, Central North Island, East Coast, Nelson/Marlborough, and southern North Island regions do not have a significant effect on productivity.

Table 9. Cable-based logging system productivity (SP_{CB}) regression results (N = 772)

Variable	Coefficient	Std. Error	P Value
Constant	9.680	1.690	0.000
Number of harvest days/Landing (A)	-0.252	0.019	0.000
Harvest area size/Landing, hectares (B)	0.586	0.040	0.000
Average Piece Size, tonnes (C)	2.297	0.439	0.000
Average Slope, % (D)	-0.052	0.015	0.001
Stand volume, tonnes/ha (E)	0.023	0.002	0.000
Felling method			
Mechanised (F)	3.445	0.620	0.000
Extraction Method			
Swing Yarder (G)	2.471	0.484	0.000
Log processing type			
Mechanised (H)	1.586	0.595	0.008
Two Staging			
Yes (I)	-1.308	0.584	0.025
Forest region			
Central North Island (J)	-0.150	1.240	0.905
East Coast (K)	-0.800	1.000	0.422
Hawke's Bay (L)	-2.570	1.210	0.034
Nelson/Marlborough (M)	-4.430	4.310	0.304
Northland (N)	-2.040	1.030	0.048
Otago/Southland (O)	2.900	1.110	0.009
South North Island (P)	-1.520	1.210	0.209
West Coast (Q)	-4.690	1.800	0.009

Felling method = 0 if manual otherwise = 1; Extraction method = 0 if hauler, otherwise = 1; Log processing type = 0 if manual otherwise = 1; Two staging = 0 if no, otherwise = 1; Forest region = 0, if Canterbury; Central North Island = 1, otherwise 0; East Coast =1, otherwise 0; Hawke's Bay = 1 otherwise 0; Nelson/Marlborough = 1 otherwise 0; Northland = 1, otherwise 0; Otago/Southland =1, otherwise 0; South North Island = 1 otherwise 0; West Coast = 1 otherwise 0; SP_{CB} *= Ground-based logging contract rate.*

CONCLUSION

The FGR Cost and Productivity Benchmarking system has successfully captured details from its member companies of completed harvest areas, that include harvest system, stand and terrain descriptors, for 12 consecutive years. This report presents the averages for data collected in 2019. It also analyses trends in logging contract rates, system productivity and the operational factors that influence using all the data in the system.

Both logging contract rates, as well as systems productivity, have generally been in an upward trend over the study period of 2008 to 2019. As expected, across the years and the various forest regions in New Zealand, the average ground-based logging contract rates are significantly lower than average cable logging rates. Rates are highest in the East Coast region of the country while they are lowest in Central North Island.

Regression analyses split by ground-based and cable yarding systems, showed that contract rates are affected by stand, terrain and logging parameters including harvest days, mechanization index, harvest area size, piece size, extraction distance, season of harvest, harvest type, terrain slope, stand volume, and forest region.

The Benchmarking data has also been used to show a transition to a more mechanised logging workforce, with an increase in the average number of machines per crew while at the same time a reduction in number of workers. It has also successfully captured details on the introduction of winch-assist, while initially adding cost not offset by gains in productivity, to the more recent data showing a clear increase in cost-effectiveness when using the technology.

By continuing with the Benchmarking data collection, future changes brought about by changes such as the continued increase in mechanisation, higher levels of automation, or adoption of new equipment and systems, will be identified and captured.

REFERENCES

Baker, S.A. and Greene, W.D., 2008. Changes in Georgia's logging workforce, 1987–2007. Southern Journal of Applied Forestry, 32 (2): 60-68.

Baker, S.A., Mei, B., Harris, T.G. and Greene, W.D., 2014. An index for logging cost changes across the US South. Journal of Forestry, 112 (3): 296-301.

Bell, C.K., Keefe, R.F. and Fried, J.S., 2017. Validation of the OpCost logging cost model using contractor surveys. International Journal of Forest Engineering, 28 (2): 73-84.

Cubbage, F.W., Stokes, B.J. and Granskog, J.E., 1988. Trends in southern forest harvesting equipment and logging costs. Forest Products Journal Vol. 32 (2): 6-10.

Dale, V.H. *et al.*, 2001. Climate Change and Forest Disturbances: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms, or landslides. BioScience, 51 (9): 723-734.

Dramm, J.R., G. L. Jackson, J. Wong 2002. Review of log sort yards, Gen. Tech. Rep. FPL-GTR-132. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 39 p.

Forest Owners Association, 2019. Facts & Figures 2018/19: New Zealand Plantation Forest Industry. Accessed on Dec. 17, 2019 at <https://www.nzfoa.org.nz/images/Facts_and_Figures_2018-2019_Web.pdf>.

Ghaffariyan, M.R., Naghdi, R., Ghajar, I. and Nikooy, M., 2013. Time Prediction Models and Cost Evaluation of Cut-To-Length (CTL) Harvesting Method in a Mountainous Forest. Small-scale Forestry, 12 (2): 181-192.

Hånell, B., Nordfjell, T. and Eliasson, L., 2000. Productivity and Costs in Shelterwood Harvesting. Scandinavian Journal of Forest Research, 15 (5): 561-569.

Hartley, D.S. and Han, H.-S., 2007. Effects of alternative silvicultural treatments on cable harvesting productivity and cost in western Washington. Western Journal of Applied Forestry, 22 (3): 204-212.

Hartsough, B.R., Zhang, X. and Fight, R.D., 2001. Harvesting cost model for small trees in natural stands in the interior northwest. Forest Products Journal, 51 (4): 54-61.

Kelly, M.C., Germain, R.H. and Bick, S., 2017. Impacts of Forestry Best Management Practices on Logging Costs and Productivity in the Northeastern USA. Journal of Forestry, 115 (6): 503-512.

McDonagh, K., Meller, R., Visser, R. and McDonald, T., 2004. Improving harvesting system efficiency through system and machine simulation. Southern Journal of Applied Forestry, 28 (2): 91-99.

Obi, O.F. and Visser, R., 2017a. Operational efficiency analysis of New Zealand timber harvesting contractors using data envelopment analysis. International Journal of Forest Engineering, 28 (2): 85-93.

Obi, O.F. and Visser, R., 2017b. Influence of the operating environment on the technical efficiency of forest harvesting operations. International Journal of Forest Engineering, 28 (3): 140-147.

Obi, O.F. and Visser, R., 2018. Including Exogenous Factors in the Evaluation of Harvesting Crew Technical Efficiency using a Multi-Step Data Envelopment Analysis Procedure. Croatian Journal of Forest Engineering 39 (2): 153-162.

Spinelli, R., Magagnotti, N. and Nati, C., 2010. Benchmarking the impact of traditional small-scale logging systems used in Mediterranean forestry. Forest Ecology and Management, 260 (11): 1997-2001.

Spinelli, R., Visser, R., Riond, C. and Magagnotti, N., 2017. A Survey of Logging Contract Rates in the Southern European Alps. Small-scale Forestry, 16 (2): 179-193.

Spinelli, R., Visser, R., Thees, O., Sauter, U.H., Krajnc, N., Riond, C. and Magagnotti, N. 2015. Cable logging contract rates in the Alps: the effect of regional variability and technical constraints. Croatian Journal of Forest Engineering, 36 (2): 195-203.

Visser, R., 2009. Benchmarking harvesting cost and productivity. Harvesting Technical Note 2 (6): 1-8, 2009. Future Forests Research Ltd, Rotorua, New Zealand.

Visser, R., 2010. Methodologies for setting timber harvesting (logging) rates. New Zealand Journal of Forestry, 55(3): 10-11.

Visser, R., 2011. 2010 Benchmarking of harvesting cost and productivity. Harvesting Technical Note 3 (10): 1-7, 2011. Future Forests Research Ltd, Rotorua, New Zealand.

Visser, R., 2012. Benchmarking to improve harvesting cost and productivity: 2011 update. Harvesting Technical Note HTN04-08: 1-7, 2012. Future Forests Research Ltd, Rotorua, New Zealand.

Visser, R., 2013. 2012 update to the benchmarking database. Harvesting Technical Note HTN05-13: 1-4, 2013. Future Forests Research Ltd, Rotorua, New Zealand.

Visser, R., 2014. Harvesting cost and productivity benchmarking: 2013 update. Harvesting Technical Note HTN06-06: 1-6, 2014. Future Forests Research Ltd, Rotorua, New Zealand.

Visser, R., 2015. Harvesting cost and productivity benchmarking: 2014 update. Harvesting Technical Note HTN07-05: 1-5, 2015. Future Forests Research Ltd, Rotorua, New Zealand.

Visser, R., 2016. Trends in harvesting cost and productivity benchmarking. Harvesting Technical Note HTN09-03: 1-5, 2016. Future Forests Research Ltd, Rotorua, New Zealand.

Visser, R., 2017. Benchmarking harvesting cost and productivity – 2016 Update. Harvesting Technical Note HTN09-08: 1-6, 2017. Forest Growers Research Ltd, Rotorua, New Zealand.

Visser, R., 2018. Benchmarking harvesting cost and productivity – 2017 Update. Harvesting Technical Note HTN10-02: 1-4, 2018. Forest Growers Research Ltd, Rotorua, New Zealand.

Visser, R., 2019. A Decade of Benchmarking Harvesting Cost and Productivity. Harvesting Technical Note HTN12-01: 1-4, 2019. Forest Growers Research Ltd, Rotorua, New Zealand.