HARVEST PRODUCTIVITY ANALYSIS BASED ON STAND BOUNDARY LENGTH OF WEYERHAEUSER'S PEMBINA TIMBERLANDS

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An Undergraduate Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Honours Bachelor of Science in Forestry

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ABSTRACT

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Keywords; Harvest productivity, Feller-Buncher, Variable boundary, r-squared, Contractors, Block size

Harvest productivity can be influenced by many different factors within a harvest block and knowing the impact of those factors allows harvest efficiency to be maximized. This thesis explored the effect that stand boundary length of different forest polygons would have on the harvest productivity of feller bunchers. The data was collected from four contractors within Weyerhaeuser's Pembina timberlands in west-central Alberta. The data was then analyzed using a sensitivity analysis and linear regression models to determine the strength of the relationship between the two variables and whether increased stand boundary length had a significant effect on overall harvest productivity. The analysis determined that stand boundary length had no significant effect on harvest productivity. However, stand boundary length could still influence harvest productivity but it appears other factors within the harvest blocks will have a greater influence.

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INTRODUCTION

The forestry industry has come a long way from horses and chainsaws to fully mechanized harvest operations and plays a vital role in the Canadian economy. With these advancements in technology, machines can collect many different types of data, which can be analyzed to examine overall harvest productivity and many other factors (Rossit et al, 2019).

The ability to record and analyze harvest productivity data allows operators, contractors and forest product companies to identify specific conditions within the stand that will either increase or decrease productivity. Being able to better understand these factors will allow for more accurate timber forecasting for the mills and increase harvest efficiency (Hiesl, 2013).

Factors affecting harvest productivity include piece size, slope, species composition, stand density, silvicultural prescriptions, and operator skill (Parajuli et al, 2020). Additionally, boundary length and skid distance could have a significant effect on productivity as well.

Stand boundary lengths can be determined by several factors such as harvest volumes and silviculture strategies (Ohman and Eriksson, 2010). In Alberta, the impact of oil and gas infrastructure has a large influence on boundary lengths. Also, Lidar-based tools are available to foresters to better analyze the potential prescriptions for the stands (Pinno, 2021). Generally, clear-cut harvest prescriptions have been used on Alberta forests and tend to have a rotation of approximately 70-100 years (Pinno, 2021).

Harvest operations in the study area employ the full-tree harvest method using four machines: feller buncher, grapple skidder, processor, and loader. Full-tree harvest consists of the tree being felled at the stump and piled for the skidder to bring roadside fully intact where it is delimbed and processed to desired lengths by the processor and finally loaded onto log trucks (Uusitalo, 2010). The species being harvested within these stands are predominantly lodgepole pine, white spruce, and trembling aspen.

OBJECTIVE

The objective of this thesis was to analyze harvest productivity data and how it was affected by different boundary lengths of the same or similar block sizes. This would allow for improved harvest scheduling, more accurate delivery forecasting for the mills and to better optimize harvest planning.

HYPOTHESIS

As variable boundary length of the harvest block increases it will have a negative effect on feller buncher harvest productivity.

LITERATURE REVIEW

CUT-TO-LENGTH VS WHOLE TREE HARVEST SYSTEMS

Mechanized harvest operations account for 45% of the world's wood harvests, with 65% of that being whole tree harvesting systems and 35% being cut-to-length (Adebayo et al. 2007). Whole tree harvesting generally consists of four machines being Feller buncher, Skidder, Processor, and loader, whereas cut to length harvesting systems have two machines being harvester and forwarder (Hiesl 2013, Adebayo et al. 2007).

Both harvest systems have their advantages and disadvantages, with cut-to-length's largest disadvantages being a large amount of capital required for initial investment, ongoing maintenance costs on machines, and the inability to harvest stems over a certain diameter (Adebayo 2007, Ledoux and Huyler 2001). One of the disadvantages of whole tree harvesting is that it requires more machines in the bush, which then causes more support and supervision needed (Adebayo 2007, Ledoux and Huyler 2001).

Two previous studies found that cut-to-length harvest systems came at a higher operating cost than whole tree harvest systems and produced lower harvest productivity (Gingras 1994, Yaoxiang et al. 2006). Adebayo et al. (2007) also found similar results with cut-to-length producing lower harvest productivity and higher operating costs than the whole tree system in both mixed-wood conifer stands that were chosen as study sites. However, operating costs and productivity can have high levels of variation due to various factors within the stands (Hiesl 2013).

FACTORS AFFECTING HARVEST PRODUCTIVITY

Many factors within a stand have effects on harvest productivity. These are species composition, stem size, stand density, slope, operator skill, and silviculture prescription (Hiesl 2013, Parajuli et al. 2020).

SPECIES COMPOSITION

Stand species composition has a large impact on overall productivity. This is due to the different attributes and stem forms of hardwood and softwood species, where hardwood species will have larger branches and different wood densities than that of softwoods (Parajuli et al. 2020). This will cause an increase in processing time when the different tree species are to be delimbed (Parajuli et al. 2020).

STEM SIZE

Stem size has a great effect on feller-buncher productivity (Wang et al. 2004). Feller-buncher productivity will increase with larger stem diameters as the feller-buncher can cut higher volumes of wood per hour as compared to smaller diameter trees (Akay et al. 2004, Parajuli et al. 2020). Productivity will continue to increase at a slowing rate as the stem size increases until the diameter gets too large for the felling head that trees become harder to handle and may require a second cut before felling (Gingras 1988, Parajuli et al, 2020). Depending on the configuration of the machine, the size of the feller-buncher's cutting head could vary allowing for the handling of larger diameter trees, but at the cost of smaller diameter performance (Parajuli et al, 2020).

STAND DENSITY

Stand density refers to the number of trees per hectare in Canada and trees per acre in the United States (Parajuli et al, 2020). Stand density and stem size will affect harvest productivity. Less dense stands will generally have lower productivity levels because the feller-buncher will have to travel larger distances between cuts unless larger diameter timber is present (Soman et al. 2019). Higher productivity is assumed to be reached in stands with high densities as more trees can be cut in a single location and less time is needed for the feller-buncher to move to the next tree (Hiesl and Benjamin 2012).

SLOPE

Slopes have a great impact on harvest productivity and the configurations of the machines being used in the harvest can determine to what degree productivity will suffer (Spinelli et al. 2010). Slopes affect machine travel speeds, the amount of time required to cut and fell a tree, and machine stability (Parajuli et al. 2020). As the slope increases, harvest productivity will decrease at an increasing rate, with slopes of 57.7 percent or higher, yielding the highest level of productivity loss (Parajuli et al. 2020). There are feller-bunchers equipped with measures in place to assist harvesting on steep slopes, allowing the feller-buncher to adjust and level the cabin to better stabilize the machine and operator (Visser and Stampfer 2015)

OPERATOR SKILL

Operator skill and experience can have a significant effect on overall harvest productivity (Parajuli et al. 2020). Many factors can attribute to operator skill, such as work experience both with the stand type and machine operation, the amount of planning done before entering the stand before harvest operations, felling techniques, and operator fatigue (Hiesl 2013). Operator skill can also impact productivity in mixedwood stands where species sorting and cut order could decrease harvest productivity by 40% to 57% (Parajuli et al. 2020, Spinelli et al. 2020).

SILVICULTURAL PRESCRIPTION

Silvicultural prescriptions have effects on other factors like stem size and stand densities which can play vital roles in overall productivity based on the stand's prescription (Parajuli et al. 2020). Silvicultural prescriptions and its implementation depends on the future objective of the stand and the site conditions within the stand (Parajuli et al. 2020). The three prescriptions used most often are clear-cut, thinning, and shelterwood, with clear-cut providing the highest level of harvest productivity (Hiesl 2013).

SEASONAL CONSIDERATIONS

Determining the season of harvest can affect harvest productivity as well as block access, while allowing for a fair comparison between different harvest blocks and time of harvest to avoid biased results (Hiesl 2013). Spring and fall have wetter soil conditions which cause limitations for the feller buncher moving from tree to tree. This is caused by the soil's bearing capacity which slows the machine and causes a decrease in productivity (Porsinsky et al. 2011). Summer harvests cause dryer soil conditions and winter harvests would have frozen ground to allow for better movement throughout the block (Simoes et al. 2008, Glade 1999). As frozen ground can improve movement, snow depth could impact productivity. Therefore, seasonal assumptions need to be analyzed between and within blocks as variable ground characteristics can affect productivity differently, as to the season of harvest alone (Struth, per comm).

HARVEST PRODUCTIVITY AND COST

Harvest costs are greatly influenced by harvest productivity, as harvest productivity improves the operation costs will decrease (Parajuli et al. 2020). Harvest productivity is measured by the volume of wood harvested per productive machine hour or m^3/PMH, and the average size per tree in volume (Andersson and Evans 1996). Grapple skidders tend to have lower productivity than feller-bunchers due to increased travel times and skid distances which can be affected by many different variables, with processors having the lowest productivity (Andersson and Evans 1996).

Operational costs can be broken down into fixed and variable costs which will vary depending on the machines being used during the harvest (Uusitalo 2010). Variable costs include fuel and oil consumption, number of shifts and shift lengths, machine repair, and maintenance; fixed costs include operator wages, machine registration, and depreciation on equipment (Uusitalo 2010).

SKIDDING DISTANCES AND CYCLE TIMES

Skidding distances have a significant effect on skidder productivity because the increased travel time will result in an overall decrease in productivity, which can be caused by many factors such as terrain, boundary shape, and size (Parajuli et al. 2020). Longer skidding distances also negatively impact cycle times throughout the harvest, but this could be offset with operator decision-making by carrying more volume per skid (Egan and Baumgras 2003). Skidder size also plays a role in productivity with smaller skidders yielding more wood volume per skid than larger skidders (Egan and Baumgras 2003), despite the large levels of variation between operators using similar equipment (Hassler et al. 2000). The average volume of skidded wood was found to be more closely related to the specific operator than the equipment being used (Egan and

Baumgras 2003). Traveling empty showed the largest levels of variation between operators but could be better managed with planning and more efficient decision making while skidding distance had a positive correlation with cycle times (Egan and Baumgras 2003).

MATERIALS AND METHODS

STUDY AREA

The study area is located in Alberta, Canada in the mid-western portion of the province within Weyerhaeuser's Pembina Timberlands Forest Management Area (Figure 1). The total size of the FMA is 955,220 hectares split between two offices in Drayton Valley and Edson (Weyerhaeuser, 2018).

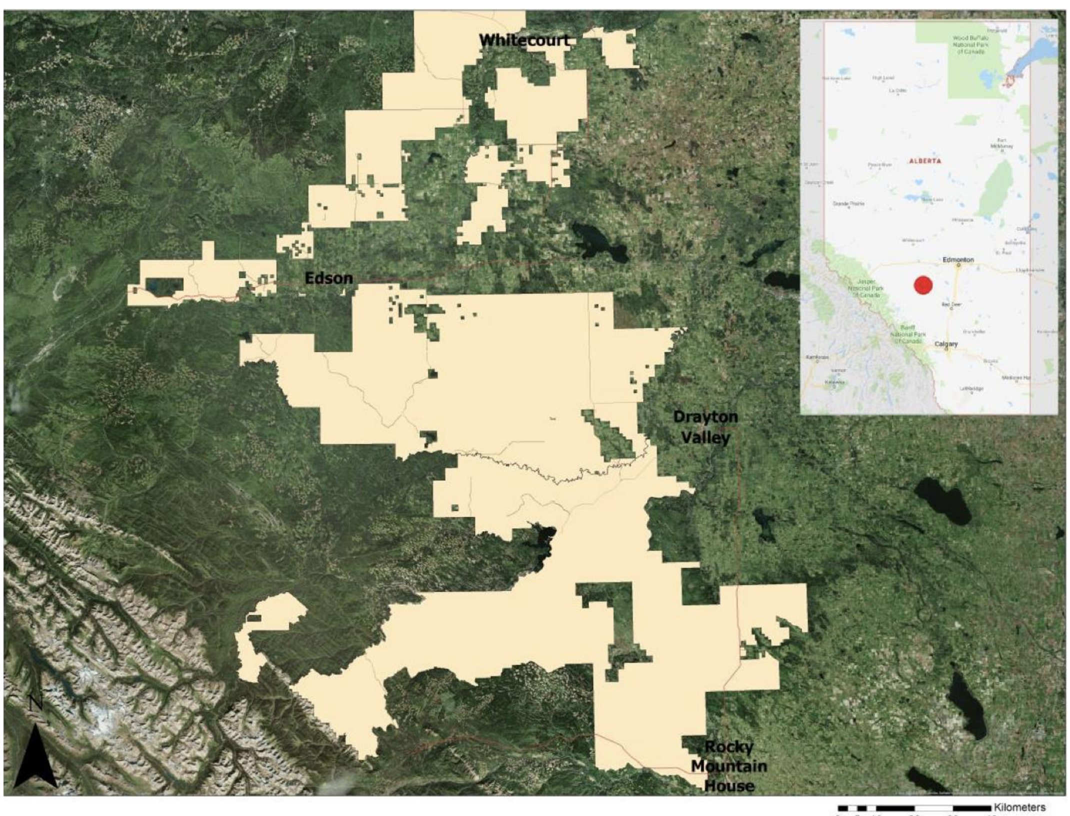

Figure 1. The geographical location of Weyerhaeuser's Pembina Timberlands Forest Management Area is outlined in beige (Chevalier, 2018).

FIELD STUDY

The study was performed in whole-tree harvesting operation blocks with clear cuts, where harvest productivity of feller-buncher teams from four different contractors were chosen to be analyzed. Data was collected through FPTrak to determine potential blocks to analyze based on the GPS data points within each stand - this ensured all blocks chosen had full data coverage to avoid inaccurate data. Data was analyzed based on total block size and compared to boundary length from 47 unique harvest blocks with similar site features to produce a ratio to analyze the different block shapes. Productivity was measured by hours worked in the block, and total volume removed, which represented the block's productivity based on m^3 harvested per machine hour worked for feller-bunchers. Factors such as slope, stem size, stand density, and species composition were considered to provide accurate results when analyzing the effects of total boundary length on harvest productivity.

PRODUCTIVITY MODELS

A sensitivity analysis was used to identify the strength of the relationship between increasing stand boundary length and harvest productivity using linear regression models. The regression models allowed the relationship to be analyzed and how it differed between contractors for stand boundary lengths to determine its overall effect on harvest productivity and if other independent variables affected those results. The datasets were analyzed in Microsoft Excel and the software tools available to the program were used to create the productivity models.

STATISTICAL ANALYSIS

The productivity of the four contractors' feller-buncher teams was analyzed and datasets with large levels of variation and outliers were further examined to avoid inaccurate data and whether that data was to be used in the productivity models. The data was categorized into blocks that have similar independent variables affecting harvest productivity and classified into block sizes with boundary lengths within a certain parameter.

RESULTS

Stand boundary length was given a numerical value to be represented by taking the shape boundary in meters over the size of the block in hectares. That numeric value was then used with the harvest productivity to determine the significance of the two variables. Table 1 shows the data from contractor 1 and how the numeric value as the variable boundary is represented

Table 1. Results from contractor 1

Block	m3/PMH	Size (Ha)	Shape Boundary (m^2)	Variable Boundary
5100503198	64	16.75	3,730.50	222.673
5110470866	77	45.86	5,080.40	110.782
5110470909	38	9.42	2,688.59	285.427
5110491515	88	14.06	1,908.19	135.679
5110491559	33	2.51	751.79	299.541
5110491578	32	3.77	893.59	236.797
5110491797	36	3.71	1,198.67	323.138
5110492100	56	6.23	1,635.71	262.423
5120463107	53	6.02	2,162.01	358.853

The four contractor's datasets were analyzed separately to identify any trends that may have skewed the data. A linear regression model was produced by combing all contractors to examine the effect across all groups (Figure 2).

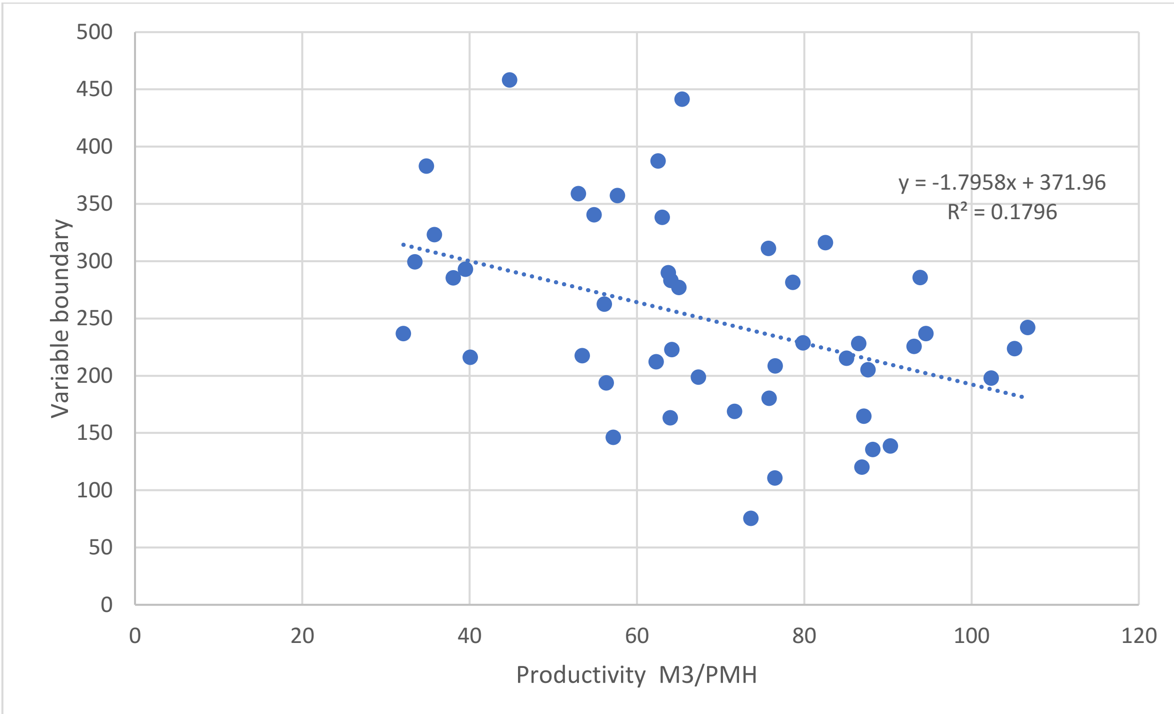

Figure 2. Stand boundary variable compared to harvest productivity across all contractors

The breakdown of all statistics within the regression analysis is displayed in Table 2 which contains the block data from all 47 unique harvest blocks used in this study.

Table 2. Displaying the results from the regression analysis for all contractors

Regression Statistics	
Multiple R	0.423776
R Square	0.179586
Adjusted R Square	0.161354
Standard Error	18.31287
Observations	47

To avoid bias a regression analysis was executed on all contractors individually - stand boundary did not significantly influence harvest productivity. Results from contractor 1 found an R-squared value of 0.567 (Figure 3).

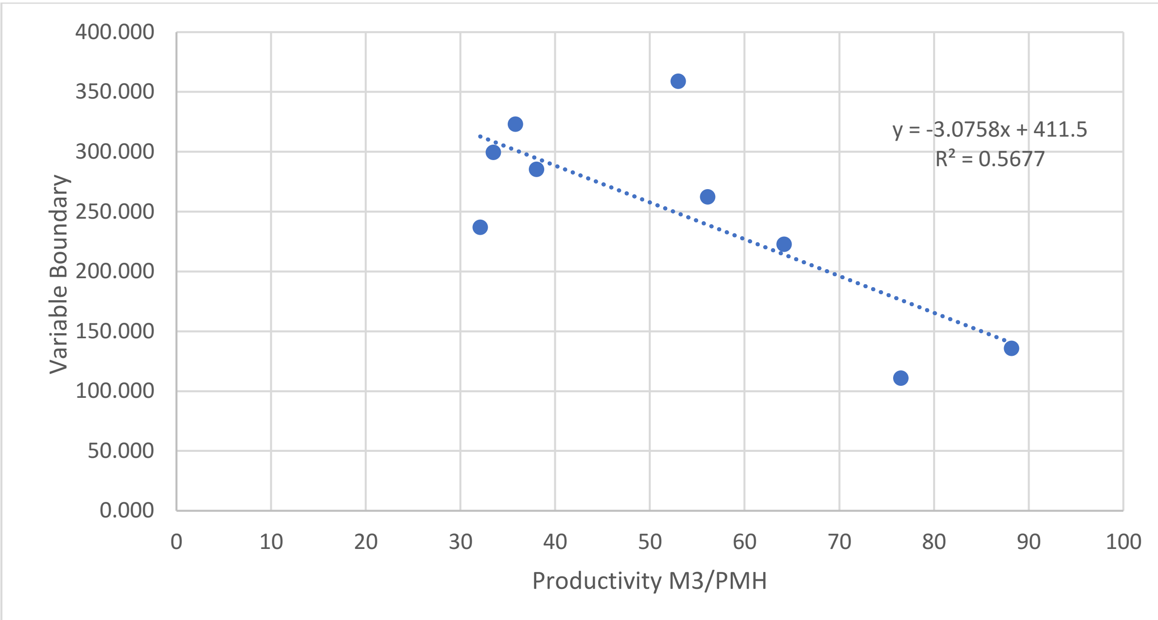

Figure 3. Linear regression for variable boundary compared to harvest productivity for contractor 1.

Contractor 2 is represented below in figure 4, which was the second-largest data set of the study between the four contractors. Its regression analysis resulted in an R-squared value of 0.19.

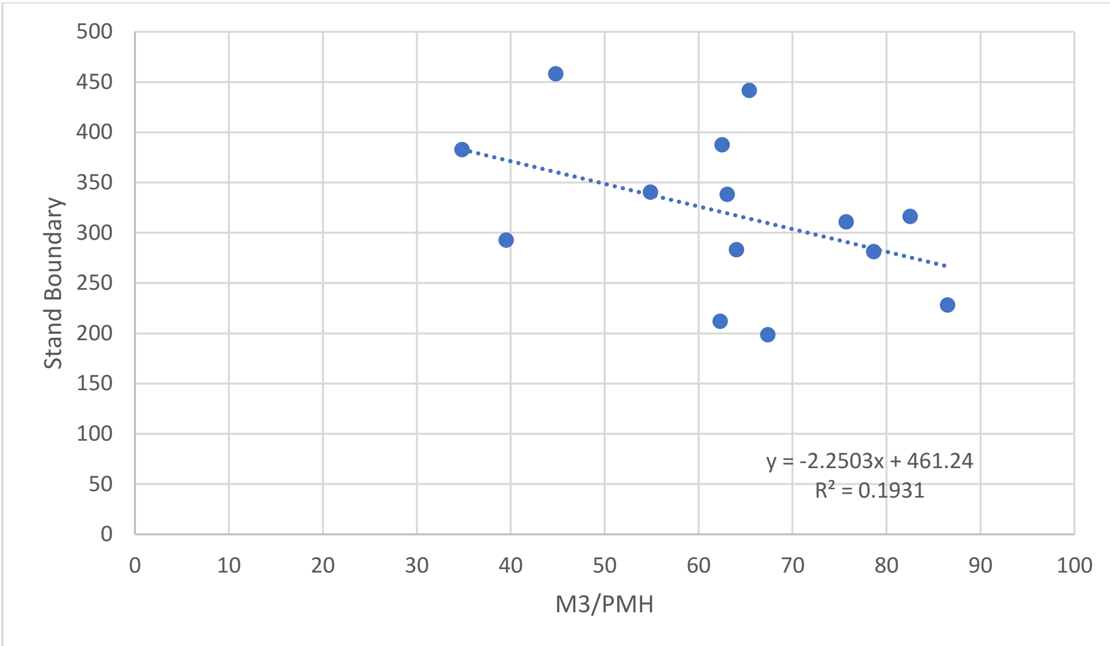

Figure 4. Linear regression for variable boundary compared to harvest productivity for contractor 2.

Contractor 3 contained the largest sample size in the study and its linear regression model is represented below in Figure 5. This regression analysis resulted in an R-squared value of 0.006, which was the second weakest relationship between all contractors used in the study.

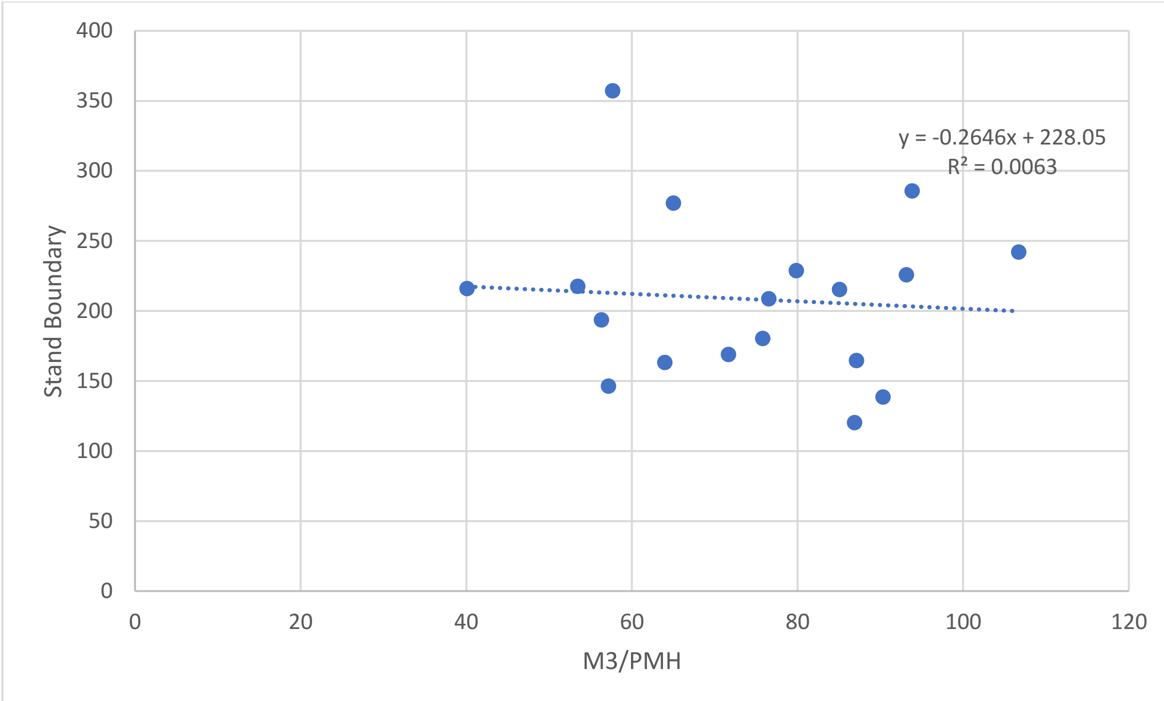

Figure 5. Linear regression for variable boundary compared to harvest productivity for contractor 3.

Contractor 4 was the smallest sample size used in the study (Figure 6). This regression model had an R-squared value of 0.0015 which was the weakest relationship used in the study.

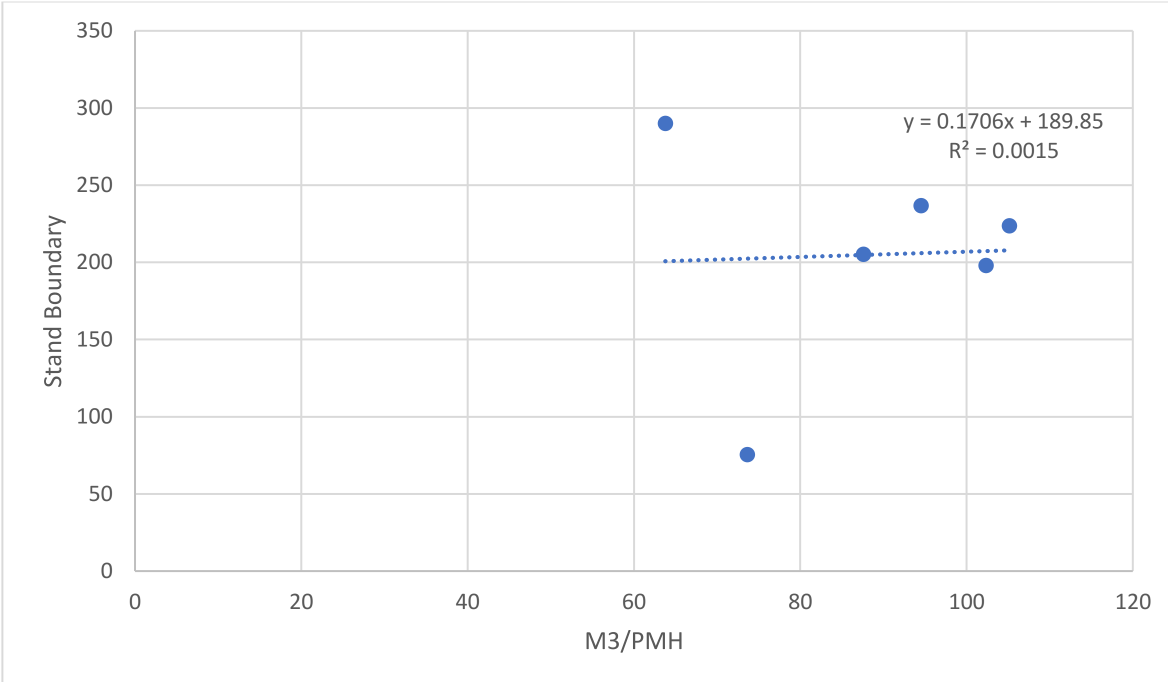

Figure 6. Linear regression for variable boundary compared to harvest productivity for contractor 4.

Each contractor's average productivity was analyzed for all the blocks used within the study (Figure 7). Contractor 1 resulted in the lowest harvest productivity whereas contractor 4 was the highest.

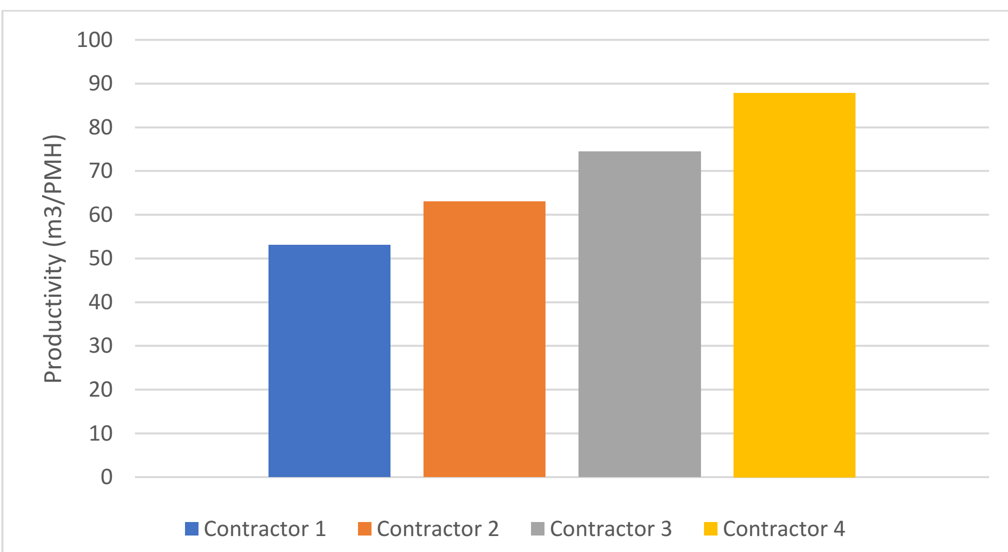

Figure 7. Average productivity for each contractor used within linear regression models.

To analyze the effect season of harvest had on productivity a box plot was used to compare variable boundary and harvest productivity between each season of harvest (Figure 8). All contractors were grouped to better represent the data and provide a comparison across seasons.

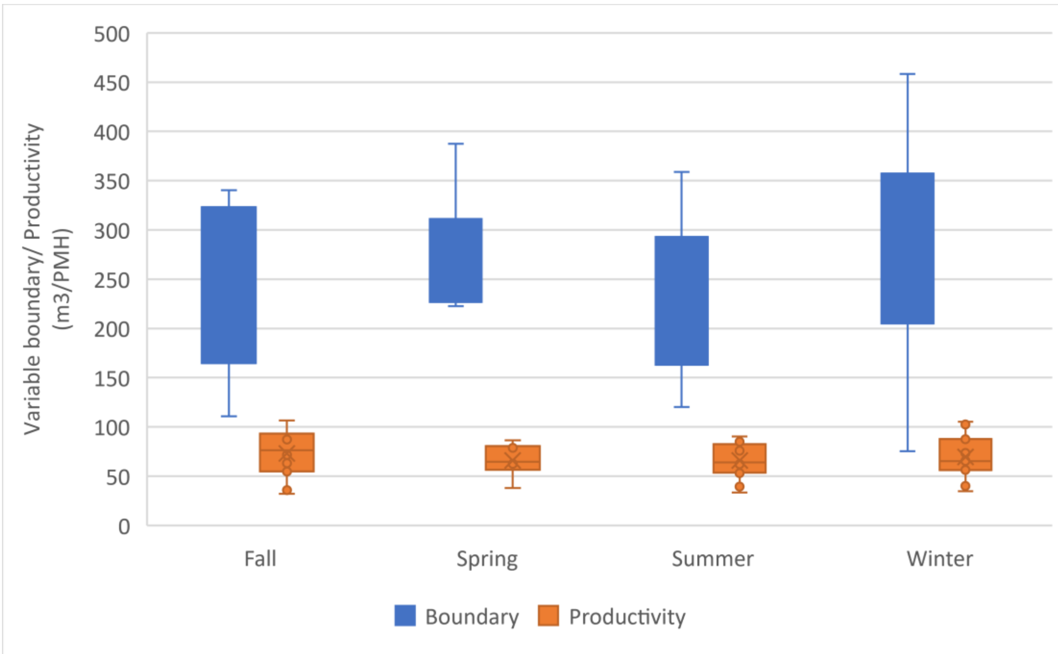

Figure 8. Box plot of variable boundary length and harvest productivity based on the season of the harvest throughout all contractors.

DISCUSSION

These findings show that stand boundary length has no significant effect on feller-buncher productivity, and other variables within these harvest blocks would have had a greater impact on harvest productivity. One of the limitations of this study was the relatively small sample size with varying harvest block sizes. This was due to the reliability of GPS data location and operator compliance using these tracking systems. A larger sample size could have been produced with a more in-depth analysis of the harvest before the commencement of operations.

The regression model in figure 2 shows a downward trendline and appears to show harvest productivity being positively affected as the variable boundary length decreases. But following the regression analysis displayed in table 2 the variable boundary length had no significant effect on harvest productivity based on the weak relationship between the two variables with an r-squared value of 0.17.

A similar study was conducted using data from Tolko using 338 unique blocks where the same findings were found to support my results. The study showed that variable edge within blocks or stand boundary length had no significant effect on harvest productivity, with the only significant variable being piece size (Pavel. M., per comm)

Other studies by Rossit et al (2019) and Aalmo et al (2020) also support these results stating that piece size and DBH were the most influential factors affecting harvest productivity. Rossit et al (2019) also examined the effects operator experience and shift time had on the productivity levels with varying DBH sizes. Night shift seemed to have lower productivity overall but was largely influenced by DBH, which had a more significant effect on harvest productivity.

FACTORS AFFECTING PRODUCTIVITY

The majority of literature identifies the effects other factors in the stand have on harvest productivity such as slope, piece size, operator skill, species composition, and time of harvest (Hiesl 2013, Parajuli et al. 2020, Spinelli et al. 2020, Visser and Stampfer 2015 and Wang et al. 2004), but do not consider the effect of stand boundary length on harvest productivity. After analyzing the results from this study, it appears stand boundary length is not included with the other factors, because they have a more significant effect on the overall productivity than boundary length presents. Stand boundary length can cause these other factors to be amplified, but on its own does not have a significant effect on harvest productivity.

OPERATOR SKILL

Operator skill influenced the overall harvest productivity within each harvest block which is evident in Figure 7 (Parajuli et al. 2020). Each contractor's productivity averages were grouped to better analyze any trends in the data while determining what could have caused the variability. Contractor 1 had the lowest average productivity at 53 m^3/PMH, this could have been caused by operator experience or fatigue (Hiesl 2013). Contractor 1 has the smallest workforce with only one feller buncher which was likely the cause for lower productivity levels. Contractor 1 had the most significant relationship with variable boundary length with an r-squared value of 0.56, while the remaining contractors all fell below 0.20. Contractor 2 had a productivity of 63m^3/PMH while operating with two feller bunchers within blocks, and was the second-largest sample size of the study with data from 14 unique blocks. Contractor 3 had the largest sample size and available workforce with eight different feller bunchers within its operating team with an average productivity of 74 m^3/PMH. Contractor 4 had the smallest sample size with only one feller buncher and the highest productivity of 88 m^3/PMH. Many other factors could have affected the operator's productivity levels such as machine configurations and different variables in the blocks (Hiesl 2013). Productivity levels can vary between contractors, so it is essential to analyze them separately to examine any trends that may persist when reviewing the dataset.

SEASONAL CONSIDERATIONS

When examining the productivity data based on the season of harvest in Figure 8, it was evident that the harvest productivity stayed relatively consistent throughout each season. Interestingly, there was little variation in the productivity between harvest seasons, with fall having the highest productivity levels. It would be assumed summer and winter blocks would have higher productivity due to soil conditions, but the productivity levels seemed unaffected by the season of harvest. This would imply that other factors must be affecting the productivity than season of harvest and variable boundary alone. Weyerhaeuser's Pembina Timberlands tends to see smaller piece sizes in its winter blocks, which would have affected the productivity as piece size was determined to be the most influential factor (Struth, per comm). The variable boundary between seasons shows large levels of variation, with the largest coming from the winter harvest blocks. This is likely caused by increased access to more wet blocks as the ground would be frozen and allow for better soil-bearing properties for the feller buncher to traverse (Porsinsky 2011).

SKIDDING DISTANCES AND CYCLE TIMES

Despite Variable boundary having no significant effect on harvest productivity skidding distance and cycle times within the block would be affected differently (Parajuli et al. 2020). This is caused by more movement within the block for skidder operators as they traverse throughout, which would affect operator decision-making and the average volume per skid. The same can be assumed for wood extraction, as the increased variable boundary of the stand will affect the location of the landing and the roads within the blocks used to access them (Egan and Baumgras 2003).

CONCLUSION

The objective of this study was to analyze the effect of variable boundary length on feller buncher productivity, and its significance compared to other site factors within the chosen harvest blocks. This study rejected the hypothesis that increasing variable boundary length had a negative effect on feller buncher productivity. This study showed that there are more significant site factors within the harvest blocks that are impacting the productivity levels of the feller bunchers and their operators. This thesis outlined the other factors that may be affecting the harvest productivity and the implications that would follow if relevant in the harvest operation.

Although feller buncher productivity was not significantly affected by variable boundary length, this does not imply other machines and configurations would be subject to the same result. From skidder cycle times to wood extraction from the harvest blocks, in block roads, and access to the stand would all be affected by the increase in variable boundary length. Therefore, all aspects of the harvest should be explored to better analyze how variable boundaries could affect the entire harvest operation.

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APPENDICES

Appendix 1. Harvest productivity model for Contractor 1

Block	Contractor	Worked Hours	M3/PMH	Volume (m3)	Size (Ha)	Shape Area (m2)	Shape Boundary	Harvest Season	Variable Boundary
5110491578	Baker	23.4	32	749	3.77	37,736.62	893.59	Fall	236.7968102
5110491559	Baker	17.2	33	576	2.51	25,098.22	751.79	Summer	299.5409702
5110491797	Baker	21.8	36	780	3.71	37,094.66	1,198.67	Fall	323.138283
5110470909	Baker	65.6	38	2,493	9.42	93,734.72	2,688.59	Spring	285.4271122
5120463107	Baker	28.8	53	1,528	6.02	60,247.69	2,162.01	Summer	358.8533955
5110492100	Baker	21.4	56	1,199	6.23	62,331.25	1,635.71	Summer	262.4226166
5100503198	Baker	63.8	64	4,098	16.75	167,532.27	3,730.50	Spring	222.6733077
5110470866	Baker	152.3	77	11,654	45.86	458,596.62	5,080.40	Fall	110.7815196
5110491515	Baker	38.8	88	3,421	14.06	140,640.08	1,908.19	Fall	135.6790649

Appendix 2. Harvest productivity model for Contractor 2

Block	Contractor	Worked Hours	M3/PMH	Volume (m3)	Size (Ha)	Shape Area (m2)	Shape Boundary	Harvest Season	Variable Boundary
5140473078	Barmac	49.03	35	1,707	8.73	78,775.40	3,341.42	Winter	382.9237516
5140472828	Barmac	29.89	40	1,181	6.14	61,395.66	1,798.28	Summer	292.9005971
5140472996	Barmac	50.84	45	2,277	8.03	80,328.98	3,680.63	Winter	458.1950716
5140472903	Barmac	10.95	55	601	2.60	26,014.45	885.57	Fall	340.4151727
5140473175	Barmac	381.37	62	23,755	95.39	953,882.51	20,232.42	Summer	212.1059755
5140473633	Barmac	30.02	63	1,877	6.01	60,074.11	2,327.90	Spring	387.5054976
5140472988	Barmac	41.03	63	2,587	12.50	124,994.40	4,227.16	Fall	338.1883351
5140472630	Barmac	107.23	64	6,868	25.10	250,965.76	7,104.72	Winter	283.0950629
5140473612	Barmac	15.15	65	991	3.16	31,588.62	1,394.87	Winter	441.5733023
5140472521	Barmac	45.32	67	3,053	10.81	108,147.02	2,148.81	Summer	198.6936236
5140472695	Barmac	26.87	76	2,034	6.39	63,853.33	1,986.14	Winter	311.0469015
5140473252	Barmac	75.35	79	5,925	19.19	191,882.67	5,399.99	Spring	281.4212139
5140472979	Barmac	50.26	83	4,148	12.50	124,991.47	3,952.57	Summer	316.2272443

5140472698	Barmac	59.03	87	5,107	16.05	160,501.46	3,663.37	Spring	228.245069

Appendix 3. Harvest productivity model for Contractor 3

Block	Contractor	Worked Hours	M3/PMH	Volume (m3)	Size (Ha)	Shape Area (m2)	Shape Boundary	Harvest Season	Variable Boundary
5120470832	Lydell	66.39	40	2660.493	11.10	110,967.56	2,397.67	Winter	216.0693946
5170491254	Lydell	20.69	53	1106.382	6.54	65,394.04	1,423.21	Summer	217.6354505
5170490191	Lydell	142.59	56	8031.765	29.68	296,812.97	5,746.61	Winter	193.6104611
5170491240	Lydell	291.75	57	16677.048	55.60	556,023.74	8,136.39	Summer	146.3316524
5120470844	Lydell	16.52	58	952.827	2.63	26,309.19	940.04	Winter	357.3057964
5130472692	Lydell	237.94	64	15220.193	45.75	457,528.95	7,471.35	Summer	163.2977963
5120471787	Lydell	117.59	65	7645.793	26.06	260,649.07	7,219.28	Spring	276.9733103
5170490286	Lydell	81.03	72	5806.041	20.02	200,229.48	3,381.71	Fall	168.8918936
5170490181	Lydell	206.33	76	15642.208	55.41	554,085.14	9,993.75	Summer	180.3647948
5170490142	Lydell	46.81	77	3582.01	8.12	81,214.82	1,694.18	Winter	208.6047481
5130472651	Lydell	59.07	80	4716.664	12.80	127,996.82	2,928.37	Summer	228.784321
5120470837	Lydell	31.39	85	2670.011	9.72	97,206.37	2,093.26	Summer	215.3421683

5130472385	Lydell	364.32	87	31653.849	109.39	1,093,869.28	13,154.19	Summer	120.2537677
5170491212	Lydell	49.09	87	4276.621	12.66	126,618.14	2,085.54	Fall	164.7107743
5130471325	Lydell	152.85	90	13804.367	47.61	476,094.81	6,596.79	Summer	138.5605086
5170490101	Lydell	20.13	93	1874.848	4.69	46,855.75	1,057.66	Fall	225.7273433
5170491245	Lydell	17.05	94	1600.261	6.58	65,768.41	1,879.53	Fall	285.7798294
5170491224	Lydell	20.16	107	2151.064	7.69	76,864.78	1,859.87	Fall	241.9662389

Appendix 4. Harvest productivity model for Contractor 4

Block	Contractor	Worked Hours	M3/PMH	Volume (m3)	Size (Ha)	Shape Area (m2)	Shape Boundary	Harvest Season	Variable Boundary
5130521535	JBL	65.44	64	4,173	16.74	167,411.17	4,855.74	Winter	290.0488395
5130521584	JBL	117.09	74	8,622	37.81	378,088.42	2,851.67	Winter	75.42336782
5130522291	JBL	70.11	88	6,143	16.43	164,254.57	3,370.69	Winter	205.2111157
5110480950	JBL	69.15	95	6,538	26.71	256,011.66	6,323.12	Winter	236.7030994
5110481610	JBL	79.87	102	8,176	33.56	327,206.90	6,642.60	Winter	197.9414844
5130522293	JBL	73.34	105	7,713	19.09	190,864.74	4,269.60	Winter	223.6977814