https://doi.org/10.5552/crojfe.2023.2250

Logging Crew Attributes by Region in the Southeast USA

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Abstract

Urbanization, shrinking markets, and reduced forestry investment may affect harvesting efficiency in regions of the US South. To monitor these conditions, logging businesses have been tracked by surveys conducted by universities and trade associations. This project used a sampling approach coordinated with FIA utilization studies to sample logging crews based on a harvesting location. The approach was used to develop relationships among firm attributes and site attributes in six southeastern states (AL, GA, FL, NC, SC, and VA) from 2011 to 2018. The data included harvest attributes (location, harvest size and stand type) and logging firm attributes (production, crew labor, crew number, the number of machines by type, and machine age). For crew capital value, an equation was developed for this study using machine number and average machine age. The data from logging crews on 419 harvests were analyzed by region, harvest size, and stand type. Mean values for crew labor ranged from 3.1 to 7.1 workers. The average capital value per crew ranged from $220,000 to $524,000 per crew in the Coastal Plain with a narrower range in the Piedmont. In the Coastal Plain, higher productivity was detected for larger harvests and pine versus hardwood and mixed stands; however, in the Piedmont those trends were less obvious. Ratio of feller-bunchers, skidders and loaders were mostly 1:1:1 or 1:2:1 with 41% and 24% of samples, respectively. There were notable trends among Coastal Plain loggers regarding capital value and productivity with evidence supported by a production function. The differences in Piedmont (e.g., ownership size, market access, terrain, population density, etc.) may combine to limit daily production and labor productivity.

Keywords: logging business, timber harvest, productivity, labor, Piedmont, Coastal Plain

1. Introduction

The United States of America is among the top five producers of industrial roundwood (Lundbäck et al. 2021). According to Oswalt et al. (2014), the USA harvested approximately 368 milion cubic meters of timber per year. The Pacific Northwest was once the leading region for timber harvest volume, but now the Southeast accounts for 63 percent of the annual harvest volume (Haynes 2003, Howard and Westby 2013, Oswalt et al. 2014).

The Bureau of Labor Statistics (BLS) data indicate that across the USA there were 8300 logging firms with an average of about 6 employees per firm in 2017. Many logging businesses in the Southeast are productive and produce more than 70,000 tons per year or 350 tons per working day (Conrad et al. 2018a). The most common harvesting system in the Southeast is mechanized full-tree systems using feller-bunchers, grapple skidders and knuckleboom loaders (Lundbäck et al. 2021, Spinelli et al. 2021).

Regional surveys of logging businesses have reported attributes of logging businesses concerning equipment, transportation, labor, products marketed, business practices, and business plans (Greene et al. 1988, Smidt and Blinn 1994, Munn et al. 1998, Cubbage and Carter 1994, Knight 2016, Barrett et al. 2017, Conrad et al. 2018a). The data from surveys identify trends and estimate aspects of business performance like capital and labor productivity. Changes in business attributes and performance over time has important ramifications for forest landowners and forest industry. Therefore, the overall goal of this study was to add to the understanding of logging crew attributes and performance when those data can be related to a specific harvest. This project used a crew sampling approach based on a harvesting location with an intent to develop relationships among firm attributes and site attributes. Both the sampling and site based approaches are novel in developing insight into logging capacity.

2. Material and Methods

2.1 Logger Data

Site selection procedures followed a stratified approach by product, species, and county and a cooperating logging firm was identified with the assistance of local contacts. Procedures are outlined in harvest and utilization studies like Wall et al. (2018). The survey data from the logging crew and the site were recorded and site parameter data followed Forest Inventory and Analysis (FIA) classification schemes. Labor and machine data referred to the crew on site, while businesses may have had multiple crews. Machine age was the average age of all machines on site. For production, daily performance in loads per day was retained as the variable. Crew capital value was estimated from predicted values based on age of the most frequent machines (grapple skidders and feller-bunchers).

This study used data from logger interviews in six southeastern states (AL, GA, FL, NC, SC, and VA) from 2011 to 2018. The data included harvest attributes (location, harvest size and stand type) and logging firm attributes (production, crew labor, crew number, the number of machines by type, and machine age). FIA codes for stand types were simplified into two stand types for pine and hardwood (mixed-pine hardwood and hardwood). County maps were used to identify physiographic region where the loggers were found as Coastal Plain, Piedmont and other uplands. Other uplands and the Piedmont were grouped and labeled as Piedmont. Production in loads per day was converted to tons per day using 26.5 tons per load. Labor productivity was estimated as tons per worker per day by dividing production by crew labor. The equation developed for this study and machine number and average machine age were used for determining crew capital value. An average use of 1400 hours per year was assumed.

To compare trade-off between labor and capital, a linear production function was fit to combinations of region and stand type. Combinations with harvest size classes had too few samples. The function was fit using Proc reg (SAS 2016), using daily production in loads (Loads), crew labor (Labor), and estimated crew capital value (Capital) in 2021 dollars (Eq. 1).

$$Ln(Loads) = a_0 + a_1 Ln(Labor) + a_2 Ln(Capital) \tag{1}$$

Where:

Loads production in loads per day

Labor crew labor

Capital estimated crew capital value, $.

2.2 Capital Value

Since age ranges were greater than typical depreciation functions of 5 or 6 years, data were collected to develop a value function for grapple skidders and feller-bunchers for an approach similar to Spinelli et al. (2011). Asking prices for wheeled grapple skidders and feller-bunchers were collected using a search of www.forestrytrader.com in mid July 2021. The search was limited to the two machine types and sorted by distance from Auburn, Alabama. Each machine less than 11 years old with a make, model, model year, machine hours and asking price was recorded. Search pages were set to 25 listings per page and full pages of listings were recorded until more than 50 of each machine were recorded. A nonlinear regression model (Eq. 2) was applied to the data using a ratio for machine life as machine hours divided by 10,000 hours. Values greater than 10,000 hours were assigned a value for machine life of 1. The age was estimated with 2021 as the current year. For interpretation, B_0 represented the average initial purchase price in 2021 dollars, B_1 represented the loss in machine value due to use, and B_2 was the annual machine depreciation in dollars. Proc nlin in SAS (2016) was used to fit Eq. 2 for each machine individually and all machines.

$$CV = (\beta_0 + \beta_1 * (L)) * \beta_2^{(-A)} \tag{2}$$

Where:

CV Capital value in US$

L Machine life ratio

A Machine age in years.

3. Results

3.1 Capital Value

Data for 58 grapple skidders and 64 wheeled feller-bunchers were collected. Feller-bunchers and grapple skidders had similar age distribution with means of 5.4 and 5.3, respectively and standard deviations of 2.2 and 2.1. Feller-bunchers had fewer average hours (5960) than skidders (7022) and were generally lower priced, \$109,524 versus \$120,188. For the nonlinear models, the p values for the three models were <0.0001,

Table 1 Model statistics and parameter estimates resulting from model fitting of Eq. 2

Statistics		Wheeled feller-buncher	Grapple skidder	All
N		64	58	122
Model *F*		561.03	229.79	633.5
MSE		5.1034 10^8	13.425 10^8	9.3559 10^8
Parameter estimate	B_0	250,768	274,454	261,007
	B_1	–111,401	–102,051	–87,361
	B_2	1.1101	1.1146	1.1245
Standard error	B_0	14,206	25,141	14,150
	B_1	21,704	49,058	25,198
	B_2	0.018	0.034	0.018

and the parameter estimates were significantly different from 0 (p<0.05) (Table 1). The wheeled feller-buncher model had the lowest *MSE* and parameter estimates with the smallest standard errors. The model with all machines has the largest *F* value and a value for *MSE* between the two machine models. Examination of residual plots showed no indication that regression assumptions were violated for the individual machine or combined datasets.

3.2 Logger Survey

Outliers were identified by examining loads per worker per day and isolating the unrealistically high (>6 loads per worker day) and low values (<0.5 loads per worker day). Most outliers appeared to be related to data entry errors in crew labor or loads per day. After the outliers were excluded, the sample included loggers on 419 harvest sites (Table 2). Most of the harvest sites (79%) were in the pine stand types. The number of crews by state and region ranged from 9 to 79 with a median of 40. For the statistics by state and region, the number of crews per firm ranged from 1.0 to 3.2 with an average of 1.5 crews. The average values for crew labor and logging machines were similar for the Coastal Plain and Piedmont. The Virginia Coastal Plain had the highest average production rate with 17.1 loads per day.

Since data were collected over several years (2011 to 2018), Pearson correlation coefficients were used to identify potential trends in production or productivity. The parameter *loads per day* was not correlated with sample year (r=0.02). Productivity (loads per worker per day) was negatively corrected with sample year for all samples (r=–0.14) and the Coastal Plain (r=–0.21), but there was no correlation in the Piedmont (r=0.01). For the six-state area the total harvest increased by 30% from 2011 to 2018 and by 16% from 2013 to 2018 with data from TPO reporting tool (USDA Forest Service 2022).

Since harvest size was a class value (1 to 10 ha; 11 to 20 ha; 21 to 40 ha; greater than 40 ha), the mean and standard error of crew labor were presented by region and stand type (Fig. 1). The mean values ranged from 3.1 to 7.1 and the only apparent trend between stand

Table 2 Logging firm characteristics means and standard errors (in parenthesis) by region (Coastal Plain and Piedmont) and state

Region	State	*N*	Crew number	Crew labor	Logging machines	Loads per Day
Coastal Plain	Alabama	47	1.7 (0.2)	5.7 (0.4)	4.6 (0.3)	12.1 (0.6)
	Florida	36	1.5 (0.2)	5.2 (0.7)	3.4 (0.2)	10.3 (0.6)
	Georgia	79	1.3 (0.1)	4.6 (0.2)	3.7 (0.1)	11.9 (0.5)
	North Carolina	53	1.0 (0.0)	4.6 (0.3)	4.4 (0.2)	11.1 (0.5)
	South Carolina	46	1.6 (0.3)	7.0 (0.5)	4.2 (0.2)	12.8 (0.7)
	Virginia	9	1.0 (0.0)	7.6 (1.1)	5.9 (0.6)	17.1 (2.9)
Sub-Total		270	1.4 (0.1)	5.4 (0.2)	4.1 (0.1)	11.9 (0.3)
Piedmont	Alabama	11	1.2 (0.1)	5.2 (0.5)	3.9 (0.3)	10.0 (0.8)
	Georgia	10	1.8 (0.6)	4.7 (0.6)	4.1 (0.4)	11.9 (0.6)
	North Carolina	40	1.2 (0.1	5.4 (0.4)	4.7 (0.3)	9.8 (0.7)
	South Carolina	35	3.2 (0.6)	7.2 (0.4)	4.0 (0.2)	13.1 (0.5)
	Virginia	53	1.4 (0.1)	4.6 (0.2)	4.0 (0.2)	8.8 (0.8)
Sub-Total		149	1.8 (0.2)	5.5 (0.2)	4.2 (0.1)	10.4 (0.4)
Total		419	1.5 (0.1)	5.4 (0.1)	4.1 (0.1)	11.4 (0.2)

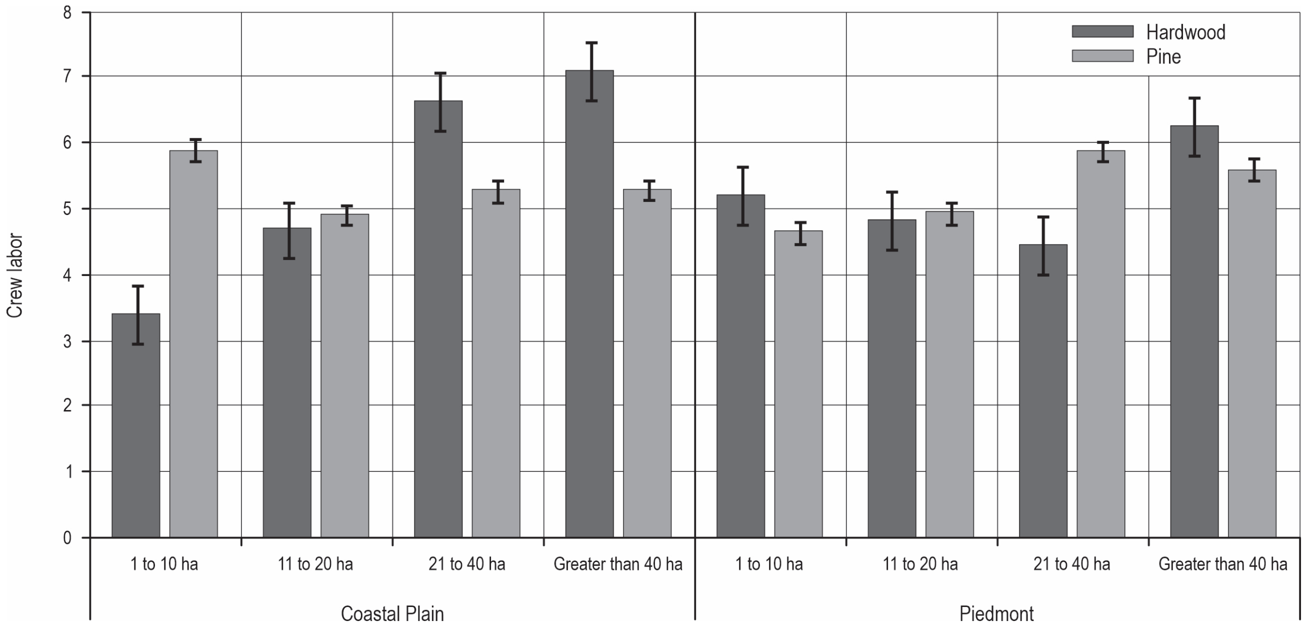

Fig. 1 Average crew labor by harvest size, stand type (pine and hardwood) and region (Coastal Plain and Piedmont)

size and crew labor was in Coastal Plain hardwood stands.

For the three most frequent machines, the differences in average number per crew were consistent between hardwood and pine stands with slightly more machines per crew in hardwood stands (Fig. 2). However, there were fewer felling machines in the Piedmont hardwood than in Piedmont pine stands. The difference might be related to the presence of chainsaw felling in hardwood Piedmont samples. Forty percent of crews indicated that they had chainsaws for felling although all but 5 crews also had a felling machine. Since machine combination averages are not whole numbers, either most systems are unbalanced or the variety of sites and processes yields different machine combinations that are balanced. A system with 1 feller-buncher, 1 skidders and 1 loader (1:1:1) accounted for about 41% and 1:2:1 systems accounted for another 24%. There were too few other machines (harvesters, forwarders, chippers and processors) to estimate a mean per crew.

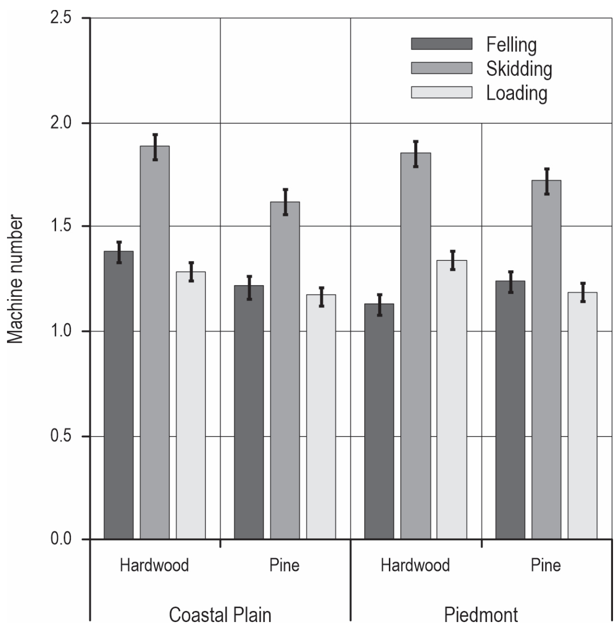

Fig. 2 Mean machine number by type (felling, skidding, loading), species (pine and hardwood) and region (Coastal Plain and Piedmont)

The estimated average capital value per crew ranged from $220,000 to $524,000 per crew in the Coastal Plain (Fig. 3). Harvest size classes were positively associated with crew capital value for both stand types. The range in capital value was smaller in the Piedmont, $300,000 to $450,000, with a reduced influence of harvest size class. For all the samples the capital value was influenced more by equipment age, with a –0.70 correlation coefficient, than by machine number (r=0.56).

In the Coastal Plain the estimated productivity (tons per worker per day) ranged from 36 to 73 (Fig. 4) and the trends in the Coastal Plain with harvest size class were similar to those for capital value. In the Piedmont, most combinations of harvest size and stand type had average productivity that ranged from

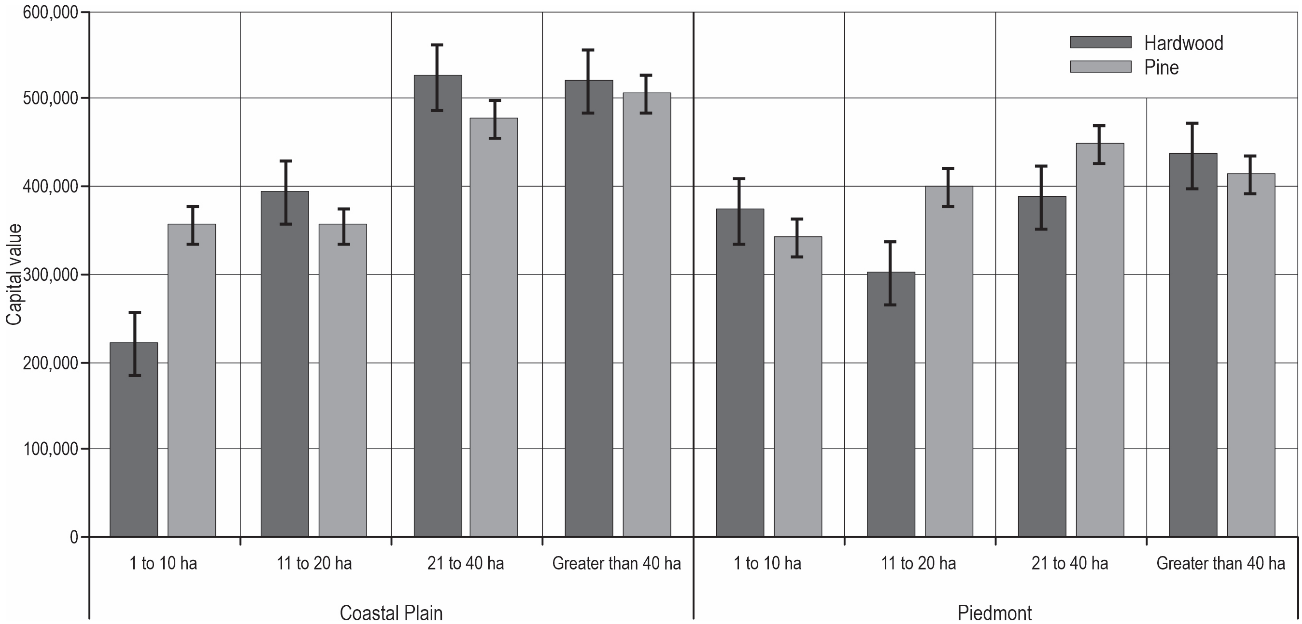

Fig. 3 Estimated crew capital value *f* (machine age, number) by harvest size, species (pine and hardwood) and region (Coastal Plain and Piedmont)

41 to 60 tons. The productivity for harvest size of 1–10 ha in the Piedmont was among the highest at 75 tons per worker per day. This notable departure from the trend could be influenced by the distribution of higher quality products (i.e. more saw timber) from smaller harvest areas (Kittredge et al. 1996).

Since the split by harvest size resulted in too few samples per regression, production functions for combinations of region and stand type were estimated (Table 3). The models were all significant at P=0.0001 and the adjusted R^2 ranged from 0.21 to 0.53. Differences in elasticity could be observed comparing both regions and stand types. The parameter estimates all demonstrate reducing returns to scale. The marginal rate of substitution (*MRS*) for capital is the estimated change in capital to replace 1 worker at the median

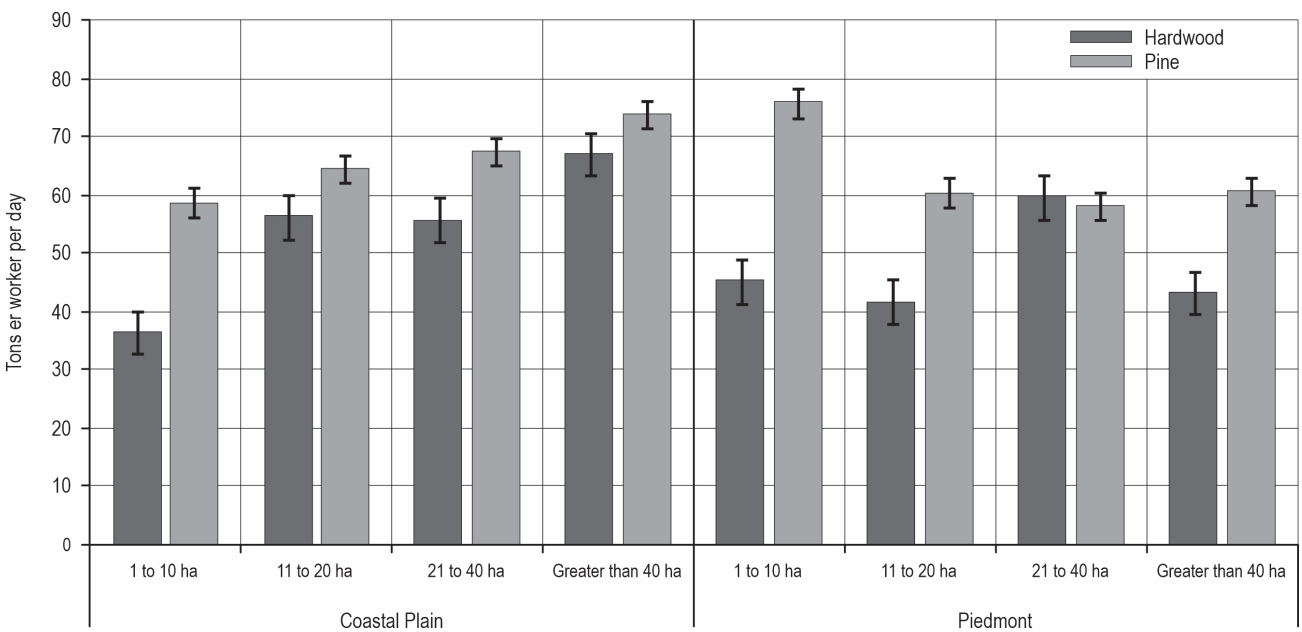

Fig. 4 Mean firm productivity by harvest size, species (pine, mix and hardwood) and region (Coastal Plain and Piedmont)

Table 3 Model statistics and parameter estimates for production functions for region and stand type combinations

Region	Coastal Plain			Piedmont		
Stand type	*P*	*H*	All	*P*	*H*	All
Intercept	–0.8851	–2.2683	–1.1607	0.3258	0.1941	0.0212
Log, labor	0.3364	0.4526	0.3583	0.3719	0.6002	0.4434
Log, capital	0.2168	0.2987	0.2339	0.1099	0.0694	0.1176
Capital, $ thousands	398	361	398	430	333	382
Labor	4	5	4	5	5	5
Loads per day	12	10	11.5	10	8	10
Marginal return of substitution, $ thousands capital	154	109	152	290	576	382
Change in labor for 10% production increase	1.3	1.2	1.2	1.5	0.9	1.2
Change in capital (thousand $) for 10% production increase	220	136	200	593	983	477
F value	56.60	24.28	78.68	14.84	10.88	25.21
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Adj. R^2	0.3288	0.5317	0.3661	0.2151	0.3004	0.2465
MSE	0.1001	0.1224	0.1070	0.1489	0.2051	0.1824
DF_{Error}	225	39	267	99	44	146

values for labor and capital. *MRS* was much higher in the Piedmont than the Coastal Plain. The labor and capital needed to increase production by 10% from the median values were estimated. The capital changes were similar to or greater than *MRS*. In the Coastal Plain, the production increase would require about 20% increase in either labor or capital. Labor changes are similar for the Piedmont but changes in capital were estimated at nearly 100% of the median capital value. The capital value estimated does not include capability, but the understanding would be that newer, more valuable machines might be more reliable and have increased capability.

4. Discussion

General sample statistics for crews agree with previous studies from the region. For Virginia, crew distribution by Coastal Plain and Piedmont from this sample was similar to the distribution from Barrett et al. (2017). Considering crew size and crew number per firm, the statistics were comparable to previous data from Virginia (Barrett et al. 2017), Georgia and South Carolina (Conrad et al. 2018a).

Total production per crew was recorded in different units than found in previous studies, but the comparable means from this study (10 to 12 loads per day) were similar to Conrad et al. (2018a) (42.5 and 44.6 loads per week in GA and SC). For equivalance, weekly production levels from this study would require just over 4 workdays per week and sum to about 200 working days per year. In Barrett et al. (2017), the Coastal Plain and Piedmont production was lower at 38 and 26 loads per week. The high production in the Virginia Coastal Plain of 17 loads per day may be attributed to the small sample size, but both Barrett et al. (2017) and this data indicate that the average productivity per worker was 18% greater for the Coastal Plain compared to the Piedmont or Piedmont and uplands, respectively.

The machine combinations were remarkably similar across region even though some differences were observed in crew size and productivity. Hardwood volume reduced productivity, which could be linked to the reduced productivity of processes which are sensitive to merchantable tree size (loading and delimbing).

The main types of machines in our sample were rubber-tired feller-bunchers (86%), grapple skidders (92%) and knuckleboom loaders (99%). Bolding et al. (2010), Barrett et al. (2017) and Conrad et al. (2018a) had similar results. The lack of harvesters, forwarders or processors was notable, especially when compared to other regions (e.g. Pacific North West (West et al. 2022), Lake States (Shivan et al. 2020) and North East

(Leon and Benjamin 2012)). Conrad et al. (2018b) commented that the absence of CTL machines in the Southern states could be a result of product specifications by mills.

Methods of generating capital value per crew differs by source and the machines included. In the Midwest, mean investments in logging machines were under $500,000 (Blinn et al. 2015, Rickenbach et al. 2015). Barrett et al. (2017) estimated $409,000 per crew for the Piedmont and $537,000 for the Coastal Plain, which are similar to the range estimated in this sample although more than 5 years apart. In 2012, Georgia and South Carolina logging businesses had a mean capital investment of $863,000 and $783,000, respectively (Greene et al. 2013). Changes over time in investment in forestry equipment may have changed in reaction to economic conditions (Barynin et al. 2013) and changes in machine technology (Diniz and Sessions 2021).

The comparisons of productivity per worker (tons per worker per day) is sensitive to assumptions of load size and workday and work week. With a ten-hour work day, the mean productivity from this sample is roughly equivalent to SC and GA at 53 and 65 tons per worker per day (Conrad et al 2018a). Conrad and Dahlen (2019) found that two different systems (processor and conventional) had a similar range in productivity (40 to 80 tons per worker per day). Even though there were no cut-to-length (CTL) systems in the sample and they are uncommon in the region, Oliveira (2013) estimated CTL productivity in similar conditions (pine, rolling terrain) at 88 tons per worker per day.

Although these results do not reflect productivity increases over time, labor productivity has grown steadily, reflected in the time series by Conrad et al (2018a) and statewide data like He et al. (2021). From 1995 to 2015, annual growth in worker income has been similar to annual growth in productivity (He et al. 2021). The sources of increased productivity overall could explain the loss of lower productivity firms (Conrad et al. 2018a) as well as incremental increases in mechanization.

The estimated production functions found decreasing return to scale as have similar studies of southern loggers (Duc et al. 2009, Lebel and Stuart 1998, Stuart et al. 2010). The increased crew investments observed in the Coastal Plain suggest that production function estimates are appropriate. In the Coastal Plain, higher production levels are supported by larger forest ownerships and market access (Conrad et al. 2018b). The stability in Piedmont logger size across the variations observed may also reflect limited returns for increased capital or labor per crew, which is also reinforced by the production function. The Piedmont regions across these six states have experienced increased population growth with related parcelization, fragmentation, reduced forestry investment, and change in management priorities (Wear and Greis 2012). Several authors have pointed to the relationships among reduced harvest volumes, higher harvest fixed costs and reduced productivity (Cubbage et al. 1989, Greene et al. 1988, Moldenhauer and Bolding 2009).

5. Conclusion

Analysis of logger data showed that there were notable trends among Coastal Plain loggers regarding capital value and productivity with evidence supported by the production function. The numerous differences between the Coastal Plain and Piedmont (ownership size, market access, terrain, population density, etc.) have produced differences in logger productivity and capital value. It appears that system constraints may limit productivity in the Piedmont. In order for growth in productivity to be maintained, system innovations must continue to produce either increased value or increased volume per worker. Innovations in value creation may evolve as supplementary biomass harvests where there is a market (Garren at al. 2022) or increased merchandizing (Cass et al. 2009, Hamsley et al. 2009, Conrad and Dahlen 2019). For some time, loggers have relied on increasing size or capability of machines to support productivity increases. If the Piedmont harvests restrict efficiency of the conventional system, adoption of innovations that improve capital productivity and especially labor productivity are critical.

Acknowledgements

This research was supported in part by an appointment to the United States Forest Service (USFS) Research Participation Program administered by the Oak Ridge Institute for Science and Education (ORISE) through an interagency agreement between the U.S. Department of Energy (DOE) and the U.S. Department of Agriculture (USDA). ORISE is managed by ORAU under DOE contract number DE-SC0014664. This paper was written and prepared by a U.S. Government employee on official time; and therefore, it is in the public domain and not subject to copyright. This research was supported the USDA Forest Service. The findings and conclusions in this publication are those of the author(s) and should not be construed to represent an official USDA, Forest Service, or U.S. Government determination or policy.

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Received: November 29, 2022
Accepted: March 24, 2023

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