FACTORS AFFECTING PRODUCTIVITY OF NEWLY ESTABLISHED THINNING OPERATIONS

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INTRODUCTION

Increased use of partial harvesting creates a potential opportunity for western contract loggers willing to concentrate on commercial thinning. A recent survey of forest products companies in Washington State indicates, for example, that those companies surveyed began using thinning harvests as a regular component of their forest management less than three years ago (Dodd, pers. comm.). In addition, lumber values have risen to historic highs in recent years, partially due to the limited supply of logs in the west [1]. These high lumber values and the increased public sentiment favouring partial harvests have prompted many western forest products companies to use commercial thinning and other types of partial harvest on company timberlands.

Many companies use ground-based, mechanized harvesting systems in thinning operations. However, the steep terrain associated with forests in the Pacific Northwest has necessitated the use of cable yarding systems for thinning some managed forests.

Planning and operational requirements for cable-based thinning harvests are significantly different from those for clear-cuts. Corridors must be laid out at appropriate spacing to balance yarder set-up time and lateral yarding times, while still allowing complete access to felled timber for yarding. Tailhold placement and the availability of guyline anchors can be a concern when working in the small timber typical of stands subjected to partial harvests. Landings are often located on existing roads and old landings, since financial returns from thinning harvests are not sufficient to finance road development or landing construction.

Felling operations must occur before the yarding, but, unlike clear-cut harvests, once the felling is finished, the yarder is restricted to operating within the corridor already created by the feller. Mistakes made during the planning phase can produce areas which do not meet the management goals of the landowner, e.g. excessive yarding corridor width and stand damage. Penalties associated with failure to adequately meet the goals of the landowner are widely used and place the onus of performance on the contract logger.

The experience necessary to make a smooth transition to cable-based thinning harvests for clear-cut harvesting is not widely available. Most logging contractors are familiar with the planning and operational constraints associated with cable-based systems in clear-cut harvests. However, few have the planning and operationally based skills needed to implement consistent profitable thinning harvests.

OBJECTIVES

This paper presents results from a long-term study of a cable-based thinning operation in coastal forests on the Olympic Peninsula of Washington State. The objective of this study was to compare hourly performance levels relative to increases in crew experience in thinning operations. These performance levels were used to determine the effect that experience has on system productivity. The study also compared other factors of the operation, specifically average slope of the yarding corridor and yarding corridor length, with hourly performance levels to determine if changes in these site conditions, combined with crew experience levels, would affect productivity.

METHODS

Background

The yarding system used throughout this study consisted of a small yarder rigged for operation as a

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running skyline and using a small, mechanical slack-pulling carriage. The yarder is completely described by Blackman [2]. The yarding crew was generally experienced with large-scale yarding operations on clear-cut harvests, but none of the crew was experienced with thinning systems. The contractor conducted all preliminary harvest planning, such as identification of landing sites, deflection-line layout and analysis, and coordination of all falling and yarding operations.

All felling, limbing, and bucking conducted during the study period was sub-contracted to a felling crew with little experience in thinning harvests. The fellers were paid based on productivity and other performance factors, such as the amount of residual damage caused through falling and the quality of limbing and bucking operations. The logging contractor was also paid based on productivity over time, although the base rate per unit of production was probably greater than that typically provided for clear-cut harvests. The contractor, like the felling crew, was evaluated based on performance. The contractor was required to meet silvicultural objectives, such as spacing and species retention, and to minimize residual stand damage. If performance was sub-standard, the landowner had the option of terminating the contractor operation before the harvest was completed.

Data Collection and Analysis

The contractor provided detailed shift-level information about the productivity of the system over 161 days of actual operation. Data collected over this period included the yarding distance and slope, productive and non-productive time, and daily production in total pieces yarded and the approximate number of loads. Daily piece counts and productive hours were used as the primary measure of system productivity. Special circumstances and equipment failures were also detailed to explain periods of down time.

Analysis of the data determined trends evident in hourly production based on pieces per hour for changing levels of crew experience, ground slopes, and yarding distance. Because piece volume was not available throughout the analysis, it was assumed that the size of individual logs yarded during the study were fairly homogeneous from day to day. This assumption is partially verified by the stand data summary presented in Table 1.

Table 1. Stand table summary for commercial thinning study blocks on U.S. Forest Service and Rayonier Inc. Timberlands.

	Size Class (inches @ DBH)						
	8-12	12-16	16-20	20-24	24-28	28+	Total
U.S. Forest Service Site:							
Mean Stems/Acre	470	200	119	48	2	4	843
Percent Stems/Acre	56	24	14	6	0	1	
Percent Basal Area	31	25	25	15	1	3	
Rayonier Site:							
Percent Stems per Acre [1]	54	34	9	2	1	0	
Percent Basal Area	33	4	18	6	3	0	

[1]Stand stocking ranged from 700 stems per acre to 850 stems per acre.

RESULTS

Crew Experience

Table 2 summarizes the observed production increases with time using average productivity in pieces per hour for a two-week (10 working days) period and the delays experienced during each period not associated with normal harvest operations. These unexpected delays included catching up to the fallers, mismarked yarding corridors, and frayed or broken lines and equipment. There appears to be no trend in the unexpected down time experienced by the system. Delays such as rigging and machine movements were not addressed by this study. Also included in this table is the average external yarding distance and slope reported for each two-week period.

A regression equation to predict the effect of increasing crew experience on productivity was developed using the data. Because two distinct rates of change were noted in the data, the regression equation was constructed as a two-piece model dependent on experience level. The regression equation follows:

$$Y = Z_1 * [14.58 + 0.106 (X)] + Z_2 * [21.83 + 0.034 (X)] \quad (1)$$

where:

Y = Productivity per scheduled hour (pieces per hr)
X = Experience level (days of operation)
Z_1 = 1 if experience level ≤ 100 days, otherwise 0
Z_2 = 1 if experience level > 100 days and ≤ 160, otherwise 0

The correlation coefficient for this model ranges between 0.933 for the first half of the regression and 0.277 for the second half. The observed increase in production with respect to increasing experience flattens significantly over the second half of the observation period, although increases still occur. The standard error of the estimate is 0.833 pieces per hour for the first portion of the regression and 1.773 pieces per hour for the second.

Table 2. Summary of observed data collected over the study period.

Time (Days)	Mean Prod. (pcs/hr)	Std. Dev. (pcs/hr)	95% C.I. (pcs/hr)	Down Time (hrs/pd)	Mean Yard Slope (percent)	Mean Yard Distance (feet)
1 - 10	15.50	2.28	1.41	10.5	77.5	500
11 - 20	15.53	2.09	1.30	7.5	80.5	520
21 - 30	18.23	3.31	2.05	2.0	72.0	530
31 - 40	17.33	0.86	0.53	0.0	58.0	500
41 - 50	18.89	4.81	2.98	6.0	55.0	515
51 - 60	20.57	2.74	1.70	9.0	57.0	470
61 - 70	20.17	5.29	3.28	7.0	60.5	715
71 - 80	22.66	6.88	4.27	2.0	48.0	645
81 - 90	24.33	2.39	1.48	3.5	51.5	390
91 - 100	28.02	5.64	3.50	1.0	64.0	505
101 - 110	26.73	5.55	3.44	0.0	71.0	500
111 - 120	22.08	4.68	2.90	3.0	74.0	615
121 - 130	21.69	5.77	3.58	7.0	60.0	1015
131 - 140	27.10	5.33	3.30	2.0	60.5	710
141 - 150	25.78	4.05	2.51	4.5	62.0	485
151 - 161	29.77	4.19	2.47	9.5	69.5	714

Figure 1 represents the observed average hourly piece count and the predicted hourly piece count for each 10 day period. Hourly production shows a nearly steady increase through the first 90 to 110 days of operation, with an approximate improvement of 1.1 pieces per scheduled hour per 10-day period between the first and the tenth period. At this point, a level of experience was achieved where continued increases in productivity were slower over time, estimated at only 0.3 pieces per scheduled hour per period.

Outliers located in the 111-120 and 121-130 day periods are explained by two days during each period where longer than usual lateral yarding led to lower productivity. In these cases, however, the use of straight piece counts to represent hourly production may not be truly representative of productivity, since operations during one two-day period produced the greatest volume recorded during the study with an estimated production of 60 to 75 tons per day. High production was due primarily to larger-than-average piece sizes, even though the production rate in pieces per hour was very low compared with other days during these two periods. Production was calculated at only 13.9 and 15.1 pieces per hour for the daily rate compared to an average of 22.1 pieces per hour over the 10-day period from days 111 to 120, while the production calculated for the two days of low piece counts for the 121-130 day period were 13.5 and 14.3 pieces per hour versus the 10-day average of 21.7 pieces per hour.

From the regression information, a multiplier was generated in order to eliminate the influence of the learning curve from subsequent slope and distance analysis. The data was normalized by dividing the production calculated for the final period (days 151 to 161) by the calculated production for each individual 10-day period prior to this period, thus generating a normalizing multiplier associated with each period. For example, productivity in the final period of the regression range, 27.3 pieces per

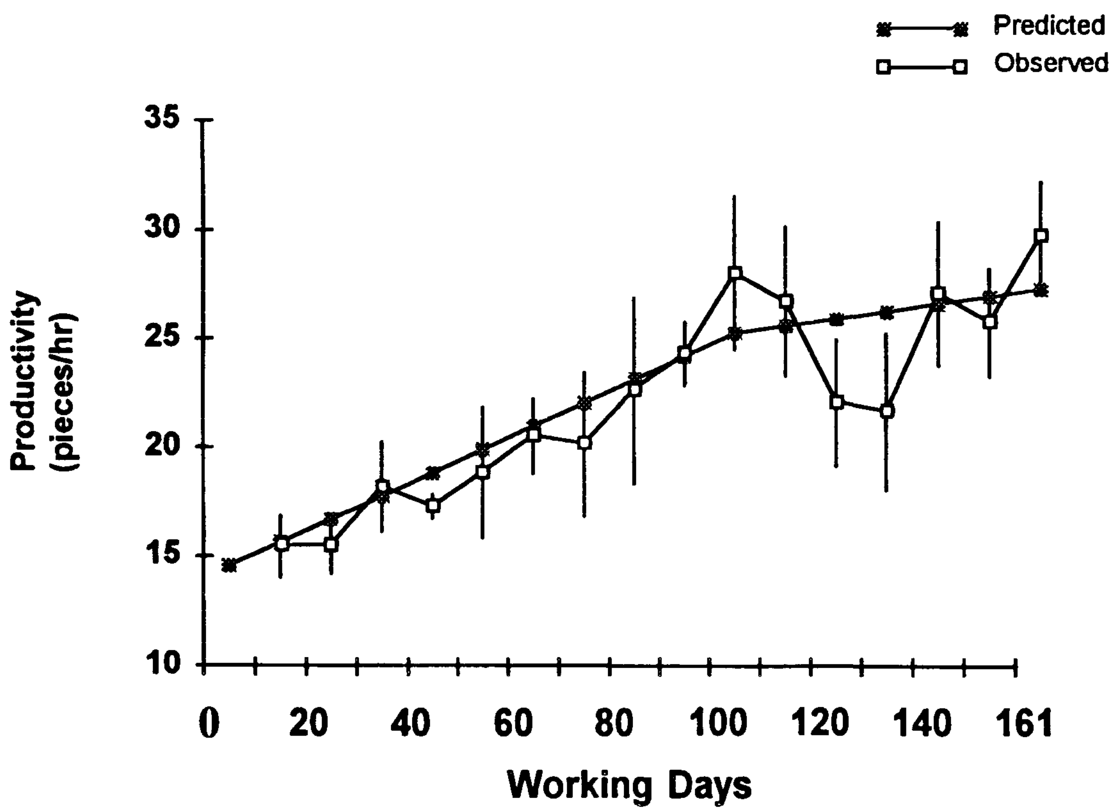

Figure 1. Average productivity relative to experience level -- observed data and regression model -- for cable thinning system.

hour was 174% of the production observed for the first period, 15.64 pieces per hour. Multipliers ranged in value from 1.74 for the first 10-day period to 1.00 for the final period. This multiplier was then applied to the observed daily production rates to eliminate the influence of the learning curve on productivity data.

Slope Effect

The effect of ground slope on system productivity without the influence of the learning curve is illustrated in Figure 2. The effect of experience was accounted for in the data by weighting observed production values based on the corresponding level of experience. The regression estimator follows:

$$Y = Z_1 * [70.622 - 0.945 (X)] + Z_2 * [23.851 + 0.094 (X)] \quad (2)$$

where:

Y = Productivity per scheduled hour (pieces per hr)
X = Ground Slope (Average for the yarding corridor)
Z_1 = 1 for ground slope $\leq$ 45%, 0 for ground slope > 45%
Z_2 = 1 for ground slope > 45%, 0 for ground slope $\leq$ 45%
Z_2 = 0 for ground slope > 85%

From the data available, there appears to be a sharp decline in productivity with increasing slope up to 45% ground slope. The slope of the regression in this region is -9.5 pieces per hour per 10% change in ground slope. After this point, productivity appears to increase with increasing ground slope at a rate of .94 pieces per hour per 10% change in ground slope, to the 85% ground slope point. This increase in productivity may be explained by the increasing deflection being generated at steeper slopes through the tailhold position or because of increased control of the yarding turns during inhaul on these steeper slopes.

Another dramatic change in slope effect was observed at 90% ground slope, possibly due to the increasing difficulty of movement across the slope, although additional data on sites with ground slope exceeding 90% is needed to establish a trend. The regression is only applied to slopes up to 85%. The correlation coefficient was estimated at 0.970 for the first part of the model and 0.754 for the second part.

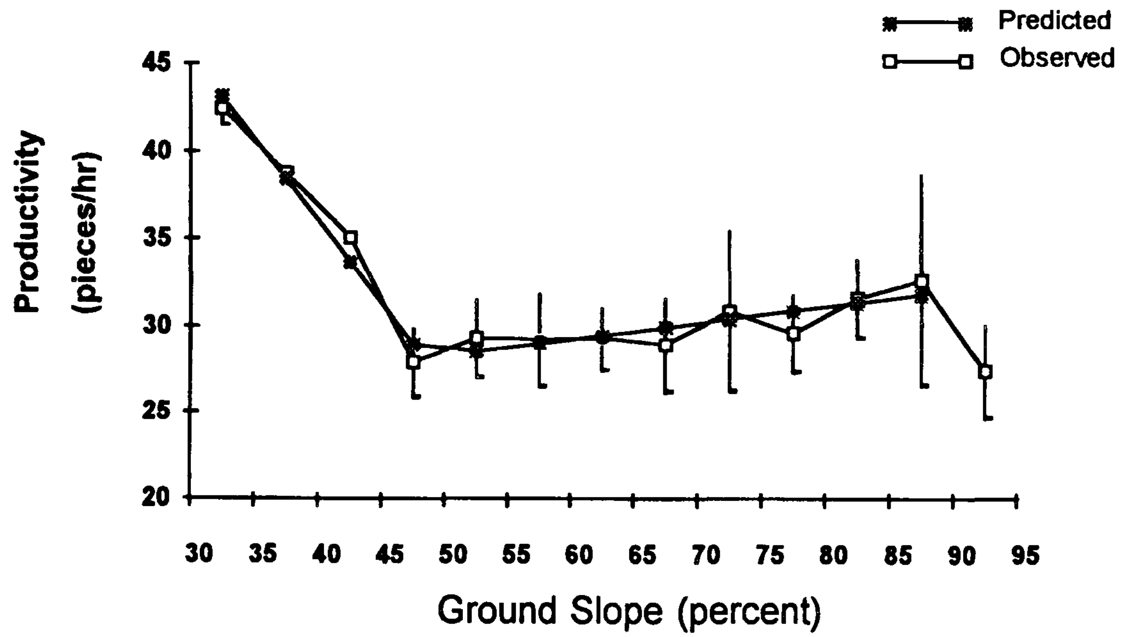

Figure 2. Effect of ground slope on system productivity without learning curve influence -- observed data -- and regression estimator.

Yarding Distance

The effect of yarding distance on system productivity without the influence of the learning curve is illustrated in Figure 3. The data suggests an increase in productivity until reaching the 600 ft yarding distance. The regression estimator follows:

$$Y = Z_1 * [28.70 + 0.00478 (X)] + Z_2 * [43.81 + -0.0204 (X)] \quad (3)$$

where:

Y = Productivity per scheduled hour (pieces per hr)

X = External yarding distance (ft)

Z_1 = 1 if External yarding distance $\leq$ 600, otherwise 0

Z_2 = 1 if External yarding distance > 600, otherwise 0

The correlation coefficient for this model ranges between 0.130 for the first half of the regression, where the data are almost cyclic in nature, and 0.977 for the second half. The observations at 850, 900, and 950 ft are treated as outliers as the 850 and 900 ft observations are both singular and therefore without confidence intervals, while the 950 ft observation lies well above the regression line. The standard error of the Y estimate is 1.809 pieces per hour for the first portion of the regression and 0.710 pieces per hour for the second portion.

The influence of yarding distance, represented by the slope of the regression, is negligible at only 0.48 pieces per hour increase per each additional 100 ft, up to the 600 ft distance. The same can be said for the slope of the line from 600 ft to 1100 ft, which is -2.0 pieces per hour per 100 ft of yarding distance.

Increases in productivity until the 600 ft point could be caused by an imbalance within the system, specifically where the chokersetter is not able to preset the chokers before the carriage returns empty and the landing crew not being able to properly service the landing. In this situation, productive time is lost waiting for these personnel to perform these actions. As average yarding distances increase, cycle times increase to where the chockersetters and landing crew have sufficient time while waiting for carriage return. In addition,

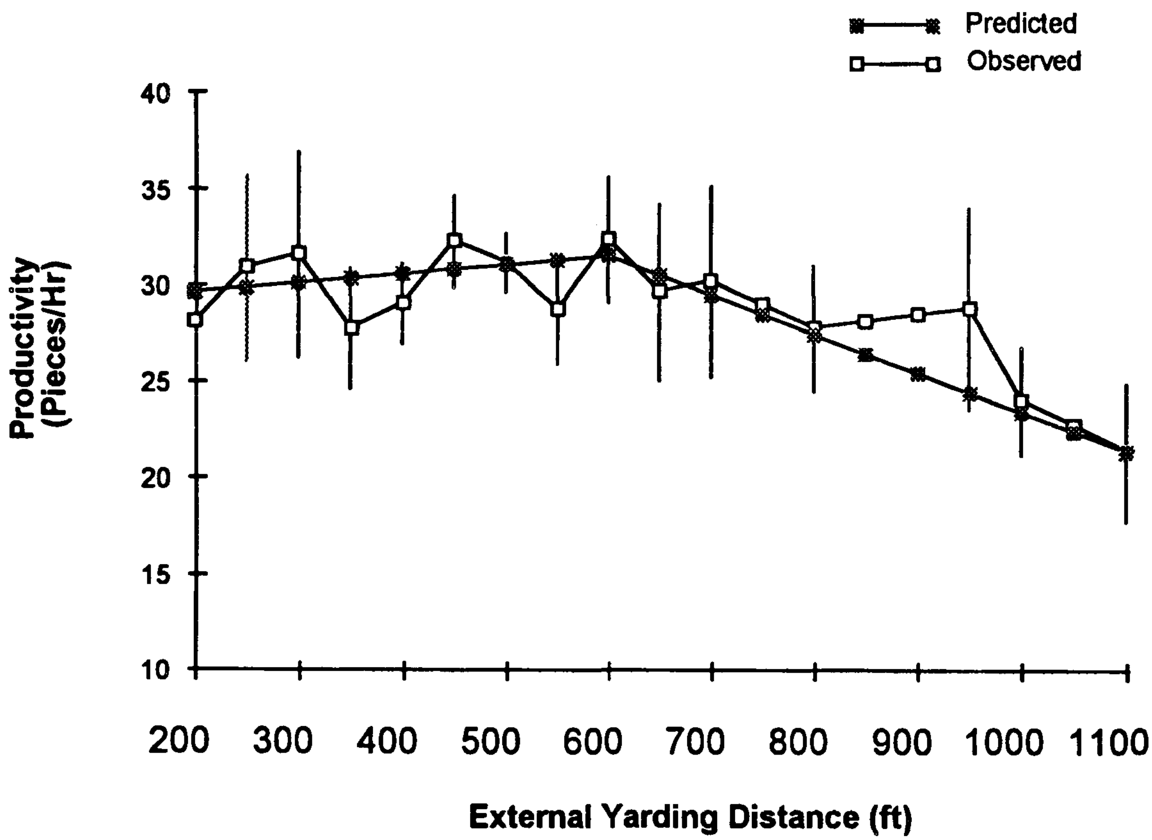

Figure 3. Effect of yarding distance on productivity without learning curve influence.

subsequent studies (Dodd, pers. comm.) showed that chokersetters increased their recruitment of logs as yarding distances increased. This could be due to the increased time available to the chokersetter to plan turns.

Based on these observations, productivity may be increased by ensuring that the faller takes additional care in limbing and bucking nearer to the road, thus freeing up the landing chaser to become an additional chokersetter while yarding is being performed at shorter distances. Then, when yarding proceeds to longer distances and actual turn inhaul and outhaul elements begin to reduce production, limbing practices can be relaxed in order to increase faller productivity and the landing chaser can again be moved up onto the road to assist with clean-up and load preparation.

Combined Effects on Yarding Productivity

Once the initial analysis had been performed, analysis of the combined effect of all the observed variables on yarding productivity was performed using the Minitab statistical analysis program [3]. Independent variables included 10-day averages for yarding slope and yarding distance as well as a dummy variable representing 10-day periods of observation which were dominated by long lateral yarding distances (periods 12 and 13). Crew experience was broken down into 10-day periods, with an additional variable created to represent the experience beyond 10 periods or 100 working days based on the results obtained from previous analysis. The regression equation obtained follows:

$$Y = 7.05 + 1.42\,(X1) - 1.21\,(X2) + 0.0845\,(X3) - 5.58\,(X4) \quad (4)$$

where:

- Y = Hourly Productivity (expressed in pcs/hr)
- X1 = Experience Level (expressed in 10-day periods)
- X2 = Number of periods beyond 10 (100 working days)
- X3 = Average slope encountered during period
- X4 = Periods dominated by long lateral yarding distances

The adjusted r^2 value for this regression is 93.8% with a mean square error of 1.24 pieces per hour. No outliers were identified by the Minitab program. It should be noted here that under the conditions observed, the average yarding distance for the period had no significant effect on productivity, largely due to the homogeneous nature of the normalized distance observations. The variable with the lowest probability that it does not belong in the regression equation is average slope, which has a 95.4% probability of inclusion.

Figure 4 represents the observed and predicted yarding productivity graphed against experience, which is measured in 10-day increments. Although this regression and the graph generated using it are very specific to the case study in question, general trends regarding experience do become clear. Increases in hourly productivity due to crew experience go from 1.42 pieces per hour per 10-day period to 0.21 pieces per hour per 10-day period, with the transition occurring near the 100-day mark of crew experience. This is an 85% reduction in the rate of increase for productivity attributed to experience.

CONCLUSIONS

The data suggest a strong correlation between the experience of the crew and system productivity, measured in pieces/hour. Findings indicate that, in this case, the crew continuously improved its performance during the entire 160-day study period. This improvement was substantial and continuous throughout the observed period, although the rate of improvement fell in the last 60 days of observation.

The data, once corrected for the learning curve influence, indicate several definite trends in production as influenced by slope and yarding distance.

Conclusions about the effect of slope and yarding distance on yarding productivity are as yet premature, although some operational trends were observed. Additional observations of production beyond 85% ground slope are needed to determine whether the decline in productivity at slopes of 90% or more continues. Further study into the impact of site conditions, as well as the relationship between yarder productivity, crew allocation, and related functions such as felling and limbing practices, seems desirable.

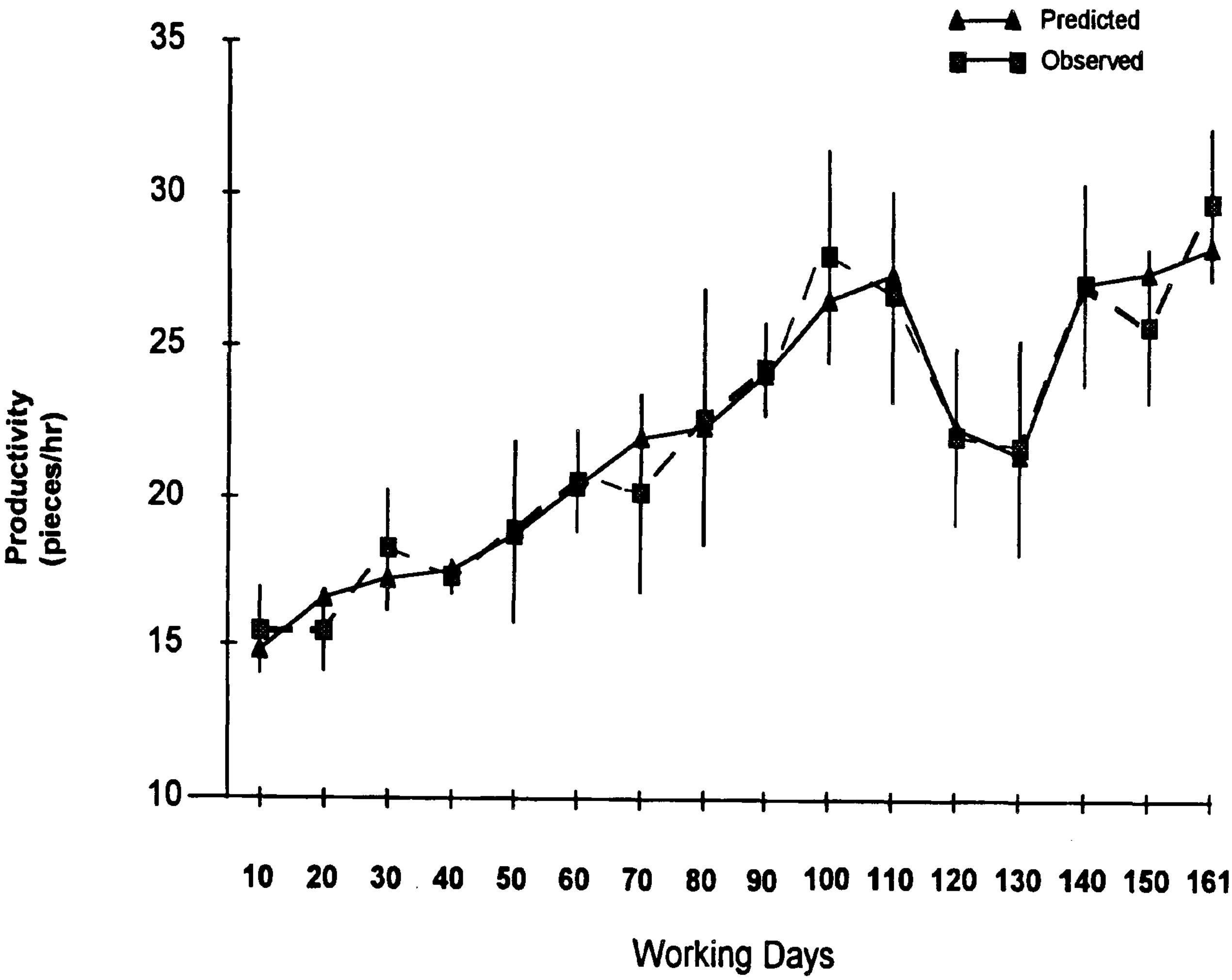

Figure 4. Regression model for harvesting system productivity based on the combined effect of experience and slope.

LITERATURE CITED

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