

MANUAL PRUNING OF DOUGLAS-FIR

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ABSTRACT

Work study of pruning of plantation Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in Kaingaroa Forest showed that production rates in first and second lifts (to 2 m and 3.8 m) were approximately 20 and 30 trees per productive hour, and varied with walk distance, hindrance rating, number of branches removed, and tree diameter. The physiological workloads of both lifts were classified as "heavy".

Keywords: pruning; productivity; work study; physiological workload; *Pseudotsuga menziesii*.

INTRODUCTION

Douglas-fir was pruned extensively in New Zealand during the 1950s (Fenton 1967). Since that time it has been given a lower priority for pruning than *Pinus radiata* D.Don (Weston 1971; James & Bunn 1978). Estimated product values and growth rates for Douglas-fir suggested that economically optimal regimes not include pruning (Fenton 1976); however, recent increases in value of Douglas-fir, especially for clear wood, have generated renewed interest in pruning of this species.

Although production studies of pruning Douglas-fir have been carried out in the past, for several reasons the results are not applicable to the current situation. Previously, many stands were pruned at 25 to 35 years of age (Bunn 1963). Trees under consideration today are much younger (c. 10 years) and therefore have different branch characteristics. An economic analysis for the Forestry Corporation of New Zealand indicated that diameter-over-stubs (DOS) should be limited to approximately 15 cm, and preliminary field measurements indicated that, to obtain a total pruned height of 6 m, a three-lift regime would be required to maintain DOS within the desirable range. Preferred equipment in New Zealand has also changed from hand saws to shears for low pruning. In higher pruning, the preference has gone from pole saws to hand saws and ladders, and finally to shears and ladders (Whitely 1963; Brown 1970; Hall & Mason 1988). Production studies in North America focused on larger trees (Eversole 1953; Smith & Walters 1961; Welch 1939) or equipment that is no longer considered optimal (Finnis 1953). Most trials in Europe (generally on larger trees) have dealt

with saws, which have been rejected by New Zealand pruners in favor of shears for all branch diameters within the capacities of the shears.

Few studies of the physiological workload of pruning have been conducted. Japanese work has concentrated on powered tree-climbing devices rather than manual methods (Takimoto *et al.* 1987; Yamamoto *et al.* 1988). Other studies have included Eggert's (1989) evaluation of mechanised and manual pole saw pruning, and a medium pruning comparison of a pole saw *v.* a ladder and short saw (Apud & Valdes 1993). No studies have investigated the workloads involved with the shears preferred by most pruning gangs in New Zealand.

The objectives of this study were to (a) determine the productivity of pruning Douglas-fir and estimate the effects of tree and stand parameters, and (b) evaluate the physical workload involved in pruning.

METHODS

Test Area

The Forestry Corporation of New Zealand Ltd commissioned the New Zealand Forest Research Institute to install a replicated pruning trial in a 10-year old plantation in Compartment 96 of Kaingaroa Forest; the productivity study was conducted in adjacent parts of this stand. Ground slope was 0° to 5° throughout the stand and hindrance levels were low. The study of first-lift pruning to 2 m was carried out in the south-east third of the plantation. A second lift to 3.8 m was conducted on slightly larger trees in the north-west third that had just been first-lift pruned; no stands were available for trialing a third lift to 6 m. A target density of 300 pruned trees/ha was specified.

Pruning Crew and Equipment

The contract pruning crew was experienced with *P. radiata* but had not previously pruned Douglas-fir. They spent 1 week in the stand testing pruning tools and adapting their technique. Hit shears, modified as described by Hall & Mason (1988), and Wilkinson shears were tried. The Wilkinson blades broke frequently, and those on the Hit shears broke occasionally, because of the hardness of the branch wood. The crew considered the branches to be much harder than those of *P. radiata*. At the end of the trial period, the crew decided to use the Hit shears normally used in *P. radiata*.

A knife was used to remove small branches that we have termed "whips". Whips were defined as being less than 2 mm in diameter and less than 30 cm in length. Most whips were dead but were too persistent to be knocked off; they had to be cut. A toolbelt was used to hold the shears and knife. A 2-m ALCO aluminum ladder was used during the second lift.

All data were collected during 8 days over the period 1–22 December 1992. Approximately equal numbers of observations were made on two crew members for both the first and second lifts. They each had one to two years' experience and both were considered to be better than average by the crew supervisor.

Data Collection and Analysis

The pruning cycle was divided into three time elements:

- (1) Walk>Select—included selecting and walking to the tree to be pruned. It ended when the pruner reached the tree. In second-lift pruning, the element also included descending the ladder after pruning the previous tree and climbing the ladder at the current tree.

- (2) Prune—covered use of the shears to remove branches or whips. It ended when the last branch was removed.
- (3) Clean—included using the knife to remove whips or stubs of small branches. It ended when the knife was replaced in the tool belt.

Any other activity was classified as a delay. Two observers using Husky Hunter computers equipped with SIWORK3 (Rolev 1988) recorded the time elements, hindrance rating, height to the base of the live crown, number of branches, whip rating, walking distance, diameter at breast height (dbh), DOS, DOS height, and pruned height.

Walking distance was defined as the straight line distance from one pruned tree to the next, measured to the nearest metre. "Hindrance rating" was a subjective measure of the resistance to the pruner while walking through and over tree foliage, brush, and other obstacles. The standard definitions of the four levels of hindrance were used:

- 1: not hindered
- 2: hindered
- 3: continuously hindered
- 4: constantly struggling

On the first lift the numbers of branches were counted as they were cut. There was generally no clear gap of 100 mm that could be used to differentiate one cluster from the next. It was not possible to count whips accurately, and so a rough visual estimate of the number of whips, by fives, was made. The rough count of whips, divided by five, was defined as the whip rating. On the second lift, where they were easier to identify, clusters were counted.

A calliper was used to measure dbh and DOS. Two orthogonal measurements, i.e., taken at 90° to each other, were averaged to get dbh; the largest single axis measurement was used for DOS. Height to the base of the live crown was estimated by eye; DOS height and pruned height were measured with a graduated pole.

Physiological workload was estimated by recording the heart rate of one of the pruners at 15-s intervals with a Polar Electro PE3000 heart rate monitor. Many studies have demonstrated that a person engaged in heavy manual labour will work comfortably at an average of up to 40% of their maximum cardiovascular load (CVL). An estimate of CVL was made from the heart rate data, using a procedure described by Apud *et al.* (1989). Work activities of the pruner were recorded simultaneously at 15-s intervals with the SIFREQ program (Rolev 1990) on a Husky Hunter to match up with the heart rate recording. Shaded dry-bulb air temperature was recorded at 15-min intervals with a Campbell Scientific CR21 data logger during the time when heart rate was being monitored.

After pruning was completed, 0.05-ha circular plots were placed in a grid to give a 10% sample of the area in which the work study was conducted. Pruned and unpruned trees in each plot were tallied and diameters recorded. Measurements of horizontal distances and angles taken with a tape measure and clinometer were used to calculate heights of six pruned trees across the diameter range in each plot. In addition, the diameter of the largest removed branch (inside bark on a horizontal axis across the pruned stub) and dbh of the tree were measured with a calliper on a random sample of 100 trees for each lift.

Regression analysis was used to develop relationships between the cycle time elements, tree characteristics, and site parameters. Observed times were used; no adjustments were made for performance, as the fact that the operators were probably not peaked out on the

learning curve in Douglas-fir was assumed to compensate for their above-average performance in pruning *P. radiata*.

RESULTS

Work study information was collected for over 300 trees in the first-lift pruning and for over 200 trees during the second-lift operation. Observed values and regression relationships developed for the first lift are displayed in Tables 1 and 2, those for the second lift in Tables 3 and 4.

TABLE 1—Observed values for first-lift pruning

| | Mean | SD | Observations |
|--|-------|------|--------------|
| Cycle time elements (observed centiminutes) | | | |
| Walk/select | 39.3 | 25.9 | 338 |
| Prune | 155.7 | 41.4 | 338 |
| Clean | 113.6 | 37.0 | 338 |
| Total cycle | 308.6 | 67.7 | 338 |
| Other variables recorded on each cycle | | | |
| Walk distance (m) | 7.03 | 5.64 | 297 |
| Hindrance rating | 1.40 | 0.61 | 347 |
| No. of branches | 54.2 | 13.9 | 339 |
| Whip rating | 3.90 | 1.32 | 343 |
| Height to live crown (m) | 0.33 | 0.14 | 337 |
| Pruned height (m) | 2.04 | 0.23 | 351 |
| Dbh (cm) | 13.0 | 2.76 | 352 |
| DOS (cm) | 17.5 | 3.71 | 351 |
| DOS height (m) | 0.61 | 0.21 | 348 |
| Stand densities from 0.05-ha circular plots (six plots were sampled) | | | |
| Pruned trees/ha | 344 | 94 | 6 |
| Unpruned trees/ha | 630 | 155 | 6 |
| Largest branch diameter sample | | | |
| Largest branch (cm) | 2.54 | 0.53 | 101 |
| Double leader (cm) | 6.77 | | * |

* Three occurrences in the sample of 101 trees

Delays for both lifts are summarised in Table 5. "Other delays", which accounted for only 2% of the total observed time, included planning discussions with the supervisor or other pruners, checking the shears, checking the tally counter, pruning malformed trees which were then abandoned when the poor form became apparent, clearing dirt or sap from the eyes, attending a minor wound, and fixing a rung on a ladder. Sharpening of the shears was done at the midday break and took a negligible amount of time as it consisted of a few passes of a stone across the edges of the blades.

Only a small portion of the variability in element times for either lift was explained by the independent variables. Three separate relationships were derived for prune time, anticipating that potential users might have different information available to them. For the first lift, dbh did not have a significant effect on prune time. There were no significant relationships between pruned height and either prune or clean time. This was due partly to the narrow range of observed pruned heights, most being clustered near the targeted 2 m. For the second lift, neither pruned height nor DOS had any additional significant effect on prune time, in combination with the stronger variables, and dbh did not affect clean time.

TABLE 2—Regression relationships for first-lift pruning (all terms were significant at the 0.01 probability level)

| | | | |
|--|---------|--|---------|
| Walk/select (centiminutes) | | | |
| = 19.88 + 2.211 * Walk distance * Hindrance rating | | | |
| r ² = 0.33 | F = 139 | | n = 289 |
| Prune (centiminutes) | | | |
| = 77.90 + 0.951 * Branches + 1.521 * DOS | | | |
| r ² = 0.15 | F = 30 | | n = 339 |
| = 96.98 + 1.087 * Branches | | | |
| r ² = 0.13 | F = 51 | | n = 339 |
| = 111.17 + 2.572 * DOS | | | |
| r ² = 0.06 | F = 22 | | n = 339 |
| Clean (centiminutes) | | | |
| = 39.93 + 12.47 * Whip rating + 1.966 * DBH | | | |
| r ² = 0.23 | F = 49 | | n = 334 |
| Branches | | | |
| = 12.73 + 14.44 * Pruned height + 0.9360 * DBH | | | |
| r ² = 0.14 | F = 28 | | n = 344 |
| Pruned height (m) | | | |
| = -0.001 + 0.2828 * DBH - 0.009294 * DBH ² | | | |
| r ² = 0.43 | F = 125 | | n = 339 |
| DOS (cm) | | | |
| = 3.073 + 1.112 * DBH | | | |
| r ² = 0.69 | F = 768 | | n = 351 |
| Total height (m) | | | |
| = 0.6116 + 0.7446 * DBH - 0.01627 * DBH ² + 1.0769 * 2nd lift indicator | | | |
| r ² = 0.82 | F = 93 | | n = 64 |
| Largest branch diameter (cm) | | | |
| = 1.100 + 0.111 - 0.1741 * 2nd lift indicator | | | |
| r ² = 0.29 | F = 40 | | n = 201 |

For each lift, DOS was highly correlated with dbh. Knowles *et al.* (1987) developed a comprehensive predictor of DOS for *P. radiata* in New Zealand, but a similar relationship is not yet available for Douglas-fir. Whip ratings on both lifts were not related to dbh or pruned height, nor were second-lift numbers of branches or clusters.

Temperatures were relatively stable, ranging from 10° to 20°C for both lifts. Three of the 8 days were dry, while intermittent rain occurred on the others. Most days were overcast.

The pruner monitored for physiological workload was 20 years old and had a resting heart rate of 70 beats/min, and a predicted heart rate of 122 beats/min at 40% CVL. Data recorded during the first 30 min of the work periods are displayed in Fig. 1. This time period had similar temperature and other conditions for both the first and second lifts. Heart rate statistics are summarised in Table 6.

DISCUSSION

Cycle Times and Production Rates

The observed mean walk distances were longer than the theoretical inter-tree square spacings calculated from the number of pruned trees per hectare (Table 7). This was caused

TABLE 3 - Observed values for second-lift pruning

| | Mean | SD | Observations |
|---|-------|------|--------------|
| Cycle time elements (observed centiminutes) | | | |
| Walk/select | 38.4 | 15.9 | 228 |
| Prune | 123.4 | 37.2 | 228 |
| Clean | 25.8 | 18.4 | 228 |
| Total cycle | 187.5 | 44.6 | 228 |
| Other variables recorded on each cycle | | | |
| Walk distance (m) | 5.47 | 4.18 | 218 |
| Hindrance rating | 1.14 | 0.39 | 231 |
| No. of branches | 42.6 | 10.7 | 224 |
| Clusters | 2.04 | 0.52 | 229 |
| Whip rating | 1.33 | 0.52 | 216 |
| Height to live crown (m) | 2 | | |
| Pruned height (m) | 3.78 | 0.14 | 222 |
| Dbh (cm) | 15.3 | 2.26 | 223 |
| DOS (cm) | 17.5 | 2.81 | 223 |
| DOS height (m) | 2.70 | 0.34 | 223 |
| Stand densities from 0.05-ha circular plots (three plots were sampled) | | | |
| Pruned trees/ha | 380 | 33 | 3 |
| Unpruned trees/ha | 880 | 33 | 3 |
| Largest branch diameter sample | | | |
| Largest branch (cm) | 2.66 | 0.48 | 100 |
| Double leader (cm) | 6.23 | | * |

* Three occurrences in the sample of 100 trees

TABLE 4—Regression relationships for second-lift pruning (all terms were significant at the 0.01 probability level)

| | | | |
|---|----------|---------|--|
| Walk/select (centiminutes) | | | |
| = 32.47 + 0.832 * Walk distance * Hindrance rating | | | |
| r ² = 0.08 | F = 18 | n = 216 | |
| Prune (centiminutes) | | | |
| = -18.58 + 1.770 * Branches + 4.149 * DBH | | | |
| r ² = 0.36 | F = 60 | n = 212 | |
| = 23.70 + 4.399 * DBH + 15.07 * Clusters | | | |
| r ² = 0.13 | F = 15.6 | n = 218 | |
| = 52.32 + 4.557 * DBH | | | |
| r ² = 0.08 | F = 19 | n = 220 | |
| Clean (centiminutes) | | | |
| = -76.58 + 16.22 * Whip rating + 21.52 * Pruned height | | | |
| r ² = 0.23 | F = 30 | n = 206 | |
| Pruned height (m) | | | |
| = 0.9701 + 0.3637 * DBH - 0.01158 * DBH ² | | | |
| r ² = 0.09 | F = 11 | n = 223 | |
| DOS (cm) | | | |
| = 2.940 + 0.951 * DBH | | | |
| r ² = 0.59 | F = 314 | n = 223 | |
| Total height (see first-lift relationship, set second-lift indicator = 1) | | | |
| Largest branch diameter (see first-lift relationship, set second-lift indicator = 1) | | | |

TABLE 5—Delay summary for both lifts combined

| Time category | Percentage of total study time |
|----------------|--------------------------------|
| Cycle elements | 72 |
| Breaks | 26 |
| Other delays | 2 |
| Total | 100 |

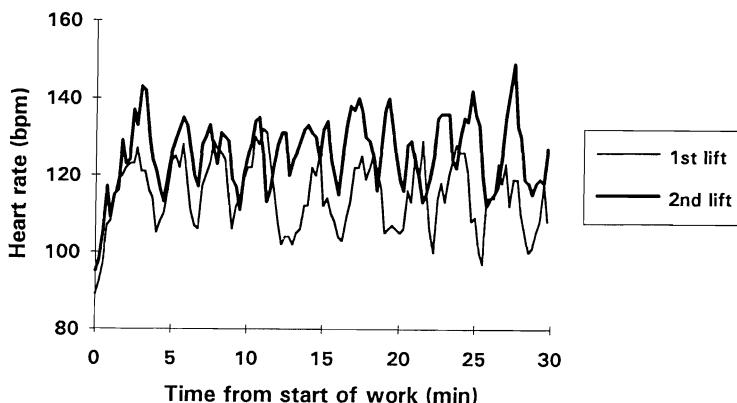


FIG. 1—Example heart rate traces for first- and second-lift pruning

TABLE 6—Heart rate and results and associated parameters for first- and second-lift pruning

| | First lift | Second lift |
|--|------------|-------------|
| Heart rate (beats per minute) | | |
| Mean | 114 | 126 |
| SD | 9.1 | 8.4 |
| Number of records (of 15 seconds each) | 120 | 120 |
| Percentage of time above 40% CVL | 26 | 69 |
| Air temperature (°C) | | |
| Mean | 15.3 | 10.9 |
| SD | 0.2 | 1.2 |

TABLE 7—Observed and theoretical walk distances for the two lifts

| | Walk distances (m) | | |
|-------------|--------------------|-------------|--------------|
| | Observed | Theoretical | Increase (%) |
| First lift | 7.0 | 5.4 | 30 |
| Second lift | 5.5 | 5.1 | 8 |

by backtracking to "fill in" an unpruned gap, occasional leapfrogging when two pruners were working on the same strip, and the longer distances walked from one strip to the next strip. When estimating productivity, theoretical distances should be adjusted upwards to account for these factors.

Care was needed to avoid damaging the Douglas-fir branch collars, which protruded from the trunk. The pruning shears appeared to cause little bark damage, but the whip knife cut through many of the sap-filled lenses in the bark because the knife was angled slightly towards the trunk to produce a clean cut through the whips. This could have been avoided by using one hand to hold the whip while cutting but this technique would have been slower than the preferred one-hand method.

There were fewer branches on the second-lift portion of the bole, but the largest branches were of the same diameter for both lifts (Fig. 2). In actual second-lift pruning, branch growth and possibly epicormic sprouting in the time interval between the pruning lifts might cause pruning and cleaning times to be longer than those in this study.

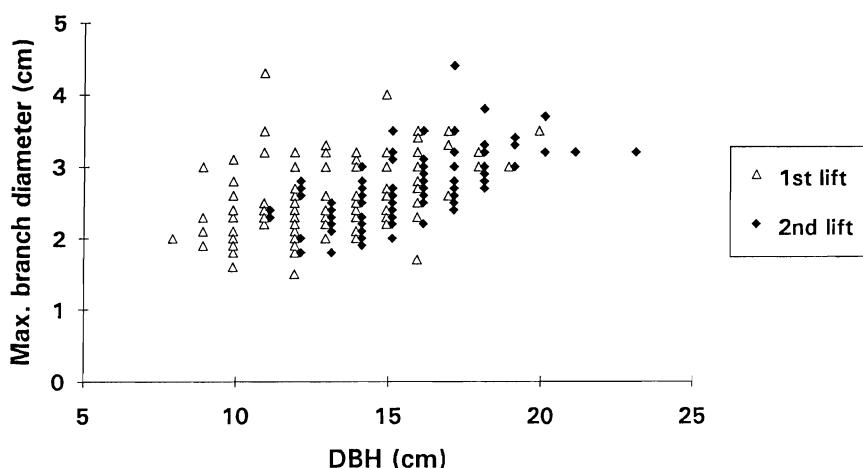


FIG. 2—Diameters of largest branches per tree, for first and second lifts

Cleaning accounted for 37% of first-lift cycle time and only 14% of second-lift time. It may be easier to leave most of the dead whips on the bole during the first pruning, then remove them during the second lift, if they dry or partially decay in the interim. These small branches generally emerge from the trunk well within the DOS, and diameter growth during the time interval between the two lifts is not likely to extend beyond the defect core.

Trees in the first-lift test area were shorter than those of the same diameter in the second-lift block. The smaller-diameter trees in both areas were not pruned to the full nominal heights because of the need to leave adequate live crown.

As would be expected, DOS on the second-lift segment was less than on the first lift, for a tree of a given diameter (Fig. 3). On the first lift, DOS was approximately 4 cm larger than dbh. The difference was only 2 cm on the second lift. To keep DOS in the 15-cm range, it appears that trees should be first pruned when they are no larger than 10 to 12 cm dbh.

The mean observed production rates for the first and second lifts were approximately 20 and 30 trees per productive hour, respectively. The strongest cycle time relationships from Tables 2 and 4 were used to estimate production rates over a range of tree sizes (Fig. 4 and 5). A walk distance of 6 m was used, corresponding to a pruned density of approximately 300

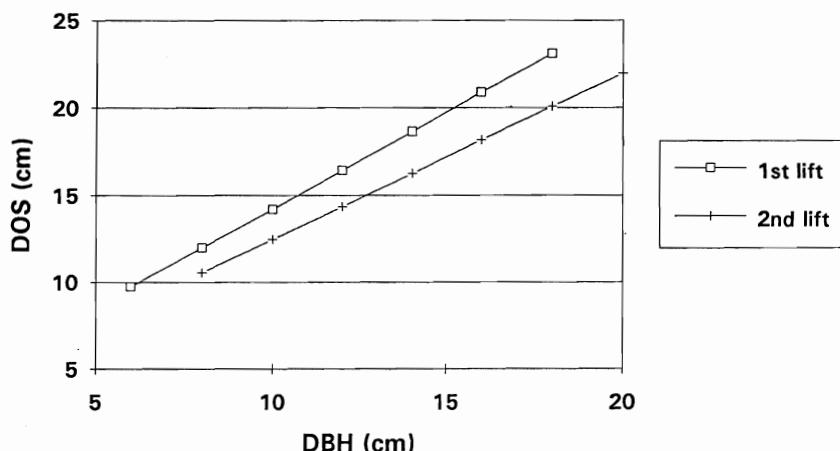


FIG. 3—DOS v. dbh relationships for first- and second-lift pruning

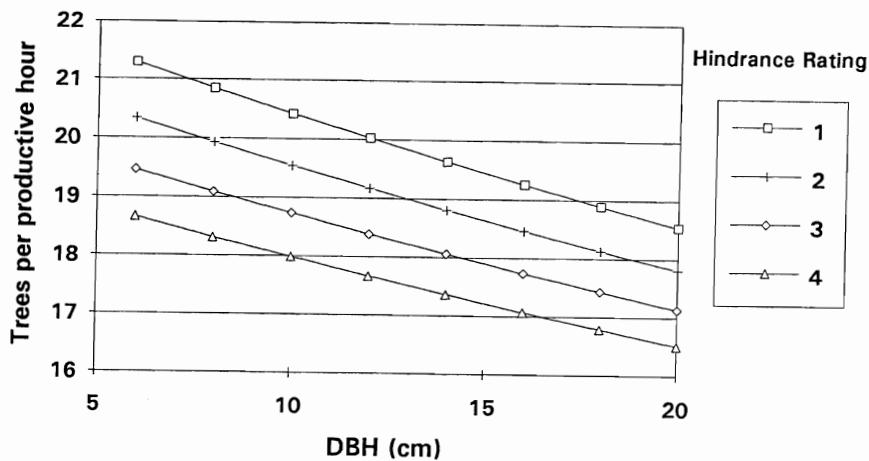


FIG. 4—Estimated productivity for first-lift pruning

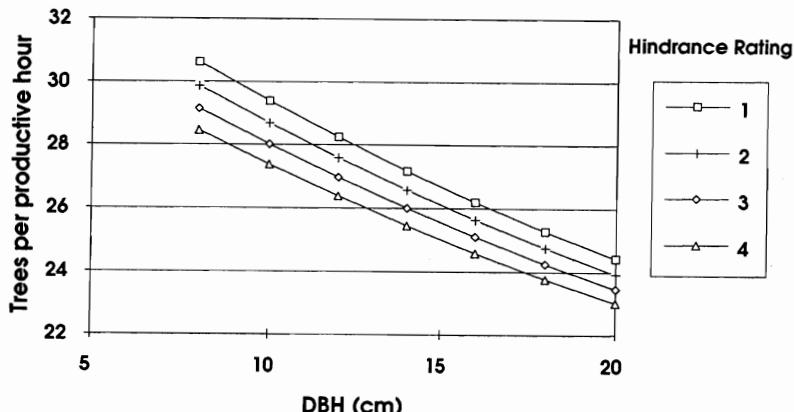


FIG. 5—Estimated productivity for second-lift pruning

stems/ha. Fixed pruned heights of 2 m and 3.8 m were assumed for the first and second lifts, across the full range of diameters.

This study was too short to estimate accurately what fractions of a day would be spent in productive cycles and in delays. Forestry Corporation supervisors estimated that 6 hours out of an 8-hour day would be productive. The 72% utilisation observed in the study was close to the estimated 75%.

Physiological Workload

The heart rates for both first- and second-lift pruning fell within the range of 110 to 130 beats/min classified by Rodahl (1989) as a "heavy" workload. On average, the mean rates for both lifts were near the 40% CVL rate of 122 beats/min. Second-lift pruning exhibited a higher physiological workload than first-lift pruning; however, more trees per hour were pruned in the second lift. Heart rate is greater where the arms are raised more, as in second-lift pruning. Additional muscular work of the legs, while the pruner wrapped one leg around the tree, probably contributed to the higher heart rate as well.

As the air temperature was somewhat lower during the heart rate data collection period for the second lift, it would have acted to delay overheating and the associated increase in heart rate. If the temperatures had been the same during both lifts, the observed difference in heart rates would probably have been greater.

A more accurate measure of the workloads associated with pruning could be determined by measurement of energy consumption via gas analysis (indirect calorimetry) and biomechanical analysis. Unfortunately, these methods are difficult and costly to implement in the field. Monitoring heart rate is a more practical if less accurate method.

CONCLUSIONS

The regression relationships developed in this study should be useful for predicting average production rates in first- and second-lift pruning of Douglas-fir, as a function of the stand parameters.

Although the workload of pruning was classified as heavy, it was relatively uniform. The monitored pruner was labouring at or near his long-term sustainable physiological workload.

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