APPROPRIATE AGE FOR SELECTION OF FINAL-CROP *PINUS RADIATA*

J. PIERS MACLAREN

New Zealand Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

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ABSTRACT

Results from four trials indicated that tree selection which takes place during the normal pruning phase of *Pinus radiata* D.Don (ages 3 to 10 years) is inefficacious. At these early ages it is not possible to identify many of those trees that are likely to be of superior form or size at the age of clearfelling. Accuracy of prediction improves with age, and by the time of production thinning (age 12–14) a manager can place considerable reliance in the choice of crop trees. Change of dominance appears to be more pronounced in lower-stocked stands.

Keywords: selection; tree selection; early selection; dominance; form; ramicorn; multi-leader; wobble; *Pinus radiata*.

INTRODUCTION

It is standard practice in New Zealand forestry to plant more trees than are required at harvest. During a typical rotation (*c.* 30 years), many trees are felled and left to decay on the forest floor ("thinning to waste") or are extracted at an intermediate age ("production thinning"). Regimes involving the latter accounted for only 25% of the national forest estate in 1992 (Ministry of Forestry 1993), and would normally involve one waste thinning and one production thinning. Waste thinning takes place when trees are between 3 and 12 years old, and production thinning when trees are 10 to 18 years of age (Maclaren 1993).

With either type of thinning, the aim is usually to fell the inferior trees. Many companies make considerable efforts to ensure that their field crews are adequately trained in good tree selection. Criteria that are used include the straightness of the stem, the tree's vigour, and the proximity of the tree to its neighbours (Maclaren 1989). Although Maclaren argued that form and vigour should be the first considerations, tree spacing continues to be a common criterion among field practitioners.

Where stands are pruned (60% of the national forest estate—Ministry of Forestry 1993), tree selection may take place many years prior to the thinning operation. As pruning is an expensive operation, it is inefficient to prune trees that are not likely to be utilised. The act of pruning therefore classifies trees as a crop (i.e., fully pruned, and a possible candidate for final harvest) or as a follower (unpruned or only partially pruned, and intended for thinning). The timing of selection in intensively-tended stands is therefore determined largely by the timing of pruning, which usually occurs between the ages of 3 and 10 years (Maclaren 1993).

Managers who allocate substantial resources to ensuring good tree selection make the assumption that there is a strong relationship between the form and size of trees at such a young age and their value at harvest. Sound factual data have not been presented to support this assumption.

In this paper, results from four trials are used to examine the efficacy of early selection.

FORM PRUNING Trial (RO 2084)

Classification of Defective Trees at Ages 3.5 and 6 Years in an Unpruned Unthinned Stand

Trial description and methods

This was a form-pruning trial, in which the control plots provided data suitable for examining change in the number of acceptable trees over time. Trees in plots in three compartments of Kaingaroa Forest were assessed for "acceptability" at ages 3.5 and 6 years. Each plot contained between 103 and 126 trees, with 345 trees in total.

Four assessors (two appropriately-trained researchers from NZ FRI and two quality control staff from the management of Kaingaroa Forest) classified each tree as either acceptable, or unacceptable because of small size, poor form, or a combination of the two. Each tree was given an "acceptability rating" of 0, 1, 2, 3, or 4 at both assessments, depending on the number of assessors who considered it acceptable at the time. This selection was somewhat artificial, in that tree spacing was not a criterion although size was determined relative to immediate neighbours.

Results

The three plots provided similar data, but there was some variation attributable to the assessors. Mean acceptability increased over the 2-year period from 34.6% to 50.5%. The acceptability rating of 46% of the trees had increased, whereas 38% retained the same acceptability, and only 16% showed a decrease in acceptability rating.

Trees with poor form were rejected mainly on the basis of possessing multiple leaders, although this was not quantified. At age 3.5 years many of the trees resembled a bush, with no single straight stem. But by age 6, this defect had spontaneously corrected in many of the trees.

The change in mean acceptability for each assessor and the reasons (size or form) for rejecting trees are given in Table 1. Over the 2-year period, there was a slight decrease in the numbers of trees accepted for size, and a distinct increase in the proportion of trees that were accepted on the basis of form.

STEM DEFECT TRIAL (LONGMILE)

Detailed Examination, and Evaluation, of Stem Defect Changes Between Ages 3 and 5 Years

Trial description and methods

All stem defects on 75 3-year-old trees growing in this trial were measured and the trees individually photographed from fixed points. The measurements and photographs were

TABLE 1–Percentage of trees accepted for size or form

Assessor	Size		Form	
	Age 3.5 years	Age 6.0 years	Age 3.5 years	Age 6.0 years
1	91.9	89.9	29.3	65.8
2	87.2	78.5	42.6	65.5
3	86.4	88.4	42.3	46.7
4	83.2	79.1	49.0	60.0
Mean	87.2	84.0	40.8	59.5

Note: some trees were rejected both for size and form

repeated at ages 4 and 5, and the trees were then pruned in order to quantify the influence of any given defect on the "defect core" (Park 1980, 1982) of the tree. The increase in diameter of the defect core could be used as an estimator of the economic cost of the stem defect.

Stem defects were classified into lean, wobble/sweep, and abnormal branching.

Lean was assessed by using a plumb bob attached to 1.4 m of string, with the top held against the underside of the stem so that the bob was just clear of the ground. The distance between the centre of the bob and the tree stem at ground level was measured.

Wobble/sweep was measured by holding a 2.0-m straight edge vertically over any concave section of the trunk and measuring the width of the greatest gap between the straight edge and the tree. The height at the top and bottom points, and the distance of the gap, were recorded. This is considered accurate to ±1.0 cm.

Abnormal branching. For abnormally steep-angled branches, branch angles (i.e., between the top side of the branch and vertical) were measured using a protractor, and this technique is estimated to be accurate to ±5°. The diameter at the branch base was also noted. Branches were classified into two main types:

(a) *Ramicorn*: The word "ramicorn", although not found in technical dictionaries in this sense of the word, is commonly used in New Zealand to refer to a steep-angled branch. Such branches are conspicuous, and are easy to distinguish from normal branches. Ramicorns can be associated with a dead, weak, or displaced leader but this is not always the case.

(b) *Potential main stem*: The leader with the greatest diameter, which was usually also the most upright and the tallest, was designated the "main stem". In situations where the main stem was deflected by one or more ramicorns, its angle and diameter were measured as for a ramicorn.

Results

Lean, stem straightness, and branching characteristics were assessed separately.

Lean. There was no detectable change in lean over the 2-year period of the study, but the data are unreliable. The first two measurements were complicated by the presence of branches, which made it awkward to hang a plumb bob free of interference. After pruning, it was discovered that only 12% of trees had no lean, and the mean degree of lean was 6.8 cm for the bottom 1.4 m (2° 20').

Wobble/Sweep. At age 3 years 11 trees displayed wobble, sweep, or some sort of stem displacement for a component of the stem. Although a visual inspection might give the impression that such trees were badly distorted, measurements indicated that the displacement averaged only 2.4 cm. This reduced to 1.9 cm at age 4 years and 1.7 cm at age 5 years. It appears likely, therefore, that wobble decreases in severity over time.

Abnormal branching—potential main stems. Changes occurred in the 19 abnormal branches classified as potential main stems at age 3 years (Tables 2a and 2b). Most of these became more vertical and assumed dominance. The mean angle change was 14.0° to 3.2° in 2 years. In the most extreme instance, a potential leader became vertical in 1 year after initially being at an angle of 40°.

Abnormal branching—ramicorns. Data on the 41 measured ramicorns are given in Tables 2c and 2d. Although ramicorns and future leaders had similar diameters at 3 years of age, the growth of ramicorns was much less over the following 2 years. Most ramicorns became more horizontal over the same period, on average increasing their angle to the vertical by 12°, mostly in the second year. The most extreme example changed from 20° to 70° in 1 year.

TABLE 2a–Mean change of diameters and angles in potential main stems

Age (years)	Mean diam. (cm)	Diam. range (cm)	Mean angle to vertical (°)	Angle range (°)
3	2.9	2.0–4.0	14.0	0–40
4	7.3	5.3–9.5	6.3	0–20
5	10.8	6.4–15.3	3.2	0–15

TABLE 2b–Potential main stems classified by type of angle change each year

Age interval (years)	Mean angle change (°)	Range (°)	Percentage stems with decreased angle (n)	Percentage stems with no angle change (n)	Percentage stems with increased angle (n)
3–4	−7.6	−40 to 0	58 (11)	42 (8)	0 (0)
4–5	−3.2	−15 to +5	47 (9)	47 (9)	6 (1)
3–5	−10.8	−40 to +5	84 (16)	11 (2)	6 (1)

TABLE 2c–Mean change of diameters and angles in ramicorns

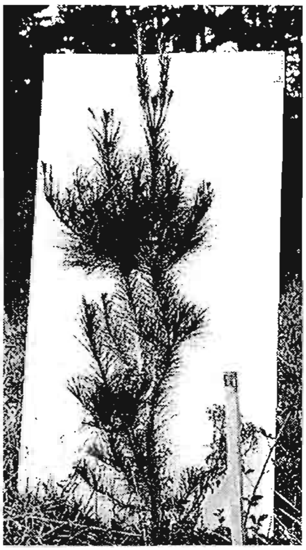
Age (years)	Mean diam. (cm)	Diam. range (cm)	Mean angle (°)	Angle range (°)
3	2.1	1.0–3.0	24.5	10–50
4	3.7	1.0–5.8	28.4	10–50
5	4.7	2.2–7.9	36.5	15–70

TABLE 2d–Ramicorns classified by type of angle change each year

Age interval (years)	Mean angle change (°)	Range (°)	Percentage stems with decreased angle (n)	Percentage stems with no angle change (n)	Percentage stems with increased angle (n)
3–4	3.9	−15 to +20	15 (6)	34 (14)	51 (21)
4–5	8.0	−10 to +50	12 (9)	22 (9)	66 (27)
3–5	12.0	−10 to +50	5 (2)	22 (9)	73 (30)

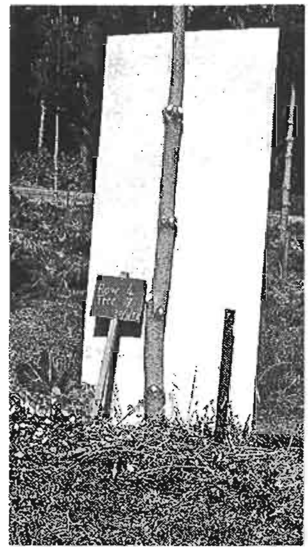
Discussion

This study demonstrated how trees that are "unacceptable" by virtue of possessing multiple leaders and ramicorns, can become acceptable in time (Fig. 1). A single leader tends to dominate, and become vertical, whereas competing leaders stagnate in growth and become



Tree 4/7 at age 3. Note the presence of a ramicorn at 80 cm above ground, and a double leader at the tip.

The same tree 2 years later, partially pruned. Ramicorn has become more horizontal and is much smaller than the stem.



The same tree fully pruned. The original lean is still present, but defects due to branching are not important.

Tree 1/6 at age 3. This would be universally rejected in any selection.

The same tree 2 years later. All defects are contained within an acceptable defect core.

FIG. 1–Change in form between ages 3 and 5 in the stem defect trial

more horizontal. There is also some evidence that stem defects such as wobble become less severe over time. With swept stems, it is possible that the pith actually straightens, although it is also possible that greater depths of new wood are deposited on the concave sides of stems. Destructive sampling would be necessary to establish the proportion of wobble reduction attributable to these two mechanisms.

Most defects, although they gave a strongly negative visual impression of the tree, were shown to have little economic importance in that they did not affect the ultimate size of the defect core. Lean was probably the most critical defect, because the tips of the trees extended vertically, and the combination of a leaning butt and a vertical tip yielded a swept butt log. A leaning tree will also generate compression wood on the underside of the stem, imparting undesirable properties to the wood (Cown 1992).

UNPRUNED AND UNTHINNED TRIAL (RO 912)

Reassessment of Defects in an Unpruned, Unthinned Stand After 22 Years

Trial description and methods

This trial involved 0.202 ha of unpruned, unthinned *P. radiata* in the Northern Boundary area of Kaingaroa Forest, planted in 1963 at 2315 stems/ha. Trees were assessed for total height, diameter at breast height, and malformation in 1967 and 1971, when the trial contained 1600 stems/ha. Trees were reassessed for malformation in 1987, and in 1993 with MARVL (Deadman & Goulding 1978; Manley *et al.* 1987) (Appendices 1 and 2). MARVL is a proprietary computer program that determines merchantable volumes of stem-wood by log grade, in individual trees or stands. It optimises the stumpage value for any given set of log specifications, and uses data based on field assessment of the quality and size of the stem of individual trees.

In 1967, when the mean height of dominants was 4.3 m, seven experienced research officers each selected the best 200 stems/ha. In 1971, four experienced forest officers repeated the process. Only trees which were alive in 1993 are included in this study. There is no remaining record of the weighting used by each selector for each of the three criteria (vigour, form, or spacing) but presumably they used their best judgement at the time.

Results

Sutton (1973) reported on early results. He noted that defects attributable to leader malformation had a 50% chance of recovery within 4 years. Using the recent assessment, these figures can be updated: of the 164 defects described as "minor" in 1967, only 12 were recorded as present in 1969, and close examination in 1987 revealed the presence of only seven. Defects described as "major" in 1967 showed greater persistence, with 34% being visible 20 or more years later (Fig. 2). Although the categorisation into minor and major was subjective, it appears that multi-leaders that occurred near the tip of the tree, or involved stems of small diameter, were described as a minor defect, whereas forking that occurred low down and that involved larger diameter stems was described as a major defect. The greatest persistence (84%) occurred with defects originating in the lowest 0.3 m of the stem.

By 1987, most "major" problems associated with double leaders had resolved themselves into a main stem with an associated steep-angled branch. Such branches would normally be removed at time of pruning.

Tree D8, aged 4 years, showing ramicorn and displaced leader

The same tree, aged 31. Ramicorn is insignificant branch.

Tree C3, aged 4 years. Rejected because of "bushy" form.

The same tree, aged 31. Steep branches, but the stem is acceptable.

FIG. 2–Change in form between ages 4 and 31 in the unthinned unpruned trial

Defects attributable to lack of stem straightness also appeared to reduce in severity, but it is not clear whether the improvement in stem straightness was due to realignment or to uneven growth of wood which disguised the original defect, or whether both effects were operating in combination.

Results of the early selections in terms of present-day average basal area, total volume, recoverable volume, and stumpage value per tree are given in Table 3.

Of the 113 trees (565 stems/ha) remaining in 1993, 58 had originally been selected by at least one officer in 1967. These 58 were only marginally better than average for the stand in 1993. The later selection at age 8 was more efficient, as at that stage trees were approximately 12.5 m tall and it would have been possible to better anticipate the final form of the butt and second logs which account for the majority of value of a mature tree. Results were still far short of those theoretically obtainable. (The theoretical optimum is the highest value that could have been obtained with the same number of trees).

Even those trees that were unanimously chosen by all assessors (six in 1967 and 14 in 1971) were still well below the ideal choice. The stumpage values of individual selections made in 1967 were found to range between $34.32 and $19.96. Note that even the worst assessment was marginally better than random choice ($18.81), but the best assessment was still far removed from the maximum obtainable.

If the choice had been made solely on the basis of diameter in 1967, results would have been slightly better than the trees actually selected, although well below the maximum.

TABLE 3–Final size and value for various components of the unthinned unpruned trial

	Number	Mean BA (m^2/tree)	Recoverable volume (m^3/tree)	Total volume (m^3/tree)	Stumpage value ($/tree)
Random (mean of 1993)	113	0.11	1.24	1.47	18.81
Any selector 1967	58	0.13	1.51	1.78	21.56
Best 58 1967	58	0.17	2.23	2.45	40.09
Any selector 1971	53	0.15	1.81	2.03	32.88
Best 53 1971	53	0.18	2.31	2.56	43.09
All selectors 1967	6	0.17	2.15	2.36	34.32
Best six 1967	6	0.29	4.08	4.30	134.57
All selectors 1971	14	0.17	2.13	2.36	41.73
Best 14 1971	14	0.25	3.41	3.64	95.92
Top 200 stems/ha by dbh in 1967	40	0.14	1.66	1.91	25.26
Top 200 stems/ha by dbh in 1971	40	0.15	1.79	2.06	26.83
Top 200 stems/ha in 1993	40	0.20	2.62	2.83	53.94

Notes: The first line is the mean of all trees existing in 1993, and is equivalent to the expected tree value of an arbitrary selection. Lines 2 and 4 are the 1993 values of trees that were selected by any one officer in 1967 and 1971. Underneath each is the equivalent value for the same number of highest-value trees in 1993. (The value of the ideal selection alters with the number of surviving trees under consideration, and this varies with individual selections, because mortality has not been uniform). Lines 6 and 8 are the 1993 values of trees that were unanimously selected in 1967 and 1971, with their highest-value equivalents below.

Diameter would have been a poor predictor of future worth because the diameter at breast height (dbh) in 1993 was not closely related to dbh of the same trees in 1967 (r = 0.21). Diameter^2 × height provided a slightly better correlation (r = 0.27).

Discussion

The efficacy of selection was poor for trees aged 4 and 8, but especially for the former. Experienced forestry researchers assessed each tree in meticulous detail, taking far more time than would be available to operational staff, and the results have been interpreted collectively. Attempts to identify criteria that would have improved selection at that time have not been successful. It is likely that there was insufficient information present at an early age to make an informed decision on the most valuable trees at harvest.

The slight superiority of size, when compared with criteria used in 1967, would not be expected in thinned and pruned stands where commercial value depends to a greater extent on stem form as well as volume.

While this trial provides a useful insight into selection, it is unsatisfactory when analysed in isolation, as it is a poor guide to the comparative behaviour of selected and unselected trees in a stand that had been actually thinned or thinned and pruned. It is intended to establish a trial where the outcomes of various selection methods can be assessed.

PRUNING AND THINNING TRIAL (RO 911)

Assessment of Tree Dominance at Ages 7 and 32 Under Three Thinning + Pruning Regimes

Trial description and methods

This pruning and thinning trial was situated adjacent to the unthinned unpruned trial (RO 912). Three treatments were used to examine the change of tree dominance over time:

- Early thinning to a low final-crop stocking, with pruning to 6.5 m. The three plots in this treatment each consisted of approximately 40 trees, and were thinned to waste at the time of final pruning (at age 6-8 years, or 10–14 m in height) to a final stocking of 200 stems/ha.
- Late thinning to a low final-crop stocking, with pruning to 6.5 m. The three plots were treated as for the early thinning treatment, except that waste thinning was to 400 stems/ha, and a further thinning occurred at age 12–14 years (height 22–24 m) to 200 stems/ha.
- Pruning, but no thinning. The two plots were pruned similarly to the early thinning treatment, but were not thinned.

The method of comparing dominance was to use the correlation coefficient (r) between diameters at breast height of individual trees for the three treatments, and to examine how this statistic increased over time. This trial provided an opportunity to check the results from the unthinned unpruned trial against stands that have been subjected to thinning and pruning.

Results

Correlation coefficients, by each of the three silvicultural treatments, of the diameters at breast height of 32-year-old trees against the values at age 7 are given in Table 4a, which shows the means of the correlations for each plot.

Correlations between dbh at age 32 and dbh at age 7 were weak, except for the unthinned plots. The addition of height, so that age 32 diameters were correlated against ($dbh^2 \times ht$), did not greatly change the values.

Correlation coefficients approached unity as the age interval decreased (Fig. 3), with all treatments attaining $r = 0.75$ when age 15 diameters were correlated with age 32 diameters. There appeared to be little difference in the shape of the curves from the early thinning regime treatment and the late thinning treatment but the unthinned treatment showed a substantially higher level of correlation for the early years.

Using an alternative approach, the proportion of 10 top diameter trees at age 8 and 14 years that were among the 10 top diameter trees at age 32 is shown in Table 4b. It can be seen that, whereas early selection for diameter would have been effective for the "no thinning"

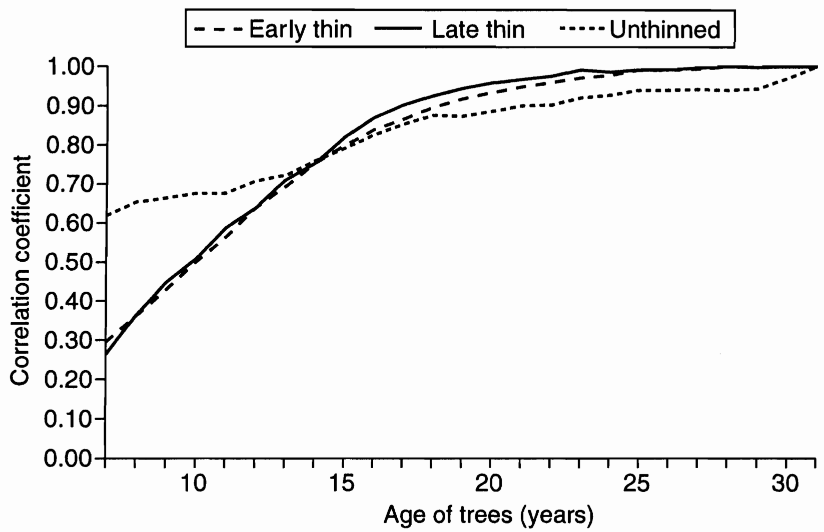


FIG. 3–Correlations between tree diameter at age 32 and tree size at ages 7 to 32 for three regimes

TABLE 4a–Correlations between tree diameter at age 32 and tree size at age 7. Mean correlation coefficients (r) by treatment.

Treatment	Number of trees	Age 7 diameter	Age 7 $dbh^2 \times ht$
Early thinning	118	0.29	0.27
Late thinning	99	0.26	0.18
No thinning	40	0.62	0.63

TABLE 4b–Ten top-diameter trees at age 32 years which were present as the top 10 at age 8 years and at age 14 years (treatment averages)

Treatment	Top 10 at age 8	Top 10 at age 14
Early thinning	3.3	6.0
Late thinning	3.3	5.7
No thinning	7.0	7.0

treatment even at age 8 years, a marked increase in effectiveness could have been expected by delaying selection in the other two regimes until age 14 years.

Discussion

It is clear that considerable change in the ranking of diameters occurs even at low stocking and with early thinning to waste. The least change occurred in the unthinned plots.

GENERAL DISCUSSION

The observations made here were not the results of rigorous statistical design, but if the results of these trials are representative of stands in general, managers in the past may have placed undue emphasis on the value of early selection. In particular, defects arising from poor branching habits are likely to disappear of their own accord or be removed in the course of normal pruning operations.

Defects arising from minor wobble may be confined within the defect core, and therefore have little economic impact. Severe lean and severe stem distortion may have persistent economic impact, and therefore should be the first criteria for rejecting a pruned final-crop.

It seems worthwhile to select trees with the largest diameters, as these are likely to possess the largest diameters at harvest, particularly if the stand is to be left unthinned. Nevertheless, the relationship is weak, and the cost of obtaining a high selection ratio may not justify the gains. High initial stockings (>1000 stems/ha) incur considerable cost—namely the planting, protecting, and removing of superfluous trees.

In a previous paper (Maclaren & Kimberley 1991) it was shown that, although the value of the mature trees increased with higher selection ratios, this was offset by increased costs. The optimum trade-off would depend on the choice of interest rates, as well as factors such as the managers' attitude to risk, the availability of tree stocks, and the need to maintain an acceptable cash-flow. The increased value of trees with higher selection ratios was due in large part to the increased height that arose from high early stockings.

Selection is considerably more effective at age 14, when production thinning could occur, than at age 8, when completion of pruning may take place.

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APPENDIX 1

DICTIONARY OF QUALITY CODES USED IN THE MARVL EVALUATION OF THE UNTHINNED UNPRUNED TRIAL

Code	Quality
E	Branches < 6cm, straight, not peeler
N	Branches < 6cm, straight, peeler
G	Branches < 6 cm, moderate sweep
F	Branches 6–10 cm, straight
H	Branches 6–10 cm, moderate sweep
L	Branches 7–14 cm, straight
K	Branches 7–14 cm moderate sweep
P	Pulp
W	Waste

Notes: (1) A log is not a peeler if two diameter measurements (measured with callipers) differ by more than 10%, if there is severe fluting, or if there is any bark damage. Note that a number of logs classified as "peeler" from external features will be downgraded on felling as a result of pith displacement.

(2) There are four sweep classes (Gosnell 1987), expressed here as a proportion of small-end diameter. Sweep Class 4 is waste, Class 3 is pulp, Class 2 is "moderately swept" (as above), and Class 1 is "straight".

Sweep Class	For 5.5 m log	For < 3.7 m log
1	< D/8	< D/16
2	D/8–D/4	D/16–D/8
3	D/4–D/2	D/8–D/4
4	> D/2	> D/4

(3) Logs can be downgraded to pulp for displaying one of more of the following types of defects: Sweep Class 3, a branch greater than 14 cm, or bark damage likely to indicate sapstain fungus.

APPENDIX 2

CUTTING STRATEGY USED IN THE MARVL EVALUATION OF THE UNTHINNED UNPRUNED TRIAL

(Stumpages were derived from a confidential source, using averages for 1986–92)

Log grade (length m)	Min. s.e.d.* (cm)	Max. s.e.d.* (cm)	Max. l.e.d.* (cm)	Stumpage value ($/m^3)	Log qualities
A export (8.1–12.1)	36	150	150	51.59	NEFGH
K export (5.5–11.1)	30	150	150	16.88	NEFGH
Pulp (1.2–6.1)	10	150	150	5.00	NEFGHLKP
Waste (0.1–20.0)	0	150	150	1.00	NEFGHLKPW

* s.e.d = small-end diameter of log
l.e.d. = large-end diameter of log

Stump height: 0.3 m
Round-off length: 0.1 m
Cost per sawcut: $0.50
Functions used were: Volume and taper 116, breakage 02 (Micro-MARVL User Guide, version 2.1)