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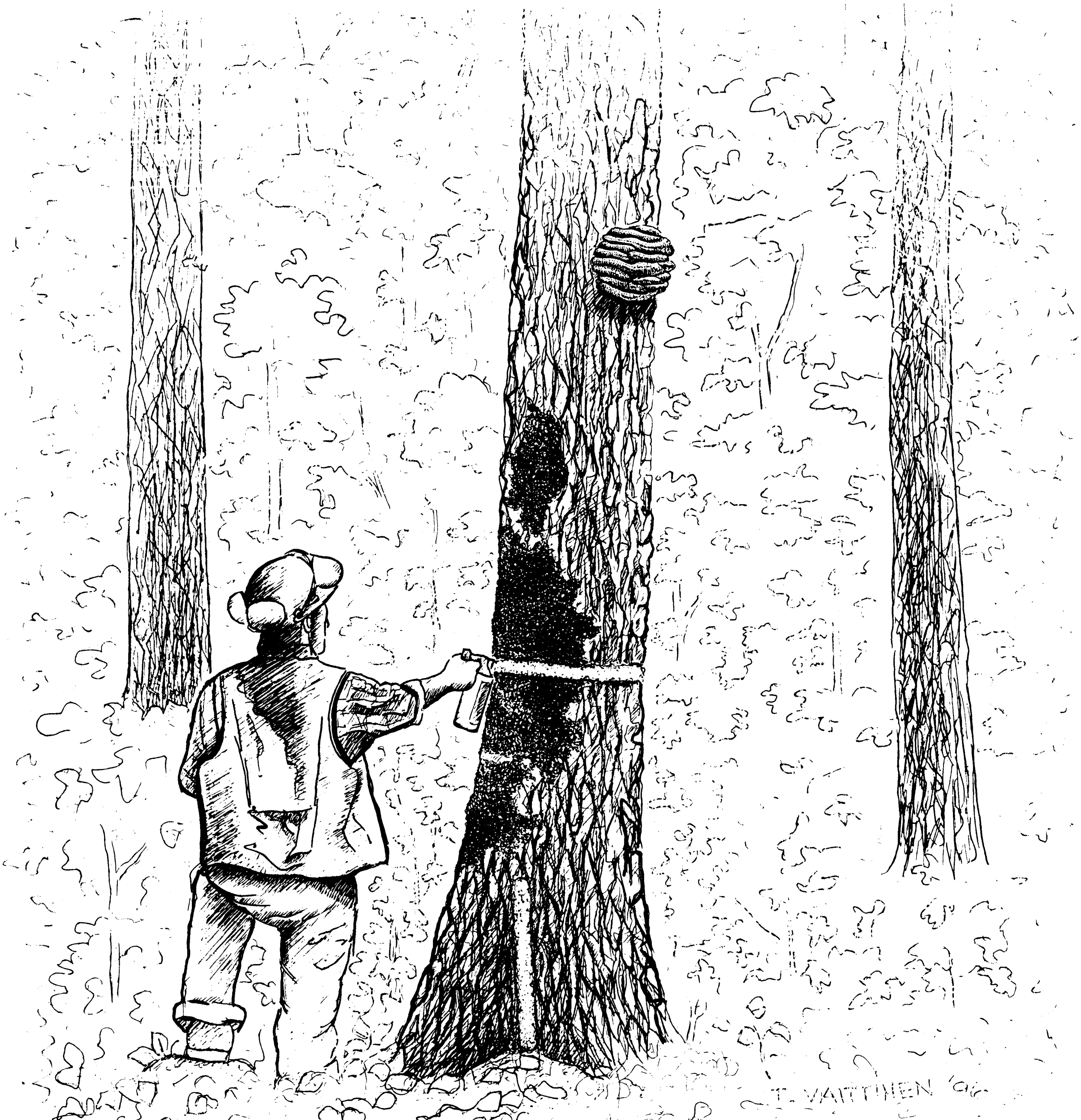
Quality Assurance in Hardwood Tree-Marking: A Case Study



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Quality Assurance in Hardwood Tree-Marking: A Case Study

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Abstract

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An intensive audit was implemented by the Ontario Ministry of Natural Resources in Algonquin Provincial Park in 1986 to monitor the quality of tree-marking operations. A total of 295 0.1-acre plots were established in 87 hardwood stands marked under a Selection Silvicultural System management prescription. Results indicate that a maximum allowable error of 10%, expressed as relative number of tree-choice and/or basal area errors, is a realistic quality standard. The need for continuous monitoring to track performance and to allow revision of these standards is discussed. Suggestions for efficient sampling design and data collection methods are outlined.

Keywords: tree-marking, hardwoods, selection system, quality assurance, forest audit, forest sustainability, sugar maple, hard maple, *Acer saccharum*.

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Introduction

In Ontario, the Tolerant Hardwoods Working Group (THWG) is usually managed using either the Single-Tree/Group Selection or the Uniform Shelterwood Silvicultural Systems (OMNR 1990). Both of these Systems involve **partial cutting** where the choice of trees to be harvested is controlled by tree-marking decisions. In Algonquin Park, tree-marking has been an integral part of the forest management system since the early 1970's. During the summer of 1986, field staff in the Algonquin Park District of the Ontario Ministry of Natural Resources (OMNR) requested the Ontario Forest Research Institute (OFRI) of OMNR to assist in the development and implementation of a more effective and quantitative method to monitor tree-marking operations within Algonquin Park. This report describes the methodology used and some results from an initial survey by OMNR of hardwood stands marked by the Algonquin Forestry Authority (AFA) and managed under the Selection System, as prescribed at that time (1986).

Background

The **Single-Tree Selection System** is a partial-cutting system, controlled by basal area, using tree vigour, risk, and growing space to determine trees to harvest. A high forest cover is always maintained and the method is suited only to species tolerant of shade, such as sugar (hard) maple (*Acer saccharum* Marsh.). Harvesting, tending, and renewal operations are carried out simultaneously, repeated at regular intervals (cutting cycles). The stand, grown without a traditional rotation, produces a "continuing" uneven-aged forest. A variation known as **Group Selection** may be incorporated locally to regenerate species of intermediate shade tolerance, such as yellow birch (*Betula alleghaniensis* Britt.). This combination of systems produces even-aged groups of semi-tolerant species as a mosaic within an uneven-aged forest.

The **Uniform Shelterwood System** is a reproduction method in which mature trees are harvested in a series of two or more cuts (preparatory, seed, removal, and final) for the purpose of obtaining natural regeneration under the shelter of the residual trees. This remaining portion of the stand acts as a seed source, and provides site protection, while the residual trees increase in size and value during the reproduction phase. The method can be applied to species with either high or intermediate shade tolerance and produces a "new", even-aged forest managed on a specific rotation length.

Silvicultural prescriptions for these Systems include marking criteria such as stand structure and density targets, individual tree vigour and quality factors, regeneration requirements, wildlife habitat maintenance, and biodiversity considerations, among others. The management process is described in *A Tree-Marking Guide to the Tolerant Hardwoods Working Group in Ontario* (Anderson and Rice 1993).

Marking decisions are based on individual tree values; however, these choices must be made within a framework of the prescribed residual stand stocking and structure targets. Thus, the marker must continually balance the trade-offs between local tree-to-tree variation and the overall residual stand target.

Since a stand prescription is based only on a partial sample (i.e., a cruise), the tree-marking operation is the only opportunity to evaluate every hectare (perhaps every tree) of a stand allocated for harvesting. The tree-marking crew chief must be competent to modify the marking prescription, on a very local basis, to adjust for conditions not recognized by the cruise. For example, marking strategy may be altered to account for unexpected site variation, understocked sections, polewood areas, pockets of low quality timber, regeneration opportunities for minor species components, or critical wildlife habitat conditions.

The ultimate success of these sophisticated prescriptions in the THWG is very much dependant on the skilful application of proven tree-marking principles and guidelines. In order to guarantee such success, quality-assurance methods must include a justifiable "standard" against which individual tree-marking operations can be judged. Such standards, founded on a scientifically-sound database derived from evaluations of a wide variety of crews and stand conditions, are not currently available.

As a first step in developing such a standard, this report provides preliminary data from a series of hardwood stands, marked under the Selection Silvicultural System, which were examined in 1986 in Algonquin Provincial Park using a provisional monitoring procedure.

Methods

The recommended sampling design consisted of a series of random-start transects of nested, circular polar plots, each 0.1 acres (0.04 hectares) in area, to be established as Permanent Sample Plots in recently-marked stands of a variety of hardwood and conifer Working Groups across Algonquin Park.

In each plot, all trees with a minimum DBH of 3.6 inches (9 cm) were identified and measured. For each tree within a plot, the following data were collected: (i) tree species, (ii) DBH, (iii) tree quality classification (using the Algonquin Park 4-Class System, shown in Appendix 1), (iv) marking status (marked or unmarked), (v) error status, and (vi) tree location mapped by polar co-ordinates from the plot centre. Two types of marking errors were considered: (a) **commission** errors where trees were marked when they should not have been, and (b) **omission** errors where trees that should have been marked were not. Collectively, they will be referred to as **tree-choice errors**.

Qualified tree-markers with extensive experience assessed the appropriateness of each tree-marking decision on each plot, based on the management prescription and local stand conditions.

A total of 369 polar plots were established across 14 townships in a variety of stands situated on Site Class 1 (Plonski 1960). Selected stands included a range of Working Groups being managed using either the Single-Tree Selection or Uniform Shelterwood Silvicultural System. A **minimum** of 3 plots, with a random start, was **recommended** for each stand.

Emphasis in this study (351 plots) was placed on stands dominated by hard maple, a species that may be managed under either partial cutting system. However, where overall tree and site quality are acceptable, Selection is usually the System of choice. A total of **295 plots** were located in **87 hardwood stands** marked under Selection System guidelines. Analysis of these 295 plots forms the basis for this report.

Management prescriptions for these hardwood stands are based on guidelines provided in *Management of Tolerant Hardwoods in Algonquin Provincial Park* (OMNR 1983), and included the following instructions:

> Whenever possible, stocking of crop trees should be maintained at levels up to the "optimum" basal area of 60 ft^2/acre (13.9 m^2/ha), in trees 10 inches (25.4 cm) DBH and larger;

Residual stocking should **not** be reduced below a level of 40 ft^2/acre (9.2 m^2/ha), in trees 10 inches (25.4 cm) DBH and larger;

Using a 4-Class system, all Class 1 and Class 2 trees 24 inches (61 cm) DBH or larger should be marked for harvest;

For trees less than 24 inches (61 cm) DBH, only Class 1 and 2 trees which compete with other Class 1 or 2 trees of equal or better quality should be marked for harvest.

All Class 3 and 4 trees, except those required to meet minimum stocking targets, should be marked.

Phase I of this survey was designed to provide information on:

(a) pre-marked stand conditions, and
(b) appropriateness of the tree-marking decisions.

This data forms the main basis of this report.

Phase II included remeasurement of plots soon after harvest to determine:

(a) adequacy of cut control and utilization of marked trees, and
(b) incidence and severity of logging damage.

This phase is briefly discussed below.

Also initiated, but not reported here, was **Phase III**, in which the plots were remeasured five years after harvest to:

(a) determine tree and stand growth following the prescribed silvicultural prescription, and
(b) update the database, which will be periodically appended in order to assess the sustainability of such treatments and to suggest possible refinements.

Results

At least three sample plots were to be installed in each stand to be audited; however, constraints such as access, travel distances, and availability of resources restricted sampling. Figure 1 indicates that, of 87 stands sampled, 28 stands contained only a single plot and 6 contained only 2 plots. The remaining 53 stands contained between 3 and 12 plots each, comprising a total of 255 plots.

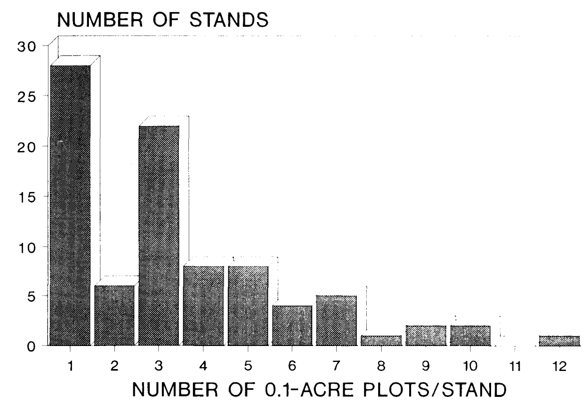

Figure 1. Frequency distribution of stands by number of sample plots.

A computer database of the individual plot records was summarized by stand number, Working Group, and prescription type. Individual tree descriptors were summarized to show: (a) **Plot-error variation** within the entire array of **295 individual hardwood plots**, and (b) **Stand-error variation** among **53 stands** each containing a minimum of three plots (comprised of an array of 255 hardwood plots). Since the original prescription and much of the data collection used imperial measure, the analysis maintained the use of that convention.

Individual Plot-Error Variation

Table 1 summarizes the mean plot data (and data ranges) for both: (a) the entire dataset (295 plots), and (b) only those 184 plots that contained marking errors. All stands were pooled for this calculation.

(a) **All Plots**: In the 295-plot array, the mean 0.1-acre plot contained 16.13 trees and supported 11.37 $ft.^2$ basal area per plot. In both cases, there was a considerable range of values exhibited over the array of individual plots, indicating both under- and overstocked conditions. The mean postmark, or theoretical residual, basal area was 7.06 $ft.^2$/plot, a value below the optimum target of 8.7 $ft.^2$/plot (Anderson and Rice 1993), but within the minimum acceptable stand basal area target (see *Individual Stand Error Variation* below). On average, 1.36 trees (8.25%), comprising 0.99 $ft.^2$/plot (8.90%) of basal area, were incorrectly marked per 0.1-acre plot.

Figure 2 shows the distribution of 295 plots within various levels of the numbers of trees marked in error (tree-choice errors). One Hundred and eleven (or 37.6%) of the plots had no tree-marking errors, 189 (or 64.1%) of the plots had 1 tree-choice error or less, and 237 (or 80.3%) of the plots had 2 errors or less. Because not all plots contained the same number of trees initially, tree-choice error, expressed as a **percentage** of the available trees, was also calculated. On this basis, 195 (or 66.1%) of the plots contained tree-choice errors comprising 10% or less of the available trees per plot.

Figure 3 indicates the plot distribution of the tree basal areas marked in error. One hundred and eleven (or 37.6%) of the plots had no errors, 188 (or 63.7%) of the plots contained basal area error levels of 1 $ft.^2$/plot or less and 244 (or 82.7%) of the plots contained error levels of 2 $ft.^2$/plot or less. On a **percentage** basis, 192 (or 65.1%) of the plots contained basal area error levels of 10% or less of the available plot basal area.

Table 1. Mean plot values (and associated ranges) for (a) the entire array of 295 sample plots (all stands pooled), and (b) for those 184 plots that contained marking errors (all stands pooled).

Parameter/Error Type	All Plots (295) *	Plots With Errors Only (184) **
	Mean (Range of values)	Mean (Range of values)
Premark Number of Trees (per plot)	16.13 (6 - 33)	16.54 (6 - 33)
Premark Basal Area ($ft.^2$/plot)	11.37 (3.9 - 19.5)	11.33 (4.5 - 18.4)
Postmark Basal Area ($ft.^2$/plot)	7.06 (2.4 - 14.4)	7.31 (3.0 - 14.4)
Number of Trees in Error (per plot)	1.36 (0 - 11)	2.18 (1 - 11)
Percent Trees in Error (per plot)	8.25 (0 - 52.6)	13.23 (3.7 - 52.6)
Basal Area in Error ($ft.^2$/plot)	0.99 (0 - 6.9)	1.58 (0.02 - 6.9)
Percent Basal Area in Error (per plot)	8.90 (0 - 61.8)	14.26 (0.1 - 61.8)

Note * : Each plot is 0.1 acres   Note ** : 111 plots had no errors

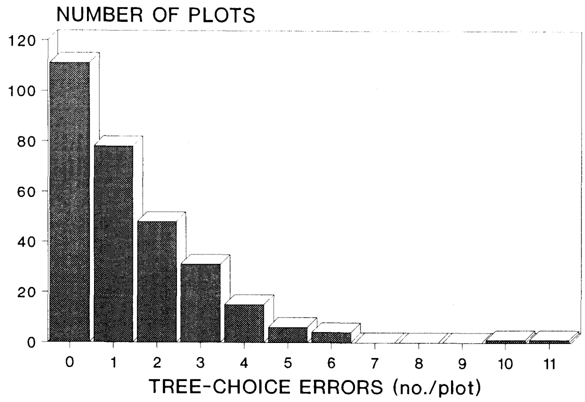

Figure 2. Frequency distribution of sample plots by number of tree-choice marking errors.

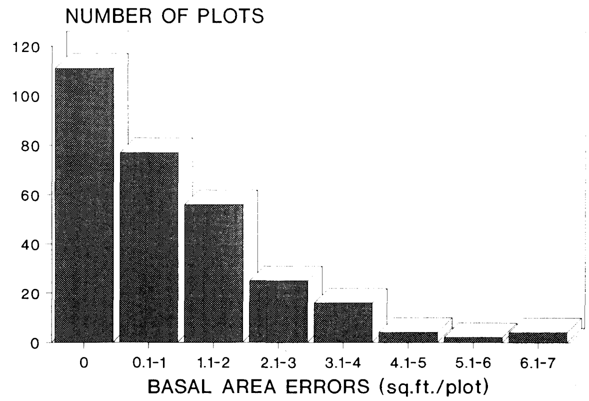

Figure 3. Frequency distribution of sample plots by number of basal area marking errors.

These error levels are based on the initial (premark) values because, theoretically at least, markers assess the size, species, quality, and habitat value of **all** trees in the plot, and therefore, each tree has an equal opportunity to be a candidate for marking.

(b) **Error Plots Only**: In the 184 plots that contained marking errors (Table 1), average premark stem frequency and basal area levels were very similar to the entire 295-plot array, suggesting that the preexisting condition of the plot did not appreciably influence marking quality. However, both tree-choice and basal area marking errors were about 60% higher than on the entire plot array. On average, about 13% of the trees and 14% of the basal area was incorrectly marked in the plots with errors. Interestingly, postmark basal area averaged somewhat closer to target in the plots with errors.

Individual Stand Error Variation

While individual plot variation provides an impression of the marking accuracy of the overall tree-marking project, the hardwood forest is managed on a stand basis. Individual crews are often responsible for marking particular stands. Therefore, mean stand values and their variability, computed from the subset of plots from each stand, may be a more practical representation of tree-marking efficacy.

Table 2 indicates the distribution of the 53 **stands** with at least 3 plots according to their marking-error level. Three (or 5.7%) of the stands were without any error, while 34 (or 64.2%) had 10% or less of the trees marked in error. In similar fashion, 32 (60.4%) of the stands had basal area errors of 10% or less. Conversely, none of the stands had more than 30% of the trees marked incorrectly, and only 1 (1.9%) had basal area errors greater than 30%.

Table 3 illustrates mean **stand** values based on stands with at least three plots each. On the average plot per stand, premark stem density and basal area were only marginally higher than was found in the entire plot array. The lack of influence of premark stand condition on error occurrence is further illustrated in Figures 4 and 5, in which mean **stand** marking error (in those stands containing 3 or more plots) appears to be randomly distributed across

Table 2. Mean tree-marking errors for 53 stands, each containing at least three sample plots, by tree-choice and basal area error levels.

Stand Error Level (Percent)	Number of Stands *	
	With tree-choice errors	With basal area errors
0	3 (5.7%)	3 (5.7%)
0.1-10.0	31 (58.5%)	29 (54.7%)
10.1-20.0	16 (30.2%)	16 (30.2%)
20.1-30.0	3 (5.7%)	4 (7.5%)
30.1 +	0	1 (1.9%)
TOTAL	53 (100%)	53 (100%)

Note * : 53 stands each containing 3 or more 0.1-acre plots

the range of premark stem density and basal area, although tree-choice error variation tends to increase somewhat at higher stem densities. This lack of strong correlation might suggest a "crew" effect is responsible for some of the marking results, although difficult weather and terrain effects may also contribute to the occurrence of error.

In contrast, mean stand error levels were generally lower than those found in the entire plot array. On the average plot, 1.44

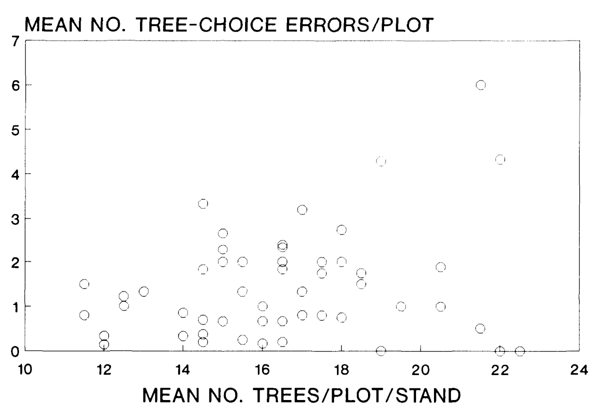

Figure 4. Relationship between mean number of tree-choice marking errors per plot and mean number of available trees per plot for 53 stands.

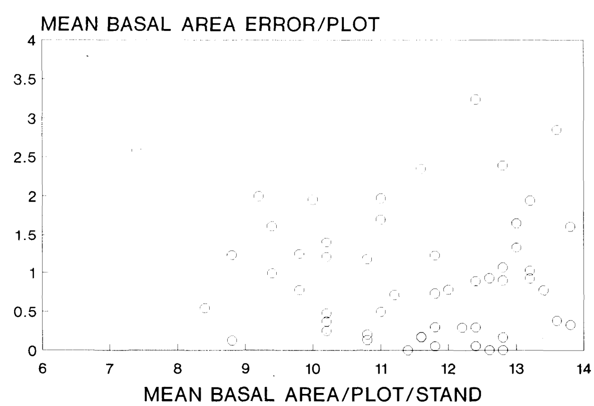

Figure 5. Relationship between mean basal area error per plot and mean available basal area per plot for 53 stands.

Table 3. Mean stand tree-marking audit values (and associated ranges) for 53 stands, each containing at least three sample plots.

Parameter/Error Type	Mean Plot Value (Range) Per Stand*
Premark Number of Trees (per plot)	16.38 (11.5 - 22.33)
Premark Basal Area ($ft.^2$/plot)	11.49 (7.49 - 13.84)
Postmark Basal Area ($ft.^2$/plot)	7.09 (4.42 - 10.27)
Number of Trees in Error (per plot)	1.44 (0 - 6.0)
Percent Trees in Error (per plot)	8.67 (0 - 28.13)
Basal Area in Error ($ft.^2$/plot)	0.98 (0 - 3.24)
Percent Basal Area in Error (per plot)	8.77 (0 - 34.47)
Post-Cut Basal Area ($ft.^2$/plot)	7.87
Basal Area Damaged ($ft.^2$/plot)	0.51
Note * : Only those 53 stands with 3 plots or more.	

(or 8.67%) of the trees were incorrectly marked, while 0.98 $ft.^2$/plot (or 8.77%) of the basal area was marked in error. The range of values about each mean, in all cases, is considerably less than for the entire data array and emphasizes the importance of adequate sample size.

The mean stand residual marked basal area was 7.09 $ft.^2$/plot. A post-harvest re-inventory of the plots initiated in Phase II revealed that the actual mean **post-cut** residual basal area was 7.87 $ft.^2$/plot or about 11% higher (and closer to the optimum target) than intended by the marking. This may be due to failure to use low quality (Class 3 and 4) trees. Of this actual mean residual stocking, 0.51 $ft.^2$/plot or about 6.5% of the residual basal area exhibited logging damage. Concurrent studies are in progress to develop standards for acceptable levels of damage associated with partial cutting (Anderson 1994, Nyland 1994, Dey 1994).

Stand Stocking Target

The prescription used in this case for marking in the Selection System employed a residual basal area value of 60 $ft.^2$/acre in trees of DBH 10 inches and larger. Figure 6 illustrates the postmark mean stand basal area distribution for the 53 stands containing 3 or more plots. The average basal area is 5.26 ± 1.37 per plot or 52.6 $ft.^2$/acre. This value is less than the "optimum" target of 60 $ft.^2$/acre but above the minimum acceptable value of 40 $ft.^2$/acre allowed when the optimum level of Acceptable Growing Stock (AGS)(Class 1 and Class 2) is not present.

Some stand marking jobs would be readily approved, from the stocking aspect, and others would be allowed with some reservation. Casual observation suggests that seven of the 53 (13%) would be unacceptable. Six of these lower values may be attributable to low original stocking

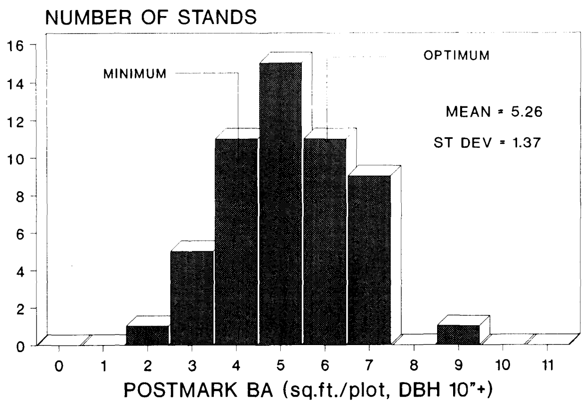

Figure 6. Frequency distribution of stands with various postmark basal areas in trees with DBH 10 inches and larger.

levels where a decision to mark at all is questionable. One high value was in a heavily stocked stand which was apparently undermarked. However, other local factors may influence marking and therefore target levels should be assessed as a separate factor during audit in the field rather than from data analysis only. Never-the-less, consistent variance from the recommended prescription targets should be an area of concern.

In current practice, basal area may be reduced below a normal "Single-Tree" Selection target for the purpose of obtaining regeneration of less shade-tolerant species (Group Selection). This is a discretionary action made available to very experienced crews having the expertise to recognize and treat such ecological opportunities. This is only of practical value when such variances are documented for further action. In such cases, these special occurrences should be flagged and analysed separately from conventional marking.

Influence of Tree Quality on Error Type

Table 4 summarizes the distribution of marking errors according to tree quality class and type of error. Of the 4757 trees assessed, 400 (8.4%) were incorrectly marked, with 349 (7.3%) being errors of **omission** and 51 (1.1%) being errors of **commission**. In some cases, such as with a pair of competing trees, a single decision could result in two tree-choice errors. By making a poor choice (decision), the wrong tree is marked (commission error #1) and the correct tree is unmarked (omission error #2). In such cases, the ability or "art" of **previsualizing** the residual stand is necessary to make a correct choice.

Two thousand four hundred and fifty-six (51.6%) of the trees examined were AGS quality and of these, 72 (2.9%) were incorrectly marked, with more errors of commission (41 or 1.7%) than of omission (31 or 1.3%). The relative marking error rate for Class 2 trees was two-to-three times that for Class 1 trees for either type of error.

Of 1918 Unacceptable Growing Stock (UGS) (Class 3 and Class 4) trees examined, 290 (15.1%) were incorrectly marked, the majority of which (281 or 14.7%) were errors of omission. There was a tendency for proportionately more errors of omission for Class 4 trees and, conversely, more errors of commission for Class 3 trees.

Of 383 trees of species that are not usually rated for quality (NO Class), 38 (9.9%) were incorrectly marked, almost exclusively (37 or 9.7%) as errors of omission.

With respect to AGS trees, the relatively low error rate indicates that the crop-quality trees were being adequately recognized by marking crews. More AGS trees were marked in error for removal (when they should have been retained) than were

Table 4. Distribution of tree-choice marking errors within 295 plots according to error type and tree quality class.

Quality Class	No. Trees Assessed	Number of Marking Errors		
		Omission	Commission	Total
1	980	7	12	19
2	1476	24	29	53
AGS	2456	31	41	72
3	629	71	5	76
4	1289	210	4	214
UGS	1918	281	9	290
NO QC *	383	37	1	38
TOTAL	4757	349	51	400

Note * Includes species not normally classified for quality (e.g., hemlock, spruce, ironwood, etc.)

retained in error. This probably reflects inadequate assessment of growing-space requirements of residual crop trees. The lower error rates for Class 1 trees compared to Class 2 trees suggests that crews accurately discriminated between the "best" trees and the "good" trees.

With respect to UGS trees, the higher error rates (compared to AGS trees) suggests some difficulty in rating the potential performance among competing trees, perhaps in the application of the Tree Classification System.

The nature of the marking prescription and the assessment of marking errors in this study reflects the knowledge and objectives of the time (1986) when timber values were emphasized. In more recent times, the required maintenance of wildlife habitat features of the forest would probably influence marking decisions and consequently, the error criteria used during an audit. Present-day objectives would give miscellaneous species (without tree classes) more value as mast producers (e.g., ironwood (*Ostrya virginiana* (Mill.) K.Koch)) or cover providers (e.g., hemlock (*Tsuga canadensis* (L.) Carr.)).

Similarly, for trees of low timber potential such as Class 4 ("cull") trees, marking errors were assessed almost exclusively as those of omission. Currently, such trees would be examined for their appropriateness as "cavity" trees with value for retention as wildlife habitat. A few of the errors assessed in Class 4 trees in this study might not qualify as errors in current marking. In most cases, however, omission errors are perhaps less critical than those of commission. In cases of doubt, it is wiser to leave trees unmarked, especially in situations of lower stand stocking levels.

Discussion

In the absence of any other comparable data, these statistics suggest that a **minimum** target of 90% acceptable marking is both realistic and achievable as a provisional standard.

Every standard must also provide "fiducial levels", which express the acceptable variance associated with each mean value. In the present dataset, there is a large range of variation around the mean error values. On both an individual plot basis and on a stand basis, 60 to 65% of the statistical units are at or below the 10% tree or basal area error threshold. This suggests that, within the 295 plots or 53 stands, most of the tree-marking might be considered acceptable, but execution in some plots or in some stands would be rated as poor and unacceptable. In a statistical sense, an acceptable standard for an **overall marking program** should provide a maximum mean allowable error level (or, conversely, a minimum acceptably-marked level) and a probability limit or standard error.

A **benchmark** by which to compare the quality of other, perhaps more recent, tree-marking operations is suggested in Figure 7. This is a Cumulative Probability Density Distribution, computed as a Weibull function from the current data pool. It suggests the probability of occurrence of plots with various levels of tree-choice error. The probability for plots having zero or more errors is 1.0 (i.e., the entire data array will sum to 1.0 (or 100%)). Similarly, the probability of plots having 1-or-more errors is 0.631, or of having 2 or more errors is 0.355, etc.

The equation can be solved by **difference** to provide the probability of plots having an error level between any two discrete number of errors (e.g., 0, 1, 2, or 3 errors, etc.), as shown in Figure 8. For example, the probability of a plot having no errors is 0.370, or, of having 1 or 2 errors is .276 and 0.165, respectively, while the probability of a plot having 8 errors is only 0.003. A similar procedure can be used to develop benchmark functions for basal area or other measures of error.

Obviously, this is a very simplistic model and does not reflect any source of replicative variation. Additional data sets will allow refinement and a better estimate of reliability and thus a more suitable quality assurance standard.

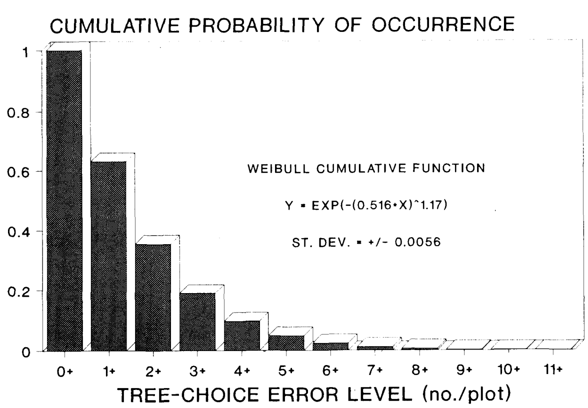

Figure 7. Weibull cumulative probability density function of number of tree-choice errors per plot.

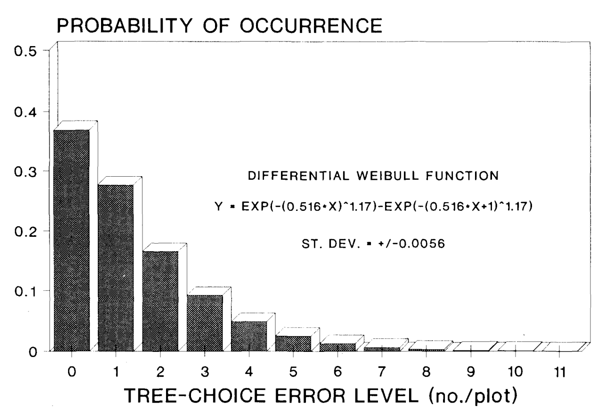

Figure 8. Weibull probability density function of number of tree-choice errors per plot.

To sustain long-term timber-value productivity, the proportion of AGS trees left to grow in the residual stand should be increased. Figure 9 illustrates the proportion of AGS basal area in the post-marked stand as a function of that in the premarked stand, for 32 stands in which less than 10% of the basal area was incorrectly marked. The non-linear relationship was conditioned at higher premarked values to maintain a component of UGS trees as a potential source of wildlife habitat (e.g., cavity trees). The residual stand would not reach 100% AGS until the premark stand is entirely AGS (i.e, there is no UGS basal area to leave). While not all UGS trees have the attributes required to qualify as habitat, allowance must be made to ensure that supplies of such trees are not eliminated in efforts to upgrade the timber value of the stand.

Adequate sampling design and effort is also critical when assembling a meaningful database. There is a need to acquire additional baseline data, from studies similar to this one, but based on a sufficient number of plots per stand to allow adequate statistical analyses. In future, simulation studies using random sampling of such new datasets may suggest minimum numbers of plots per stand, which will ensure efficient estimates with low standard errors.

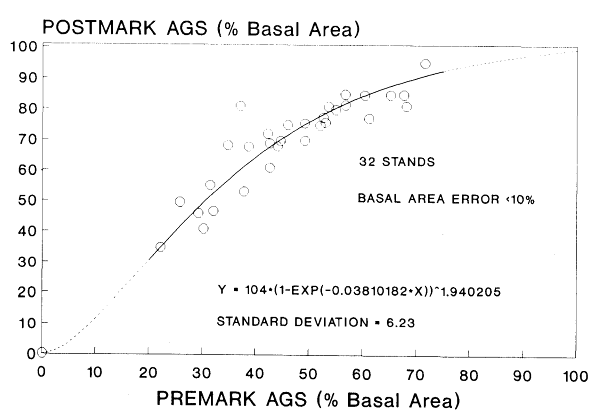

Figure 9. Relationship of postmark AGS basal area (%) to premark AGS basal area (%) for stands with error levels of less than 10%.

However, because audits must monitor the marking operation **as it progresses**, a practical process control application, such as "Sequential Sampling" (Oakland 1951), should be developed. In such techniques, reliable baseline datasets are used to compute control levels for defining sampling strategies that allow field audit decisions to be made on site, with minimum sample size, time, and effort. The use of programmable data-loggers makes immediate analysis of current data both practical and precise. It also provides an opportunity to construct an historical, cumulative database by uploading each audit record into a permanent electronic file at the office. This would allow realistic monitoring of overall operational performance on a continuing basis.

Tree-marking is both an art and a science (Anderson and Rice 1993). The **science** supplies the biological and ecological basis for the decision process, while the **art** reflects the marker's judgement in making interpretive decisions that use this science to evaluate, differentiate, and choose candidate trees. The recent inauguration of the *Provincial Tree-Marker Licensing Program* will help to ensure consistent and correct application of these principles, not only through training, but also through the associated compulsory examination and audit of its graduate's performance. This will ultimately result in more rigorous standards which will reflect the higher marking-quality expectation.

In a similar vein, any tree-marking quality-assurance procedure is a highly developed art - in fact, a type of ***expert system*** - in which the same marking principles are applied during an audit by certified individuals who possess extensive experience and comprehensive knowledge of the process. Evaluation of the appropriateness (quality) of any tree-marking job must be assessed both at the stand level, to ascertain if management objectives were met through the tree-marking process, and at the individual tree level, to see if local guidelines and rules have been followed. Adequate quality control procedures should not strive for just an "accept/reject" result based on some arbitrary value, but should consider the on-site rationale for a particular marking decision.

Advantages of the installation of Permanent Sample Plots as a basis for marking audits evolve from their availability for: (a) post-harvest inspection to ensure that all (and only) designated (marked) trees were cut, (b) assessment of logging damage (using another unique set of quality assurance standards), and (c) subsequent determination of growth response over time following silvicultural treatments for improving yield estimation and habitat evaluation.

Tree-marking errors may have short- and long-term effects on timber production by their impacts on stand structure and stand stocking levels. Large basal area errors may arise with a few tree-choice errors involving large trees, affecting the high-end structure and stocking target, and consequently the **short-term** productivity (i.e., volume growth over the next cycle). A large number of tree-choice errors involving small trees will have slight impact on basal area stocking level, but will seriously compromise stand structure, especially at the low end, which will affect the **long-term** sustainability of production (recruitment).

Incorrect marking decisions can also affect tree quality development and ecological values such as wildlife habitat, species diversity, and critical "areas-of-concern".

Conclusion

Long-term sustainability of forest production and ecosystem stability is put at risk if the quality of a marking job is unacceptable. Because tree-marking is part art as well as science, it will always be subject to some degree of potential error. Adequate quality assurance standards and procedures, based on sound information towards which this preliminary study is directed, must be developed to ensure protection of all forest values.

This study indicates that a minimum 90% marking accuracy level should be adopted as a **provisional** standard of acceptable tree-marking practice. However, recent developments in marker training and certification suggest that future marking will be accomplished with more accuracy and consistency. Therefore, there is a need to accumulate **current** baseline datasets, derived from statistically sound, intensive sampling, as a basis for revising such standards. Audit results should form a cumulative record to facilitate such modifications and to track performance. More rigorous expectations will also evolve in response to increasing knowledge of the sensitivity of ecosystem dynamics.

While more extensive management practices, such as those used in the Boreal Forest, can be effectively monitored on the basis of **results** determined at some date **after harvest**, such is not the case in the Tolerant Hardwoods Working Group. A suitable tree-marking quality-assurance program must monitor the **process**, and accept or correct the marking job **prior to harvest**. A planting job can be repeated if it fails; a Selection forest cannot be replaced so easily.

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APPENDIX 1: Algonquin Park 4-Class System.

(For more detail, see OMNR (1983)).

TOLERANT HARDWOOD TREE CLASSIFICATION	
Class 1:	Minimum DBH = 4 inches. No major defects allowed -- contain or have potential to develop high-quality products. These trees are considered crop or potential crop trees and will maintain their present quality for the next 20-year period.
Class 2:	Minimum DBH = 4 inches. May contain Value-Affecting Defects[1] -- contain or have potential to produce medium-quality products (sawlogs). These trees are considered crop or potential crop trees and will maintain their present quality for the next 20-year period.
Class 3:	Minimum DBH = 10 inches. Contain Decline-Causing Defects[2] but also contain medium-to-high quality products. These trees are expected to decline in value over the next 20-year period.
Class 4:	Minimum DBH = 4 inches. Contain severe Value-Affecting Defects or Decline-Causing Defects -- contain or have potential to produce, at best, low quality products. This class also includes trees which are unmerchantable according to the Crown Timber Act.

DEFECT DEFINITIONS
[1] **Value-Affecting Defects** are mechanical or form defects. These defects limit or reduce the value of products that can be recovered from a tree but will not cause continued deterioration or decline. The size and position of these defects determines the degree to which they affect value. **Examples**: wounds, cracks, seams, holes, dead limbs, branch stubs, live branches, twisted grain, bumpy surface, sweep, crook, forks, burls, and lean.
[2] **Decline-Causing Defects** are severe mechanical or pathological defects. These defects cause continued deterioration of the products that may be recovered from a tree. They also may severely limit the potential of a tree to produce anything better than low-value products (i.e., pulpwood, poker poles, bolter logs, and fuelwood). **Examples**: rot or decay when associated with Value-Affecting Defects or when indicated by the presence of conks, fruiting bodies, cankers, barrelling, etc. Severe mechanical defects such as broken tops, excessive lean, or severe sugar maple borer damage will cause either decline or cause the tree to be a high risk.