F.R.I. PROJECT RECORD

NO. 1583

THE RETROSPECTIVE SAMPLING TECHNIQUE

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REPORT NO. 5 JUNE 1987

THE RESTROSPECTIVE SAMPLING TECHNIQUE
A METHOD USED TO QUANTIFY PAST STAND DEVELOPMENT

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THE RETROSPECTIVE SAMPLING TECHNIQUE : A METHOD USED TO QUANTIFY PAST STAND DEVELOPMENT

SUMMARY

A methodology has been developed to estimate past values of basal area, height and stocking in even-aged stands of *Pinus radiata* (D.Don). This technique is however constrained by the inability to estimate basal areas prior to

i) thinning, and
ii) mortality, where decay is too severe to allow measurement;

and also requires further refinement to overcome technical deficiencies. Errors in estimation of both past and present basal area and height can cause bias in results which increases as time tracked back increases. As a result, skilled field crew members and close supervision during data collection are imperative.

The technique does have considerable potential however; growth modellers can obtain data quickly and thus decrease the time-span inherent in model development. Furthermore, the costs of obtaining data using this method are generally lower in the long term than using monitoring methods. This technique may also have applications in other fields of study.

1.0 INTRODUCTION

Data used for the construction of 'third generation' stand growth models (Tennent, 1982) have originated from permanent sample plot measurements (McEwen, 1976) where the growth of a live forest stand has been monitored on a periodic basis. Such data are particularly suitable for construction of even-aged stand growth models using the 'state-space' approach (Garcia, 1979, 1983, 1984) which uses three variables; top height, basal area and stocking, to estimate stand parameters. Tennent (1982) describes a suitable monitoring system which also provides the necessary information for growth modellers. These sampling techniques however, require a minimum of three measurements per plot to adequately estimate stand height development (Shula, 1987 unpubl. report).

A methodology has been developed to estimate past values of height, basal area and stocking at any one point in time. This methodology, the Retrospective Sampling Technique, may provide a series of 'paired' plot measurements thus supplying the growth modeller with an immediately-utilisable data set. The technique is however, constrained by the inability to estimate pre-thinning and severely decayed pre-mortality basal areas. This technique is essentially an amalgamation of stem analysis procedures (Assmann, 1970), and increment boring methodology (Pressler, 1968) which have been coordinated on a plot basis with the aim of quantifying past stand development.

This report describes the methodology and associated validation studies employed, as well as discussing the various aspects of this sampling technique.

2.0 DESCRIPTION OF METHODOLOGY

Because this methodology was specifically designed to be utilised by modellers using the 'state space ' approach it was necessary to estimate the value of three stand variables back in time, viz. predominant mean height, basal area and stocking. This section provides a description of methodology and given constraints; validation is covered in the following section.

2.1 PLOT ESTABLISHMENT

2.1.1 Site Selection

Selection of stands for sampling was based on three aspects:

i) deficiencies in existing PSP data (i.e. filling in gaps)

ii) availability of adequate stand histories - particularly age and date of the most recent thinning. This was also necessary to ensure plot measurement was worthwhile (usually a maximum of four years since most recent thinning)

iii) stand suitability : stands with excessive windthrow, regeneration (i.e. uneven aged) and/or had received fertiliser, were considered unsuitable.

Once these conditions were fulfilled, site selection was undertaken. This encompassed an inspection of the particular stand chosen to be sampled. Areas with windthrow were avoided, and any mortality was inspected prior to plot establishment for feasibility of measurement.

2.1.2 Data Collection

Collection of data was coordinated on a plot basis by establishing diamond-shaped plots with one diagonal running along the contour. Size varied according to stocking : a minimum of 20 trees per plot was considered necessary to estimate both past and present basal area.

Following boundary demarcation, individual trees were numbered and marked at DBH. Diameter over bark and bark thicknesses were recorded and increment boring along with height measurements were subsequently undertaken.

2.2 BASAL AREA ESTIMATION

2.2.1 Measurements

Following plot establishment (Section 2.1), diameter at 1.4 m (over-bark) was measured on all trees. This provided sufficient data to calculate current basal area.

To estimate past basal area, two further sets of measurements were required:

(a) current bark thicknesses

b) ring widths using either increment cores or individual radii from discs.

Bark thicknesses were measured using a Swedish bark gauge. Four measurements were taken, placement based on angle division.

Annual ring measurements were used to estimate past underbark basal area increment. Two increment cores or individual disc radii were measured per tree. In the case of felled trees in which discs were extracted at breast height, two radii were measured (usually at 90° to each other) which were representative of the under bark diameter.

Increment core selection was similar: two cores placed at 1.4 metres at 90° to each other were extracted per tree on relatively symmetric stems. For elliptic, leaning or irregular shaped stems, one core was placed in the direction of maximum diameter, and the other usually at 90° to this. Core selection was rigorous: off-centre cores unrepresentative of under bark diameter were rejected.

Following core extraction, cumulative distances from the stem perimeter were measured either in the field or under laboratory conditions (Appendix 1).

2.2.2 Calculation of Past and Present Basal Area

Following data collection, past and present basal areas were calculated.

Current basal area was calculated using the following formula:

$$BA = \pi \cdot \sum dbhob^2 \div 4 \times 10^7 \qquad (1)$$

Where,
BA = Basal Area (m^2/ha)
dbhob = Diameter at breast height (over bark) in mm

Individual tree under bark diameters were calculated by subtracting the doubled quadratic mean bark thickness. Past underbark diameters were calculated by subtracting the doubled arithmetic mean of each annual radial increment (obtained from cores or discs). This is represented by:

$$DOB_n = DUB_c - 2 \times \frac{C1n + C2n}{2} \qquad (2)$$

Where
DUBn = underbark diameter at year n
DUBc = current underbark diameter

C1n = core/disc 1 measurement at year n
C2n = core/disc 2 measurement at year n

Past overbark diameters were estimated using an 'adjusted' bark thickness based on changes in predicted bark thickness. A function developed by Gordon (1983) to predict bark thickness was used:

$$\overline{BTn} = (DUBn - (0.961424 - 2.0308 \times 10^{-3} \times DUBn + 8.365 \times DUB^2 \times 10^{-6})) - DUBn \quad (3)$$

Where,
$\overline{BTn}$ = predicted bark thickness at year n
DUBn = diameter under bark at year n

To obtain 'actual' bark thickness back in time, a 'predicted' bark thickness change is subtracted from current bark thickness:

$$BTn = BTo - (\overline{BTo} - \overline{BTn}) \quad (4)$$

Where,
BTn = adjusted or 'actual' bark thickness at year n
BTo = measured (quadratic) mean bark thickness at year o
$\overline{BTo}$ = predicted bark thickness at year o
$\overline{BTn}$ = predicted bark thickness at year n

From here, over bark diameters back in time may be calculated:

$$DBHOBn = DBHUBn + BTn \quad (5)$$

Where
DBHOBn = Diameter at breast height over bark at year n
DBHUBn = DBH under bark at year n
BTn = 'actual' bark thickness at year n

Past plot basal areas were subsequently calculated by inputting each individual tree diameter at year n into formula (1).

2.2.3 <u>Constraints</u>

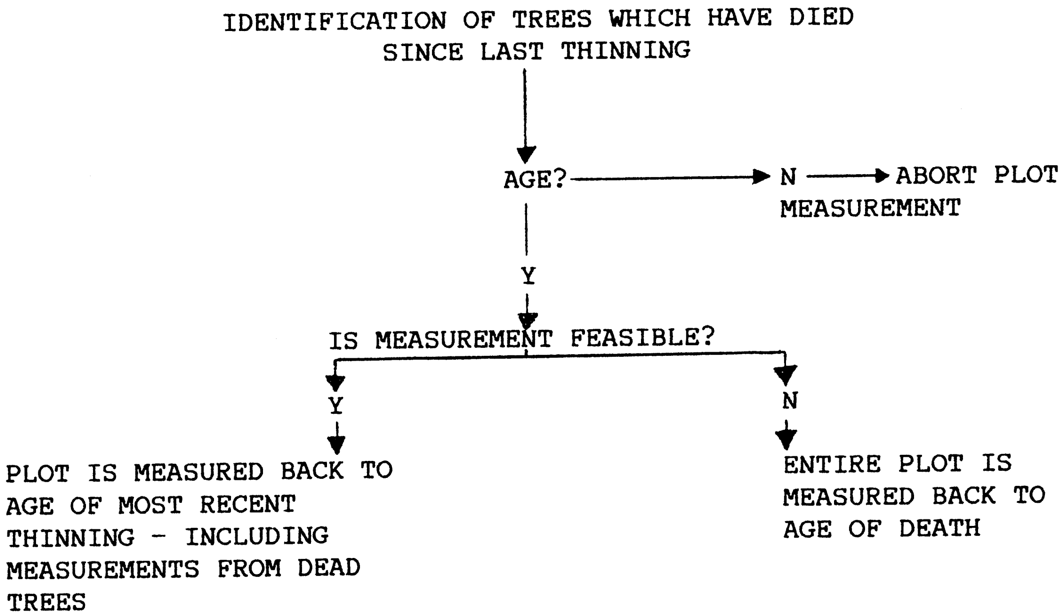
Basal area estimation was constrained by two factors:

i) most recent thinning

ii) identifiable and measurable mortality.

Pre-thinning basal areas were, in most cases, impossible to determine due to difficulty in stump and stem location as well as decay which had occurred since thinning.

To estimate past basal area, it was necessary to identify and measure any mortality which had occurred in the period of interest (i.e. since the most recent thinning). To achieve this, dead trees within the plot were identified and aged by counting rings at stump height. Following this, a disc at 1.4 m was extracted and checked for feasibility of measurement. If decay was too severe to allow measurement of two radii representative of underbark diameter, the entire plot was measured only back to the age of the particular trees' death. If measurement of the disc was feasible, the entire plot would be measured back to the age of last thinning - including measurements from any dead trees. This may be represented in the following decision tree:



The technique used to measure ring increment on the discs was the same as that used for live trees. Individual tree basal areas were calculated, and subsequently added to plot basal areas manually to obtain basal areas back in time.

Mortality also accounted for changes in stocking, thus allowing the second required variable, stocking, to be evaluated.

2.3 ESTIMATION OF PREDOMINANT MEAN HEIGHT

A destructive sampling technique was used to estimate individual tree height back in time: height trees were felled with annual shoot extensions providing the basis for determination of past heights. Each annual shoot extension was identified by branching characteristics using the method described by Bannister (1962) and Jacobs (1937). Heights back in time were attained by directly measuring length along the stem. A check for age was provided by ring counts on discs taken at any point from an internode of given age.

Two predominant mean height trees were measured per plot to estimate stand PMH back in time. In each plot, the tallest tree in each 0.01 hectare was identified and the two sample trees were subsequently selected on a random basis.

Plot PMH was estimated by calculating the arithmetic mean of the two height trees.

3.0 VALIDATION

Validation steps were confined mostly to the basal area methodology. Validation of the individual height tree measurement technique was considered unnecessary due to the self checking nature inherent in ring counts from discs. Evaluation of stocking levels involved counting trees within the plot boundaries hence required no validation.

Basal area validation consisted of measuring existing permanent sample plots using the methodology outlined in Section 2.1.1. The plots had also been monitored at past intervals. Subsequent comparison of results obtained using the two techniques provided the basis for validation.

Three plots were established, two in a 34-year-old stand in Kaingaroa which had been measured annually over a five-year period; and one in a 40-year-old stand in Whakarewarewa which had received five measurements over the past eighteen years. Results are presented in Figures 1a, b and c.

The graphs show basal area is adequately predicted back in time with a maximum error of +6% in the Whakarewarewa plot eighteen years back in time. The growth curves in all cases are mirrored adequately - imperative for modellers using the 'state space' methodology - and any plot error tending to either consistently over or underpredict past basal areas. Figure 1b shows a difference in basal area at age 34, probably due to differences when measuring 'current' diameter with a dbh tape. On this basis it was considered the methodology was adequate such that data collection could commence.

FIG. 1a - BASAL AREA VALIDATION - KAINGAROA

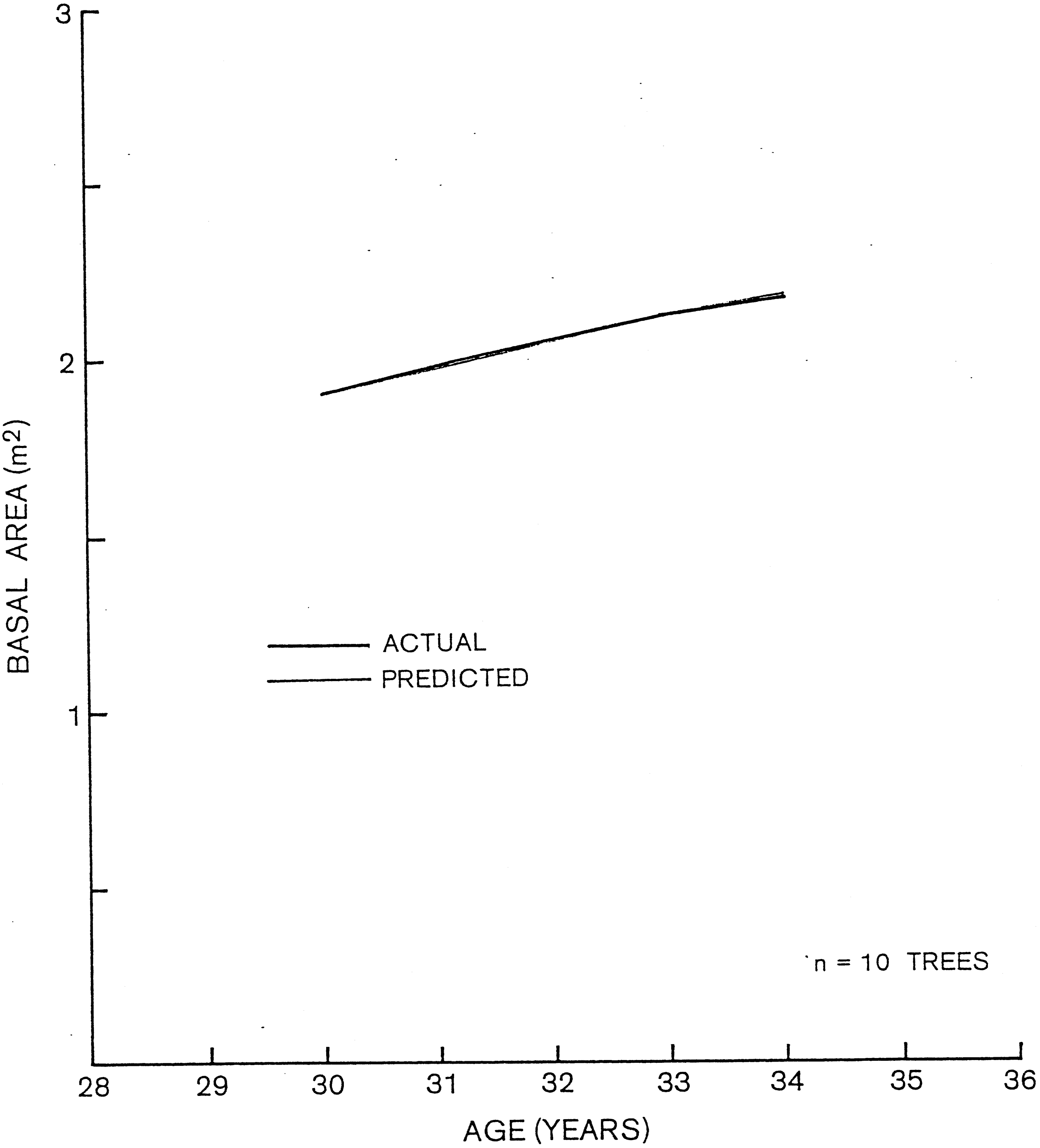


FIG. 1b - BASAL AREA VALIDATION - KAINGAROA

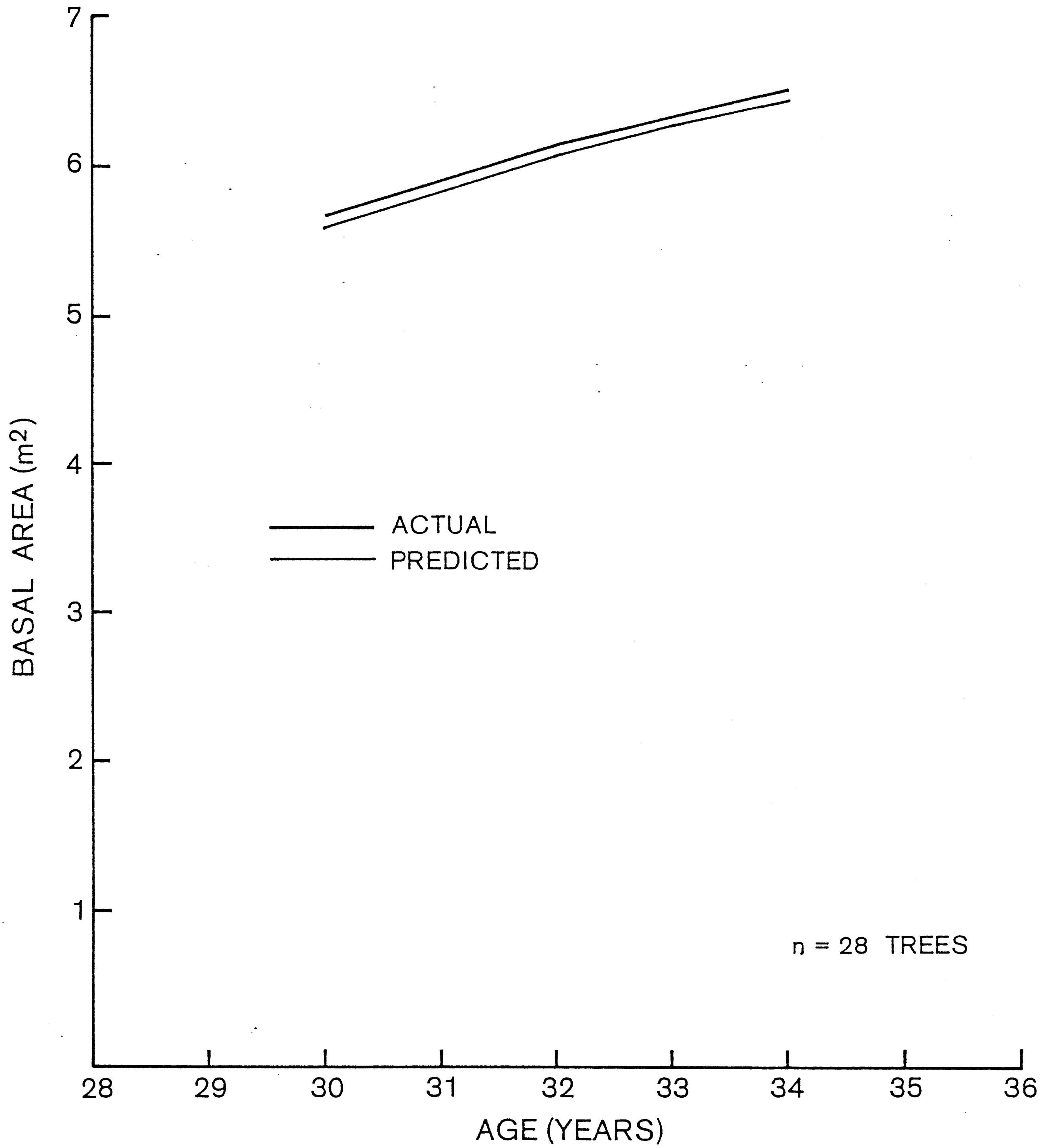
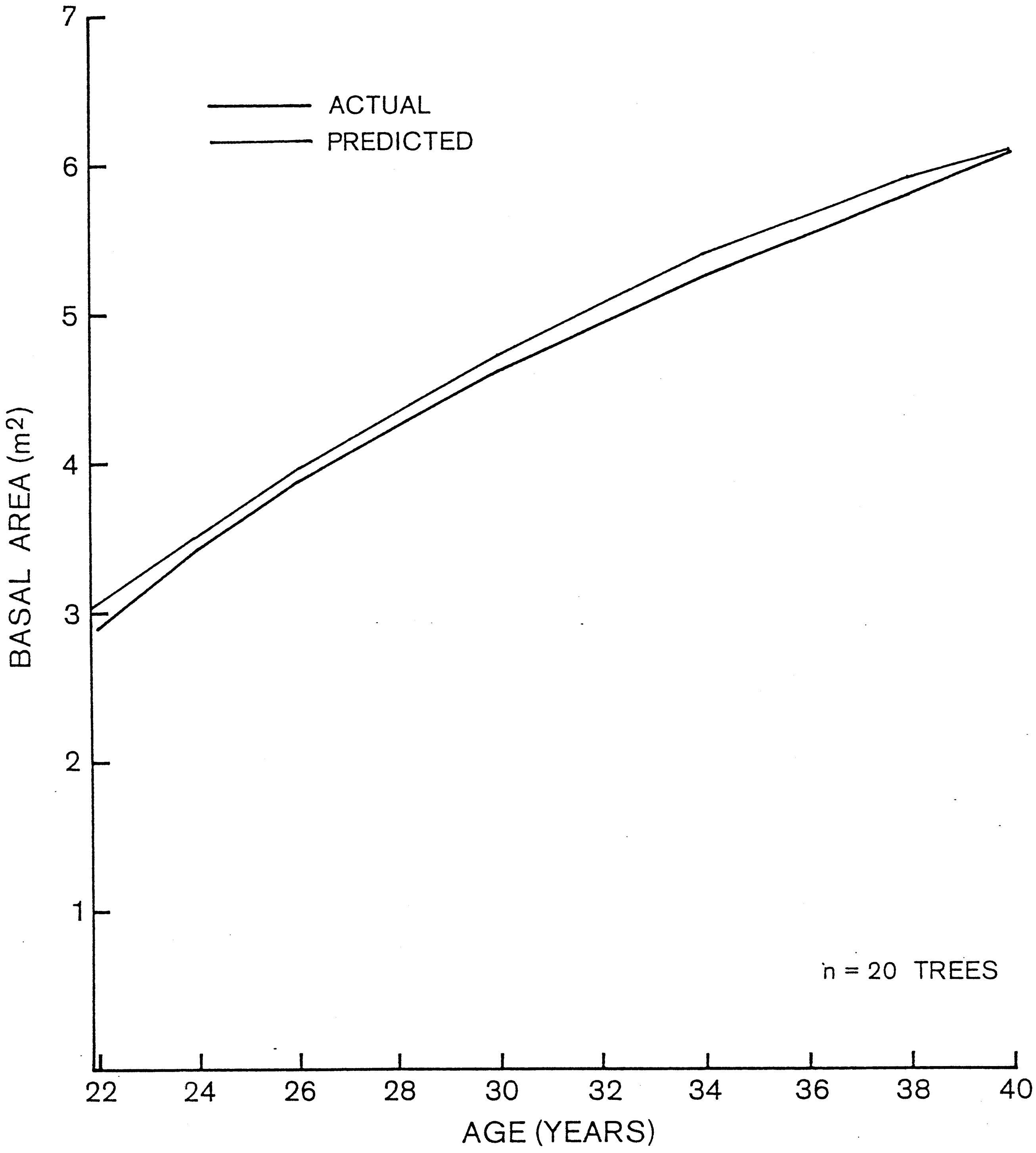


FIG. 1c - BASAL AREA VALIDATION - WHAKAREWAREWA



4.0 DISCUSSION OF METHODOLOGY

4.1 BASAL AREA DETERMINATION

In comparison to growth monitoring techniques, significantly more potential sources of error are inherent in the Retrospective Sampling Technique. In the case of the former, basal area is usually estimated by measuring individual tree diameters with diameter tapes or dendrometer bands. Some error does occur using this method: incorrect measurement technique may lead to imprecise estimates while some degree of bias does occur irrespective of technique (Matern, 1956): basal area is usually overestimated. This type of error can also occur in the case of the Retrospective Sampling Technique as current basal area is estimated using this method. Because past basal areas are calculated using current measurements as a basis, any error due to incorrect determination of current basal area will bias subsequent results (Siostrzonek, 1958). Results from the validation studies in both Kaingaroa and Whakarewarewa (Figures 1b and 1c) show a small bias in basal area prediction indicating error in determining current basal area. Therefore it is necessary to use correct measurement techniques when estimating current basal areas as measurement error can lead to bias, and furthermore, the lack of remeasurement precludes checking results for precision.

Potential for measurement error exists also when placing and measuring tree cores. Firstly, precise increment core placement is necessary to ensure errors are minimised. Two conditions should be satisfied:

i) increment core placement is representative of underbark diameter

ii) cores should not deviate excessively from the pith.

The method outlined in Section 2.2.1 involved using two increment cores or disc radii to obtain estimates of past basal area. This method was considered suitable following the validation studies, where bias was attributed to current basal area determination rather than the increment boring technique per se. However Siostrzonek (1958) found the accuracy of basal area estimates decreased when fewer cores per tree were used. As a result, he suggested four cores per tree be extracted, with placement based on angle division - although satisfactory results could be obtained using two cores per tree with careful placement. He also found it was necessary to bore either right to, or in the precise direction of the pith to eliminate error. Any deviation from pith will induce underestimation of basal area with error increasing as depth of boring increases. Difficulty in striking the pith often occurs, thus necessitating several attempts to obtain an acceptable core. Siostrzonek (1958) suggests this is not, in actuality, particularly difficult and recommends the operator 'practice on available branches or branch stubs in whose backward extension the pith should be located'. It should be noted however that it is somewhat difficult to use this technique on a five-metre pruned butt log which are now commonplace in many of NZ's forests. Thus core extraction can be time consuming, particularly with inexperienced operators.

Obtaining radial increment measurements by disc measurement was used on dead stems, height trees and, where possible, other live stems to estimate past basal area also. This method was considered to be more desirable than increment cores due to

i) faster measurement, and

ii) more accurate due to selection of radii representative of underbark diameter.

Matern (1956) found measuring a convex region 'from the inside' (e.g. discs) induced less bias than measurements from 'the outside' (e.g. cores). Furthermore, van der Pas, et al. (1981, unpubl.) found using one radii from a disc which is representative of underbark diameter is suitable for basal area estimates. Therefore some scope exists for less intensive (hence faster) measurement of discs without sacrificing accuracy. However, the major disadvantage with the use of discs is the destructive nature of sampling, thus this technique is limited to height trees or dead, malformed or heavily suppressed trees which are of little economic value.

Some potential for error also occurs when estimating bark thickness. There are two possible sources of error:

i) measurement of current bark thickness, and

ii) estimation of bark thickness changes.

Measurement of bark thickness using a Swedish bark gauge encompasses some degree of error. Overestimation of bark using this gauge has been reported by von Althen (1964) and specifically identified for P. radiata by Carron and McIntyre (1959) and Gordon (1983). The latter identified overestimates of stem volume due to bark measurements from 0.83% (five measurements) to 1.31% (two measurements). Further error induced by the operator may also occur; bruised hands inducing fatigue may cause bias, and inaccurate measurements may occur due to operator inexperience (Gray, 1956).

The bark thickness function developed by Gordon (1983) is used to estimate change in bark thickness according to change in underbark diameter. Error in estimation of bark thickness changes would be due to i) determination current diameters and bark thickness, and ii) error associated with the bark thickness function. Although this error may be biased, it is considered to be relatively small. Thus any resultant errors are more likely to be induced by (i), and would result in a biased estimate of bark thickness change.

The potential for erroneous estimates of basal area, both post and present, is considerable compared with monitoring techniques. Initial errors lead to bias, with error increasing as time tracked back increases. Furthermore, there are many potential sources of error, thus necessitating trained, skilled field crew members with an emphasis on quality, rather than quantity, of results.

4.2 ESTIMATION OF PREDOMINANT MEAN HEIGHT

The methodology used is based on the assumption that interchange of dominanace during stand growth is negligible. This implies a PMH tree at age 25 would have occupied the same physiognomic position at all stages of stand development (e.g. at age 12). However, Sutton (1973) and McLaren (unpubl. data) have shown interchange of dominance does occur within unthinned stands throughout the length of stand life. Furthermore, very little information regarding dominance interchange in thinned stands is available, thus the assumption of negligible changes in individual tree dominance status has not been validated. It is therefore necessary to either validate this assumption, or use an alternative method for estimating heights back in time.

Any possible error would bias results: current PMH trees may have been co-dominants at earlier stages of stand development, thus underestimating plot PMH back in time. If such bias does occur, it is necessary to evaluate the magnitude of bias.

Tennent and Burkhart (1981, unpubl. report) suggest a method to estimate mean top height back in time for the construction of site index curves. This method involves using two trees with DBH values closest to the mean diameter of the 100 largest diameter stems per hectare for estimation of height development. However, this method is also vulnerable to error resultant from dominance interchange as this phenomena may occur throughout the entire population of a forest stand.

However, extensive validation is necessary before any technique is widely adopted as accuracy in estimation decreases as the length of time tracked back increases. Any error due to this inaccuracy would have to be minimised to maintain validity of results.

Measurement error can also occur : seasonal fluctuation in height growth (e.g. autumn 'flushes' may confuse measurement. Recent experience in Canterbury, where autumn height extension is common following summer drought, suggested disc extraction is essential for checking age at every annual height extension. Further problems were encountered with the destruction of the tree tip during felling: difficulty in reconstruction of the upper regions of the stem often occurred, particularly where undergrowth is heavy. It was therefore necessary to have experienced tree fellers to ensure good tree placement hence minimising tip damage.

5.0 DISCUSSION OF ATTRIBUTES

5.1 ADVANTAGES

The major advantage of this technique is the immediacy of results. Rather than wait three to five years to gain an adequate amount of information, modellers may obtain data virtually immediately, thus reducing the time frame necessary for construction of stand growth models. This technique can therefore be used to supplement existing databases to various degress (Wilcox, unpubl. report).

Another major advantage is the timing of data collection: whereas remeasurement of sample plots should be undertaken during winter (Tennent, 1982), data collection using the Retrospective Sampling Technique may be undertaken at any time of the year. The only constraint here is the first measurement (current height/diameter) in plots established during spring/summer should not be used for model development. This would provide some flexibility for field crews - data collection could alternate between winter measurement and obtaining supplementary data during summer using the Retrospective Sampling Technique.

This technique has applications in other spheres also: modelling the effects of genetic improvement and fertiliser addition on stand development, validation of existing site index equations and regional growth models as well as dendroclimatic investigations (cores only). Validation and/or construction of taper equations and volume functions could be obtained also from sectional measurements on height trees.

5.2 DISADVANTAGES

As already mentioned, the technique is constrained by thinning: the interval of interest (measurement period) is constrained to within either the pre-, post- or inter-thinning phase of stand development. Because of expense, the most profitable application is the post thinning phase of stand development, thus necessitating the use of permanent sample plots to obtain data in the early phases of stand growth. The technique is therefore by no means comprehensive.

A further disadvantage is the destructive nature of the height methodology: remeasurement of the plot at a later date is effectively hindered due to the removal of current PMH trees. The technique is therefore a 'one-off' sampling system which is by no means cheap, thus placement of plots requires careful consideration and a reasonable degree of planning before establishment.

Furthermore, the increment boring techniques requires a systematic, disciplined approach to obtain precise and accurate increment cores, thus skilled labour is necessary. In addition, increment boring is tedious and therefore requires a reasonable degree of motivation on the part of field crew members. The technique is also relatively slow - recent experience suggests a rate of one plot per day for a four person crew. As a result, data collection is also expensive - at $1000 per plot at the above rate.

5.3 RELATIVE ECONOMICS

Figure 2 shows the comparative costs of obtaining data by either a permanent sample plot (monitoring) system or using the Retrospective Sampling Technique. Two variations of each system are shown: annual and biannual permanent sample plot measurements, as well as two options for the RST:

i) option 1 - obtain results immediately rather than waiting five years

ii) option 2 - waiting five years rather than obtaining data immediately.

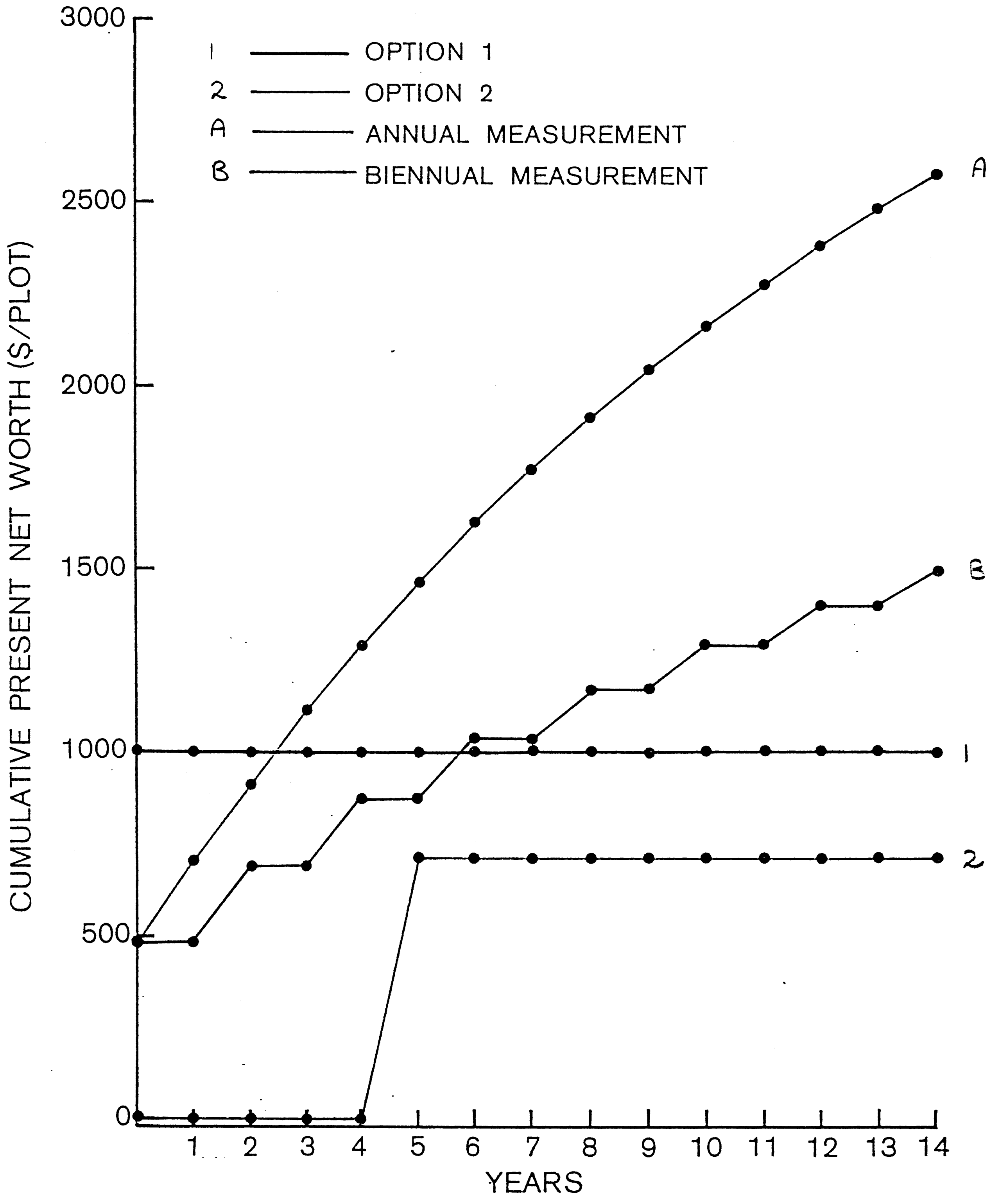
A discount rate of 7% is used in all cases.

The costs of each technique can be broken down into various components: for each measurement of a permanent sample plot a cost of $240/plot is incurred. Plot establishment also incurs a cost of $240/plot. The two costs are combined at age 0 to provide an initial price. For the Retrospective Sampling Technique however, a combined cost of $1000/plot is incurred (includes both establishment and measurement costs).

Results show the cost of obtaining data using the Retrospective Sampling Technique (option 1) is equivalent to establishment plus three measurements of a permanent sample plot. Option two is cheaper than both sample plot techniques at all stages due to the time lapse before obtaining data (i.e. associated opportunity cost of capital).

Despite the high cost of plot establishment and measurement the 'one-hit' nature of the Retrospective Sampling Technique means total cost of data collection is less than a monitoring/measurement system. Furthermore, administrative costs of plot maintenance is virtually eliminated (this has not been included in the analysis). Thus data may be obtained by cheaper methods than current permanent sample plot measurements.

FIG. 2 - COMPARATIVE COSTS OF PERMANENT SAMPLE PLOT AND R.S.T. MEASUREMENTS



6.0 CONCLUSIONS

In the current state, the Retrospective Sampling Technique possesses technical deficiencies which require further refinement viz. the height methodology. Furthermore, a technically sound version of this technique is still vulnerable to measurement error that is not immediately recognisable. It is necessary therefore to use skilled field crews with close supervision to ensure such errors are minimised. Given adequate resources however, these deficiencies are not impossible to overcome.

This technique does, however, possess considerable potential in its application. In the growth modelling field, production of models may be obtained relatively quickly with costs of data collection actually less than a stand monitoring system. Further applications of this technique are possible also, e.g. quantifying genetic improvement, response to fertiliser application and dendroclimatology.

ACKNOWLEDGEMENTS

The author would like to acknowledge the assistance of the following:

N.A. Robertson for assistance at all stages in the development and validation of the technique.

J. Penman for writing the relevant programs.

A. Gordon for developing the bark thickness function.

Drs C.J. Goulding and O. Garcia for technical advice.

Dr M.J. Carson for advice and support.

J.R. Tustin for providing the resources which otherwise would have precluded the development of the technique.

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APPENDIX 1: CORE MEASUREMENT TECHNIQUES

1.1 Measurements on site

Cores which presented storage difficulties (e.g. broken cores) were usually measured immediately following extraction. Because these cores were at or near green moisture content, no conditioning was necessary.

Cumulative radial increments were measured by either steel ruler or digital calipers. In both cases, measurements were recorded in millimetres.

1.2 Laboratory measurements

Cores measured in the laboratory were enclosed in airtight plastic tubes immediately following extraction and refrigerated until measurement.

Prior to measurement, cores were immersed in water for up to six hours to ensure moisture content exceeded fibre saturation point (30% m.c.). Cores were then measured as described above.

Other laboratory-based measurement techniques are available. X-ray techniques using methods described by Lenz (1957) or Ellis (1971) are available. These techniques are particularly good for measurement of cores with very close rings or partially decayed cores; however the correct radiographic units are necessary to ensure good photographic quality. The Addo-X tree ring counter is specifically designed for measurement of radial increments using cores. However this technique is tedious and the extra accuracy of measurement is not sufficient to justify use instead of steel ruler or digital calipers.