THE CONTROL OF BASAL AREA INCREMENT IN YOUNG PINUS RADIATA

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SYNOPSIS

The effects of early heavy thinnings on increment of Pinus radiata *(D. Don) are analysed. Results are considered in terms of basal area increment per acre, of increment for particular tree-vigour classes, and for individual stems. The synthesis is presented graphically and permits prediction of increment for 5 to 7 years after first thinnings between 5 and 10 years of age.*

INTRODUCTION

Although the timing and magnitude of yield are essential concerns of forest management, the available means of control are almost entirely dependent upon silvicultural manipulation of increment. Since no two forests are alike in yield potential and commercial opportunity, or in availability of labour and finance, the schedules selected by management for the most profitable exploitation of yield as saleable produce must also be different. There is a danger that current preoccupation with idealized silvicultural schedules and regional yield tables will obscure this.

Moreover none of the above factors are static, particularly during the early stages of forest establishment and development. Silviculture must be correspondingly adaptable to changing circumstances, if vulnerable accumulations of growing stock or wastages of potential revenue are to be avoided. It is only when each forest and its dependent industries have become fully established that supply and demand can be equated to produce realistic stumpages and yield tables that have been empirically tested to fit the unique socio-economic environment of each forest. Historical aspects of this evolving practice have been considered by Hinds (1962).

The initial control of yield from a site is exercised through selection of species. Following planting, the forester can influence volume production only by thinning, and its potential value only by a combination of pruning and thinning. His ability to adjust tending schedules to fit the fluid management situation is dependent upon analysis of the limits within which both the amount and distribution of annual increment may be controlled. Nowhere is this understanding more important than in New Zealand, where the need to secure maximum quantities of clear knot-free wood is one of the axioms of national forest policy. Attainment of this objective will be determined by the overall area under exotic production, by the species used, and by tending operations designed to transform normal knotty growth into clear annual increment. Two other

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factors which have impelled us towards practising early heavy thinnings have been the need to anticipate natural mortality (particularly in the event of another *Sirex* epidemic) and latterly the emphasis on reducing production of wood with encased knots by maintaining green crown-level as close as possible to the limit of pruning on the stem.

INCREMENT PER ACRE

A forester, faced with the problem of making sound prescriptions for thinning and pruning, requires some means of predicting results of any prescription he may devise. To be of use to him, the means of making this prescription must be based solely on data that are available at the time. The following analysis provides means for such a prediction.

Source of Data

This was provided by 27 permanent assessment plots, established at random in 6 to 8 year old thinned stands of *Pinus radiata* on Gwavas Forest, Hawke's Bay. Originally planted at 6 × 6 ft spacing, the residual stocking after thinning ranged from 280 to 590 stems (47 to 124.5 sq. ft) per acre and mean top height from 24 to 42 ft.

Reassessment of these plots was carried out after an interval of 6 to 7 years. In order to produce values for net increment (corresponding with that available for subsequent utilization) figures for dead trees were eliminated from the data. Adjustment was made for the different intervals between assessments of various plots by expressing increment on an annual basis. Although the corresponding figure will accordingly represent a periodic annual increment (P.A.I.) it is important to bear in mind during the ensuing analysis that the period referred to is not current but applies to the 6 or 7 years immediately following first thinning. This will obviate several of the anomalies that appear if the graphs are regarded as depicting normal trends of current increment.

Form of the Analysis

The objective was to compare quantitatively and test the relative importance of factors over which the silviculturist has some measure of control (*i.e.*, residual stocking or density) against those over which, after planting, he has none (*i.e.*, age, site-productivity and the endogenous pattern of growth). Regarding these factors as independent variables, a normal regression analysis was carried out against P.A.I. as the dependent variable. A brief discussion of these variables is necessary.

1. The dependent variable, P.A.I., refers specifically to increment of basal area, and not of total volume. There are two reasons for adopting this distinction — first, that volume increment is prone to much greater errors of measurement; and, second, that basal area increment is closely correlated with growth of clear wood volume. Moreover, once basal area increment has been determined, and mean top height being known, the conversion to volume increment is a relatively simple matter using Lewis's (1954) relationship between the three variables.

2. The simplest independent variables expressing stand density are number of stems per acre (S.P.A.) and residual basal area per acre (R.B.A.). A number of other measures are used by various authorities: namely, Reineke's (1933) "stand density index", the theoretically-based indices of "critical basal area percent" (Assmann, 1961) and Hart-Becking's "spacing percent" (Assmann, 1960), and Schumacher's empirically derived measures of "stocking percent" (Schumacher and Coile, 1960). These are, however, all derived from the simpler measures or from interrelationships of them with age and/or height, which are considered below. Attention was therefore concentrated upon the simpler expressions with the particular aim of testing for *P. radiata* the widely accepted belief in existence of an optimum plateau of basal area and the corollary that increment remains more or less constant over a wide range of stand density. A logarithmic transformation was used for purposes of analysis.

3. Of the independent variables not amenable to manipulation, it was expected that age and/or mean top height would be closely correlated with increment. Preliminary graphical plotting indicated that the latter relationship was the closer. This is not surprising, as height expresses the interaction in time of growth-potential and site productivity, for which it is a most convenient and frequently used index. As the relationship is not linear the data were again transformed logarithmically.

Results

Solution of the regression equation for logarithm of P.A.I. against the three variables — logarithm of residual basal area (R.B.A.), logarithm of residual stems per acre (S.P.A.), and logarithm of mean top height (M.T.H.) — provided the following analysis of variance:

Source of Variation	*D.F.*	*Sum of Squares*	*Variance Ratio*
Log (S.P.A.)	1	0.1200	44.4**
Log (M.T.H.)	1	0.0259	9.6**
Log (R.B.A.)	1	0.0280	10.4**
Residual sum of squares	23	0.0606	E.M.S. = 0.0027
Total variation and error	26	0.2345	—

As the minimum variance-ratio (F) for significance at the 1% level is 7.88 it is apparent that all three independent variables are in fact highly correlated with P.A.I., and must all be taken into account in relating the variations of increment to their silvicultural determinants.

Initially a single equation containing all three independent variables was constructed. However, the inter-relationships between basal area and stems per acre, both in the same equation, are so confusing for interpretation that it was considered preferable to provide for their use independently of each other, even at the expense of some loss of accuracy. The separate equations are accordingly as follow:

$$\text{Log (P.A.I.)} = 0.4699 + 0.7111 \log \text{(S.P.A.)} - 0.7034 \log \text{(M.T.H.)}$$

or

$$\text{Log (P.A.I.)} = 2.2803 + 0.6699 \log \text{(R.B.A.)} - 1.4881 \log \text{(M.T.H.)}$$

These relationships, when reconverted from the logarithmic form, may be expressed graphically, as in Figs. 1 to 3.

Interpretation and Discussion

1. *Mean Top Height* — see Fig. 1. The most striking feature revealed by this synthesis is the rapid reduction of future basal area increment with increase in mean top height, even so early in stand life as 6 to 10 years after planting. It is evident that very high values must be attained immediately prior to this age, after the abrupt ascent of the curve from its initial minimum. There have hitherto been no data available on this culmination of basal area increment for *P. radiata*. It is therefore of interest that a very early assessment plot established on Esk Forest during 1962 (at age 4 and mean top height of 15 ft) has given an annual increment of 39 sq. ft per acre.

   Beyond a mean top height of 50 ft the curves of future net increment for a given residual stocking begin to flatten out and become relatively constant. If attempts to secure a redistribution of increment among certain selected trees of the crop (*i.e.*, high pruned stems) are to be successful, it is obvious that they should begin very much earlier than we have become accustomed to accept as normal practice.

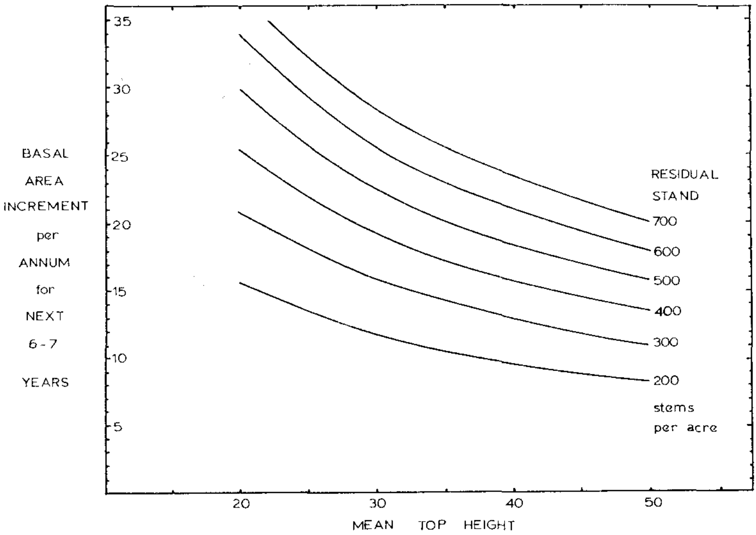

Fig. 1: Annual basal area increment for 6–7 years after thinning, as affected by residual number of trees per acre and mean top height at time of thinning.

2. *Residual Stocking.* Figure 2 depicts the relationship between future P.A.I. and residual stocking after thinning, expressed in terms either of basal area or of stems per acre, at each of the stages of stand-development indicated by mean top heights of 20, 30, 40, and 50 ft.

Considering first the correlation with basal area, it will be noted that increment increases almost linearly with increase in residual basal area after thinning. The only hint of the postulated optimum or "plateau of maximum increment" is the curvilinear form of the graph; but it is clear that such an optimum must lie well beyond the range of stocking which could be maintained without suffering undue mortality (Jackson, 1955).

The fact that the slope of individual parameters diminishes as top height increases, again implies a progressive loss of silvicultural flexibility — with advancing age progressively higher residual basal areas will be required to maintain a given increment.

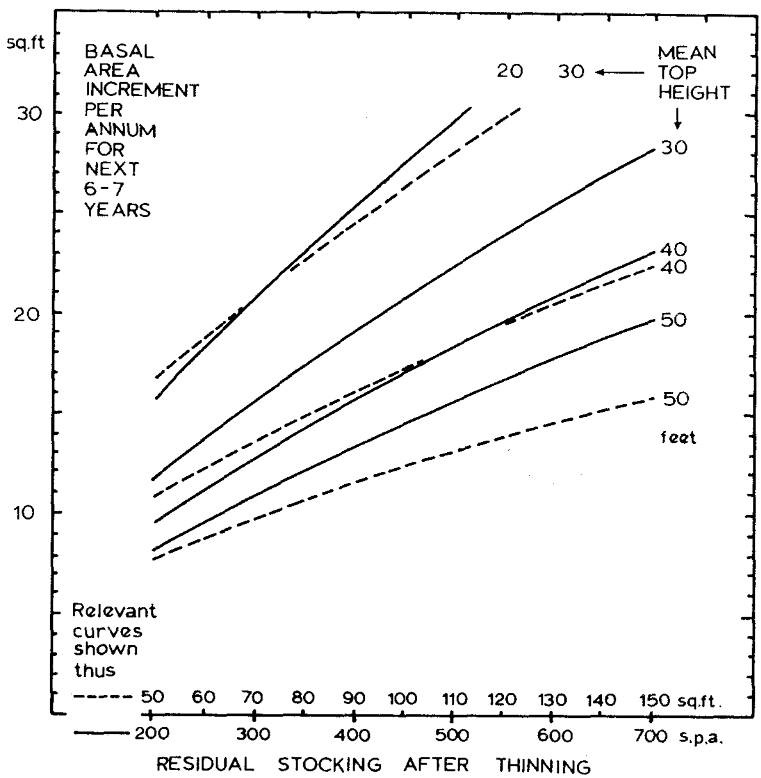

Fig. 2: Effect of residual stocking, expressed either as basal area or number of stems per acre, upon annual basal area increment for 6–7 years after thinning at mean top heights of 20, 30, 40, and 50 ft.

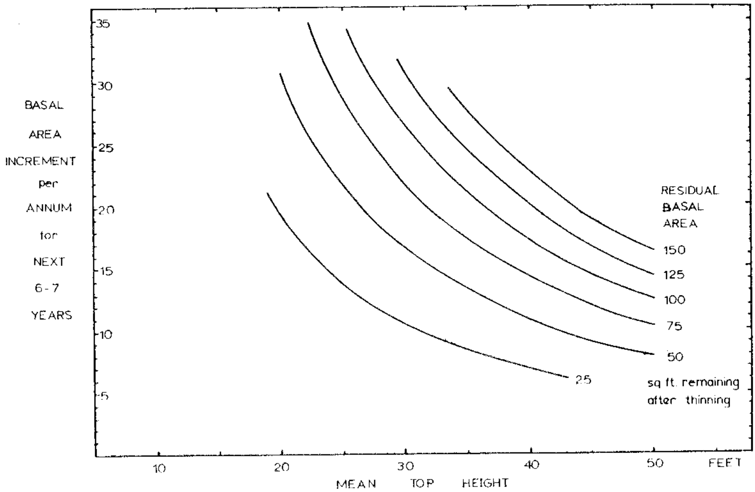

Fig. 3: Annual basal area increment for 6–7 years after thinning, as affected by residual basal area and mean top height at time of thinning.

Correlation of increment with residual stocking in terms of stems per acre follows very much the same slightly curvilinear relationship as for basal area. For all practical purposes it would seem that either of the two expressions of stocking may be used in defining thinning prescriptions for young stands planted at conventional spacings. In these circumstances, basal area and stems per acre are highly correlated, so that within the limits of our usual thinning techniques a reduction of either automatically involves a reduction of the other. In Fig. 3, therefore, the P.A.I. is shown in relationship to mean top height as parameters for residual basal areas of 150, 125, 100, 75, 50, and 25 sq. ft per acre.

These statements do not, of course, hold true for comparisons between forests or regions, for older stands, or for those which have been naturally regenerated. Under these conditions, a more reliable prediction can be derived from the original equation relating basal area increment to all three significant variables:

$$\text{Log (P.A.I.)} = 1.6903 + 0.2126 \log (\text{S.P.A.}) - 1.2991 \log (\text{M.T.H.}) + 0.5325 \log (\text{R.B.A.})$$

This equation accounts for more than 74% of the variation and error involved in predicting the increment.

3. The limitations of the data are emphasized Until they have been tested on forests other than Gwavas, use of the equations for predictive purposes should be confined to that forest. Nevertheless the implications of this synthesis are very much wider, in permitting the forester to visualize and anticipate the surge of

increment in his stands. Once this capacity for response has passed, his manipulative advantage is greatly reduced and can never be wholly regained during the remainder of the rotation.

INCREMENT BY VIGOUR CLASSES

How is the total increment per acre distributed among various components of the stand? The need for investigation arises out of the general practice of restricting the pruning investment to certain trees selected for their relative vigour or desirable form and branching characteristics (Fenton and Familton, 1961). However, the number of trees selected for high pruning may range from only 70 or 80 to as many as 250 per acre. There has been no published attempt at defining the extent to which trees other than dominants should be chosen for silvicultural improvement, although Spurr (1962) concluded that trees producing less than 0.02 sq. ft basal area per annum had a life expectancy of approximately 8 years.

Much of the reason for this neglect must be ascribed to our systems of tree classification, which are almost invariably based on subjective estimates of relative dominance and do not lend themselves to quantitative expression. Yet a quantitative analysis is essential for determining the tree of marginal vigour, below which limit the inclusion of trees of inferior capacity for response will not repay compounded costs of pruning and thinning.

It is notoriously difficult to secure a simple numerical estimate of all that is implied by the term "relative dominance", but an acceptable way out of the impasse is to adopt individual height and/or diameter as indices that are closely correlated with dominance. The latter expedient was adopted for this study, utilizing data from the series of assessment plots already considered. These tenth-acre plots had originally been selectively high pruned to a density of at least 160 stems per acre. The principal criteria for selection were straightness of stem and freedom from malformation, and a range of vigour from dominant to larger subdominant trees was included. Objectivity can be secured by ranking the 16 largest pruned trees per plot according to d.b.h. at time of initial measurement. This range may then be subdivided into quartiles of 4 trees each, from the largest down to the smallest group. For each of these quartiles, the average annual basal area increment per acre over the 6–7 year period of growth may be calculated and expressed as a percentage of that for the whole 16 together. Results were as follows:

Quartile:	Largest 40	Second 40	Third 40	Smallest 40	*stems per acre*
Annual increment:	32.7%	26.1%	24.0%	17.2%	*of the total*

These differences between quartiles were highly significant. It should be noted particularly that of the 160 stems per acre selected for high pruning the largest 40 put on very nearly twice as much increment as the smallest 40. Differences between the second and third quartiles were not significant, however, and on closer examination it was apparent that there had been several interchanges between the two groups. These were due to some of the smaller groups making more growth than the larger group in the same plot, indicating that competitive relations between smaller dominants and larger co-dominants were still very fluid.

Further analysis, intended to demonstrate the expected correlation between increment of selected pruned stems and the total residual stocking of the stand after thinning, revealed a startling anomaly. Although enhanced increment of select pruned stems is the primary objective of thinning to waste, the data from this series of plots indicated that there was in fact no significant correlation between residual stocking and subsequent increment of the 160 selected stems per acre. A significant correlation was lacking also for the largest quartile of selected trees and, even more surprisingly, for the smallest quartile.

It might be deduced from this that the commonly assumed advantages of early heavy thinning are a delusion — *i.e.*, that dominance and vigour are all-important for growth and that, once established, they are virtually unaffected by residual competition. The deduction is unwarranted; but the search for explanations of the anomaly leads directly to a problem which is crucial for much contemporary silvicultural practice.

Statistically, the reason for the absence of expected correlation is simply that the variation in growth responses of individual trees within groups is so large that the difference between groups cannot be ascribed to causes other than random variation and error. This in turn brings out the point that basal area or other indices of stocking, if expressed simply as an average over the whole plot, seldom indicate the intensity of competition which may or may not be suffered by individual trees within that plot. What is obviously needed, if the response of individual stems is to be measured and related accurately to factors affecting the increment, is some measure of competition suffered by the individual tree. It must again be entirely objective in application.

INCREMENT OF INDIVIDUAL STEMS

There is one other reason why the variation in response between individual trees within a plot was particularly large in this series of assessment data. The stands concerned were originally group-thinned, and not according to what is now the standard prescription on Gwavas forest — *i.e.*, specifically to favour the select pruned stems. In fact the very basis of selection itself was different; corresponding with the first of the three alternative marking practices summarized below:

1. Accepting the given random distribution of dominant trees of good form, mark all of these for high pruning, with no attempt at preventing mutual competition within groups of dominants.
2. Modify the given distribution by removal of the poorer competing dominants, to secure a balanced distribution of growing-space for those stems which are to be pruned.
3. Select the finer co-dominants for pruning and preferential treatment in thinning by elimination of most of the vigorous dominants. These are frequently assumed to be "too coarse" and "of inferior timber quality".

The first of these practices must obviously produce a much greater range of density within a plot and correspondingly increase variation due to unmeasured differences in the competition suffered by individual trees.

A measure of individual competition, in the form of a competition index, may be derived from the close connection that is known to exist between d.b.h. and the crown-diameter of free-growing trees. A prism of appropriate power can provide the objective test of whether a tree is or is not competing with the central tree, and the index may be tested empirically against data which are purported to be affected by intensity of competition. (A note is to be published on this shortly.)

In this instance trees which had been selected for high pruning were measured at d.b.h. and for residual competition (using prisms of 5 and 6 diopters) immediately after thinning. Initial d.b.h. ranged from 5.8 in. to 11.5 in., with a corresponding height range of 36 to 51 ft. The competition index indicated from 0 to 4 trees competing with each of the 54 trees observed. For these stems, d.b.h. increment was measured over the three years following thinning.

The mean annual increment was subsequently tested for correlation with initial d.b.h. and with the competition index. In conformity with the results for groups of trees by dominance or vigour, the annual d.b.h. increment proved to be highly and positively correlated with initial d.b.h. of the same stem. In addition to this, however, there was a negative correlation (at the 2% level of significance) with the number of competing trees, as defined by the above index. The relationship may be expressed by the regression equation:

Annual d.b.h. increment

= 0.2 (initial d.b.h.) - 0.06 (number of competitors) - 0.61 inches.

The same relationship may be expressed graphically, as in Fig. 4.

From this figure it is apparent that vigour and dominance of the selected tree must be the paramount factor determining subsequent growth and increment. However, there is also a substantial effect due to the number of trees which may be left in direct competition with the selected stem, this effect being proportionately much greater for small sub-dominants than for large dominant trees.

It is apparent that the third method of thinning must result in considerable loss of increment, both through sacrifice of vigour and also through correspondingly increased degree of competition. On the other hand, with the first method of marking, immediate losses due to retaining all the most vigorous trees, regardless of spacing, will not be so great. Nevertheless losses due to competition may be expected to increase with advancing age of the stand. There will also be future losses due to windthrow and windbreak of unbalanced crowns, and no less important but hidden potential losses due to increased formation of compression wood. Both these methods of thinning are frequently used because they can be applied more or less automatically and with a minimum of instruction. Only the second method is silviculturally and economically sound, but it requires the marker to exercise discrimination and a sustained nicety of judgement.

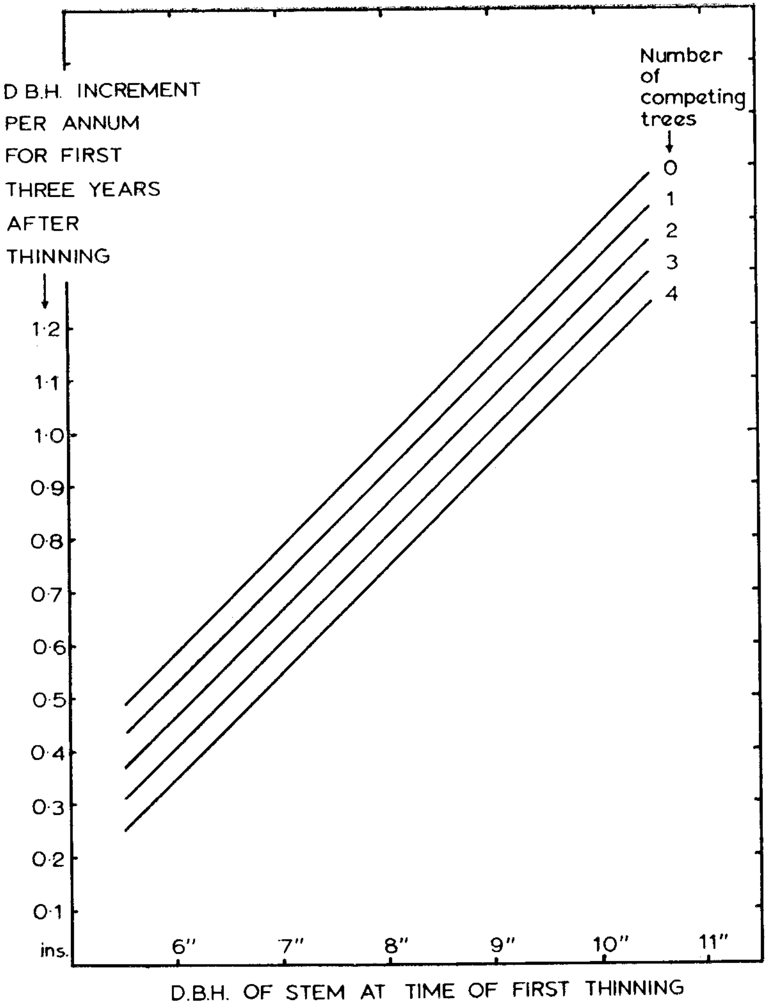

Fig. 4: Diameter increment of individual stems for first three years after thinning, showing interacting effects of initial stem diameter and number of residual competing trees.

FLEXIBILITY OF CONTROL

The writers' purpose in presenting this analysis from one particular forest has been to indicate the means whereon predictions may be based more soundly and the necessary flexibility of prescription be preserved. They would conclude with two corollary pleas for deeper consideration:

1. The first of these concerns silvicultural practice, where the responsibilities involved in marking stands for their first thinning and pruning are commonly underestimated. The facile application of some rule-of-thumb provides no substitute for skilled marking. This skill is indefinable, but it lies in preserving a consistent balance of judgment despite endless variations of choice and corresponding opportunities for error. It demands experience, and it is all to rare. It must be cultivated and rewarded accordingly.
2. The second plea concerns forest management, and the administrative temptation to impose some neat but inflexible silvicultural regime upon our developing forests. There is again no substitute for a dynamic outlook towards the shifting bases of our markets and forest economy. It is, for example, possible that future technical developments (in chipboard, structural lamination, and surface coatings with metals or plastics) will vitiate our current pre-occupation with clear wood increment, and all its silvicultural consequences.

The art of the forester will always dwell, not in his competence at forcing a forest to fit a preconceived regime, but in his craft at devising practice that is adapted to each forest's unique and changing environment.

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