

Contradictory behaviour of site index when utilised in basal area projection functions for *Pinus radiata* in the Hawkes Bay region of New Zealand

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Summary

In the Hawke's Bay, *Pinus radiata* growth models have the property that basal area/ha is predicted to decrease a little with a higher site index.

This illogical outcome is explored by examination of PANPAC permanent sample plot data, obtained from five forests. There is abundant evidence of site index decreasing at higher altitudes. The data are reduced to allow more balanced comparisons of the forests at various elevations. A basal area/ha projection equation shows a highly significant negative site index coefficient that increases the precision of the model by 17 %. To examine the data further, the equation is simplified so that site index appears as a straight line model with the slope parameter determining the sign of the site index coefficient. The slope of the model is shown to be negatively correlated with site index.

Examination of the growth data in the five forests suggests that the effect is likely to be a result of higher stockings resident in the high altitude plots together with low lying plots probably being under-occupied. The negative site index coefficient is thus the result of climatic and historical silvicultural effects.

Introduction

Site index for *Pinus radiata* is defined in New Zealand as the mean top height of a stand at age 20 (Goulding, 1995). Two definitions of mean top height have been used in New Zealand:

- (a) The height predicted by the Petterson height/ dbh curve for a dbh corresponding to the quadratic mean dbh of the 100 largest trees per hectare (based on dbh) in a stand.
- (b) Mean top height is the average height of the 100 largest trees per hectare (based on diameter). (Johnson and Bradley, 1963).

The difference in estimation of top height by these definitions is trivial (Woollons, 2003).

Site index is often used to classify forest stands for differences in yield productivity. Although far from perfect (there is evidence, for example, site index is not completely independent of stocking at low and high densities (Woollons, 1994; Maclaren *et al.*, 1995) the concept of site index has been utilised in many countries (Husch *et al.*, 1972).

Site index has been used in growth and yield models usually to refine asymptotic basal area/ha yields for the effects of differing site productivity (Clutter, 1963). In New Zealand, Garcia (1984) included site index in the suite of growth models produced by the Forest Research Institute (Goulding, 1995). Output from some of these models can be unusual. For example, whereas model PPM88 logically predicts more basal area/ ha with increasing site index in Kaingaroa forest, model NAPIRAD predicts a little less basal area for a bigger site index in the Hawke's Bay Region. A subsequent model for Napier by this author (unpublished)

gives the same effect. This does not necessarily produce biased estimates of volume/ha, but the result is puzzling and from a yield perspective, illogical.

A study was made of Hawke's Bay permanent sample plot data with the objective of determining why site index behaves in this way in the region.

Modelling Data

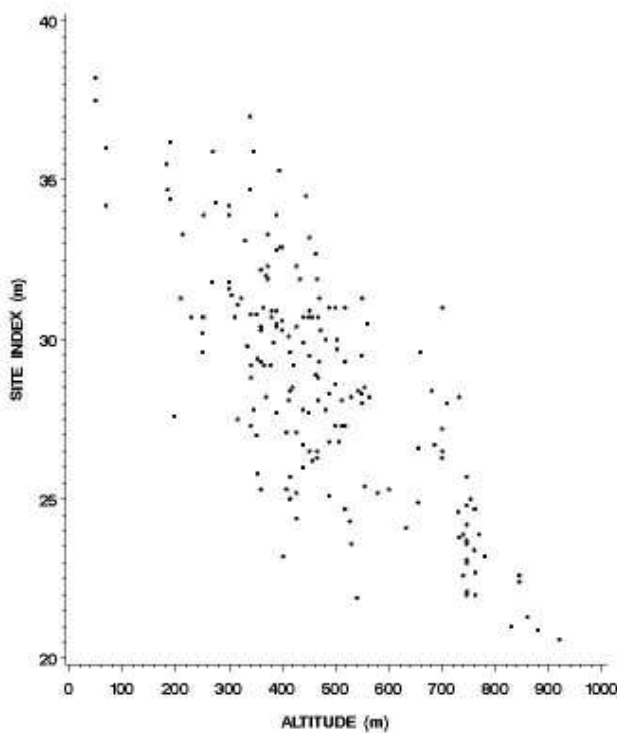
The sample plot data were from PANPAC Forest Products Limited which owns or possesses cutting rights to five *Pinus radiata* forests in the Hawke's Bay, namely Tangoio and the four former Forest Service forests Esk, Gwavas, Kaweka and Mohaka. Tangoio is a coastal forest whereas the other four forests are largely inland and mainly reside at higher elevations, especially Kaweka. Table 1 summaries plot frequency, altitude, site index and basic climatic data for the five forests.

Table 1 Sample plot data: mean altitude, site index and climate. The figures in parentheses represent minimum and maximum values.

Forest	No. Plots	Altitude (m)	Site Index (m)	Ann. Temp. (C.)	Ann. Rain. (mm)
Esk	84	330 (195-579)	29 (23-37)	12.6	1618
Gwavas	95	479 (323-680)	28 (22-36)	10.9	1556
Kaweka	38	682 (426-762)	26 (21-31)	10.3	1637
Mohaka	54	344 (70-550)	32 (28-36)	12.4	1585
Tangoio	25	129 (20- 346)	34(28-38)	13.8	1099

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Figure 1: Site index and altitude in Napier Forests



The big range in altitude assures that there is an equally large range in site index. Several authors have reported lesser height development (and thus site index) at higher altitudes (for example, Stansford *et al.*, 1991; Lindgren *et al.*, 1994). For *Pinus radiata* in New Zealand, Mountford, 1978 noted a negative linear relationship between site index and altitude in Kaingaroa forest in the central North Island. Figure 1 shows a plot of site index against stand altitude. The negative relationship is very marked.

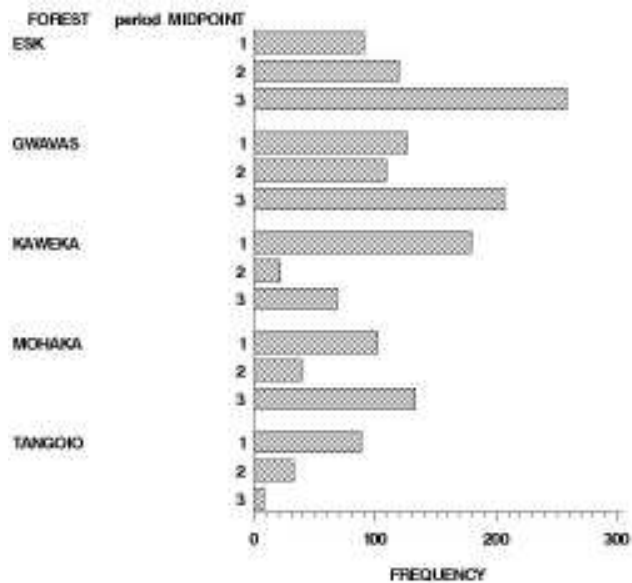
The permanent sample plot growth data differ widely in stocking, ranging from 89 to 3012 stems/ha. The stems/ha distribution is very sharply skewed to the left with a median value of only 346 stems/ha. Mohaka in particular has a preponderance of plots where very heavy thinning has occurred, a legacy of the so-called saw log regime (Sutton, 1976). To place the data as much as possible on an equal footing with respect to the five forests, all plots in excess of 400 stems/ha were dropped.

Further examination of the growth data revealed another source of undesirable variation. Figure 2 shows histograms of the re-measurement periods for the five forests. The intervals in the respective forests form two general groups. Whereas Tangoio and Kaweka have mainly been measured annually, Esk, Gwavas and Mohaka are dominated by three- yearly intervals. To maintain unity among forests with respect to the measurement periods, those in excess of approximately one year were omitted.

Preliminary Analyses

Omission of higher stocked plots and measurement intervals of greater than one year still left 535 measurement

Figure 2: Histogram of measurement intervals by forest.



data.

A well known basal area/ha projection equation (Clutter and Jones, 1980) is:

$$\log(G) = \log(G_1) \left(\frac{T_1}{T}\right)^\beta + \alpha \left(1 - \left(\frac{T_1}{T}\right)^\beta\right) \quad (1)$$

where in (1)

G_1, G = basal area/ha at ages T_1 and T

α, β = asymptote and shape parameters estimated by non-linear least squares

When fitted to the edited PANPAC data equation (1) gave a plausible fit although there was a strong trend with residual values and site index. The model was accordingly augmented to:

$$\log(G) = \log(G_1) \left(\frac{T_1}{T}\right)^\beta + (\alpha + \gamma S) \left(1 - \left(\frac{T_1}{T}\right)^\beta\right) \quad (2)$$

where in (2)

S = site index. (Clutter *et al.*, 1992)

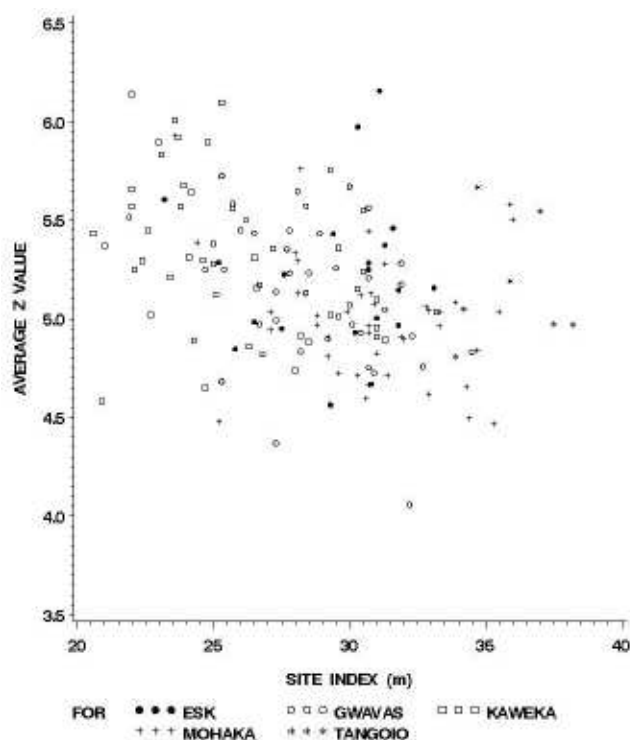
Model (2) gave an excellent fit to the data with the model unbiased for the five forests. Moreover, the error mean square fell by 17 % compared to model (1), a considerable gain in precision. As expected however, the coefficient associated with site index was negative, suggesting less basal area/ha was forthcoming at lower altitudes.

Models (1) or (2) can usually be adequately fitted without the shape parameter because it is frequently close to unity (For example in model (2) above, $\beta = 1.1227$). Rearranging and simplifying (2) we have:

$$Z = \frac{Y}{X} = \frac{\log(G) - \log(G_1)(T_1/T)}{1 - (T_1/T)} = \alpha + \gamma S \quad (3)$$

The advantage of utilising (3) is that it becomes a simple straight-line model with the asymptote parameter now an

Figure 3 : Plot of the variable Z and site index



intercept and the site index coefficient simply defined by the slope of Z and S. Figure 3 shows the relationship between average Z and site index; the relationship is clearly negative.

Factors Causing the Negative Site Index Relationship

In equation (3) Z will be larger if Y is also larger through more basal area/ha growth (G less G_1) but Y is also part dependent on the re-measurement period function (T_1/T) and to a small extent, absolute age, T. The effect of the period function will be minimal with small re-measurement intervals. Conversely, Z will also be larger if X is small which will occur with large re-measurement intervals.

Table 2: Growth data for the five forests. The figures in parentheses represent a range.

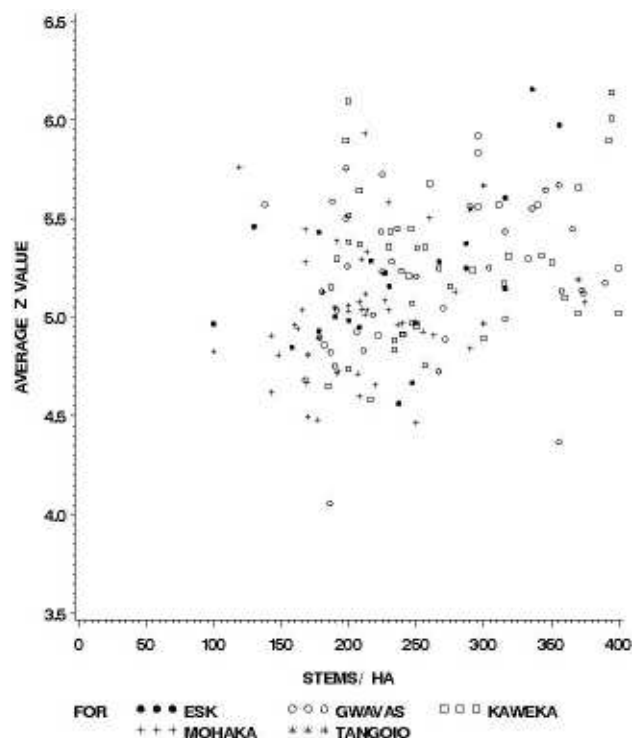
Forest	Stems/ha	Ave. Age	Ave. X	Ave. Y	Ave. Z
Esk	257	15.3 (9-27)	0.077	0.395	5.10
Gwavas	274	17.4 (7-28)	0.068	0.344	5.18
Kaweka	305	17.2 (8-29)	0.065	0.350	5.37
Mohaka	209	18.2 (8-30)	0.063	0.318	5.01
Tangoio	250	17.9 (7-30)	0.065	0.325	5.01

The advantage of editing the data as described above is that the five forests can be reasonably compared without the confounding effects of radically different stockings and contrasting measurement periods. Table 2 summarises the growth data for each forest.

The data now have similar absolute ages (average and range) and comparable $X = 1 - T_1/T$ values, to an extent that it is reasonable to regard the latter as a constant in (3). Thus, the larger Y values must be mainly attributable to larger basal area/ ha growth. We note that the Z values are higher with altitude and thus negatively correlated with site index.

It is very doubtful however, if the high altitude forests, Gwavas and especially Kaweka are innately capable of higher basal area/ha production. From Table 1, although annual rainfall is far from limiting, the average temperatures are considerably lower than the low elevation forests. Much more likely, the higher basal area growth can be explained simply by the presence in general of greater stockings in the higher altitude plots (Table 2). By definition, stems/ha and basal area are strongly correlated, and the availability of 50 - 100 additional trees must materially add to the size of basal area/ha growth. Figure 4 shows a plot of Z and stems/ha.

Figure 4: Z values and stems / ha



The Z values increase with larger stockings. These results may also be exacerbated by the very low stockings (at lower altitudes) representing under-occupation of the site with consequent slower basal area/ ha growth, as observed by Whyte and Woollons, 1990.

Some Concluding Comments

Most users of the growth model NAPIRAD are well aware of the eccentric behaviour of basal area/ ha at lower site indices and react accordingly, but otherwise personnel should be alert to this property, so that unsound conclusions are not made.

It is suggested that the negative site index coefficient present in Napier basal area/ha prediction functions can be

reasonably explained by a combination of climatic and silvicultural factors. Lower mean top height values are to be expected at higher altitudes by virtue of colder and more exposed conditions. Because of the high elevation and concern as to the possible effects of exposure, historically Kawaka was not subjected to extensive thinning and pruning (B.Garnett, *pers. comm.*) and consequently the stockings were relatively high. However at lower altitudes (in Mohaka in particular), intensive silviculture occurred with resultant low stockings.

Site index can thus occasionally behave unexpectedly. In fact, in New Zealand it may be the rule rather than the exception. At Tokoroa, it does not increase precision at all in basal area/ha predictors, while at Nelson the coefficient is again negative-although not as decisively as is the case here (Woollons, unpublished work).

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