FOREST & FARM PLANTATION MANAGEMENT COOPERATIVE

A MODEL TO PREDICT BRANCH INDEX IN RADIATA PINE DIRECT SAWLOG REGIMES

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EXECUTIVE SUMMARY

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Branch measurements from second logs in 26 direct sawlog stands were used to develop a model for predicting branch index. The variables used in the model were DBH at age 20 yrs, site index, the GF value as an indicator of genetic improvement, and the height of final thinning. The effects of stocking and site fertility on branch size were found to be adequately explained by DBH at age 20 years. Before it can be recommended for general use, the model should be validated against independent branch data. It should be relatively straightforward to extend the model for use in upper log height classes.

A MODEL TO PREDICT BRANCH INDEX IN RADIATA PINE DIRECT SAWLOG REGIMES

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INTRODUCTION

Branch size has always been recognised as one of the dominant quality determining variables in *Pinus radiata* unpruned logs, particularly where such logs are sawn to framing timber (Cown et al, 1987). An earlier report (Knowles and Kimberley, 1993) described how branch size measurements were collected across a range of sites, and identified the factors which appeared to influence branch diameter. In this report, the derivation of a model utilising these factors to predict branch index (BIX, the mean diameter of the largest four radially distributed branches per 5.5 m length) in second logs (5.7-11.2m height) from stands subjected to direct sawlog regimes (i.e. thinned early to final crop stocking), is described.

The original data, described in Knowles and Kimberley (1993) and extended by inclusion of a recently measured stand, consists of 26 stands in each of which samples of 22 to 50 trees were measured. Sites were selected where variations in genetic material, or stocking were available. Nine sites, five farm and four forest, were measured. On all the farm sites, trees had been planted onto improved rye-grass - white clover pasture. Two forest sites, Matea and Goudies, were planted as second rotation crops while at Northern Boundary and Rotoehu, the trees were established following felling and burning the previous *Leptospermum* scrub. The stands were aged between 17 and 23.5 years at time of measurement. All stands received a direct sawlog regime with early thinning to waste. However the Mourea site was given a production thinning from 200 stems/ha to 100 stems/ha at age 17 yrs and was therefore not included in the model data set.

Inglis and Cleland (1982) developed a model for predicting branch index using data from 628 trees across 25 site/treatment combinations. They found that branch index could be predicted from the log height class, site index (SI - mean top height at age 20), mean DBH at age 20 yrs (DBH20), and predominant mean height at the time of last thinning (HTTHIN). A more recent study based on three sites within Kaingaroa Forest was reported by Tombleson et al, who found that the Inglis and Cleland model under-predicted branch index at low stockings, particularly at a low site index. A model based on the Cleland & Inglis data and more recent data was developed by Grace (1989).

Knowles and Kimberley (1993) compared actual values of branch index for all sites and treatments with values predicted using the models developed by Inglis and Cleland (1982), and Grace (1989). The Inglis and Cleland model under-predicted branch index at stockings less than 200 stems/ha, with maximum error in prediction of 3cm occurring on the farm sites at 100 stems/ha. The Grace model showed better accuracy for forest sites, but errors in under-prediction of up to 2.5cm occurred for farm sites. They concluded that neither model could be recommended for predicting branches on farm sites, particularly at low stockings.

METHODS

The factors identified in Knowles and Kimberley (1993) as influencing branch size were: site index, stocking, site fertility and genetics. Larger branches occurred at lower site indices, presumably because on such sites, they can grow for a longer period before being suppressed by neighbouring tree crowns. Branches were also larger in stands with larger diameter trees, whether resulting from greater site fertility (generally farm sites as opposed to forest sites), or lower stocking densities. It was suggested that DBH20 could be used to account for this, and that direct inclusion of site fertility or of stocking in a BIX model should be unnecessary. Stands established with seedlings from seed orchards generally had smaller branches than those established with routine seedlings. One measure of genetic improvement is the GF (growth and form) factor. Although a rather approximate measure, it was decided test this for inclusion in the model to give some indication of genetic improvement. In contrast to most genetically improved trees, those selected for uninodal habit tended to have larger branches than routine trees. Given that only one site (at Ngatira) contained uninodal trees after the Mourea site was excluded, it was decided to omit this stand from the model data set.

The independent variables chosen to be tested for inclusion in the model therefore were DBH20, SI and GF. In addition, it was decided to test the effects of final crop stocking, site fertility (farm or forest) and HTTHIN. If the hypothesis of Knowles and Kimberley is correct, site fertility and stocking should not affect branch index once DBH20 is accounted for, but this had to be tested formally. As the stands were all direct sawlog regimes subject to early thinning to waste, the height of final thinning was expected to have little influence on branch size, but again it was necessary to test whether this was true.

The basic relationship between BIX, DBH20 and SI is shown in Fig. 1. Although the relationship appears fairly linear, there is an indication that it is flatter for smaller values of BIX. An examination of the BIX frequency distribution for individual trees across all stands (Fig. 2) shows a positively skewed distribution with no trees having a BIX less than 3cm and hardly any with less than 3.5cm. Out of 50 stands measured for 2nd and 3rd log BIX by Inglis and Cleland, including stands at higher stockings than normally found in direct sawlog regimes, the lowest two mean BIX values were 2.9 and 3.3, all others being greater than 3.5. This suggests this that stands with a mean BIX of less than 3cm are very rare, and implies that the relationship between BIX and any independent variables is non-linear, with a slope increasing for larger values of BIX.

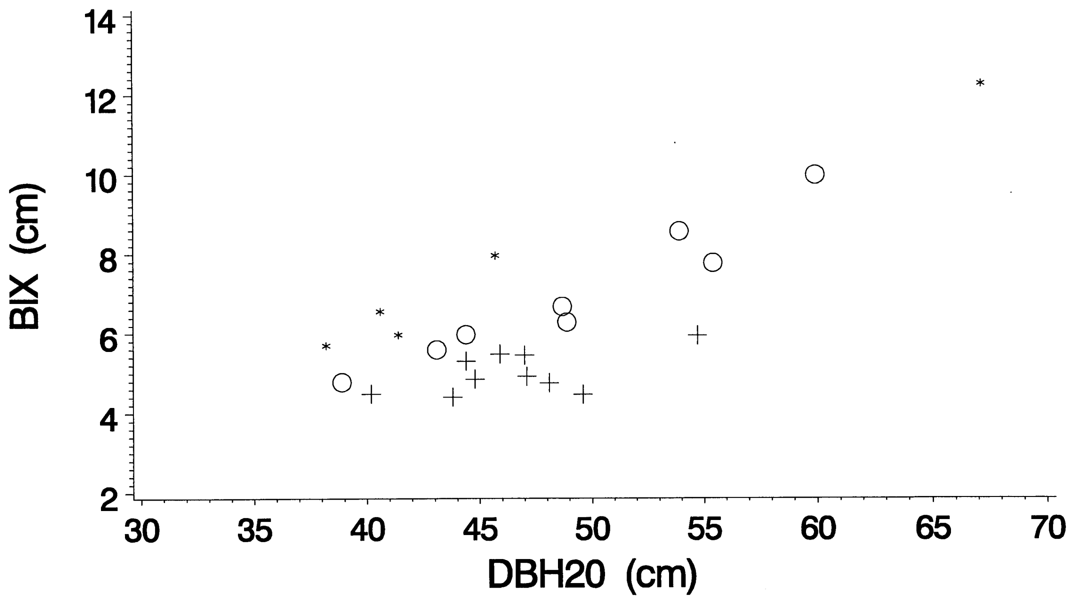

Fig. 1. BIX vs DBH20 and SI. * SI < 27.5, o 27.5<SI<32.5, + SI>32.5.

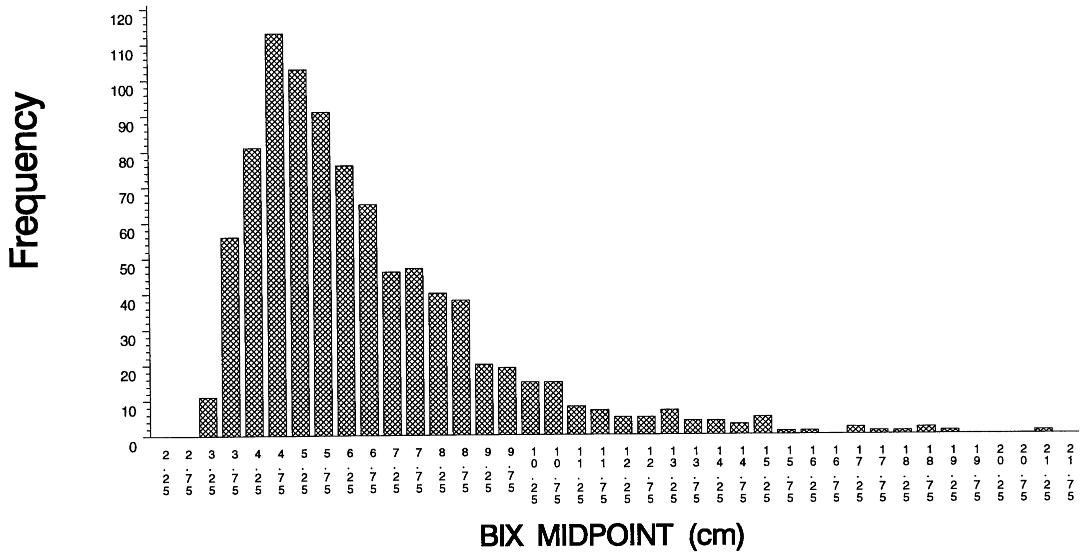

Fig. 2. Frequency distribution of individual tree BIX, all stands combined.

The procedure adopted was therefore to fit a multiple linear regression, and to compare it with two non-linear regression equations appearing to have the desired form. The equations tested were:

1. BIX = a + b x1 + c x2 + . . .

2. BIX = a + b * exp(c x1 + d x2 + . . .)

3. BIX = a + b * ln(1+ exp(c/b + d/b x1 + e/b x2 + . . .))

In these equations, independent variables are represented by x1, x2, etc., and coefficients by the letters a, b, c, etc. Exp(x) and ln(x) are e to the power of x and the natural log of x, respectively. The first equation is a multiple linear regression. The second is an exponential equation, the slope of which continues to increase as BIX increases. The third equation gives a flat response for small values of BIX, curving upwards and assuming a constant positive slope for larger vales of BIX. Equations were fitted to the data using SAS procedures. Variables were only included in the model if they were statistically significant.

RESULTS

The data used in deriving the model is summarised in Tables 1 and 2.

Table 1. Stand means of branch index and largest branch.

Stand	Site	Number of trees	BIX (cm)	Max branch (cm)
1	Whatawhata	48	10.0	12.8
2	Whatawhata	47	8.6	11.0
3	Whatawhata	45	6.0	7.6
4	Tikitere	48	12.3	15.1
5	Tikitere	48	7.8	9.5
6	Tikitere	48	5.5	6.5
7	Mourea	24	8.2	9.8
8	Mourea	24	7.4	8.9
9	Ngatira	24	7.5	9.2
10	Ngatira	24	5.9	7.1
11	Rotoehu	47	5.3	6.7
12	Rotoehu	50	5.5	6.4
13	Rotoehu	48	4.8	5.5
14	Rotoehu	47	4.4	5.1
15	Rotoehu	48	4.9	5.9
16	N. Boundary	24	6.3	7.5
17	N. Boundary	23	4.9	5.9
18	N. Boundary	24	4.5	5.3
19	N. Boundary	23	4.6	5.5
20	Goudies	23	6.7	7.8
21	Goudies	22	5.3	6.5
22	Goudies	24	4.8	5.8
23	Matea	24	8.0	9.5
24	Matea	23	6.6	7.7
25	Matea	24	5.7	7.1
26	Otago	40	6.0	7.2

Table 2. Stand means of variables tested for use in branch index model.

Stand	DBH age 20	Site index	Stocking (sph)	GF factor	Site type	selection ratio	Height thinned (m)
1	59.9	31.0	91	7	farm	4:1	10.0
2	53.9	31.1	183	7	farm	4:1	10.0
3	44.4	31.4	387	7	farm	4:1	11.0
4	67.1	27.5	95	14	farm	5:1	10.0
5	55.4	29.5	200	14	farm	5:1	10.5
6	45.9	33.8	400	14	farm	5:1	11.0
7	57.3	29.6	192	uninodal	farm	5:1	11.0
8	60.0	29.1	200	14	farm	5:1	10.0
9	52.5	33.9	200	uninodal	farm	3.75:1	11.0
10	54.7	35.0	220	14	farm	3.75:1	13.0
11	44.4	34.3	248	7	forest	6:1	11.0
12	47.0	33.8	230	14	forest	1:1	11.0
13	48.1	35.2	245	14	forest	3:1	11.0
14	43.8	35.2	247	14	forest	4:1	11.0
15	47.1	35.4	248	14	forest	6:1	11.0
16	48.9	32.2	150	7	forest	NA	12.5
17	44.8	33.1	250	7	forest	NA	12.5
18	40.2	33.9	341	7	forest	NA	12.5
19	49.6	34.0	360	20	forest	NA	14.0
20	48.7	29.4	117	7	forest	NA	12.5
21	43.1	29.6	250	7	forest	NA	12.5
22	38.9	29.6	383	7	forest	NA	12.5
23	45.7	24.0	150	7	forest	NA	11.8
24	40.6	23.8	250	7	forest	NA	11.8
25	38.2	24.0	333	7	forest	NA	11.8
26	37.6	24.5	398	7	farm	NA	8.2

It was found when fitting equations 2 and 3 that the coefficient 'a' was estimated very imprecisely. This coefficient was therefore set to equal 3.0, which also ensured that BIX predictions of less than 3.0 could not be produced from either of these equations. It would be desirable to obtain data from stands on very infertile sites, and/or growing at higher stockings to check whether this restriction is justified.

The residual standard deviations obtained from the three equations when fitting successively DBH20, SI, GF and HTTHIN are given in Table 3.

Table 3. Residual standard deviations (cm) for BIX models.

	Equation number		
Independent variable	1	2	3
DBH20	1.22	1.04	1.08
+ SI	0.611	0.653	0.553
+ GF	0.457	0.387	0.341
+ HTTHIN	0.368	0.331	0.264

In general, equation 3 gave the best fit. When DBH20 and SI only were fitted, the following equation, model A, was obtained:

$$BIX = 3.0 + 2.57 * \ln(1+ \exp(-0.751/2.57 + 0.306/2.57\ DBH20 - 0.376/2.57\ SI))$$

The percentage variance explained by this equation was 92.9%. Asymptotic standard errors of the coefficients b, c, d and e were: 1.6, 2.0, 0.067 and 0.11. Both SI and DBH20 were highly significant. Observed and predicted values of BIX for this equation are plotted in Fig. 3.

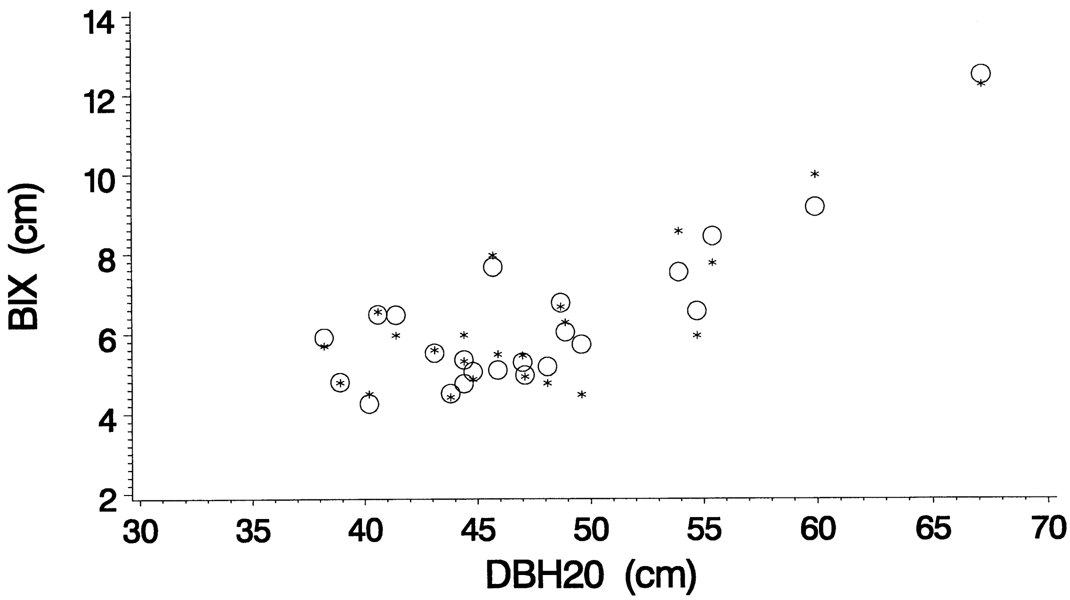

Fig. 3. Actual (*) and predicted (o) BIX vs DBH20, model A.

Both GF and HTTHIN resulted in significant further reductions in variation giving the following equation, model B:

$$BIX = 3.0 + b * \ln(1+ \exp(0.985/b + 0.356/b\ DBH20 - 0.354/b\ SI -0.212/b\ GF -0.321/b\ HTTHIN))$$

with $b = 3.52$

The percentage variance explained by this equation was 98.5%. Asymptotic standard errors of the coefficients b, c, d, etc. were: 1.3, 1.8, 0.064, 0.077, 0.059 and 0.11. All independent variables were significant at the 5% level. Observed and predicted values of BIX for this equation are plotted in Fig. 4. Neither final crop stocking nor site type (farm or forest) gave any significant further improvement in fit, indicating that DBH20 alone can adequately account for their effects on branch size.

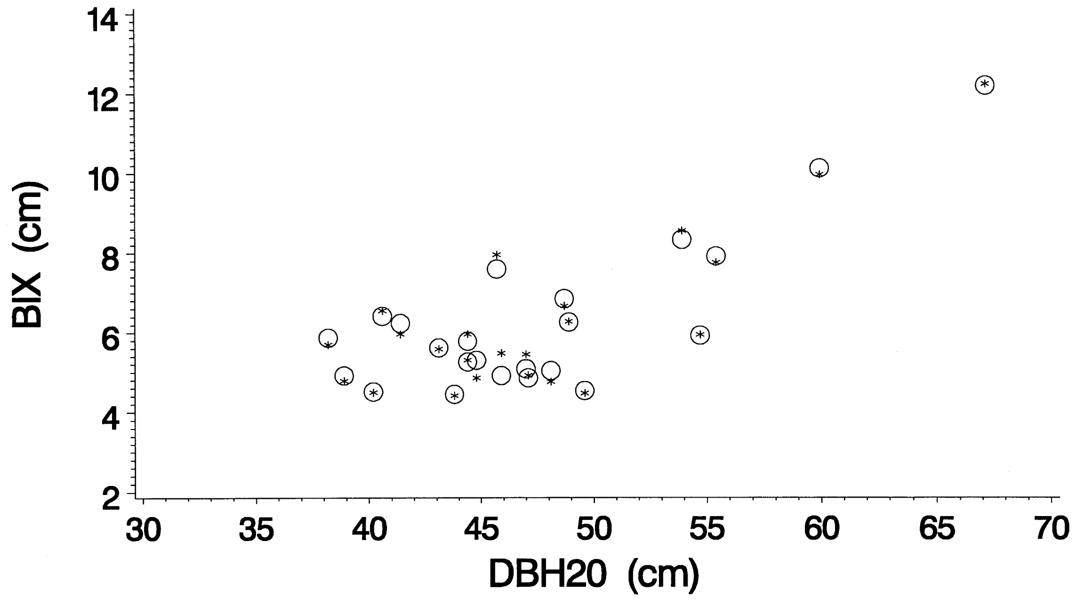

Fig. 4. Actual (*) and predicted (o) BIX vs DBH20, model B.

DISCUSSION

For comparison, observed and predicted values for the two previous BIX models are shown in Figs. 5 and 6. As noted earlier, both models tend to underpredict BIX in certain situations. This problem appears to have been rectified in the current model.

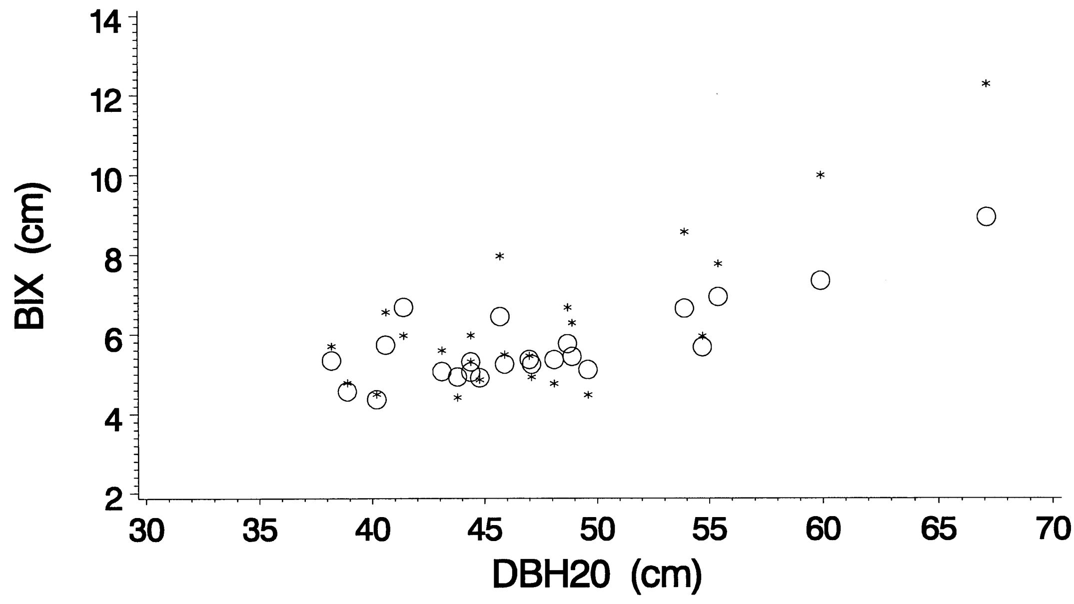

Fig. 5. Actual (*) and predicted (o) BIX vs DBH20, Inglis and Cleland model.

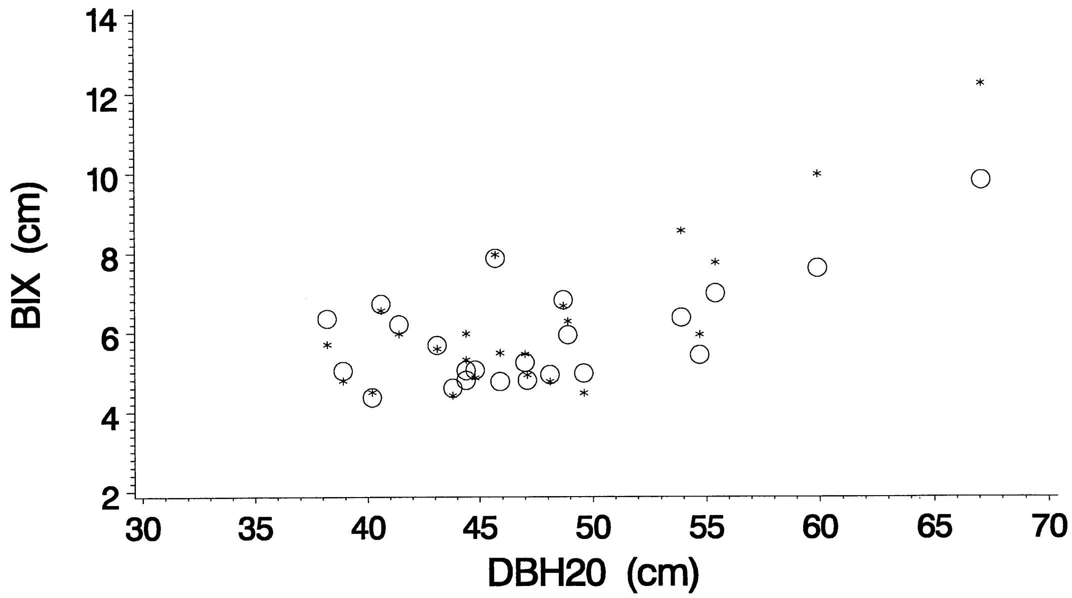

Fig. 6. Actual (*) and predicted (o) BIX vs DBH20, Grace model.

Before it can be recommended for widespread use however, the model should be validated against independent data. Some of the Inglis and Cleland data may be suitable for this but it may also be necessary to measure additional stands. As suggested by Knowles and Kimberley (1993), BIX can be determined with minimum effort from measurements of the largest branch in a sample of about 50 logs, making collection of validation data reasonably inexpensive. Data is sparse for stands with larger BIXs, particularly at high site indices. Very low fertility stands may also be useful in validating the model at the lower end of the BIX range. Higher GF stands should also be measured when they become available.

When applied to the two stands at Mourea not used in developing the model because they had been subjected to a late production thinning, the model overpredicted BIX by 2.1cm for the seed orchard origin trees, and 1.3cm for the uninodal trees. This is much as expected, as the selection of trees during the thinning is likely to have artificially increased DBH20 without affecting branch size. The lesser error for the uninodal trees is consistent with their known tendency to produce larger branches. At Ngatira, BIX is overpredicted by 0.4cm for the uninodal stand but is exactly predicted for seed orchard derived trees at the same site.

Some model predictions are illustrated in Figs. 7 to 9. They show the strong relationship between BIX and DBH20, and hence indirectly, the effects of stocking and site fertility on branch size. The direct effects of stocking and fertility cannot be determined from the model alone. In practice, the model will be used in conjunction with a tree growth model which will, in effect, be used to grow the branches as well as the stem. An increase in site index of 5m will result in a reduction in BIX of about 1cm (Fig. 7). Amost all the stands used had GF values of either 7 or 14. The difference in BIX between these appears to be about 1cm (Fig. 8). The effect of HTTHIN on BIX can be considerable even on these direct sawlog stands, those thinned at 8m having a BIX about 1cm greater than those thinned at 12m (Fig. 9).

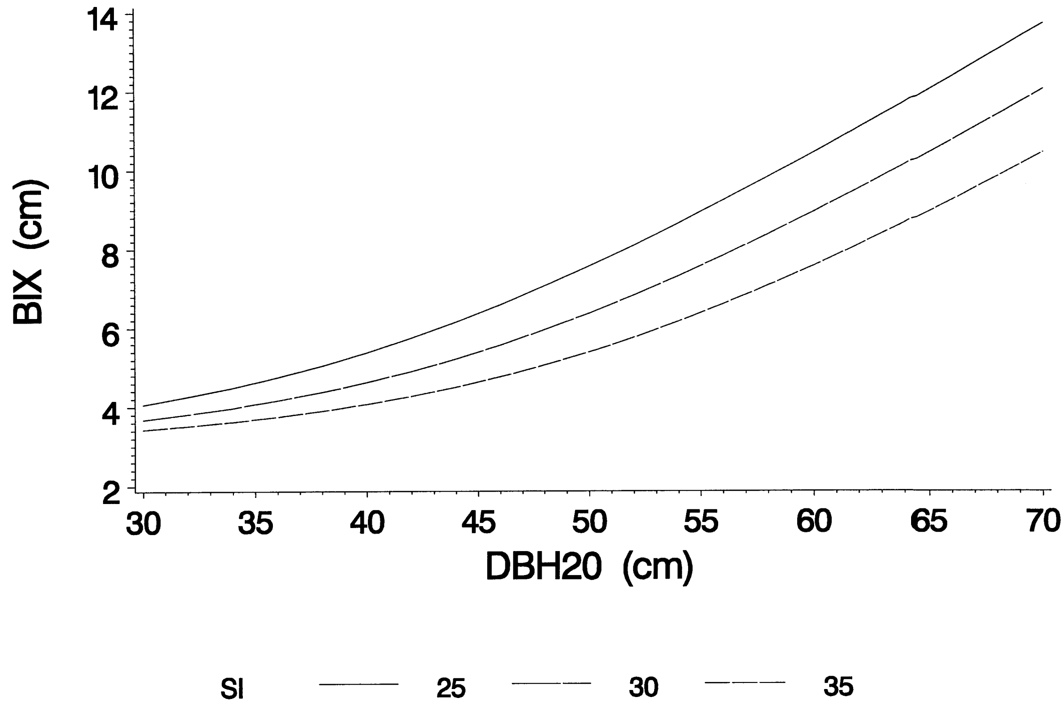

Fig. 7. Predicted BIX vs DBH20 for a range of site indices, for GF14 trees, final thinning at 11m.

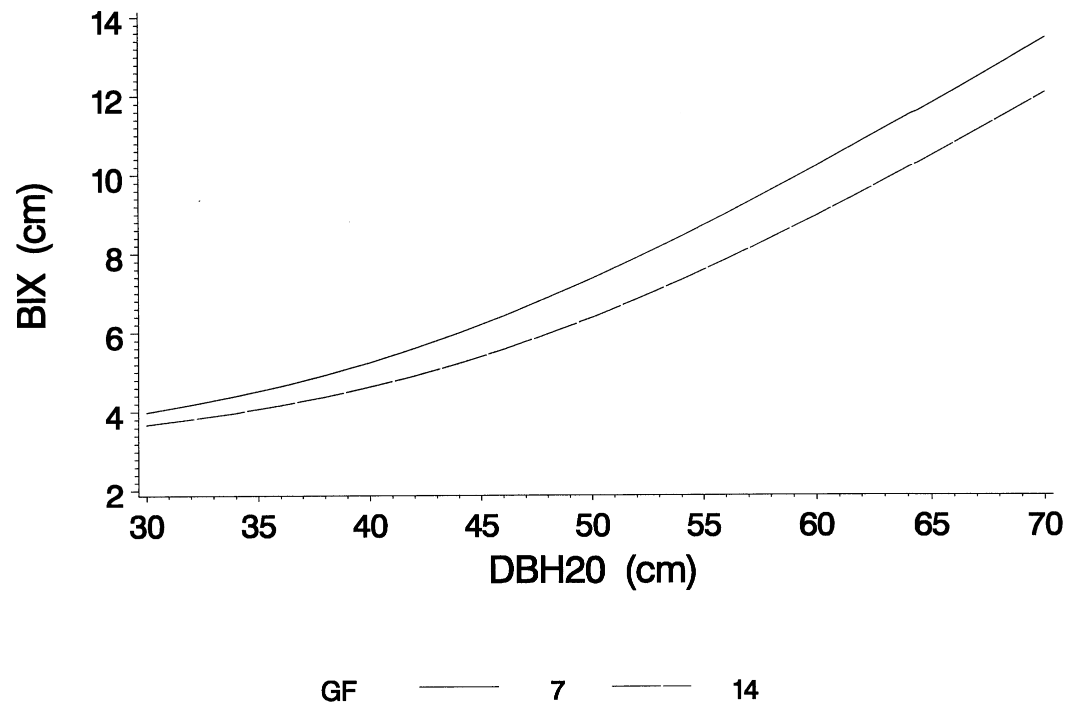

Fig. 8. Predicted BIX vs DBH20 for GF7 and GF14 trees, site index=30m, final thinning at 11m.

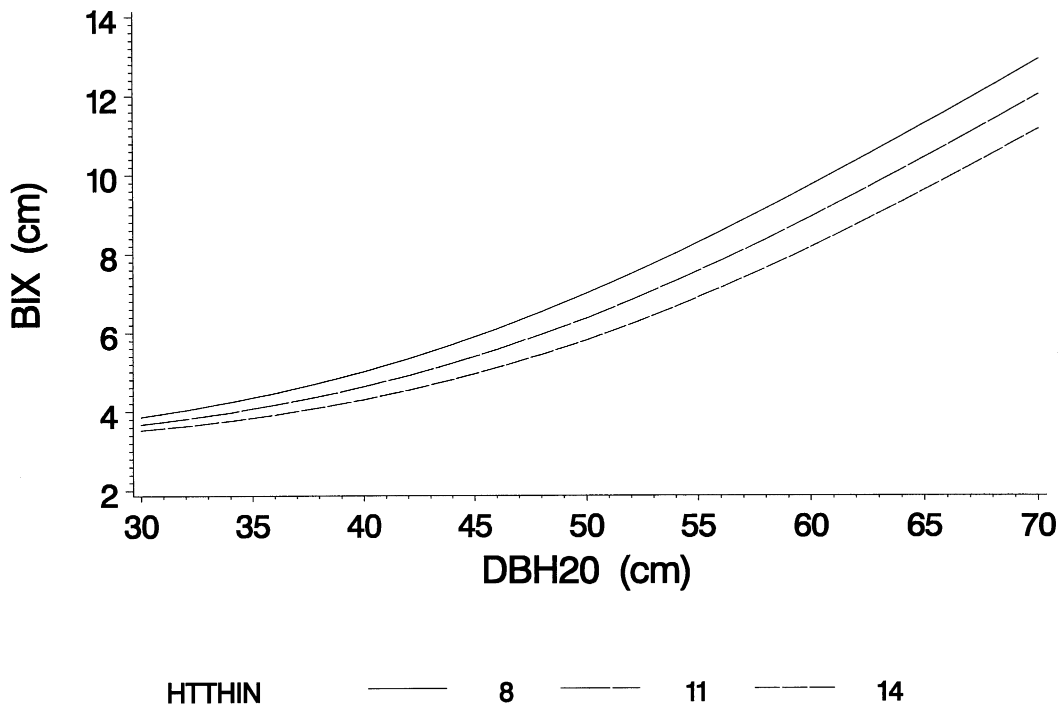

Fig. 9. Predicted BIX vs DBH20 for a range of final thinning heights, site index 30m, for GF14 trees.

The model should not be used in stands dissimilar to those used in its development. It should be restricted to stands of between about 100 and 400sph final crop stocking and for site indices between about 25 and 35m. If the model is used in stands thinned at less than 8m height, a value for HTTHIN of 8m should be used, as it is unlikely that thinning below 8m will result in any increase in BIX in 2nd logs. The model should not be applied to stands thinned at heights much greater than 14m. The effect of the GF factor in the model should be treated with some caution as almost all the stands used had GF values of either 7 or 14. Although the single GF20 stand had a particularly low BIX, much in line with the observed trend between GF7 and GF14, extrapolating predictions to this or higher GF values should be done with caution. The GF factor is a somewhat subjective measure of tree breeding improvement and it cannot be assumed that the tendency for branch index to decrease as the GF value increases will hold for higher GF trees.

Extension of the model to upper log height classes should be fairly straightforward. Upper log branches are likely to be affected by the same factors as 2nd logs, with the exception of height of thinning. A relatively small set of upper log branch data may therefore be sufficient to adjust the model for use in upper logs.

CONCLUSIONS

1. An examination of branch measurements in 2nd logs from direct sawlog stands indicated that site fertility, stocking, site index, genetics and height of final thinning all had an affect on branch index.

2. The effects of site fertility and stocking on branch index could be adequately represented by average DBH at age 20yrs.

3. The following model was derived from the data:

$$BIX = 3.0 + b * \ln(1 + \exp(0.985/b + 0.356/b\ DBH20 - 0.354/b\ SI - 0.212/b\ GF - 0.321/b\ HTTHIN))$$

with $b = 3.52$

4. This model should only be applied to direct sawlog regimes and needs validating using independent data before it can be recommended for widespread use.

5. Extension of the model to upper log height classes should be straightforward.

ACKNOWLEDGEMENTS

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