Analysis of branch data from final crop stocking trial

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EXECUTIVE SUMMARY

ANALYSIS OF BRANCH DATA FROM FINAL CROP STOCKING TRIAL

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THE PROBLEM

Knot size is one of the most important characteristics affecting the commercial use of wood, particularly when used for structural use. Branch size has been shown to be influenced by both site quality and number of stems per hectare. To make decisions on branch controlling site specific silviculture requires an understanding of how site and silviculture interact to effect branching.

COOP INITIATIVES

The radiata pine final crop stocking trial was set up in 1966-1968 at three sites in Kaingaroa Forest. The trial was set up as a uniform precision, response surface design experiment. In 1989 the Stand Management Cooperative produced a report (No.13) analysing the branching characteristics of the second log (5.5 – 11 metres) using this trial. The study showed that branch index (BIX) decreased with increasing stocking and site index.

THIS PROJECT

Branch characteristics of *Pinus radiata* were examined over a range of site qualities and final crop stockings at three sites in Kaingaroa Forest. BIX was measured for all the log classes up the stem once the trees had been felled. The trees were felled and measured in 2002. The data was used to determine the impact of site index and final crop stocking on BIX, as well as validating the BIX models. Internode length was analysed for one site.

RESULTS

The analysis of the BIX measured in 2002 showed that in the 2nd log it had decreased since 1989. Only the 3rd log showed a significant relationship between BIX and final crop stocking and site index. For this dataset the BIX 2nd log model seems to be over predicting while the n'th log model showed little bias for the 3rd log with the bias increased for the upper logs.

IMPLICATIONS FOR THE COOP

This study showed interesting results in terms of the impact of stand age on BIX. However, due to the size of the study, further work is required to confirm these results. A lack of relationships, with the exception of the 3rd log, indicates that the precision to which different stocking regimes has to be matched to site only affects branch size of the third log class (between 11m – 16.5m).

INTRODUCTION

Knot size is one of the most important characteristics affecting the commercial use of wood, particularly when used for structural uses (Cown et al, 1987). The most common branch index for radiata pine growth and yield modelling used in New Zealand is BIX. It is the mean diameter of the largest four branches on a 5.5 – 6 metre log, one branch being selected from each quadrant.

Branch size is known to be affected by spacing, branch orientation, site quality, genetics, cutting vs. seedling and silviculture. Grace (1992) and Kimberley et al. (unknown) give a good review of the literature in this area. This paper focuses on the impacts of spacing and site quality on branch size. The spacing affects branch size into main ways, it affects the length of the time that a branch has enough resources to continue to grow. Secondly, branch growth is very highly correlated to diameter growth (Cromer and Pawsey 1957) which is in itself affected by stocking.

In New Zealand branch index has been found to decrease with increasing site index (Inglis and Cleland, 1982; Tombleson et al. 1989). On high site index sites trees have faster height growth, it therefore hypothesis that branches are shaded out and become moribund earlier and at a smaller size than on lower site index sites (Kimberley et al. unknown).

This report examines the branching characteristic at the time of harvest of the final-crop stocking trial located at Matea, Goudies and Northern Boundary in Kaingaroa Forest (RO 589). The trial was originally set up to evaluate the response of mean annual increment to the two factors of site index and final crop stocking and their interactions. The three sites were planted between the years 1966-1968. All three stands were harvested in the period 2000 – 2002 at rotation ages ranging from 34-36 years.

The harvesting of these stands provided an opportunity to re-examine the influence of stocking and site index on branch characteristics and compare these measurements to previous measurements. As the trees were being felled, there was an opportunity to measure the branches in the upper logs of the trees. This data also allowed for the checking of the reliability of the models of Kimberley and Knowles (1993), and the n'th log equation (Hansen et. al. 2004).

METHODS

Response Surface

The original trial was designed as a "Fully Rotatable, Second Order, Central Composite, Uniform Precision Response Surface" (see Goulding and Inglis 1990). This design was used as it allows a model to be developed to make predictions of the response of the stand to the various levels of treatment, rather than solely suggesting that treatment A was better than treatment B. The design tested the response at five different stocking and site quality levels (Table 1).

Table 1. Experimental Design of the Trial

	Final Crop Stocking				
Site Index	110	150	250	350	390
35			A		
33		A		A	
29	B		A,B,C		B
25		C		C	
23			C		

Trial Locations
       A = Northern Boundary
       B = Goudies
       C = Matea

It was originally hoped that site variation within the compartment would allow the site index 23.4 and 34.6 to be found at the sites with site indices of 25 and 33 respectively. This turned out not to be the case. The stockings of 110 and 390 stems per hectare were also used as extreme points in the design. The experimental design is normally analysed by fitting a two-factor second order regression model as in Eq. 1 to the response.

$$z = b_0 + b_1 X + b_2 X^2 + b_3 Y + b_4 Y^2 + b_5 XY \tag{1}$$

Where
       z is the response variable of interest
       X is site index
       Y is the final crop stocking

Data Collection

The trees were measured on the ground once they had been felled, allowing the branch index to be determined for each log height class. The suggested sample size for estimating BIX is 24 trees. A summary of the sample size for each treatment is given in Table 2.

Table 2. Sample sizes

Design Final Stocking	Site Index ('Design')	Number of Trees
250	23.4	0
150	25	0
350	25	0
117	29	18
250	29	21
383	29	24
150	33	24
350	33	25
250	34.6	24

Four quadrants were marked at the base of each tree before felling. Quadrant 1 was marked so it always faced magnetic north. Hand-held callipers were used to measure the diameter of the largest branch in each quadrant of each log height class. The log length for this study was 5.5 metres. Other important information was obtained from the Ensis PSP system.

Unfortunately on the Matea site either the data was never collected or mislaid. This has seriously reduced the analysis potential of this study. Losing this data, combined with the inability to obtain the upper and lower site indices, means that the proposed model had to be reduced to (Eq. 2):

$$z = b_0 + b_1 X + b_3 Y + b_4 Y^2 + b_5 XY \tag{2}$$

Unfortunately the trees were sampled evenly across the response surface design. The "centre" treatment of the design (in this case site index 25, stocking 250) has five replicates where as the other treatments only have one replicate each. When the BIX was measured it was measured evenly across the treatments, meaning that some replicates in the centre treatment only had one or two trees measured.

BIX model Validation

The plot level results were used to validate the BIX model for the second log developed by Kimberley and Knowles (1993), as well as the BIX model for the "n" log. The equation for the 2nd log is:

$$BIX_2 = a + b \ln\left(1 + \exp\left(\frac{c}{b} + \frac{d}{b} DBH_{20} + \frac{e}{b} H_{thin} + \frac{f}{b} SI + \frac{g}{b} GF\right)\right) \tag{3}$$

Where *DBH20* is the DBH at age 20 (cm), Hthin is the mean top height (m) at first thinning, SI is site index (mean top height (m) at age 20), and GF is the GF rating, nominally set at 7. The coefficients are a=3, b=3.52, c = 0.985, d=0.356, e=-0.321, f=-0.354 and g=-0.212.

The BIX for the n'th log is calculated from mean top height at thinning (H_{thin}) (m) and final crop stocking (SPH) (stems/ha) as

$$BIX_n = BIX_2 (a + bH_{thin} + cSPH + dH_{thin}SPH) \tag{4}$$

The *DBH20* and Hthin were obtained from the Ensis PSP database.

RESULTS AND DISCUSSION

Summary Statistics
The mean BIX and 95% confidence intervals were calculated for the different treatments. Table 3 shows the results for the 2nd log branch index at age 34 and 36, in comparison to those calculated for the stands at age 21 and 23 in Tombleson et. al. (1989).


Table 3. Summary statistics comparing the BIX as at 1989 and 2002

Site	Site Index (m)	Target Final Stems/ha[1]	Tombleson et .al. (1989)		Actual Average BIX as measured in 2002	
			BIX (cm)	95% CI (cm)	BIX (cm)	95% CI (cm)
Matea	24	150	8.0	7.4-8.5		
		250	6.6	60-7.1		
		350	5.7	5.2-6.3		
Goudies	29	117	6.7	6.0-7.4	4.8	4.31-5.32
		250	5.3	4.8-5.7	4.9	4.33-5.37
		290	4.8	4.4-5.2	5.7	5.07-6.29
Northern	33	150	6.3	5.8-6.8	5.7	5.1-6.24
Boundary		250	4.9	4.5-5.4	4.3	3.82-4.82
		390	4.5	4.2-4.8	4.0	3.64-4.3

[1] This is the design stocking not the actually stocking when the branches where measured.

The comparison shows that in all but one of the treatments there is a clear reduction in the BIX on the second log from when measured by Tombleson et. al. (1989). There are a number of possible reasons for this reduction in BIX:

1. Potential decrease in branch size over time due to stem diameter growth (Fig. 1).
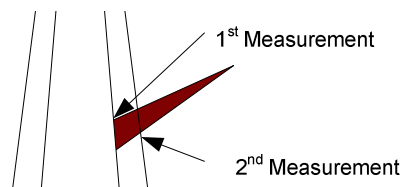
Fig 1. The potential interaction between stem diameter growth and branch taper.

2. Reduction in the diameter due to shrinkage, potentially caused by water loss and increase rot as the branch will have been dead for many years.
3. Difference in measurement techniques.

The mean BIX for the upper logs is given in Fig 2.
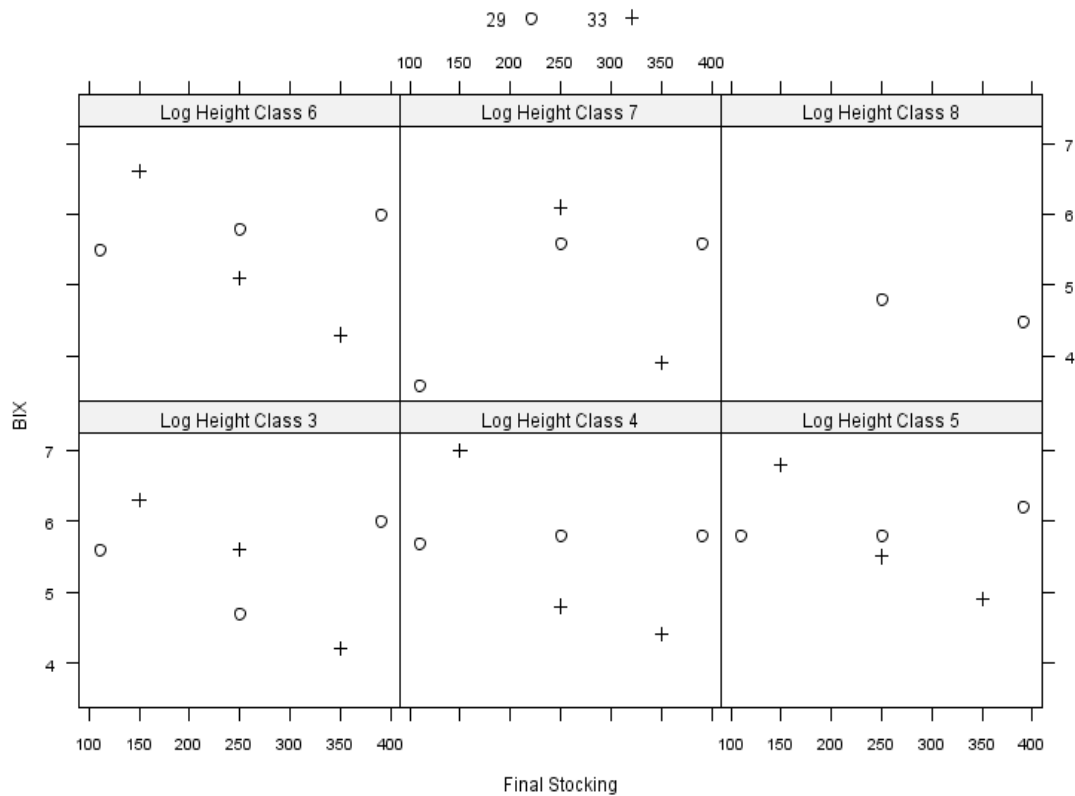
Fig 2. BIX in Upper Log Classes

There is a clear reduction in the BIX with final stocking on the site with the site index of 33. In comparison the BIX shows no clear pattern, with little change between stocking levels at the site with a site index of 29.

Internodes
The number of whorls per 5.5 metre log length was measured at the North Boundary (Site Index 33) plots. Fig. 3 shows the internode length for the different log class. The pattern is that internode length seems to decrease with increasing log class.
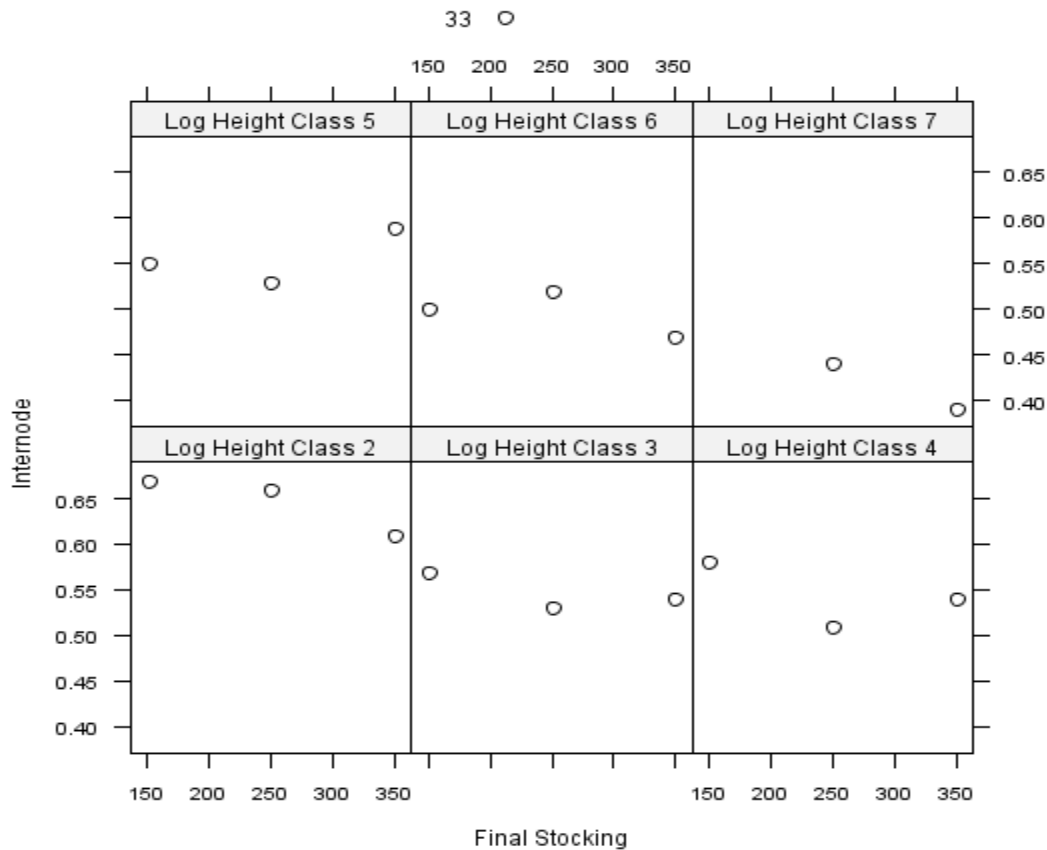
Fig. 3. The mean internode length (metres) for the North Boundary trees

Response Surface

The analysis was performed on the different log height classes separately. There was not enough data for some of the upper log height classes, namely 7 and 8. Only one of the log height classes shows a relationship that had individual terms that were significantly different from zero. The following relationship was found for the 3rd log height class which is from 11 to 16.5 metres in height:

$$z = 0.209X + 0.050Y - 0.0017XY \tag{5}$$

Where

      z is BIX for n'log (cm)
   X is site index
      Y is the final crop stocking.

This relationship combined with the lack of relationships for the other log height class indicates that being precise and site specific about your final crop stocking decision is only important to control branching in the third log. Given that the majority of the value of a tree is contained in the lower section of a tree, precisely prescribing and carrying out site specific final crop stocking regimes may not be economically justified.

BIX Model Validation

Fig. 4 shows the errors (predicted – actual) from the validation of the BIX model (2nd log) against the stocking. In total 19 plots were used in the validation exercise.
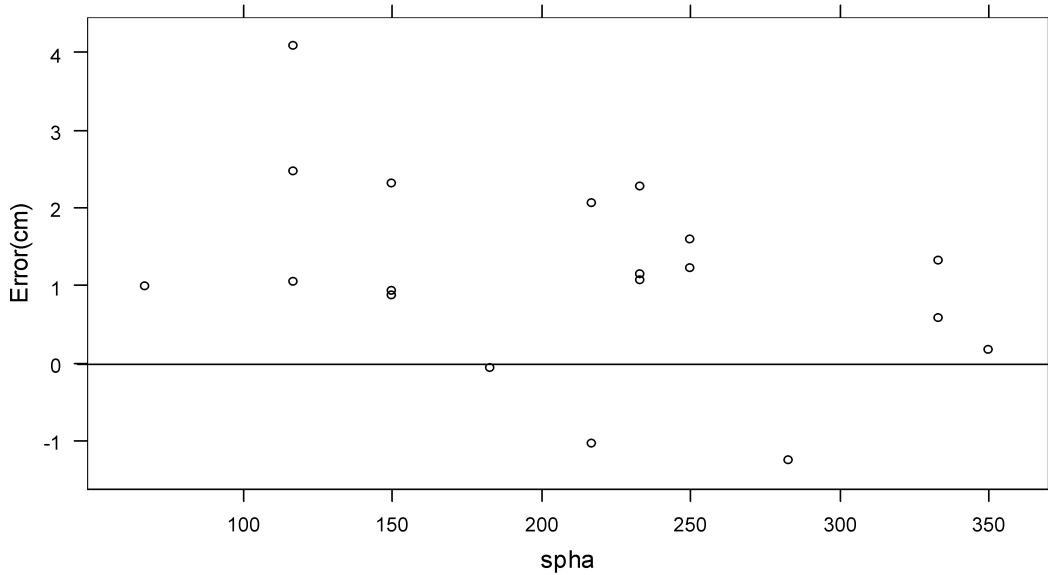
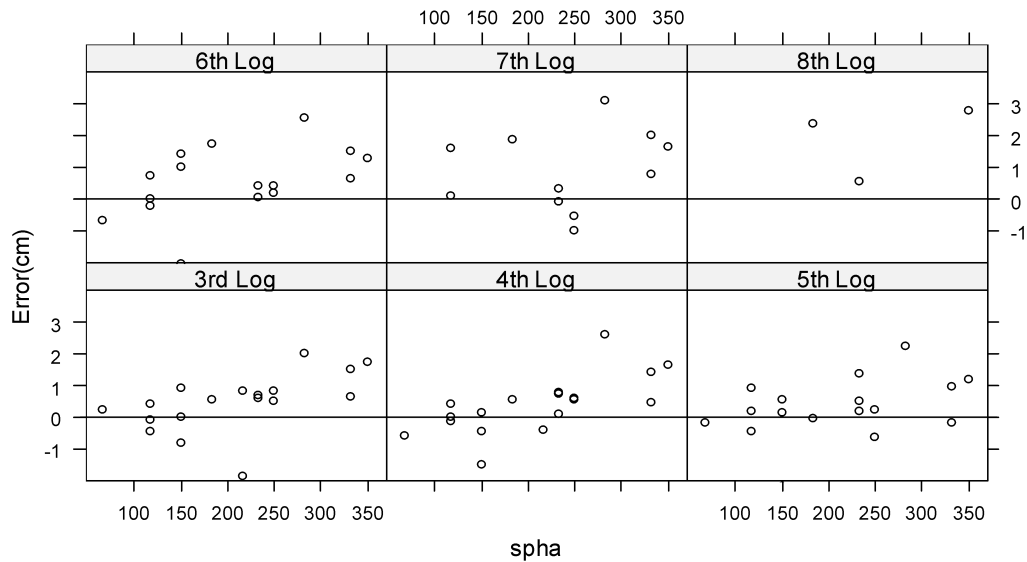**Fig. 4. Errors in predicting branch index for the 2nd log.**

The Kimberly and Knowles model appears to over-predict the branch index on all but three of the plots. This is consistent with the result obtained from the validation exercise carried out by Middlemiss and Knowles (1994). They found that the model over predicted by 7.3mm, which is substantially less than for this validation data set.

The validation results for the n'th log BIX equation are given in Fig. 5. The n'log BIX was predicted using Eq. 4 and the predicted 2nd log BIX.
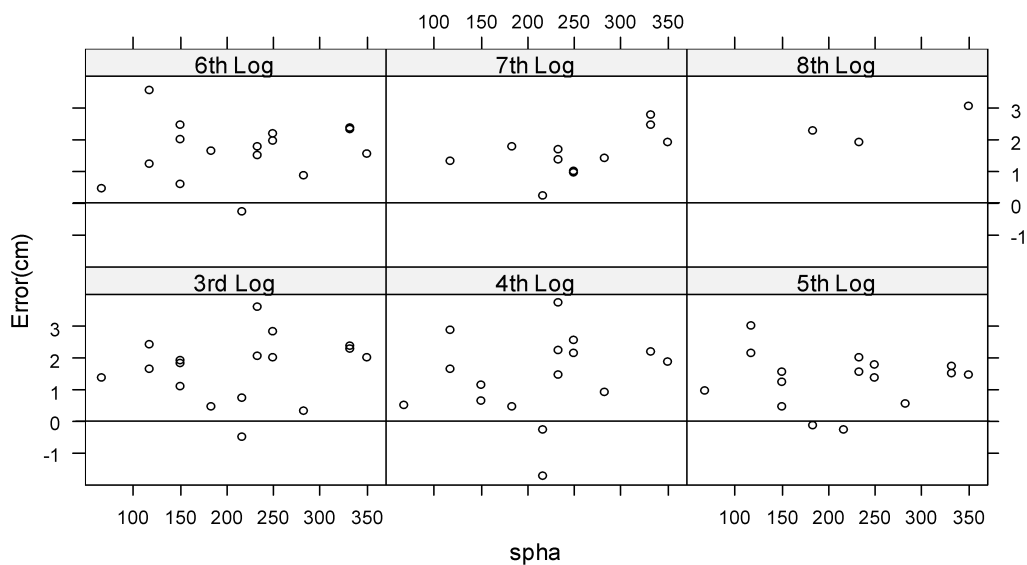
Fig. 5. Errors in predicting branch index for the nth log.

To remove the impact of apparent bias in the 2nd log BIX model, the n'th log BIX model was used to predict the BIX for the upper logs using the actual 2nd Log BIXs. The errors in Fig. 6 are more centred on zero then those in Fig. 5. This indicates that much of the bias in the prediction comes from the original 2nd log BIX prediction.

Fig. 6. Errors in predicting branch index for the nth log.

The mean errors for these two validation exercise are given in Table 4.

Table 4. Mean error for the BIX n'th model.

Log	3	4	5	6	7	8
Predict 2nd Log BIX	1.84	1.59	1.63	1.80	1.78	2.42
Actual 2nd Log BIX	0.46	0.21	0.10	0.36	0.61	1.90

CONCLUSION

The ability to analyse this data has been restricted by the loss of data, and that the data was collected in a manner that seems incompatible with the original design of the experiment. The analysis of the data did, however, highlight some interesting results. The comparison of these measurements on the 2nd log and those reported in Tombleson et al. (1989) showed that with the exception of one treatment the BIX had reduced. The BIX for the upper logs (log height class three and greater) seemed to decrease with increasing final crop stocking for high site index site (SI = 33) but showed no clear trend for the other site.

A lack of the relationships with the exception of the third log class, between the BIX and site index and final stocking indicates that the precision at which different stocking regimes have to be matched to site only affects branch size of the third log class (i.e between 11m – 16.5 m).

The validation of the 2nd log BIX and n'th log BIX models indicated that the 2nd log model over predicted yet there was no noticeable bias in the n'th model's prediction when using the true 2nd log BIX. The conclusion of this validation can only be applied to Kaingaroa forest.

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