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TITLE: THE EFFECT OF SITE, STOCKING, AND GENETICS ON SECOND LOG BRANCHING IN *PINUS RADIATA*

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ABSTRACT*

Some 44,000 branch diameters were measured in second-logs from 25 direct sawlog stands, covering a range of sites, stockings and genetic material. Currently used branch index models were found to under-predict branch size on farm sites by up to 3 cm. The larger branch size on farm sites was directly related to the larger DBH growth apparent on farm sites. In addition to site fertility, other factors found to affect branch size were stocking, site index and genetics. Branches were smaller with higher stockings, higher site indices, and higher GF values.

Branch diameter frequency distributions were found to be similar for stands of equal branch index. This ensured that relationships between branch variables such as branch index and largest branch, remained consistent across a wide variety of sites and treatments.

Branch index can be linked to a number of commercial log-grade definitions. Functions used in STANDPAK to predict the largest branch from branch index, and internode index from the number of whorls per metre of log length, were found to be inaccurate.

Internode index was found to decrease with decreasing stockings on farm sites, but not on less fertile forest sites. A new clearcutting index involving number of whorls and whorl depth is suggested as a possible improvement to internode index.

Field measurement of only the largest single branch/log will give similar accuracy as measuring branch index, but at a reduced cost.

THE EFFECT OF SITE, STOCKING, AND GENETICS ON SECOND-LOG BRANCHING IN *PINUS RADIATA*

R. L. Knowles and M. O. Kimberley

INTRODUCTION

Branch size is recognised as the dominant quality determining variable in unpruned logs, particularly where such logs are sawn to framing timber (Cown et al, 1987). Inglis and Cleland (1982) measured branch index (mean diameter of the largest four radially distributed branches per 5.5 m length) on 628 trees across 25 site/treatment combinations. They found that branch index could be predicted from the log height class, site index, mean DBH at age 20 yrs, and predominant mean height at the time of last thinning. 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 Inglis-Cleland data and more recent data, was developed by Grace (1989).

In the STANDPAK modelling system, log grades are determined from the maximum branch diameter for individual log lengths. A function is used to derive maximum branch size from the predicted branch index. An obvious problem arises when users of STANDPAK wish to predict log grades which incorporate different definitions - for example a grade may allow two branches over 10cm.

There is also a need to validate existing branch index models for a range of sites, silvicultural regimes and genetic material for which data were not available when earlier models were developed. This study has three aims.

- To check current branch index prediction models using branch data collected from a range of farm sites.

- To examine the relationship between branch index and the following :

Site	- Farm vs. Forest
	- Site index
Silviculture	- Final crop stocking within the range 100 - 400 stems/ha
	- Selection ratio
Genetics	- GF rating from 5 (climbing select) to 20 (control pollinated crosses) and also including uninodal (long internode) material

- To define some basic branch statistics and branch size frequency distributions.

The first objective is necessary so that STANDPAK users can have confidence in using predictions of branch index, particularly for farm sites. Given that the current models may not be accurate, the second objective is a step towards constructing an improved model. The third objective is required to link various commercial log grade definitions of branch characteristics to branch index, and to give a better understanding of the way branch sizes are distributed within a standard sized log.

METHODS

To be suitable for measurement, branches need to be moribund or dead. Accurate records of stand histories are also required, so that genetic material, tree stocking and timing of thinning are known. For this study, sites were selected where variations in genetic material, or stocking were available. Eight sites, four farm and four forest, were measured. On all the farm sites, trees had been planted onto improved ryegrass - white clover pasture. Two forest sites, Matea and Goudies, were planted as second rotation crops following felling and logging previous plantations. 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. Twenty five different treatments were sampled including stocking (5 sites), genetics (4 sites), and selection ratio (Rotoehu Forest only). Details of tree stocking, genetic material and site characteristics are shown in Table 1. Trial locations are shown in Fig. 1.

In total, some 44,000 branches were measured on the second logs (5.7-11.2m) of 860 trees. The diameters of all branches over 0.5cm were measured on the horizontal axis, and recorded in relation to quartile and whorl height. In addition, whorl depth, height to the lowest green branch and green whorl, DBH and tree height were also recorded. In almost all cases, the trees were located in permanent sample plots, or if insufficient in number, in the immediate surrounds. Where necessary, the growth data was either extrapolated or interpolated to obtain site index (mean top height at age 20 yrs) and DBH at age 20yrs.

RESULTS

Basic results are shown in Table 2. It can be seen that branch index varies between 4.4cm and 10cm, with coefficient of variation of between 17% and 29%. The average absolute largest branch varies from 5.1cm to 12.8cm, with a slightly larger coefficient of variation than branch index. The internode index, defined as the proportion of log length in clear internodes of 0.6m or greater, varies between 0.02 and 0.35, with a large coefficient of variation. The number of branches per whorl varies between 5.2 and 7.2, and the number of whorls per metre of log between 1.4 and 2.0.

In general, variation about the mean for most variables is similar across the sites and treatments when expressed as a percentage of the mean, with the uninodal (long internode) material indicating some increase in variation.

Table 1. Stand details for second log branches study

Site	Seed source	selection ratio	Number of trees	Site index	Stocking (sph)	DBH age 20
Whatawhata	routine	4:1	48	31.0	91	59.9
Whatawhata	routine	4:1	47	31.1	183	53.9
Whatawhata	routine	4:1	45	31.4	387	44.4
Tikitere	s/o	5:1	48	27.5	95	67.1
Tikitere	s/o	5:1	48	29.5	200	55.4
Tikitere	s/o	5:1	48	33.8	400	45.9
Mourea	uninodal	5:1	24	29.6	192	57.3
Mourea	s/o	5:1	24	29.1	200	60.0
Ngatira	uninodal	3.75:1	24	33.9	200	52.5
Ngatira	s/o	3.75:1	24	35.0	220	54.7
Rotoehu	routine	6:1	47	34.3	248	44.4
Rotoehu	s/o	1:1	50	33.8	230	47.0
Rotoehu	s/o	3:1	48	35.2	245	48.1
Rotoehu	s/o	4:1	47	35.2	247	43.8
Rotoehu	s/o	6:1	48	35.4	248	47.1
N. Boundary	routine	NA	24	32.2	150	48.9
N. Boundary	routine	NA	23	33.1	250	44.8
N. Boundary	routine	NA	24	33.9	341	40.2
N. Boundary	s/o	NA	23	34.0	360	49.6
Goudies	routine	NA	23	29.4	117	48.7
Goudies	routine	NA	22	29.6	250	43.1
Goudies	routine	NA	24	29.6	383	38.9
Matea	routine	NA	24	24.0	150	45.7
Matea	routine	NA	23	23.8	250	40.6
Matea	routine	NA	24	24.0	333	38.2

Table 2. Basic data on second log branches

Site	Branch index mean	CV	Max. branch mean	CV	Int. index mean	CV	Br. / whorl	Whorls / metre	Whorl Depth (m)
Whatawhata	10.0	26	12.8	34	0.12	159	6.0	1.6	0.28
Whatawhata	8.6	26	11.0	34	0.20	89	5.5	1.6	0.24
Whatawhata	6.0	29	7.6	41	0.22	89	5.2	1.6	0.22
Tikitere	12.3	31	15.1	32	0.04	225	5.9	2.1	0.17
Tikitere	7.8	27	9.5	32	0.17	101	5.8	1.8	0.20
Tikitere	5.5	20	6.5	23	0.22	92	5.5	1.6	0.19
Mourea	8.2	27	9.8	34	0.27	92	5.8	1.4	0.25
Mourea	7.4	18	8.9	22	0.19	110	5.3	1.6	0.20
Ngatira	7.5	27	9.2	43	0.24	85	6.5	1.4	0.30
Ngatira	5.9	23	7.1	25	0.28	74	6.1	1.4	0.25
Rotoehu	5.3	21	6.7	34	0.32	68	5.9	1.6	0.21
Rotoehu	5.5	25	6.4	29	0.22	91	6.0	1.7	0.19
Rotoehu	4.8	17	5.5	21	0.24	78	5.8	1.6	0.21
Rotoehu	4.4	17	5.1	20	0.24	65	6.1	1.5	0.22
Rotoehu	4.9	19	5.9	27	0.35	52	5.9	1.5	0.15
N. Boundary	6.3	20	7.5	25	0.29	73	6.4	1.6	0.19
N. Boundary	4.9	23	5.9	24	0.27	72	5.7	1.6	0.17
N. Boundary	4.5	18	5.3	23	0.29	68	5.7	1.6	0.17
N. Boundary	4.6	21	5.5	24	0.27	74	4.9	1.5	0.16
Goudies	6.7	24	7.8	24	0.25	92	6.2	1.7	0.18
Goudies	5.3	18	6.5	21	0.20	88	6.1	1.8	0.17
Goudies	4.8	21	5.8	25	0.20	100	5.8	1.9	0.15
Matea	8.0	17	9.5	19	0.18	102	6.6	1.9	0.21
Matea	6.6	19	7.7	20	0.27	64	7.2	1.7	0.22
Matea	5.7	23	7.1	23	0.23	77	6.0	2.0	0.15

CV - coefficient of variation (= 100.std.dev. / mean)

Branch Index

1. Validation of current branch index prediction models.

The actual values of branch index for all site/treatment combinations were compared with values predicted using the models developed by Inglis and Cleland (1982), and Grace (1989). The errors in prediction are shown in Figs. 2 and 3. The Inglis and Cleland model shows under-prediction 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 shows better accuracy for forest sites, but errors in under-prediction of up to 2.5cm are evident for farm sites. Clearly, neither model can be recommended for predicting branches on farm sites, particularly at low stockings.

2. Examination of factors which affect branch index.

The data shows a strong negative correlation between branch index and site index (Fig. 4), as noted by Grace (1989), with each 5m increase in site index reducing branch index by about 1cm. In addition, a 100 stems/ha increase in tree stocking reduces branch index by approximately 1cm. Typically, farm sites produced a branch index 2cm larger than forest sites. However, when the farm data is corrected for the larger DBH at age 20 years which these sites produce, and when site index and genetic material are held constant, branch index is 'normal' (Fig. 5).

The only anomaly shown in these figures is the Mourea data which produced a smaller branch index than the general trend. This is the only set which received a production thinning at age 17 years, two years before measurement. Although the branches were dead at time of thinning DBH would have responded, and it may also be concluded that many of the rougher, larger branched trees were removed in the thinning. In effect this sample represents the 'best 100' stems/ha out of a 200 stems/ha population. This example suggests that for stands not receiving a direct sawlog regime, results will differ from those shown in Figs. 4 and 5, according to the increasing DBH. There is also an effect of the selection ratio imposed during the thinning. This is confirmed by the Rotoehu data, which indicates a reducing branch index as the selection ratio increases, all other factors being equal.

The effect of genetic improvement on branch index is relatively small compared to other influences, with an indication of about 1cm larger branch index than the trend for long internode material, and slightly smaller branches with higher GF material. For example, trees of similar DBH had a smaller branch index at Tikitere than at Whatawhata as did trees grown from GF20 compared with routine material at Northern Boundary.

Some basic branch statistics

1. Effect of stocking on number of branches over 0.5cm.

On farm sites, the number of branches over 0.5cm in second logs reduces as tree stocking increases, presumably because smaller branches are suppressed at higher stockings. This phenomenon was not apparent on forest sites (Fig. 6). As a result, some statistics such as average branch size are not seen as particularly useful in describing the effects of treatment on branch size. On the other hand, the shape of the branch distribution for the 10% or so largest branches seems quite static in relation to treatment, and as these larger branches are those which cause degrade during processing, it is logical to concentrate any analysis on this component.

2. Relationship between branch index and maximum branch.

An examination of the relationship between branch index and maximum branch for the 25 site/treatment combinations show a strong relationship with no apparent site/treatment affects (Fig.7). The data is compared with the relationship used in STANDPAK, and it can be clearly seen to be biased for larger branched trees. The STANDPAK function overestimates largest branch, and hence overestimates the proportion of L grade logs when branch index is large.

3. Relationship between branch index and commercial log grade definitions.

Commercial log grade definitions often specify the following:

(a) A 'benchmark' branch size, such as 6cm or 10cm.

(b) A maximum number of branches per log permitted greater than the benchmark size

(c) A percentage of the log grade population which must meet the definition, or otherwise be rejected.

Figs. 8-10 show that it is possible to determine the percentage of any population which meets, or exceeds by a certain number of branches, a benchmark size, relative to branch index. These curves have been derived by fitting logistic regression equations to the percentage of logs meeting the grade definitions at each site/treatment. For example, in Fig. 8, if a stand was predicted to have an average branch index of 6cm, for a log grade specification requiring no branches greater than 6cm, over 80% of the logs would be rejected.

4. Effect of site and treatment on distribution of branch diameter within a log.

Because of the need to relate one branch measure such as maximum branch, to another, such as branch index, it is useful to know whether two populations which have a similar branch index, but are dissimilar in terms of other characteristics such as site or stocking, have similar branch size distributions. Figs. 11-13 show diameter frequency distributions for pairs of stands, together with Weibull distribution functions of identical shape, but scaled to fit the data. Fig. 11 shows that two sets with identical branch index of 5.5cm but on different sites and stockings, have similar branch size distributions as indicated by fitted Weibull functions.

Fig. 12 shows another example with different stockings and site indices. At the lower site index there are more branches per log. However the shapes of the branch size distributions are very similar. Uninodal trees had larger branches (Fig. 13), but the branch size distributions are again similar, after scaling for the larger branch size.

5. Factors affecting internodes.

(a) Internode index.

On farm sites internode index was reduced at low stockings but this result was not apparent for forest sites (Fig. 14). The smaller internode index on low stocked farm sites was partly due to greater whorl depths, and at Tikitere to a larger number of whorls per log. Because all sites were situated in the central North Island, other factors identified as affecting internode index by Grace (1992), such as latitude and altitude, could not be examined with any confidence.

(b) Number of whorls per metre.

The number of whorls/m can be used in STANDPAK as an alternative to internode index in expressing the potential of a stand for yielding clear cutting grades during sawing. The internode index for the 25 data sets was predicted from number of whorls/m and whorl depth, using the relationship in STANDPAK. The residuals (actual - predicted internode index) are shown in Fig. 15. It can be seen that the function under-predicts internode index for both farm and forest sites.

(c) An alternative measure of clearwood potential.

If the number of whorls per log , is multiplied by the average whorl depth, then a measure of 'knotty length' of that log is obtained. This measure obviously needs to be divided by the log length to provide the proportion of log length affected by the log length affected by knotty material. Fig. 16 shows that such an index tends to increase as stocking reduces, on both farm and forest sites. This contrasts with internode index, which was recently shown by Grace (1992) to be unaffected by stocking on forest sites.

Sampling stands for branch size.

This study has shown that because of the consistent relationships which occur between various branch measures across a range of treatments, it is possible to rationalise branch sampling in the following manner:

1. Measure the largest single branch on the log.

2. Increase the sample size, perhaps by 50% over that indicated necessary for branch index

This would result in an equivalent or improved accuracy at a greatly reduced cost. For example, measuring the single largest branch in 50 trees, and converting to branch index using the close relationship illustrated in Fig. 7, should give a value with a 95% confidence interval of plus or minus 8%. If branch index was measured, a sample of 45 trees would be required to give the same precision.

CONCLUSIONS

- The existing branch prediction model in STANDPAK derived by Inglis and Cleland (1982) does not work well for farm sites with stocking below 200 stems/ha. This confirms earlier studies by Tombleson et al, who found a similar trend at Kaingaroa.

- A more recent model developed by Grace (1992) also under-predicts branch index on farm sites.

- The data indicate that a simple model to predict size of moribund or dead branches for direct sawlog regimes can be developed for stands at stockings between 100 - 400 stems/ha, and for a range of genetic material. The addition of data from South Island sites will be necessary before such a model is constructed. This is scheduled for the 1992/93 work programme of the collaborative.

- Provided such a model uses DBH at age 20 years, there is no indication that tree stocking needs to be included as a prediction variable.

- There are strong relationships between branch index and maximum branch which hold across a wide range of site, silvicultural and genetic variations. However, the relationship used in STANDPAK appears to be biased.

- It is feasible to link branch index to a number of commercial log grade definitions, without having to reconstruct prediction models.

- The data indicate a trend of reducing internode index with reduced stocking on farm sites. There is no such trend evident on forest sites.

- The relationship between whorl count and internode index as used in STANDPAK appears to be biased.

- An alternative measure of the clear cutting potential of a log can be derived from number of whorls and whorl depth. This index is affected by stocking on both farm and forest sites. The usefulness of this index as a predictor of sawn clear cutting recovery needs to be tested.

- Field measurement of branch index can be rationalised by measuring only the largest single branch on a slightly increased sample size. This can give the same precision at a reduced cost, as measuring branch index.

ACKNOWLEDGEMENTS

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Fig. 1: Stand Locations

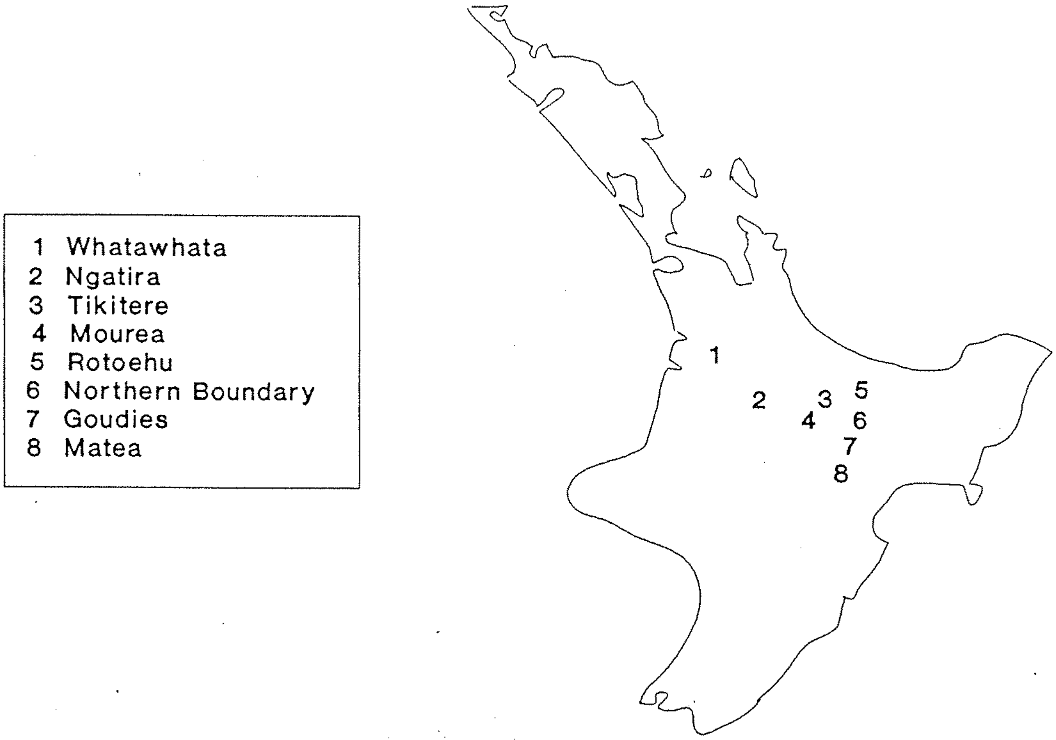

Fig. 2: BIX prediction errors,
Inglis and Cleland Model

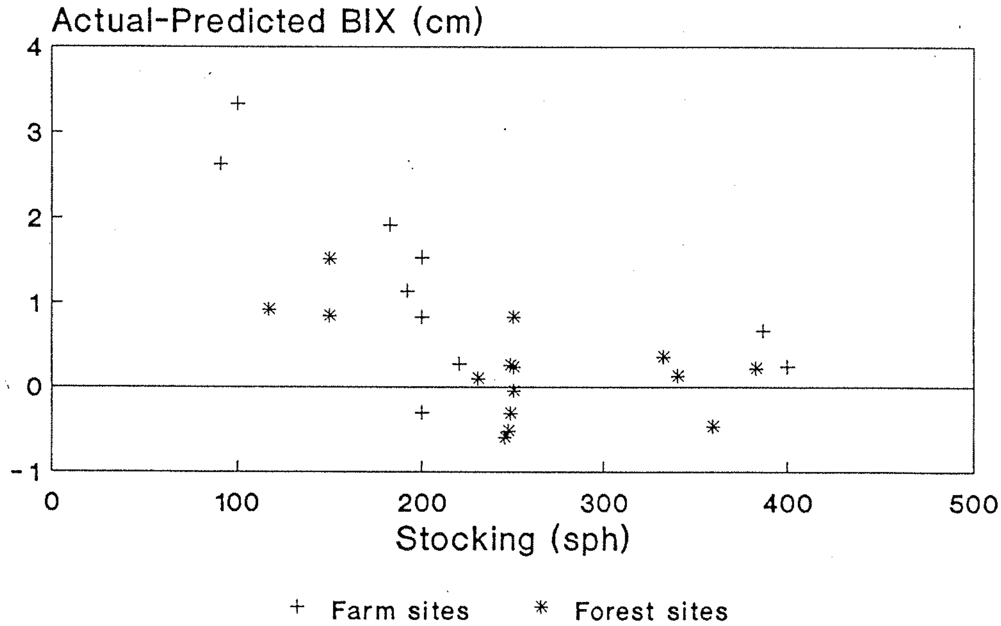

Fig. 3: BIX prediction errors,
Grace Model

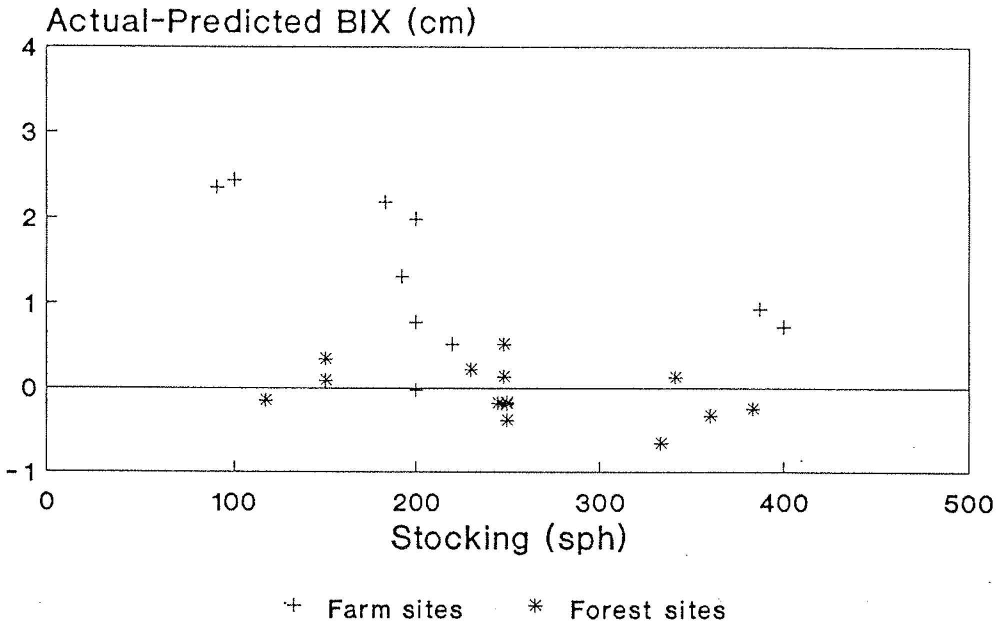

Fig. 4: Branch Index vs. Site Index

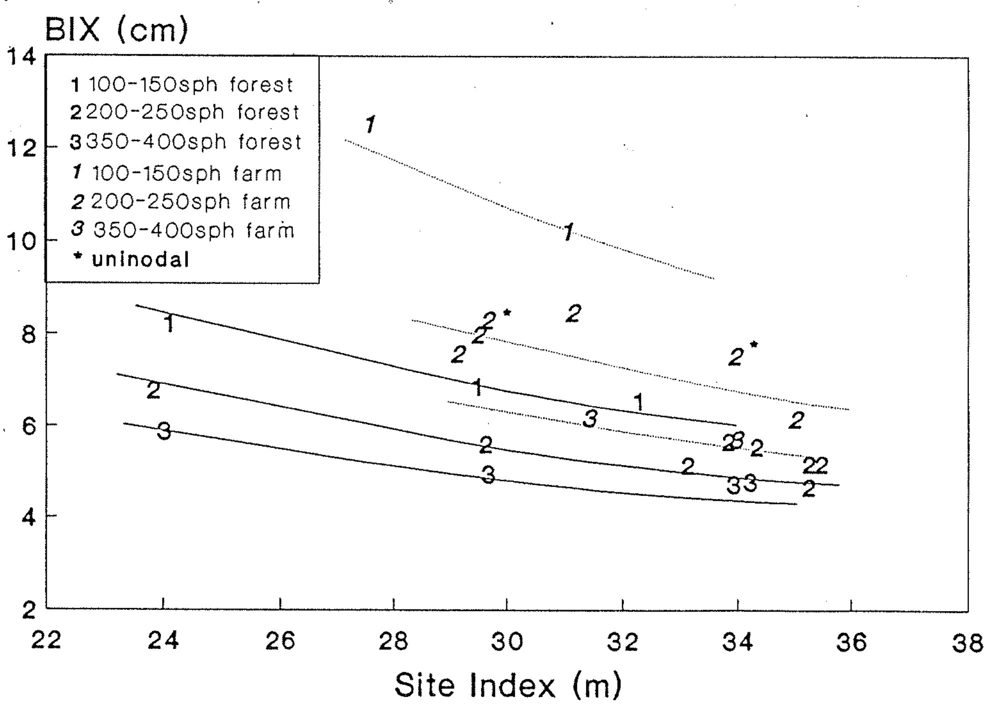

Fig. 5: Branch Index vs. DBH at age 20

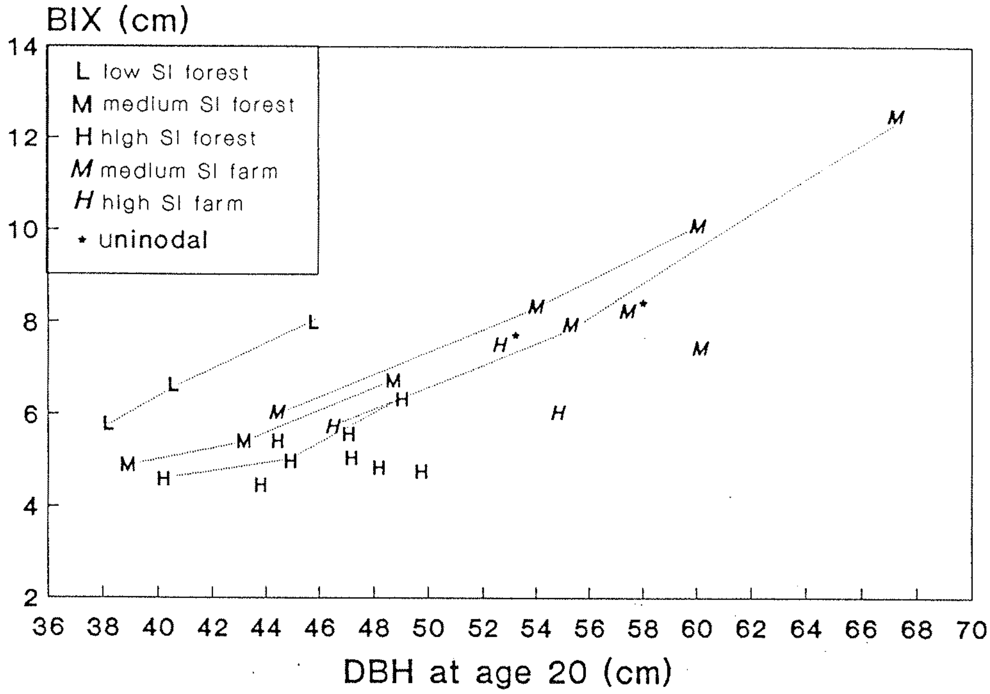

Fig. 6: No. branches vs. Stocking

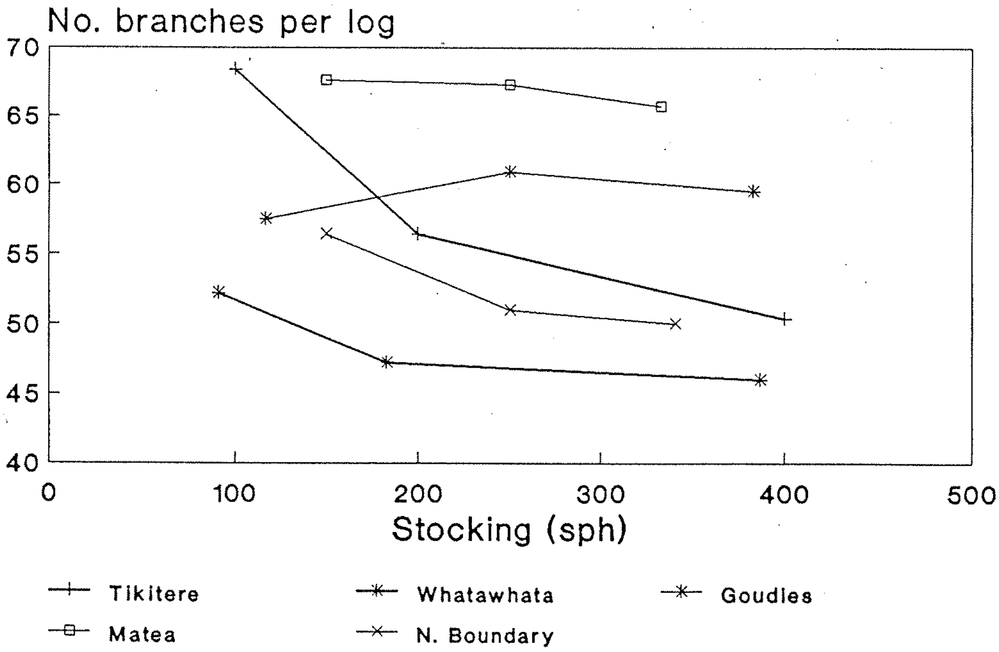

Fig. 7: Mean BIX vs. Maximum branch

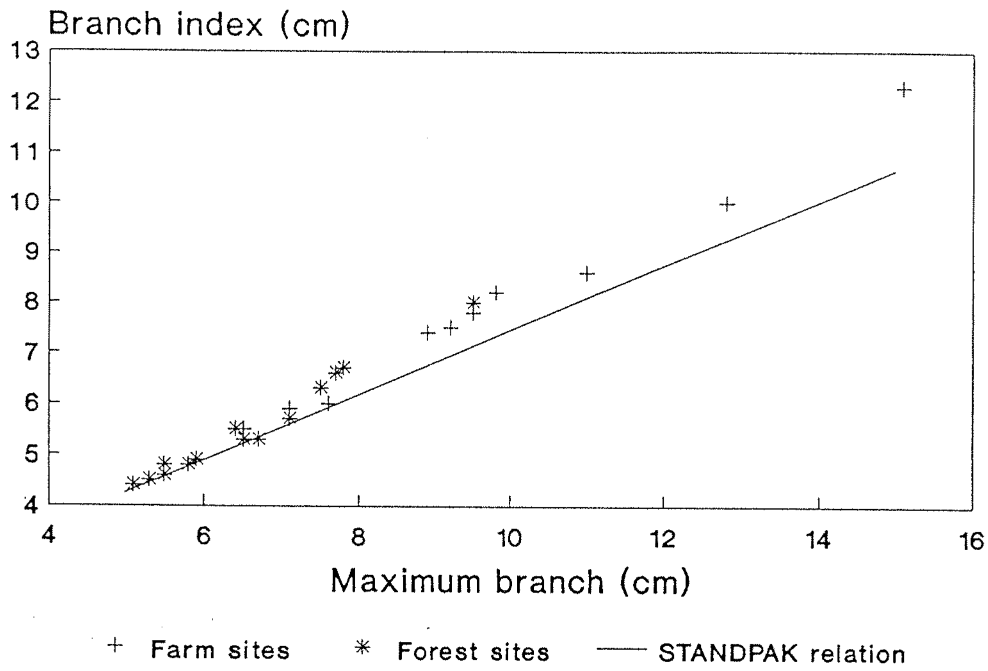

Fig. 8: Percentage of logs with no branch greater than x cm

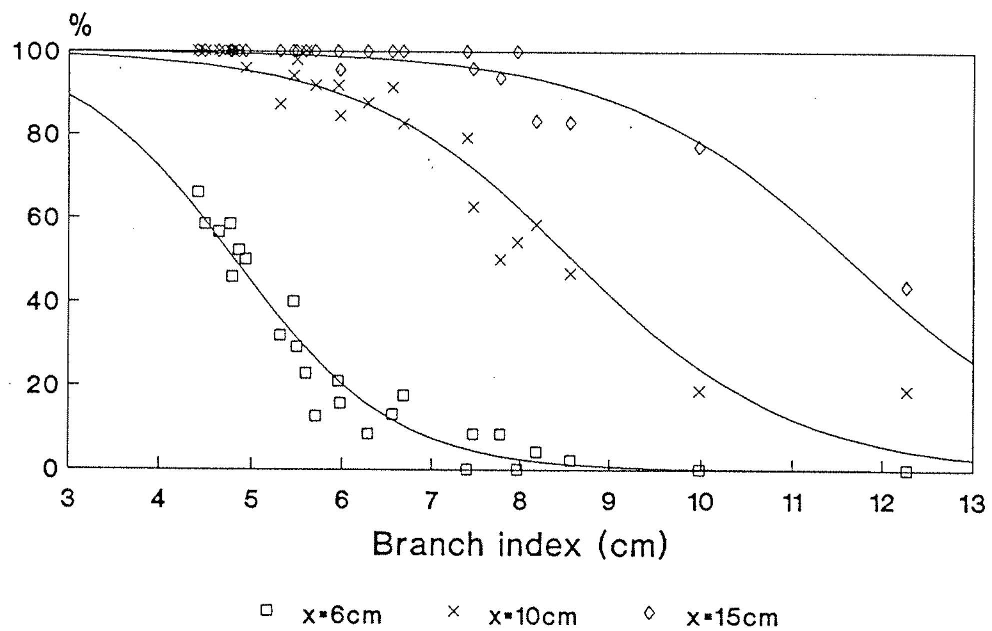

Fig. 9: Percentage of logs with one branch greater than x cm

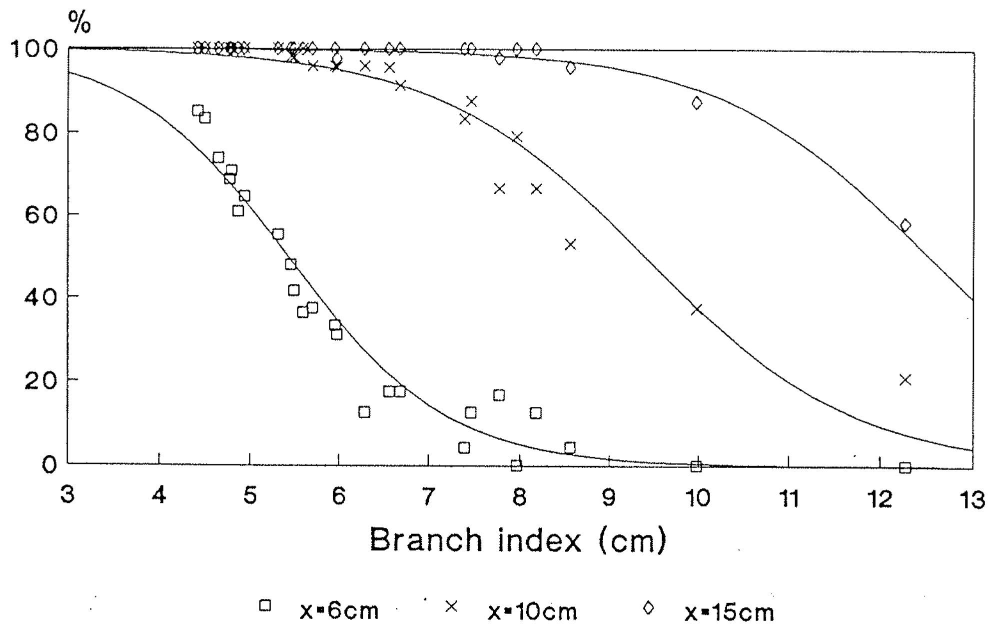

Fig. 10: Percentage of logs with two branches greater than x cm

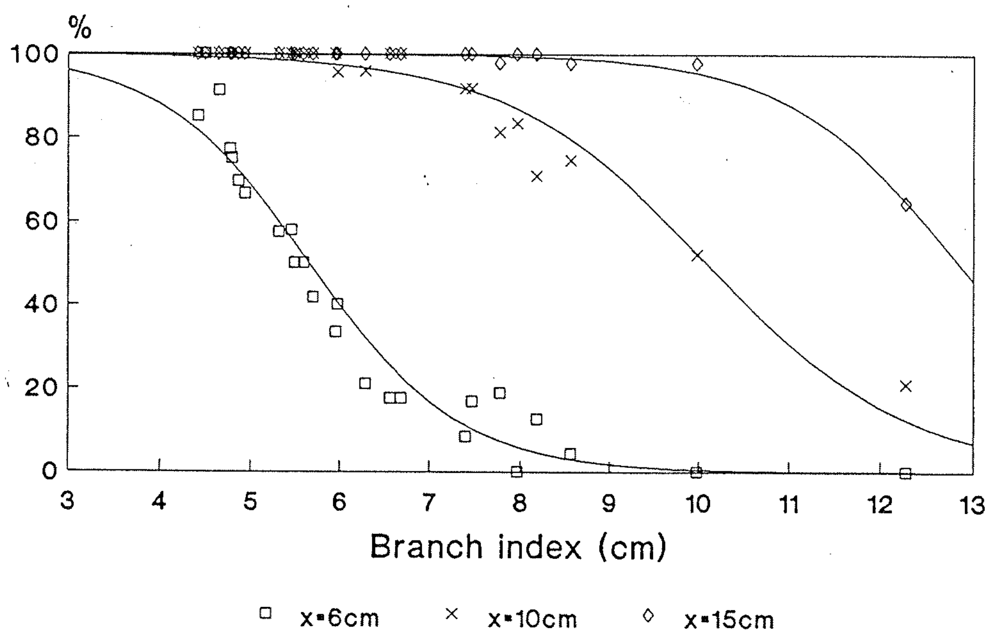

Fig. 11: Branch diameter frequencies, fertile vs. less fertile site

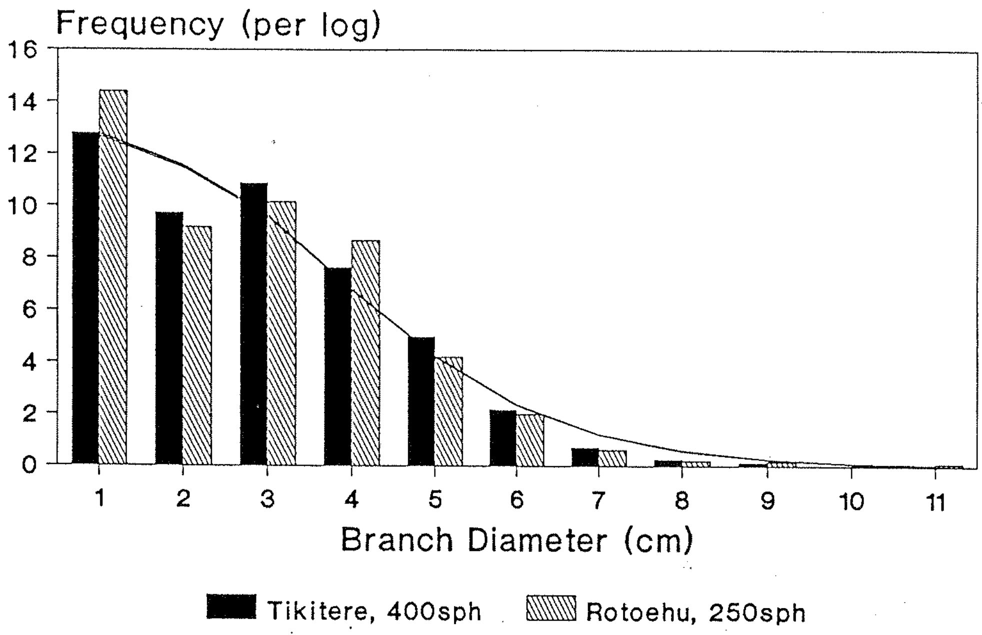

Fig. 12: Branch diameter frequencies, high vs. low site index

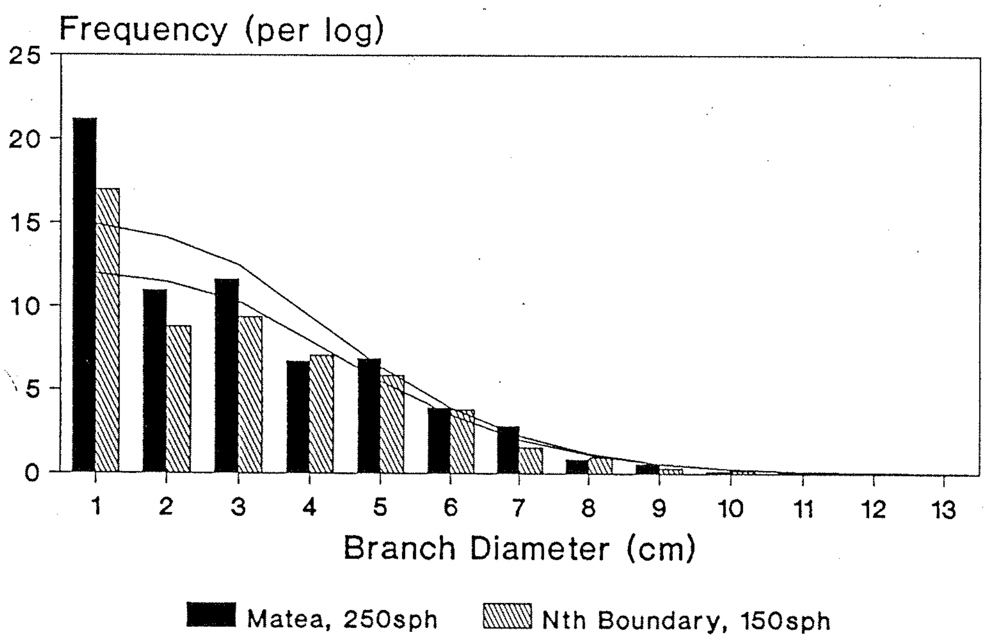

Fig. 13: Branch diameter frequencies, uninodal vs. normal

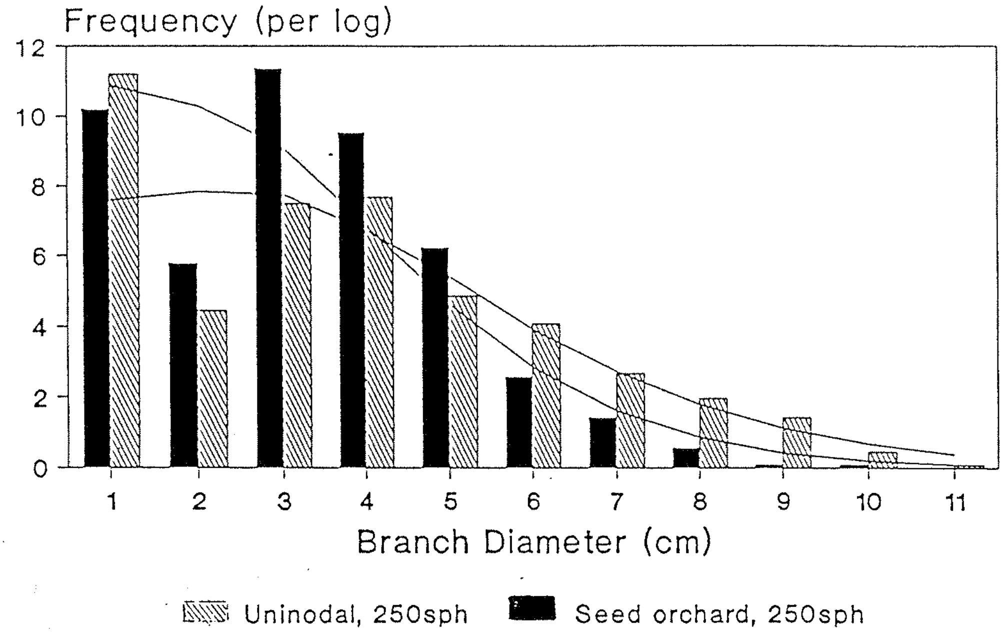

Fig. 14: Internode Index vs Stocking

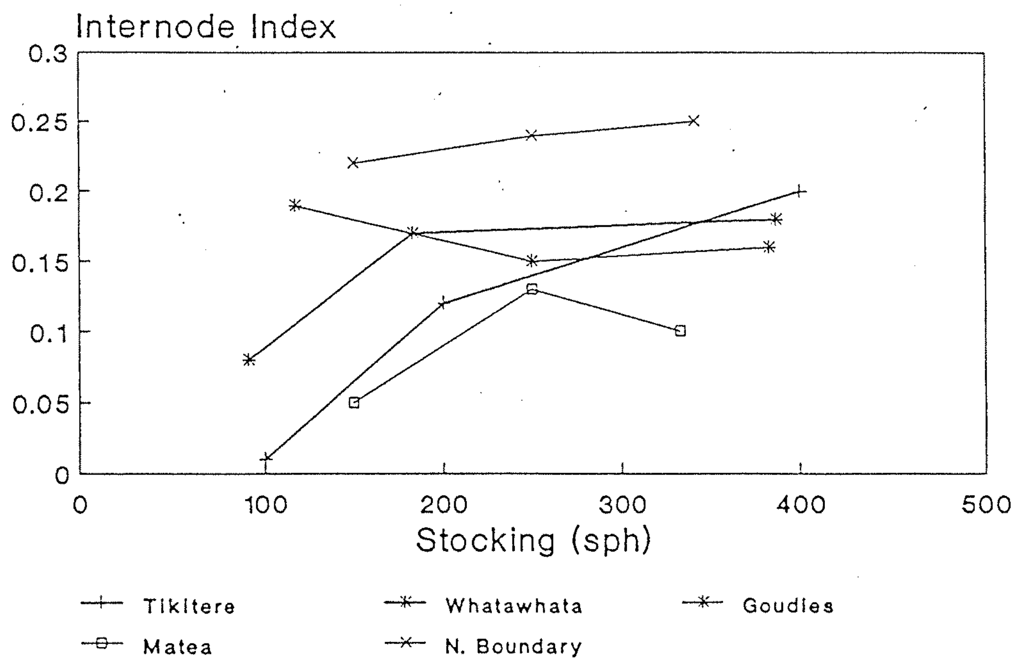

Fig. 15: Internode index prediction errors, STANDPAK model

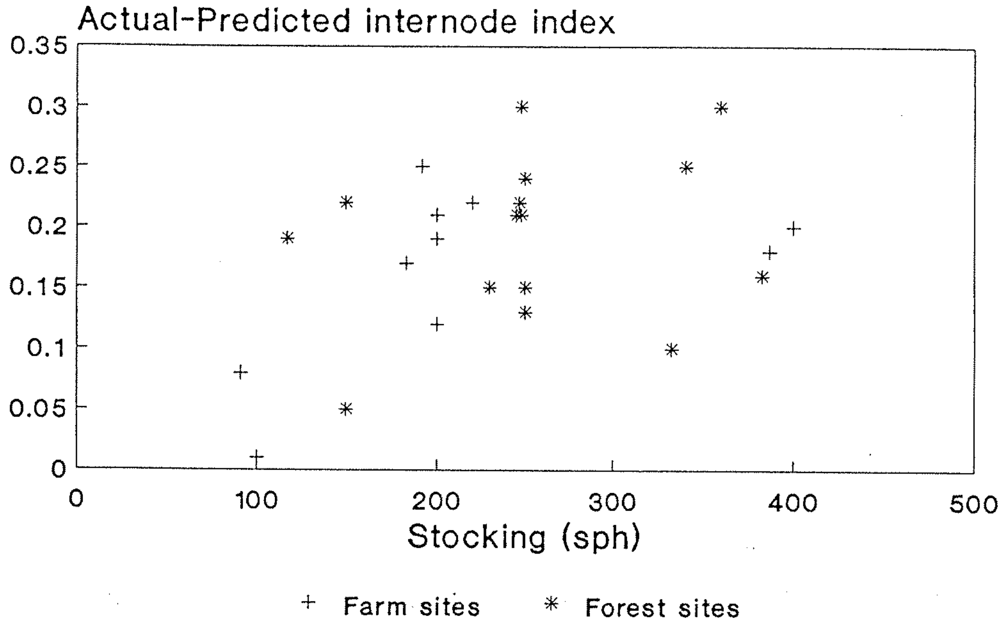

Fig. 16: 'Clear cutting' index vs. Stocking