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INTERNODE LENGTH ESTIMATES FOR IMPROVED BREEDS OF *Pinus radiata*

N.G. WOODS and M.J. CARSON

Report No. 7 November 1988

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EXECUTIVE SUMMARY

INTERNODE LENGTH ESTIMATES FOR IMPROVED BREEDS OF *P. RADIATA*

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REPORT NO 7. NOVEMBER 1988

Internode length is an important variable in the determination of sawn timber quality from unpruned logs of radiata pine. The effect of internode length has been modelled in program STANDPAK, which requires inputs of "Mean Internode Index" (MIX) to generate estimates of timber grade outturn - principally in the 'clearcutting' sawn timber grades. Although MIX can be measured directly on standing trees, it can more easily be derived from estimates of Mean Internode Length (MIL), obtained from counts of branch clusters. This study developed a method for estimating MIX from MIL, while also building a database of MIL estimates for the Growth and Form and Long-internode Breeds of radiata pine. The resulting 'lookup' table of regional estimates of MIX for improved breeds can be used for STANDPAK simulations relating to current and future forest stands. More reliable predictions of unpruned log quality and regime profitability should result.

INTRODUCTION

Internode length is an important variable in the determination of sawn timber quality from unpruned logs of *P. radiata* (D. Don).

The effect of internode length on sawn timber outturn has been modelled in the PREVAL component of SILMOD (produced by the Radiata Pine Task Force at FRI) and subsequently in programs LOGRAD and SAWMOD which are components of STANDPAK (FRI 1987).

At present these models require inputs of internode length in the form of "Mean Internode Index" (MIX). MIX can be entered as either (a)user inputs of MIX where

$$MIX = \frac{\text{Sum of internodes} > 0.6 \text{ metre}}{\text{Log length (m)}}$$

or (b) the user to select a regional value of MIX from a list provided in the user manual.

The MIX values are employed in SAWMOD using regression relationships to predict "timber grade outturn", principally in the "Clear Cuttings" and "Factory Grades" of sawn timber (Cown *et al.* 1987)

MIX can be measured directly on standing trees, or it can be derived from its relationship with Mean Internode Length (MIL) (C. Inglis, unpub. results). Estimates of MIL can, in turn, easily be obtained from counts of branch clusters (C. Inglis, unpub. results, Woods, 1988). This ease of measurement combined with the better statistical properties of MIL make MIL the preferred trait for measurement on standing trees.

OBJECTIVES

Objectives of this study were to:

1. Obtain estimates of MIL and MIX for trees of the Growth and Form and Long-internode Breeds over a range of forest sites.

2. Develop a relationship for converting MIL estimates from cluster counts to MIX estimates for use in STANDPAK.

METHOD

MIL measurements on standing trees

A large data base (consisting of measurements on 1128 trees) had previously been collected primarily by Inglis but also by Carson, Briscoe and Shelbourne (Carson and Inglis, 1989).

Each tree was representative of one of three improved categories with the Growth and Form Breed "GF16" being further divided into three seedlots as shown in Table 1. Trees were located in Genetics and Tree Improvement trials representing the oldest plantings of each of the breeds available on six sites within New Zealand (see Appendix 1).

TABLE 1 - Breed characteristics

Breed characteristics	GF rating[1]
Growth and Form Breed	14
Growth and Form Breed (Short Seedlot)	16 s
Growth and Form Breed (Medium Seedlot)	16 m
Growth and Form Breed (Long Seedlot)	16 l
Long Internode Breed	8 (LI 19)

1] see Vincent, 1987

The seedlots for which measurements were taken are shown in Table 2. A brief description of the sites included in the study is shown in Appendix 2.

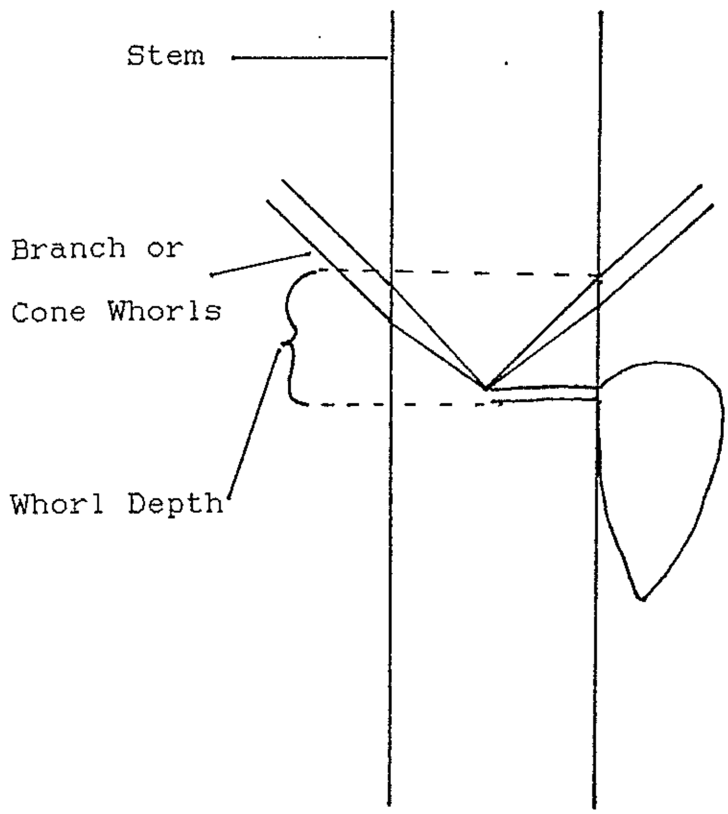
TABLE 2 - Seedlots measured at each site

Sites	Breeds				
Golden Downs	GF14	GF16s	GF16m	GF16l	Long
Northern Kaingaroa			GF16m	GF16l	
Ngatira	GF14				Long
Omataroa	GF14				Long
Otago Coast		GF16s	GF16m	GF16l	Long
Woodhill		GF16s	GF16m	GF16l	Long

Each tree was climbed to a height of 11.2 metres with recordings made on the height to the bottom and top of each whorl from the ground with an allowance of 0.2 metres for stump height. From these measurements MIL and "Whorl Depth" were calculated with the use of BRAN 3, (a program written by J. Parsons of FRI). Whorl Depth is defined as "the vertical depth of stem associated with the presence of branches or cones" (Figure 1).

For the purposes of this study MIL and MIX estimates are given for two 5.5 metre logs from 0.2 metres to 11.2 metres. This made the estimates compatible with STANDPAK for which calculations are based on 5.5 m log lengths from a height 0.2 m above ground level.

FIGURE 1 - Whorl depth illustrated



Using the General Linear Models procedure in SAS (Proc GLM) variables MIL and MIX were compared for differences between breeds and sites and the breed*site interaction, with the significance of differences in breed and site means tested with the "Waller" option in SAS (which uses the Waller-Duncan multiple comparison test).

MIL estimates from cluster counts

MIL estimates were also calculated for data from other sites involving cluster counts in a more recent series of improved breeds trials (see Appendix 1 for trial locations and Appendix 3 for site descriptions).

MIX estimates were calculated on the same data with the use of the appropriate derived regression relationship.

RESULTS AND DISCUSSION

MIL measurements on standing trees

MIL was analysed in an ANOVA comparing sites and breeds. However since the frequency of MIL was not normally distributed about the mean value a logarithmic transformation was performed on the data. The analysis (Table 3) indicates that there are significant differences for Log (MIL) between breeds and sites and that the site*breed interaction is also significant.

TABLE 3 - Analysis of variance for log (MIL)

Source	df	MS	Breed SS	F	Pr > F
Site	5	4.695	23.473	14.39	0.0005
Breed	4	2.242	8.967	6.87	0.0081
Site*Breed	9	0.326	2.935	3.85	0.0001

Table 4 shows the differences between sites and between groups for the estimates of mean MIL. The Long Internode Breed expresses significantly higher MIL than elements of the Growth and Form breed, and the GF16s seedlot expresses the lowest MIL indicating that this trait is under strong genetic control (Carson and Inglis, 1989). The interaction effect (although significant statistically) is of minor importance compared with the site and breed differences and did not cause changes in ranking. The absence of meaningful site*breed interaction for internode length has been confirmed by Genetics and Tree Improvement studies (Shelbourne unpubl data) and reported by Carson and Inglis (1989).

TABLE 4 - Means of MIL (m) by Site and Breed

Site[1]	Long	GF16l	Breed GF16m	GF16s	GF14
GD	0.53	0.46	0.46	0.39	0.41
NB		0.51	0.48	0.40	
NG	0.70				0.39
OC	0.54	0.46	0.45	0.41	
OM					0.49
WH	0.37	0.34	0.34	0.30	
Means[2]	0.54 A	0.44 B	0.43 B	0.37 C	0.43 B

1] GD = Golden Downs; NB = Northern Boundary Kaingaroa; NG = Ngatira; OC = Otago Coast; OM = Omataroa; WH = Woodhill

2] Means with different letters are significantly different at Pr ≥ 0.05.

(Appendix 2 for brief site descriptions).

Internode length appears to depend greatly on site characteristics, although the actual causes of variation are not well understood. It is thought that internode length may be related to latitude, with decreasing internode lengths occurring at lower latitudes, although other factors such as soil type, site fertility, soil moisture conditions and position on the stem (Bannister 1962) may also have an effect.

In this study Woodhill, which is a nitrogen deficient site at the highest latitude or any of the sites studied has the shortest MIL estimate of all sites measured for each of the respective breeds (Table 4).

Results in Tables 4 and 5 indicate that the difference in MIL between the Growth and Form and Long Internode Breeds increases as the site mean MIL increases, (i.e. Woodhill with a mean site MIL of 35 cm has a range from the shortest seedlot (GF16s) to the longest seedlot (Long Internode) of only 7 cm whilst Golden Downs with a site mean MIL of 46 cm has a range from the shortest seedlot (GF16s) to the longest seedlot (Long Internode) of 14 cm).

There may be a trend of a greater range of mean MIL expression on more fertile sites, as was reported by Inglis (unpublished) from data on the unimproved breeds. Sites with a high mean MIL(e.g. Ngatira) tend to express a much wider range in MIL than sites with a low mean MIL (e.g. Woodhill) as illustrated in Table 5.

TABLE 5 - Ranges in MIL (m) for six sites

Site	Range	MIL[1]	Std error
GD	0.25 - 1.03	0.46 D	0.0074
NB	0.24 - 1.15	0.48 CD	0.0113
NG	0.26 - 2.20	0.55 A	0.0313
OM	0.25- 1.29	0.52 B	0.0197
OT	0.16 - 1.62	0.50 BC	0.0148
WH	0.22 - 0.86	0.35 E	0.0067

1] Means with a different letter are significantly different in a Waller Duncan multiple range test at $Pr \geq 0.05$

MIL estimates from cluster counts

Estimates of MIL by seedlot for six further sites (Appendix 3 and 4) were obtained using the cluster count technique.

$$MIL = \frac{L - (n \times d)}{n + (I-1)}$$

where L = length of stem or log being measured

n = number of branch or stem cone whorls per length of stem or log being measured

d = whorl depth (Figure 1)

I = number of times per stem (or log) that the log end does not coincide with a branch or stem cone whorl (with values of 0, 1, or 2 - see Woods, 1988).

The trees measured were part of an extensive range of Genetics and Tree Improvement progeny tests and represent some of the oldest plantings of the respective improved breeds growing in NZ.

Since seedlots at each site were growing at between 600-800 spha stocking can probably be ruled out as having any major effect on the variation in MIL for these data.
Thirty trees of each breed at each site were randomly selected and measured. From a preliminary sample on a high fertility site near Rotorua (Mangaone Seedling Seed Orchard, Tasman Forestry Ltd) it was calculated that a sample size of 25 trees would be adequate to estimate the stand mean MIL to within 5 cm with 95% confidence. In all cases 30 trees were measured at each site to supply extra confidence in the estimate as well as being a comfortable single day effort.

The data were collected from both pruned and unpruned stems from 0.2 m to 11.2 m height with two 5.5 m logs being identified within this portion. Care needed to be exercised during the whorl counting on pruned stems so as not to miss any small whorls which had occluded and whorls which did not have branch stubs right around the stem.

TABLE 6 - MIL Estimates for improved breeds on six sites
Log 1 (0.2 - 5.7 m)

Site[1]	Breed					
	Unimproved		Growth and Form[2]			Long internode
	GF1	GF7	GF14	GF14s	GF16	
K327		0.38	0.42	0.31	0.39	
K1218		0.42	0.44		0.33	0.55
Onepu		0.34	0.35	0.33	0.36	
Mang	0.45	0.46	0.42	0.40		
Taupo	0.36	0.32	0.32	0.29	0.32	
Weiti	0.40	0.34	0.38	0.34		

1] K327 Kaingaroa Forest Compartment 327
K1218 Kaingaroa Forest Compartment 1218
Onepu Tasman Forestry Ltd Kawerau
Mang Mangaone Seed orchard Tasman Forestry Ltd Kawerau
Taupo Lake Taupo Forest Compartment 221
Weiti East Coast Bays Auckland NZFP Ltd

2] The GF14s seedlot represented crosses amongst clones of the '875 series', which are derivatives of the '268 series' (represented by the GF16 seedlot). The GF14 seedlot was a seed orchard seedlot of '850 series' origin.

The results from these field measurements are shown in Tables 6 and 7. They tend to confirm the trends between sites and breeds that were identified from the earlier analysis of the Inglis *et al* data set.

TABLE 7 - MIL Estimates for improved breeds on six sites
Log 2 (5.7 - 11.2 m)

Site[1]	Breed					
	Unimproved		Growth and Form[2]			Long internode
	GF1	GF7	GF14	GF14s	GF16	
K327		0.64	0.42	0.31	0.39	
K1218		0.60	0.56		0.47	0.97
Onepu		0.54	0.57	0.61	0.54	
Mang	0.66	0.63	0.61	0.55		
Taupo	0.64	0.59	0.62	0.48	0.59	
Weiti	0.50	0.39	0.42	0.41		

1] K327 Kaingaroa Forest Compartment 327
K1218 Kaingaroa Forest Compartment 1218
Onepu Tasman Forestry Ltd Kawerau
Mang Mangaone Seed orchard Tasman Forestry Ltd Kawerau
Taupo Lake Taupo Forest Compartment 221
Weiti East Coast Bays Auckland NZFP Ltd

The MIL estimates in the second log (i.1. 5.7 - 11.2 m) are in most cases longer than those in the first log (i.e. 0.2 - 5.7 m) which tends to reinforce the findings of Inglis (unpublished) that the maximum internode length occurs in the 3-11 m height range. The range of mean MIL at each site also tends to be smaller in the first log.

In most cases the GF16 and GF14s seedlots expressed the shortest MILs whilst the Long Internode Breed had the longest MIL. This tends to reflect the selection emphasis for the two breeds with the Long Internode Breed being selected to produce "clears" without the need for pruning whilst the GF14, GF14s and GF16 seedlots of the Growth and Form Breed were selected for good form and vigour, which is positively correlated with branch cluster frequency (Carson 1987).

MIX estimates (Tables 8 and 9) tend to show similar trends between breeds as MIL (as expected, since MIX is derived from MIL).

TABLE 8 - MIL Estimates for improved breeds on six sites
Log 1 (0.2 - 5.7 m)

Site[1]	Breed					
	Unimproved		Growth and Form[2]			Long internode
	GF1	GF7	GF14	GF14s	GF16	
K327		0.27	0.30	0.20	0.27	
K1218		0.30	0.32		0.22	0.42
Onepu		0.23	0.24	0.22	0.25	
Mang	0.33	0.34	0.30	0.28		
Taupo	0.25	0.21	0.21	0.19	0.21	
Weiti	0.28	0.23	0.27	0.23		

1] K327 Kaingaroa Forest Compartment 327
K1218 Kaingaroa Forest Compartment 1218
Onepu Tasman Forestry Ltd Kawerau
Mang Mangaone Seed orchard Tasman Forestry Ltd Kawerau
Taupo Lake Taupo Forest Compartment 221
Weiti East Coast Bays Auckland NZFP Ltd

2] The GF14s seedlot is of "875 series" origin, and has similar branching habit to the GF16 seedlot

TABLE 9 - MIL Estimates for improved breeds on six sites
Log 2 (5.7 - 11.2 m)

Site[1]	Breed					
	Unimproved		Growth and form[2]			Long internode
	GF1	GF7	GF14	GF14s	GF16	
K327		0.50	0.30	0.20	0.27	
K1218		0.46	0.43		0.35	0.79
Onepu		0.41	0.43	0.47	0.41	
Mang	0.51	0.49	0.47	0.42		
Taupo	0.50	0.45	0.48	0.35	0.45	
Weiti	0.37	0.27	0.30	0.29		

1] K327 Kaingaroa Forest Compartment 327
K1218 Kaingaroa Forest Compartment 1218
Onepu Tasman Forestry Ltd Kawerau
Mang Mangaone Seed orchard Tasman Forestry Ltd Kawerau
Taupo Lake Taupo Forest Compartment 221
Weiti East Coast Bays Auckland NZFP Ltd
2] The GF14s seedlot is of "875 series" origin, and has similar branching habit to the GF16 seedlot

Prediction of MIX from MIL

At present in STANDPAK a MIX value is input either as a regional value from the "look up" table or from field data relevant to the area being investigated.

There is no mechanism as yet for converting MIL to sawn grade outturn in STANDPAK. For the method of estimating MIL in the field to be useful in the meantime it must be possible to predict a value for MIX.

The regression of MIX on Mean whorl (Log length/.whorl no.) and Whorl Depth (Table 10) showed that these variables were associated with a large proportion of the variation in MIX. There were however additional statistically significant site and breed effects, although the site*breed interaction was not significant. Even though the amount of variation explained

TABLE 10 - Regression of MIX on Mean whorl, Whorl depth and class variables

Source	DF	SS	MS	F	Pr>F
Mean whorl	1	18.458	18.458	1043.31	0.0001
Whorl depth	1	1.072	1.072	60.56	0.0001
Site	5	2.619	0.525	29.60	0.0001
Breed	4	1.284	0.321	18.15	0.0001
Site*Breed	9	0.257	0.029	1.61	0.1062

by site and breed effects is relatively small compared with Mean Whorl and Whorl Depth it was necessary to determine their importance. A further regression analysis showed that at Woodhill and with the Long Internode Breed the model for predicting MIX from MIL needed to include coefficients for site and breed effects.

A regression relationship to predict MIX with calculated MIL was derived from the data. The resulting relationship had an R^2 of 0.77 and the following characteristics.

TABLE 11 - Model for estimating MIX from MIL

	Estimate	T	Pr>T	Std Error
Intercept	-0.7306998	-6.71	0.0001	0.010897
b1	0.89039118	41.12	0.0001	0.021653
b2	-0.08586627	-4.41	0.0001	0.020885
b3	0.06558381	2.65	0.0008	0.024742

Coefficient b2 is included in the equation for Woodhill sites and coefficient b3 where measurements of MIL were derived from the Long Internode Breed. i.e. for Woodhill, all breeds except Long Internodes

MIX = -0.0731 - 0.0859 + 0.8904 * (MIL)

for Woodhill Long Internode Breed

MIX = -0.0731 + 0.0656 -0.0859 + 0.8904 * (MIL)

for the Long Internode Breed at other sites

MIX = -0.0731 + 0.0656 + 0.8904 * (MIL)

for other sites and other breeds

MIX = -0.0731 + 0.8904 * (MIL)

Measured mean values for MIX as derived by BRAN 3 from the Inglis Data base are shown in Table 12.

TABLE 12 - Means of MIX (m) by site and breed

Actual

Site[1]	Long Internode	Growth and Form GF16l	GF16m	GF16s	GF14
GD	0.52	0.40	0.39	0.28	0.36
NB		0.45	0.40	0.26	
NG	0.56				0.25
OC	0.56	0.36	0.33	0.28	
OM					0.42
WH	0.24	0.14	0.18	0.09	
Means[2]	0.47 A	0.34 B	0.33 B	0.23 C	0.34 B

1] GD = Golden Downs; NB = Northern Boundary Kaingaroa; NG = Ngatira; OC = Otago Coast; OM = Omataroa; WH = Woodhill

(Appendix 2 for brief site descriptions).

When the predicted MIX values (Table 13) were compared with the measured MIX values (Table 12) it was seen that the models generally gave reasonable estimates of MIX. The greatest over-prediction was of 5 cm with the Ngatira Long Internode Breed and the largest under-prediction was 9 cm with the Otago Coast Long Internode Breed.

TABLE 13 - Predicted Means of MIX by site and breed
(from MIL data in Table 4)

Predicted.

Site[1]	Long Internode	Growth and Form GF16l	GF16m	GF16s	GF14
GD	0.46	0.33	0.33	0.27	0.29
NB		0.38	0.36	0.28	
NG	0.61				0.27
OC	0.47	0.34	0.33	0.29	
OM					0.36
WH	0.18	0.14	0.14	0.11	

1] GD = Golden Downs; NB = Northern Boundary Kaingaroa; NG = Ngatira; OC = Otago Coast; OM = Omataroa; WH = Woodhill

Development of regional "lookup" table

From the results presented in Tables 8, 9 and 12, and other data collected in recent years (Inglis, Carson, unpub. data) a "lookup" table has been compiled for MIX of improved breeds (Table 14). Estimates of MIX for seedlots in the 'Central North Island pumice' region can be considered fairly reliable, as they are each based on measurements from seven or eight trials. Remaining measurements in Table 14 must be considered preliminary at this stage, but they are likely to be more appropriate than the estimates for unimproved radiata pine currently available in STANDPAK (see Appendix 3 of STANDPAK manual).

Further estimates of internode length will be required from trials containing improved breeds (as they become old enough to measure) to obtain reliable indications of site and regional groupings for this trait. Future research may be undertaken to develop a predictive model for MIL, based on knowledge of climatic, soil and stand variables.

CONCLUSIONS

This study has provided internode length estimates for Growth and Form and Long-internode Breeds at a range of New Zealand sites. Estimates of MIL from cluster counts can now be used to estimate MIX, so that STANDPAK users can either (a) more easily obtain MIX estimates for their own forest stands, or (b) use the "lookup" table provided in this report. Predictions of timber grade outturn and the relative profitability of stands established with improved breeds should be more reliable as a result of this research.

TABLE 14 - Regional 'lookup' table for MIX estimates representing improved breeds

Region	Breed Growth and form				Long Internode
	GF1-7	GF14("850")	GF14-16("268")	GF20	
North Island clays	0.32	0.30	0.29	-	-
North Island sands	0.17	0.15	0.15	0.09	0.24
Central North Island pumice	0.50	0.42	0.34	0.26	0.68
CNI Farms	-	0.25			0.56
Nelson	0.43	0.30	0.39	0.28	0.52
Southland	0.42	0.37	0.33	0.28	0.56

NOTE
1. Estimates for CNI pumice are most reliable
2. Above estimates apply to 5.7 m - 11.2 m log height class
   - for all regions except 'North Island sands'
   subtract 0.2 m from above values for 0.2-5.7 m log height class, and
   subtract 0.1 m for log height classes greater than 11.2 m
   (for 'North Island sands', subtract 0.1 m and 0.05 m, respectively)

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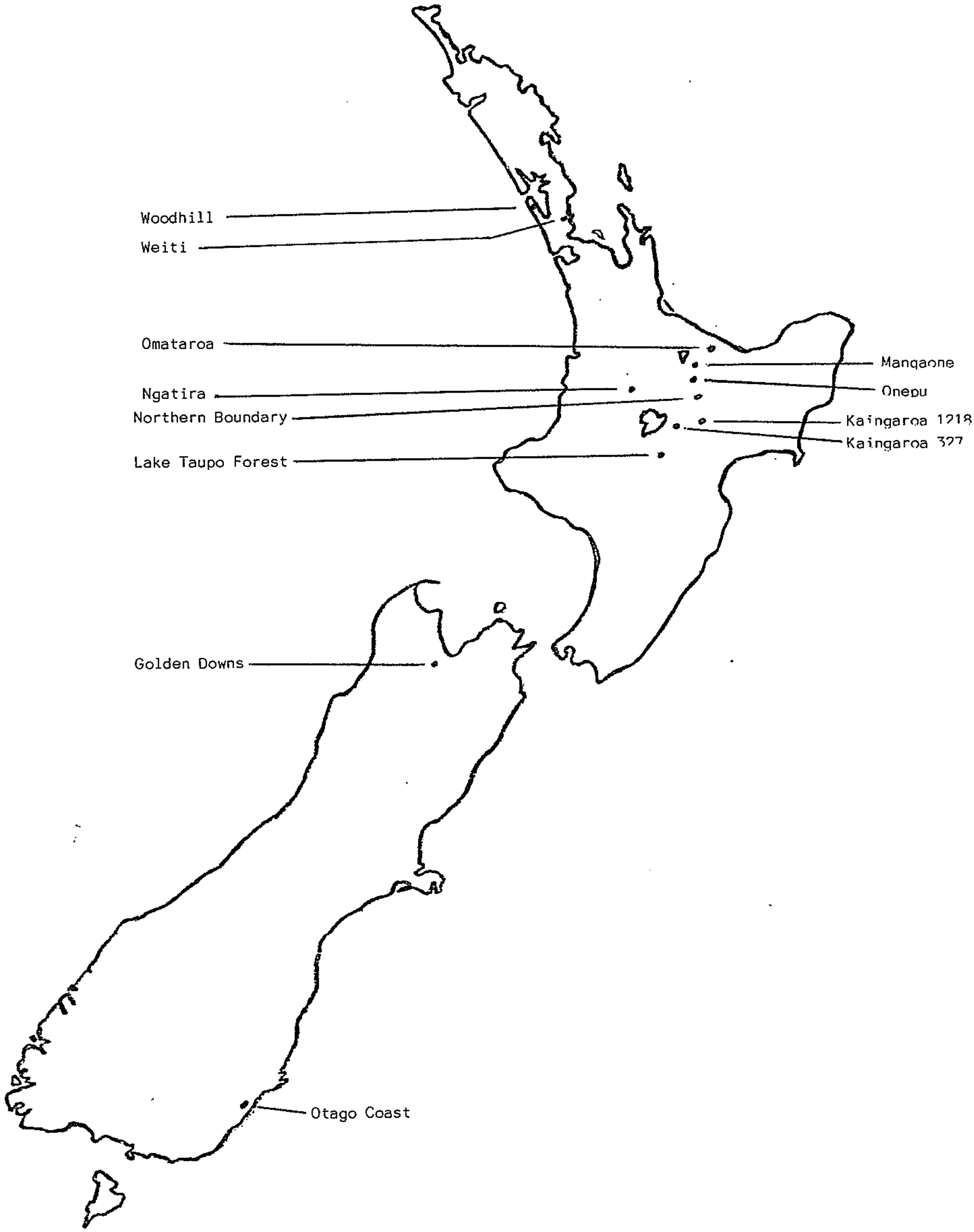
APPENDIX 1 - Sites measured for Inglis et al data base and cluster count technique



APPENDIX 2 - Site description for sites measured by Inglis *et al*

Site	Lat (degs)	Alt (m)	Aspect	SI[2] (m)	Soil[3]
GD	41.33	335	SW	25	Loams derived from Moutere gravel
NB	38.33	450	var	35	Recent pumice
NG	38.20	400	NE	36	Yellow brown pumice soils
OM	38.17	50	N	35	Recent gley and organic soils
OC	45.83	250	N	24	Silty loams derived from sedimentary rocks
WH	36.50	30	W	24	Recent sands

1 From "NZ Atlas" A.R. Shearer 1976
2 Site index estimates from heights taken in this study and converted to height (in metres) at age 20 years according to R. Tennent and H.E. Burkhart (unpublished tables)
3 From "Soil Bureau Bulletin 1968" NZ DSIR

1] GD = Golden Downs; NB = Northern Boundary Kaingaroa
NG = Ngatira; OM = Omataroa
OM = Omataroa; WH = Woodhill

APPENDIX 3 - Site description for sites measured using the "cluster count" technique

Site[1]	Lat[2] (degs)	Alt (m)	Aspect	SI[3] (m)	Soil[4]
K327	38.50	570	W	28	Taupo yellow brown pumice
K1218	38.42	220	SE	28	Taupo yellow brown pumice
Mang	38.08	200	E	30	Tarawera recent volcanic ash
Taupo	38.83	570	S	25	Taupo yellow brown pumice
Weiti	36.66	30	N	25	Yellow brown earths
Onepu	38.08	150	N	30	Tarawera recent volcanic ash

1] K327 = Kaingaroa Cpt 327
K1218 = Kaingaroa Cpt 1218
Mang = Mangaone seedling seed orchard
Taupo = Lake Taupo Forest
Weiti = Weiti Block, NZFP Ltd
Onepu = Onepu, Tasman Forestry Ltd., Kawerau

2] From "NZ Atlas", A.R. Shearer 1976

3] Site index estimated from heights taken in this study and converted to height (in metres) at age 20 years according to R. Tennent and H.E. Burkhart (unpublished tables)

4] From "Soil Bureau Bulletin 1968" NZ DSIR.

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