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RELATIONSHIP BETWEEN ENVIRONMENTAL VARIABLES AND RADIATA PINE GROWTH WITHIN THE CANTERBURY GROWTH MODELLING REGION

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EXECUTIVE SUMMARY

The objective of the Cooperative project 'Growth variation among sites' is to understand the relationship between radiata pine growth and easily measured environmental variables, with the long term objective of being able to improve the current growth models.

An understanding of how trees grow is needed to determine whether it is realistic for the environmental variable to influence growth.

The relationship between environmental variables and the residuals from fitting the Canterbury Growth Model have been examined.

It may be possible to explain some of the residual variation through the inclusion of environmental variables in a growth model.

RELATIONSHIP BETWEEN ENVIRONMENTAL VARIABLES AND RADIATA PINE GROWTH WITHIN CANTERBURY GROWTH MODELLING REGION

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INTRODUCTION

The objective of the Stand Growth Modelling Co-operative project "Growth Variation among Sites" is to:

understand the relationship between radiata pine growth and easily measured environmental variables with the long-term objective of being able to improve the current growth models by one or more of the following methods:

- revision of the current growth modelling regions
- inclusion of environmental variables in growth models
- development of indices of site quality that are an improvement on site index

The relationship between environmental variables and growth can be determined by plotting the residuals (errors) from fitting a growth model against environmental variables. Trends in the residual plots will indicate a relationship between the residuals and environmental variables. The significance of such trends can be determined by calculating correlation coefficients. However such analyses do not tell us whether the environmental variable under consideration is actually influencing growth. An understanding of how trees grow is needed to determine whether it is realistic for the environmental variable to influence growth.

OBJECTIVE

The objective of the current study is to investigate the relationship between environmental variables and the growth of radiata pine in the Canterbury Growth Modelling Region by examining the relationship between environmental variables and the residuals from fitting the Canterbury radiata pine growth model.

DATA

The Canterbury Radiata Pine Growth Model was developed by M. Lawrence (Lawrence, 1988). Most of the data used to develop the model were from the PSP system, and covered the period up to and including the 1986 measurements. 6% of the data were from sectional measurements from Selwyn Plantation Board Forests.

Measurements which fell into the following categories were deleted from the database:

- measurements taken in December, January, or February
- poisoned thinned
- regeneration in the stand
- fertilised stands
- more than 2 trees per plot windblown
- mean DBH of windblown trees > mean DBH of remaining trees
- basal area, stocking or height missing
- less than 4 height trees
- only crop trees measured
- average height substituted for mean top height
- less than two measurements per plot
- measurement dates less than 7 months apart.

The majority of observations are from Eyrewell, Balmoral and Ashley Forests (see Table 1).

Table 1. Location of data used to develop the Canterbury Growth Model

Forest	Number of Plots	Number of Measurements
Eyrewell	51	213
Balmoral	37	147
Burnham	12	45
Bottle Lake	3	33
Ashley	41	147
Hanmer	7	17
Omihi	17	50
Waimate	6	16
Geraldine	16	50
Sectional Measurements	11	49

In his report on the development of the Canterbury Growth Model, Lawrence (1988) noted that:

* there is some evidence that there are differences in growth patterns between the Foothills and the Plains other than those indicated by site quality, but they are not likely to be great.

* for all practical purposes , the combined model is a much simpler approach that will provide good estimates on both the Plains and the Foothills.

* any error in the estimate for the combined model will increase as the model is applied outside the range of sites normally found in that sub-region.

* there is insufficient data (112 measurement pairs for the Foothills and 215 for the Plains) to construct separate models with as much confidence as that gained from using the combined approach.

The data used in the current analysis were the residuals (actual measurements - predicted values) for mean top height, basal area and stocking from fitting the Canterbury growth model (Lawrence, 1988). There were 327 observations.

The environmental variables considered (obtainable from Plot History Sheets) were:

altitude
slope
aspect
soil type

Plot histories were not available for the plots with sectional measurements and a few other plots.

Average climatic variables for each location were obtained from summaries (for an appropriate meteorological station) published by the New Zealand Meteorological Service (1983). The meteorological stations were:

Forest	**Meteorological Station**
Eyrewell	Eyrewell Forest
Balmoral	Balmoral Forest
Burnham	Christchurch Airport
Bottle Lake	Christchurch City
Ashley	Ashley Forest
Hanmer	Hanmer Forest
Omihi	Waipara
Waimate	Waimate
Geraldine	Geraldine

The climatic variables considered were:

- rainfall averages by month
- mean annual temperature
- number of days of ground frost per year
- number of days of air frost per year

The drop in temperature with altitude, the dry adiabatic lapse rate, is approximately 1° C per 100 m increase in altitude (see e.g. Peters, 1982). To account for this phenomenon, the mean annual temperatures recorded at the meteorological stations were adjusted using the above formula to give a mean annual temperature for each plot.

For most environmental variables less than a third of the data points were missing values. However aspect was missing for nearly 200 observations.

DATA ANALYSIS

A. Are the residuals related to stand variables?

Initially the residuals were plotted against other stand variables to check that there were no patterns in the residuals which could be explained by stand variables.

The residuals from predicting mean top height were plotted against:

- initial age
- initial basal area
- initial stocking
- site index

In all cases there were no obvious patterns in the residuals. There were 5 points with residuals between -2 m and -3 m but there were no residuals greater than 2 m.

The residuals from predicting basal area were plotted against:

- initial stocking
- initial age
- initial height
- site index

In all cases there were no patterns in the residuals.

The residuals from predicting stocking were plotted against:

- initial basal area
- initial age
- initial height
- site index
- initial stocking

There was no obvious trend in the residuals with these variables. However, for each independent variable, there was a group of measurements with large negative residuals of between -50 and -250 stems/ha. These points were from a range of forests.

It can be concluded that the inclusion of further stand variables in the growth model is unlikely to improve the model.

B. Are the residuals related to environmental variables?

The residuals from predicting mean top height, basal area and stocking were plotted against the following environmental variables:

soil class
altitude
aspect
slope
mean annual temperature adjusted by plot altitude
mean annual rainfall
rainfall for June and July
rainfall for November, December, January and February
rainfall for June - November inclusive
rainfall for December - May inclusive
average days of ground frost per year
average days of air frost per year

Summaries of the observed trends in the residual plots are given in Tables 2 - 4.

Correlation coefficients between residuals and environmental variables (except for soil class and aspect) were calculated.

Aspect was transformed into a continuous variable by calculating:

$$\cos(\text{aspect} + 45^\circ)$$

45° was added to the aspect, due to the relationship indicated by the residual plots. The correlation between the residuals and cos (aspect +45°) was then calculated.

Significant correlations are shown in Table 5.

Table 2. Relationship between mean top height residuals and environmental variables.

Environmental Variable	Comments on residual plot
Soil Class	Distribution of residuals generally unbiased for soil classes with many data points. Soil classes with few data points are generally biased (either +ve or -ve).
Altitude	No obvious pattern in the residual plot.
Aspect	Residuals generally appear to be evenly distributed. Negative residuals tend to predominate for a westerly aspect.
Slope	No pattern in the residual plot.
Mean Annual Temperature	No pattern in the residual plot.
Mean Annual Rainfall	No pattern in the residual plot.
Rainfall June + July	No pattern in the residual plot.
Rainfall Nov+Dec+ Jan+Feb	No pattern in the residual plot.
Rainfall Jun- Nov	No obvious pattern in the residuals.
Rainfall Dec - May	No obvious pattern in the residuals.
Average days of ground frost per year	No pattern in the residual plot.
Average days of air frost per year	No pattern in the residual plot.

NOTE:

residual = actual value - predicted value
negative residual implies overprediction
positive residual implies underprediction

Table 3. Relationship between basal area residuals and environmental variables.

Environmental Variable	Comments on the residual plot
Soil Class	There appears to be a bias in the distribution of residuals for most soil classes.
Altitude	There appears to be a slight trend for the residuals to increase with increasing altitude, i.e. basal area tends to be underpredicted more with increasing altitude.
Aspect	Residuals tend to be positive with NW aspects and negative with SE aspects. (The two points with S aspect have positive residuals.)
Slope	Trend for residuals to increase with increasing slope
Mean Annual Temp. adjusted by altitude	Residuals positive for mean annual temperature less than 8° C.
Mean Annual Rainfall	No overall pattern in residuals.
Rainfall for Jun+Jul	No overall pattern in residuals.
Rainfall for Nov+Dec+Jan+Feb	No overall pattern in the residuals.
Rainfall: Jun - Nov	No obvious pattern in the residuals.
Rainfall: Dec - May	No obvious pattern in the residuals.
Average days of ground frost per year	Perhaps a slight trend for residuals to increase with increasing days of ground frost.
Average days of air frost per year	No obvious pattern in residuals.

NOTE:

residual = actual value - predicted value
negative residual implies overprediction
positive residual implies underprediction

Table 4. Relationship between stocking residuals and environmental variables.

Environmental Variable	Comments on residual plot
Soil Class	Large negative residuals found on soil classes: 21bE, 22, 22hH, 27 and 27a.
Altitude	Most of large negative residuals occur at an altitude below 200 m.
Aspect	Aspect was not recorded for many data points with large negative residuals.
Slope	Most of large negative residuals occur on slopes of less than 7 °.
Mean Annual Temp - adjusted for altitude	Large negative residuals occur with mean annual temperatures above 8° C.
Mean Annual Rainfall	Large negative residuals occur across most of the range in rainfall.
Rainfall Jun+Jul	Large negative residuals occur across most of the range in rainfall.
Rainfall Nov+Dec+Jan+Feb	Large negative residuals occur across most of the range in rainfall.
Rainfall: Jun - Nov	No obvious pattern in the residuals.
Rainfall: Dec - May	No obvious pattern in the residuals.
Average days of ground frost per year	Perhaps a slight trend for large negative residuals to become less negative as number of days of ground frost increases.
Average days of air frost per year	No obvious pattern in the residuals.

NOTE:

residual = actual value - predicted value
negative residual implies overprediction
positive residual implies underprediction

Table 5. Significant Correlations (p <= 0.05) between residuals and continuous environmental variables.

Mean Top Height Residuals

Variable	Correlation Coefficient (r)	Probability of obtaining this correlation under hypothesis of no correlation
Number of days of ground frost per year	0.15	0.016
Number of days of air frost per year	0.17	0.006

Basal Area Residuals

Variable	Correlation Coefficient (r)	Probability of obtaining this correlation under hypothesis of no correlation
Altitude	0.24	0.0001
Slope	0.19	0.0021
Number of days of ground frost per year	0.25	0.0001
Number of days of air frost per year	0.20	0.0011
Mean annual temperature (adjusted for plot altitude)	-0.21	0.0011
Winter Rainfall (Jun-Nov)	0.12	0.047
cos (aspect + 45°)	0.35	0.0001

Stocking Residuals

Variable	Correlation Coefficient (r)	Probability of obtaining this correlation under hypothesis of no correlation
Number of days of ground frost per year	0.22	0.0004
Number of days of air frost per year	0.21	0.0004

For height, basal area and stocking, the residuals were positively correlated with the number of days of frost, i.e. the greater the number of days of frost, the more these variables were underpredicted.
The height and stocking residuals were not significantly correlated ($p < 0.05$) with any other variables.

A possible reason for a positive correlation between residuals and days of frost is that frosty nights are usually followed by sunny days. These sunny conditions may be suitable for tree growth.

Other studies have shown that rainfall can affect radiata pine growth (see Grace (1994) for a literature review). More recently Gordon and Lawrence (1994) have shown that annual rainfall affects radiata pine diameter growth in Canterbury. However in this study, only the correlation between basal area residuals and winter rainfall was significant, i.e growth underprediction increases with increasing winter rainfall. This correlation appears to be logical.
Two possible reasons for no other correlation coefficients between growth and rainfall being significant are:

In this study, long-term average rainfall values have been correlated with errors in growth over a short period (i.e. between two measurements).

Growth is limited by lack of water. However annual rainfall does not indicate the length of time that plants lack water. Growth may be better correlated with length of drought periods.

The basal area residuals were also positively correlated with slope, altitude, aspect and negatively correlated with mean annual temperature.

However a number of these variables are significantly correlated with each other. For example winter rainfall is correlated with days of frost, days of frost are correlated with altitude and slope, altitude and slope are correlated with mean annual temperature and aspect.

A negative correlation with mean annual temperaure does not seem logical. This implies that growth is overpredicted as temperature increases. As the mean annual temperature for these Canterbury plots is less than 12° C and a mean annual temperature of between 10.3°C and 14°C seems to be optimum for radiata pine (see Grace, 1994), one might expect better growth as the temperature increased.

No references to a correlation between basal area growth and slope, altitude or aspect have been found.

C. Are trends between residuals and environmental variables consistent at a forest level?

One way to check whether it would be reasonable to include any of the above environmental variables in growth models is to check whether the same trends occur when the data is examined on the basis of a forest.

For each forest, the correlation between the residual basal area and cos (aspect + 45°), altitude and slope was caclulated (see Table 6). It was not feasible to calculate correlations for the meteorological variables where there was only one value per forest.

Table 6. Correlation coefficient (r) between environmental variables and basal area residuals (by forest).
Probabilities of obtaining r under the hypothesis of no correlation are in parentheses.
Missing values are indicated by a hyphen.

Forest	Cos (aspect + 45°)	Altitude	Slope
Canterbury Region	0.35 (0.0001)	0.24 (0.0001)	0.19 (0.0021)
Eyrewell	-	-0.12 (0.29)	-
Balmoral	0.24 (0.10)	-0.24 (0.10)	-
Burnham	-	-0.24 (0.10)	-
Bottle Lake	-	-	-
Ashley	0.21 (0.32)	0.11 (0.45)	0.03 (0.84)
Hanmer	-	-0.06 (0.94)	-0.30 (0.70)
Omihi	0.42 (0.07)	0.04 (0.85)	0.65 (0.0016)
Waimate	0.76 (0.24)	0.45 (0.45)	0.27 (0.83)
Geraldine	-0.21 (0.39)	-0.04 (0.86)	-0.16 (0.50)

A number of these correlations are based on a very small number of observations. (As the size of the dataset decreases a higher correlation coefficient is necessary for it to be significant).

For all the forests, apart from Geraldine, there is a positive correlation between residual basal area and cos (aspect + 45°). There was a positive correlation between residual basal area and cos (aspect + 45°) for the whole dataset. It may therefore be feasible to improve the growth model for most forests by the inclusion of aspect.

The correlation with aspect may well be due to wind direction as basal area was underpredicted for a NW aspect.

For the forests classified as plains, there is a negative correlation between residual basal area and altitude which is contrary to the overall trend. Hence it unlikely that the addition of altitude to a Canterbury-wide growth model would be satisfactory.

The overall correlation between residuals and slopes appears to be due to the correlation within one forest, Omihi. The inclusion of slope is therefore unlikely to improve a Canterbury-wide growth model.

D. Trends in residuals by forest

An approach to investigate whether the Canterbury growth modelling region should be considered as one region is to examine the trends in the residuals by forest and group forests with similar trends in the residual plots.

Basal area residuals were plotted against predicted basal area, mean top height residuals were plotted against predicted height, and stocking residuals were plotted against predicted stockings. Separate graphs were plotted for each forests. Trends in the residuals were classified as positive, negative or no trend based on the significance of the correlation coefficient ($p < 0.10$). The classification is shown in Table 7.

Table 7 Classification of forests based on significance of correlation coefficient.

	Positive Correlation	No trend	Negative Correlation
Height Residuals		Balmoral Bottle Lake Burnham Geraldine Hanmer (-ve, but only 4 data points) Omihi Waimate	Eyrewell Ashley
Basal Area Residuals	Balmoral	Eyrewell Geraldine Hanmer Omihi Waimate	Bottle Lake Burnham Ashley
Stocking Residuals	Balmoral	Burnham Eyrewell Geraldine Hanmer (+ve, but only 4 data points) Omihi Waimate (+ve, but only 6 data points)	Ashley Bottle Lake

This analysis indicates that there could be at least 4 different growth trends in the Canterbury area.

CONCLUSION

The analyses indicate that there are differences in growth patterns within the Canterbury Growth modelling region. However there does not appear to be two distinct regions, "the plains" and "the foothills". The presence of significant and logical correlations between residuals and environmental variables indicates that it may be possible to explain some of the differences in growth through the inclusion of environmental variables in the growth model.

OPTIONS FOR FUTURE RESEARCH

The above analyses should be repeated for the other growth modelling regions for two reasons. Firstly some different environmental variables have been considered compared to Gordon and Lawrence (1994). Secondly, height and stocking have been considered as well as basal area.

There has been discussion on whether a country-wide model should be developed. Comments from other studies (see Grace, 1994) indicate that we are unlikely to gain any accuracy from that approach. However, I think it would be worthwhile to take the dataset developed by Gordon and Lawrence (1994) and develop a countrywide model, a countrywide model with dummy variables and regional models to understand the pros and cons of different methodologies and the inclusion/exclusion of environmental variables.

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