Individual tree-level growth models for Douglas-fir in New Zealand

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INDIVIDUAL-TREE-LEVEL GROWTH MODELS FOR DOUGLAS FIR IN NEW ZEALAND

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ABSTRACT

The development of a system of equations that models the growth of distance-independent individual tree for Douglas fir (*Pseudotsuga menziesii*) in New Zealand is described. Growth and yield models are the most important components in long term planning of forest inventory. Individual tree growth models rather than stand growth models as the basic prediction option is particularly useful for inventory projection, when the forester wishes to use an existing tree list obtained from inventory as the starting point. An individual tree growth model predicts the growth and yield of a stand of trees at an individual tree level of detail. It makes use of starting data on an individual tree list, predicts diameter at breast height (dbh) and total tree height growth and the probability of a tree dying in order to project the stand into the future. Stand statistics are accumulated from the tree list. Typical information contained for each tree in a tree list are individual tree dbhs, heights, and the weighting of each individual (the number of trees per hectare represented by the individual). This is in contrast to a stand growth model that only requires stand level statistics to predict growth, before predicting a dbh distribution at the desired future age. The advantage of an individual tree model is that in projecting inventory information, the data collected on individual trees (e.g., on stem quality) is not lost by any amalgamation to stand level averages.

The current analyses used the same development method previously applied to *Pinus radiata* individual-tree growth models developed for the Stand Growth Modelling Cooperative (Shula and Gordon, 2000). In general, over 80% of growth of trees in a Douglas-fir stand fall within ±0.5 cm for predicted DBH annual increment and predicted Height annual increment. On average across the growth modelling regions and range of initial tree diameters, heights and survival can be estimated within reasonable error limits. A probability of survival was also developed. Given the fact of mortality as an irregular event, the fitted models behave well and have an appropriate level of reliability.

Key words: Pseudotsuga menziesii, sample plots, New Zealand, individual tree model, growth model.

INTRODUCTION

Growth and yield models are the most important components in long term planning of forest inventory. Clutter et al (1983) and Munro (1974) discussed options to improve quantitative information on forest resources so log yield prediction could be more precise. With the availability of computer software, growth modellers find it more feasible to develop individual tree growth models rather than stand growth models as the basic prediction option. These are partially useful for inventory projection, when the forester wishes to use an existing tree list obtained from inventory as the starting point. An individual tree growth model predicts the growth and yield of a stand of trees at an individual tree level of detail. It makes use of starting data on an individual tree list, predicts diameter at breast height (dbh) and total tree height growth and the probability of a tree dying in order to project the stand into the future. Stand statistics are accumulated from the tree list. Typical information contained for each tree in a tree list are individual tree dbhs, heights, and the weighting of each individual (the number of trees per hectare represented by the individual). This is in contrast to a stand growth model that only requires stand level statistics to predict growth, before predicting a dbh distribution at the desired future age. The advantage of an individual tree model is that in projecting inventory information, the data collected on individual trees (e.g., on stem quality) is not lost by any amalgamation to stand level averages.

This project developed a distance-independent individual tree growth model for Douglas fir (*Pseudotsuga menziesii*) in New Zealand.

DIAMETER AND HEIGHT ANNUAL INCREMENT MODELS

DATA

Plots were selected from the Permanent Sample Plot system (Pilaar and Dunlop, 1989) covering all regions in New Zealand. In brief, data was extracted according to the following acceptance criteria:

- at least 15 trees measured per plot,
- at least 3 or more consecutive measurements per plot with the first PSP measurement taken between age 15 to 40 years (inclusive),
- only ‘normal’ levels of mortality (excluding windthrow and poison thinnings)
- Age difference between two measurements must be less than 6 years.

A total of 652 plots were extracted from the PSP system and compiled into three data sets. Plots with missing crown ratio information were taken out from selection. The data used in the analysis is extensive as shown in Table 1 with approximately equal number of plots in both the North Island (DF TLNI) and South Island (DF TLSI). Some plots were set aside by using random selection with varying probabilities for later validation of the models. DF TLNZ is the combined data of DF TLNI and DF TLSI.

Table 1. Descriptive Statistics of DF TLNZ data by location

Region	No of Plots	Obs	Variable	Mean	Std Dev	Min	Max
DF TLNI	209	5497	Dbh_i	34.4	11.5	11.5	73.6
			Ht_i	24.3	8.37	9.20	48.0
			Age_inc	2.09	0.93	0.96	6.00
			Age	30.4	12.0	15.0	62.0
			SPH	568	360	140	2250
			MTH	25.8	8.64	11.1	45.1
			BA	44.5	22.0	5.14	132
			SI	35.5	3.17	19.8	42.3
DF TLSI	227	5945	Dbh_i	26.2	9.06	6.60	81.7
			Ht_i	16.2	6.76	6.20	46.9
			Age_inc	1.65	0.96	0.67	6.00
			Age	21.5	9.49	15.0	55.0
			SPH	800	502	148	2283
			MTH	17.0	6.76	8.30	43.2
			BA	35.7	17.9	4.17	108
			SI	29.8	2.86	18.8	40.2

Notation

Dbh_i = Individual tree diameter at breast height (cm)
Ht_i = Individual tree total tree height (m)
Age_inc = Age increment (year)
SPH = Stocking per hectare
MTH = Mean Top Height (m)
BA = Basal Area (m^2/ha)
SI = Site Index with base age of 40 (m)

METHODS

Background

Earlier studies in developing an individual tree model for *Pinus radiata* included fitting a diameter increment as a function of time, as a function of stand basal area and as a linear function of predictor variables. As for height increment, Gordon (1996) and Shula (1997) explored two approaches: fitting an indirect prediction of height increment (by static prediction of height ratio as a function of diameter ratio) and fitting height increment directly.

It was concluded that the linear model that accounts for the position of the tree within the stand diameter distribution is the most promising model in estimating the diameter increment. As for the height modelling approach, the best option is to model the height increment directly even though the goodness-of-fit statistics would be poor (Shula and Gordon, 2000).

The current analyses used SAS (SAS Institute Inc. 1989) weighted, non-linear regression procedure, NLIN, (method=Marquardt) to estimate parameter coefficients (α=0.05).

The equation forms that were fitted included:

- linear ……..… $y = a_0 + a_1*x_1 +…+ a_n*x_n$, and [1]
- exponential … $y = \exp[\, a_0 + a_1*x_1 +…+ a_nx_n \,]$. [2]

The dependent variable (y) was either individual-tree diameter breast-height (dbh_i) increment (cm) or total tree height (ht_i) increment (m). Potential explanatory variables (x_n) included all those tried by Shula (1997) for *Pinus radiata* and Shula and Knowe (1998) for Douglas-fir.

To ensure homogenous variance of residuals, a variety of weighting schemes were investigated, including:

- the reciprocal (or not) of tree-size attributes (e.g., dbh, height), and
- iterative re-weighting using the reciprocal (or not) of the predicted values.

Criteria for judging equation goodness-of-fit, homogeneity of residual variance, and acceptance included:

- adjusted R^2 (Kmenta 1986) and
- Furnival's Index (Furnival 1961).

Adjusted R^2 was used because it considers the number of explanatory variables (p) in an equation in relation to the number of observations (n) in the dataset. Thus, it provides a standardised measure of the predictive ability of equations, differing in *n* and *p*, to account for variation from the mean in respective datasets.

Explanatory Variables
The following variables were used as explanatory variables:
dbh_i = individual-tree, breast-height (1.4m) diameter (cm)
dbh_q = stand, quadratic mean breast-height diameter (cm)
exp(x) = e^x; e is the base, 2.71828, of the natural logarithm
BA = stand, basal area (m^2/hectare)
log = natural base 2.71828 logarithm
$\log_{10}$ = base 10 logarithm
MTD = stand, mean top breast-height diameter (cm)
MTH = stand, mean top height (m)
SI = site index (m)
SPH = stems per hectare

In addition, additional explanatory variables (including transformations) were tried based upon successful screening for variables from stepwise linear regression and for purpose of greater tree level specificity:

- SDI,
- RD,
- HPIT,
- chg_pdbh, and
- bal_ratio.

SDI (Stand Density Index). SDI (Reineke 1933) provides a relative measure of intra-specific competition, and is a function of quadratic mean dbh (dbh_q) and tree stocking (SPH):

$$SDI = 1.0147*(10) \wedge [\log_{10}*N + 1.605*\log_{10}(dbh_q) - 2.25]$$

SDI is the number of trees per hectare, as if, dbh_q was 25.4 cm (10 inches); and is independent of species, site quality, and age (Reineke 1933).

RD (Relative Density). RD (Curtis 1982) was developed for coastal Douglas-fir in the Pacific Northwest USA to provide a relative measure of intra-specific competition. RD is a function of dbh_q and basal area stocking (BA):

$$RD = BA / (dbh_q)^{0.5}$$

SDI and RD can be shown to be highly correlated.

HPIT (Height Potential Index of a Tree). Height Potential Index, HPI, (analogous to site index, SI, or mean top height, MTH, at a base-age) was developed for each of the regions to index potential site productivity as a function of tree height and plantation age. Shula (1997b) described the method to calculate HPIT and Chg_pht. Regional HPI datasets were developed using the 3 tallest trees per plot (plot size approximately 0.04-ha) at the start of each re-measurement period. This replacement sampling method was chosen to accommodate change in tree-dominance through time.

The HPI equation is an algebraic-difference formulation (Clutter *et al* 1983), ADF, of a exponentiated and generalised Schumacher growth equation (Schumacher 1939), and is polymorphic with respect to (w.r.t.) shape. Through algebraic manipulation, the ADF predicts potential tree height given current and future age, and HPI. Herein, HPI base-age is 40 years plantation age, although the ADF is inherently base-age invariant (i.e., in application, any base-age can be specified).

In the current analyses, the appropriate regional HPI equation was applied to each individual-tree in the regional dbh growth datasets, as if it were a MTH-tree, to obtain the 'height potential index of the tree' (HPIT). HPIT, then, represents a particular tree's maximum expected height at base-age, or an index of the tree's potential micro-site height productivity.

Chg_pdbh. Analygous to HPI, Diameter Potential Index (DPI) was developed to index potential site productivity as a function of tree dbh and age. The same regional datasets used in the HPI analyses were used to derive DPI. This approach, to use the most dominant trees based on height, was used to minimise the influence of stand density, and thereby, make DPI less dependent on management regime and to be congruent with HPI. The method to calculate Chg_pdbh or DBHPIT is fully explained in Shula (1997a) .

Analogous to the HPIT analyses, the appropriate regional DPI equation was applied to each individual-tree in the regional dbh growth datasets, as if it was a MTH-tree, to obtain the 'diameter potential index of the tree' (DBHPIT). DBHPIT, then, represents a particular tree's maximum expected diameter at base-age, or an index of the tree's potential micro-site diameter productivity.

Through algebraic manipulation, the ADF predicts the potential dbh of a tree (PDT) given current and future age, and DPI. Herein, DPI base-age is 40 years plantation age. Collective potential-dbh-by-age paired data produce dbh curves that represent dbh maximum growth trajectories.

The prediction of individual-tree growth often uses a combinatory approach, whereby, maximum expected growth (free-to-grow) is predicted, then, subsequently modified by other explanatory variables pertinent to specific tree-size and competition indices. In the present analyses, maximum expected annual growth or 'change in potential dbh' (chg_pdbh) was derived from calculated annual increments w.r.t. DBHPIT, PDT (at time2), and initial dbh (at time1). DBHPIT, chg_pdbh, and transformations thereof, were tried as explanatory variables in combination with other tree- and stand-level variables to predict individual-tree dbh annual growth.

Bal_ratio. This variable is the ratio of BAL (basal-area-in-trees-larger-than-the-subject-tree) to the subject tree's dbh (dbh_i). This transformation of bal provides greater specificity in implementation because trees from different plots may have an identical bal (identical 'position' in the stand's hierarchy), but have a different dbh (tree-size). Bal_ratio, then, indexes or quantifies intra-specific competition w.r.t. within-plot and between-plot relativity.

SDIratio. This variable gives the measure of the stand's intra-specific competition with respect to stocking, tree size and growing space. It is calculated as $\frac{SDI(time1)}{SDI(time2)}$

RESULTS

General

For all three models, exponential equation [2] was selected as it provided:

- predicted annual diameter increment greater than zero without the need to statistically bound parameter estimation during fitting procedures,
- a smooth and continuous approach to a zero growth increment, and
- fit statistics similar to or better than linear equation [1].

In all cases, weighted regression provided a better Furnival Index than unweighted regression, indicating most constant standard error of prediction, and for the construction of confidence intervals, then, the most asymptotically efficient parameter estimators. For individual tree diameter increment models, the weight, 1 / DBHPIT, was the best weighting scheme (provided the best Furnival's Index). In estimating individual-tree height increment, 1/ HPIT, was the best weighting scheme.

Fit Statistics and Parameter Coefficients

Table 2. Diameter and height increment models using exponential equation [2]:

Variable	Equation
Diameter	D_{inc}= exp[a_0 + a_1*DBHPIT +a_2*SDIratio*exp(a_3*ysth) +a_4*Cr_ratio +a_5*MTD]
Height	H_{inc}= exp[a_0 + a_1*LspctBAL+a_2*Chg_pht+a_3*HTsqd +a_4*SqdlDbh]

Parameter definitions (not previously described):

D_{inc} = annual dbh_i increment, (cm)
H_{inc} = annual ht_i increment, (m)
DBHPIT = Diameter potential index of tree
SDIratio = SDI at age (t) ÷ SDI at age (t+1).
ysth = Number of year since last thinning
MTD = Mean Top Diameter
HPIT = Height Potential Index of a Tree
Cr_ratio = Crown length/Ht
Chg_pht = Change in potential height
LspctBAL = Log [(BAL/BA)*100]
Htsqd = Ht^2/1000
SqdlDbh = $[\log(dbh)]^2$

Table 3. Regions, parameters, coefficients, and coefficient standard errors from the regression analyses

Model	Parameter	DF TLNI Coefficient (Std Dev)	DF TLSI Coefficient (Std Dev)	DF TLNZ Coefficient (Std Dev)
D_{inc}	a_0	1.4249 (0.1335)	2.6186 (0.1181)	2.3958 (0.0853)
	a_1	0.0311 (6.8E-4)	0.0252 (5.2E-4)	0.0260 (4.0E-4)
	a_2	-3.1348 (0.1363)	-3.4083 (0.1207)	-3.5622 (0.0876)
	a_3	-0.0025*	-5.3E-3 (1.7E-3)	-0.0025 (7.5E-4)
	a_4	0.7032 (0.0370)	0.3515 (0.0308)	0.5820 (0.0222)
	a_5	-0.0130 (5.9E-4)	-0.0230 (9.3E-4)	-0.0025 (7.5E-4)

H_{inc}	a_0	-1.1946 (0.0559)	-1.0758 (0.0659)	-1.1946 (0.0327)
	a_1	0.0327 (0.0051)	0.0223 (0.0058)	0.0327 (0.0051)
	a_2	0.1145 (0.0058)	0.1101 (0.0059)	0.1145 (0.0058)
	a_3	-0.3921 (0.0295)	-0.3004 (0.0438)	-0.3921 (0.0295)
	a_4	0.0713 (0.0040)	0.0561 (0.0050)	0.0713 (0.0040)

* A_3 coefficient for TLNI failed to converge and hence was fixed at the same value of TLNZ's coefficient.
All coefficients are significantly different from zero at α=5% test level.

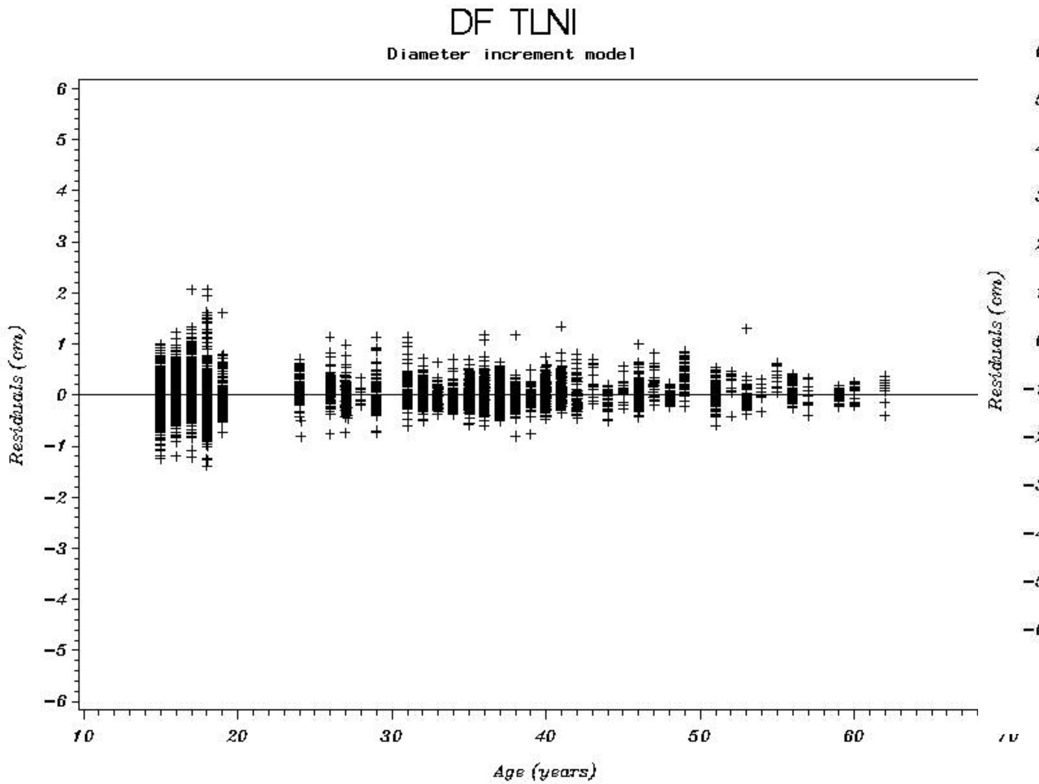
Table 4. Region, mean residual, adjusted R^2, and Furnival's Index from the regression analyses.

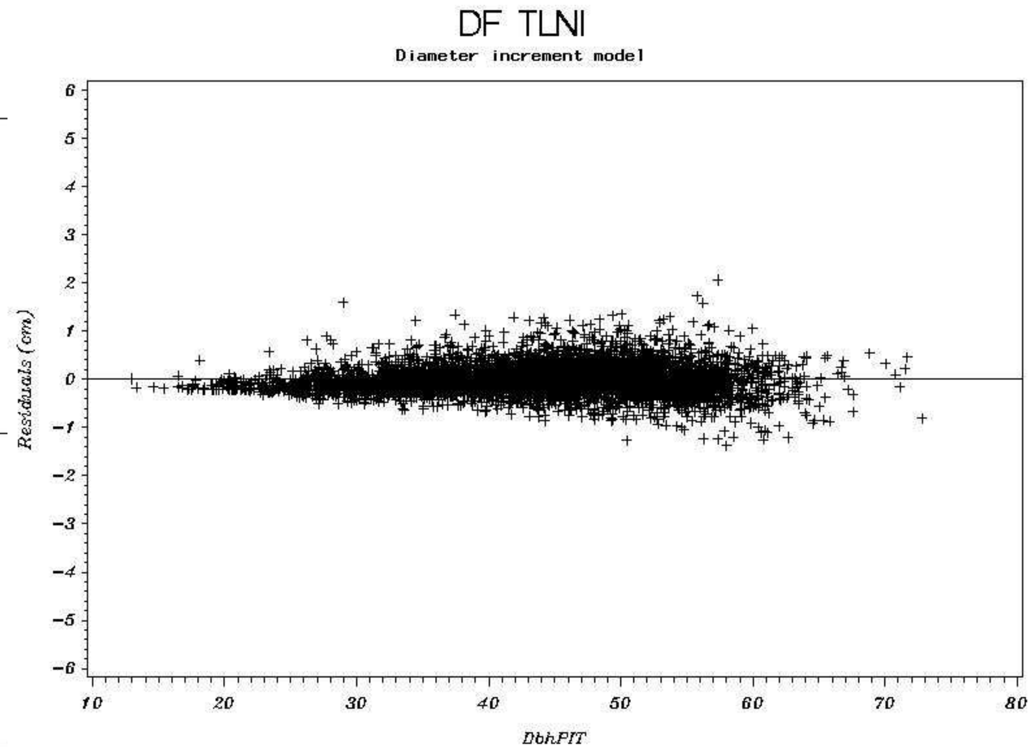
Variable	Model	Mean Residual in cm (std. dev.)	Adjusted R^2	Furnival Index	% of obs falls within ±0.5cm	% of obs falls within ±1cm
Diameter	DF TLNI	3.7E-3 (0.309)	63.5%	0.3003	91.2%	98.9%
	DF TLSI	2.4E-3 (0.429)	54.4%	0.4298	78.9%	97.8%
	DF TLNZ	3.5E-3 (0.382)	62.8%	0.3783	84.1%	98.3%

Variable	Model	Mean Residual in m (std. dev.)	Adjusted R^2	Furnival Index	% of obs falls within ±0.5m	% of obs falls within ±1m
Height	DF TLNI	8.5E-4 (0.376)	13.2%	0.3775	84.3%	98.8%
	DF TLSI	2.6E-3 (0.347)	14.0%	0.3511	86.5%	99.2%
	DF TLNZ	8.5E-4 (0.376)	13.2%	0.3775	84.3%	98.8%

Residuals
Figures 1-36 present Dbh_i and Ht_i growth residuals plotted against the independent variables for the three modelling sets. Residuals range widely around zero errors. Table 4 shows the fit statistics and the percentage of observations that fall within ±0.5 cm and ±1 cm of the observed Dbh_i and Ht_i increments. In general, over 78% of data fall within ±0.5 cm for Dbh increment and 84% for Ht increment.

Across most regions, residuals were centred around zero. Three obvious outliers for diameter increment prediction in the DF TLSI plots came from Ribbonwood and Craigieburn forests. No explanation is on hand for the over-estimation as different age predictions from the same trees were within acceptable error range. These forests are located in the South Island high country area with high stockings and high levels of BA productivity.


DF TLNI
Diameter increment model
Residuals (cm)
Age (years)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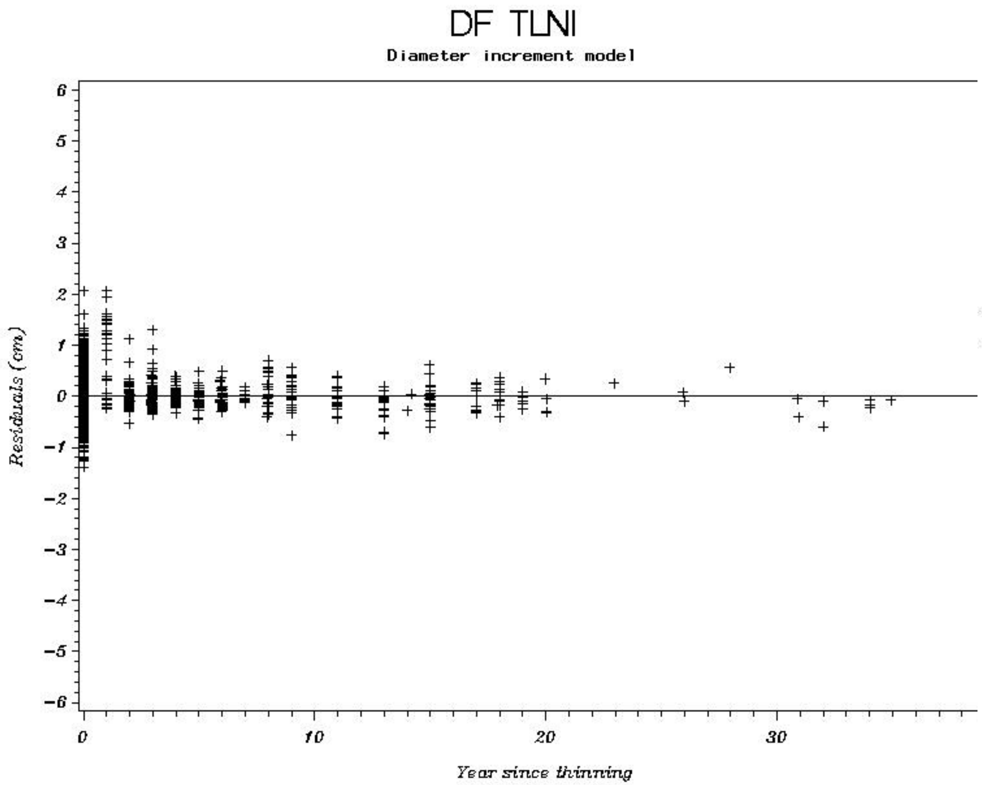
Residuals (cm)
DbhPIT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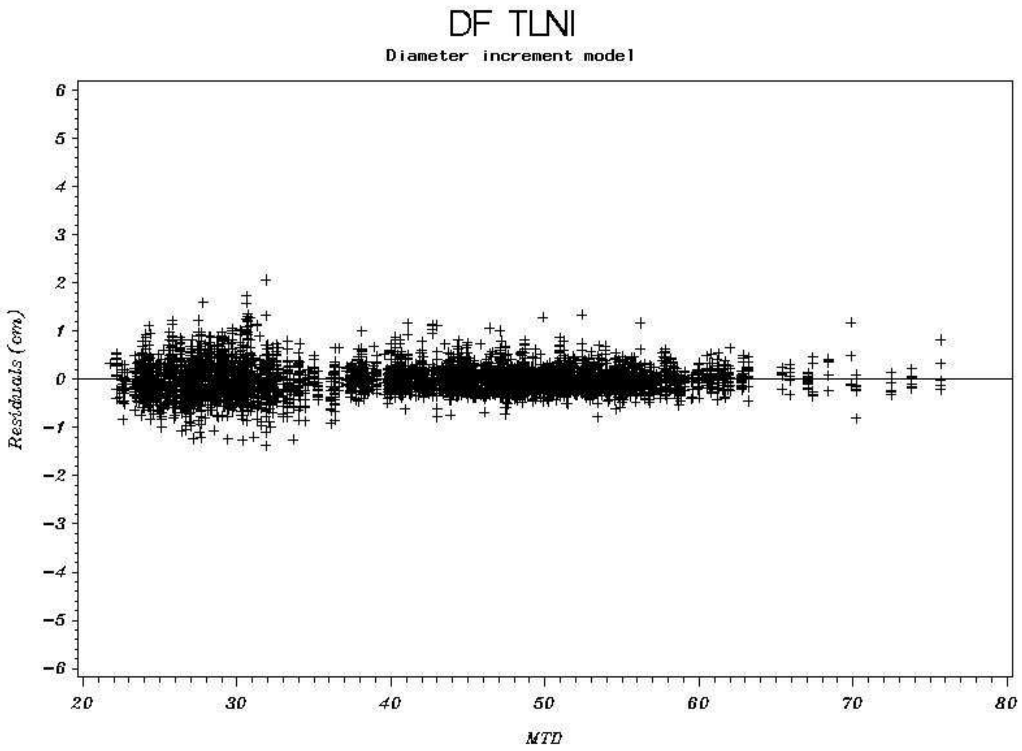
Diameter increment model
Residuals (cm)
Year since thinning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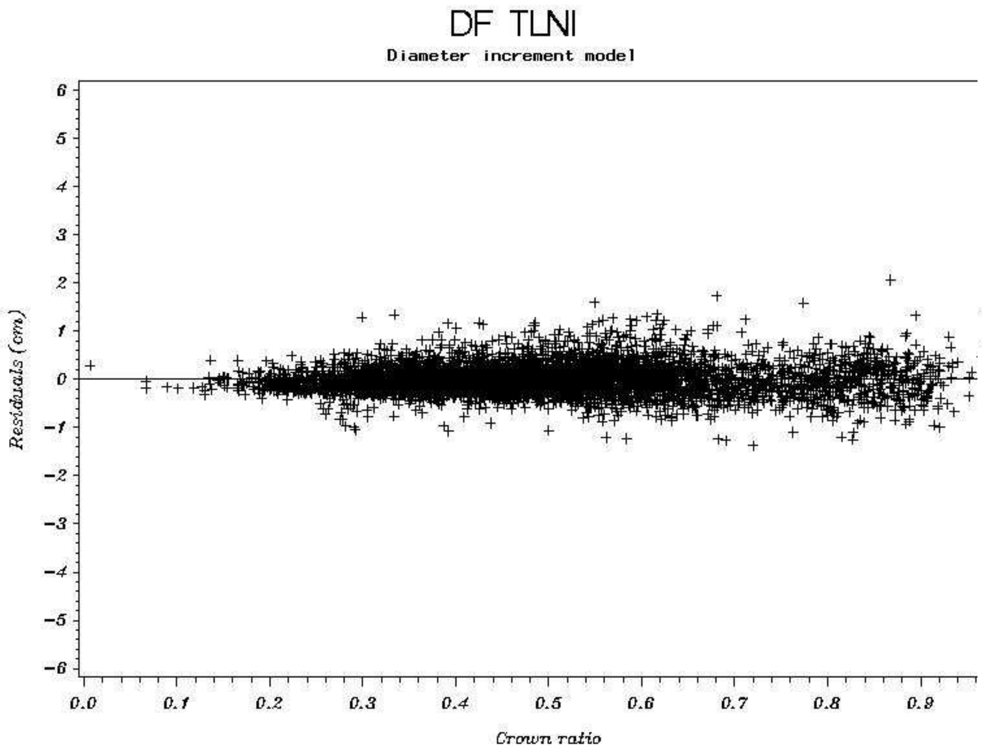
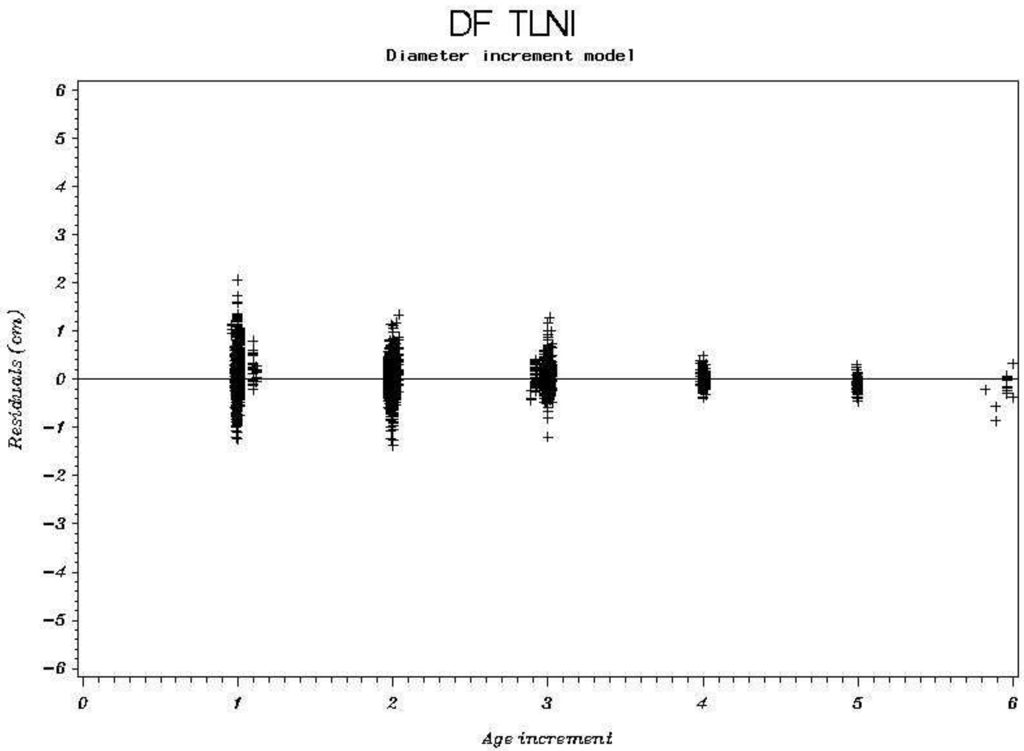
Diameter increment model
Residuals (cm)
MTD



DF TLNI
Diameter increment model
Residuals (cm)
Crown ratio



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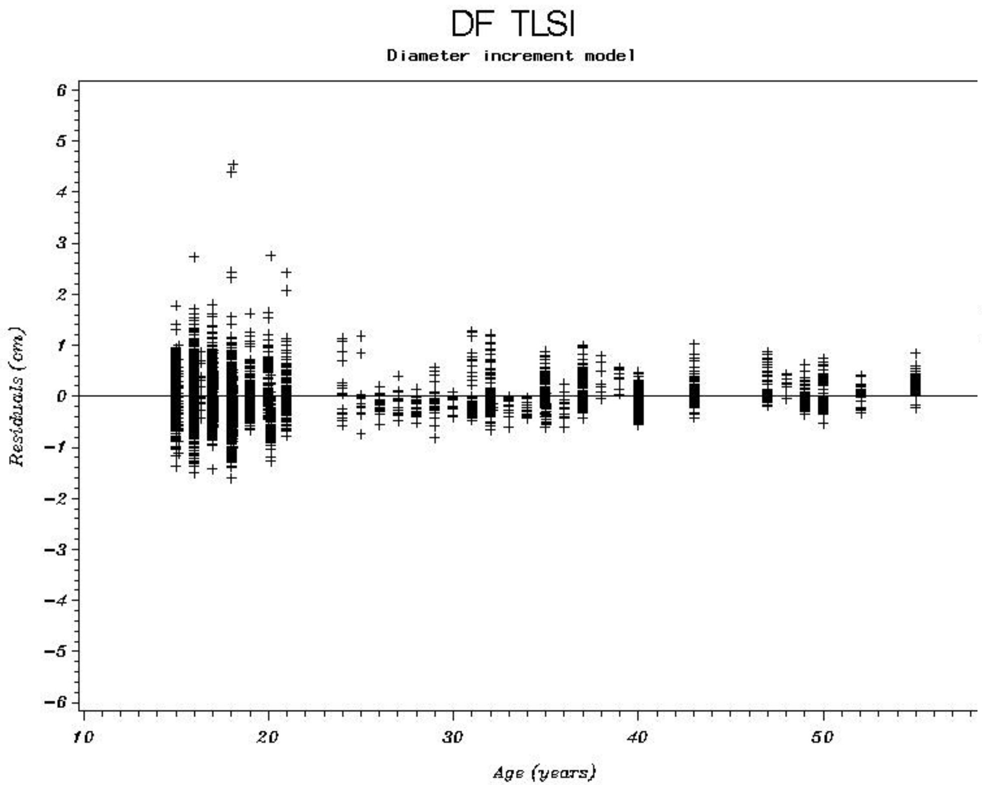
Diameter increment model
Residuals (cm)
Age increment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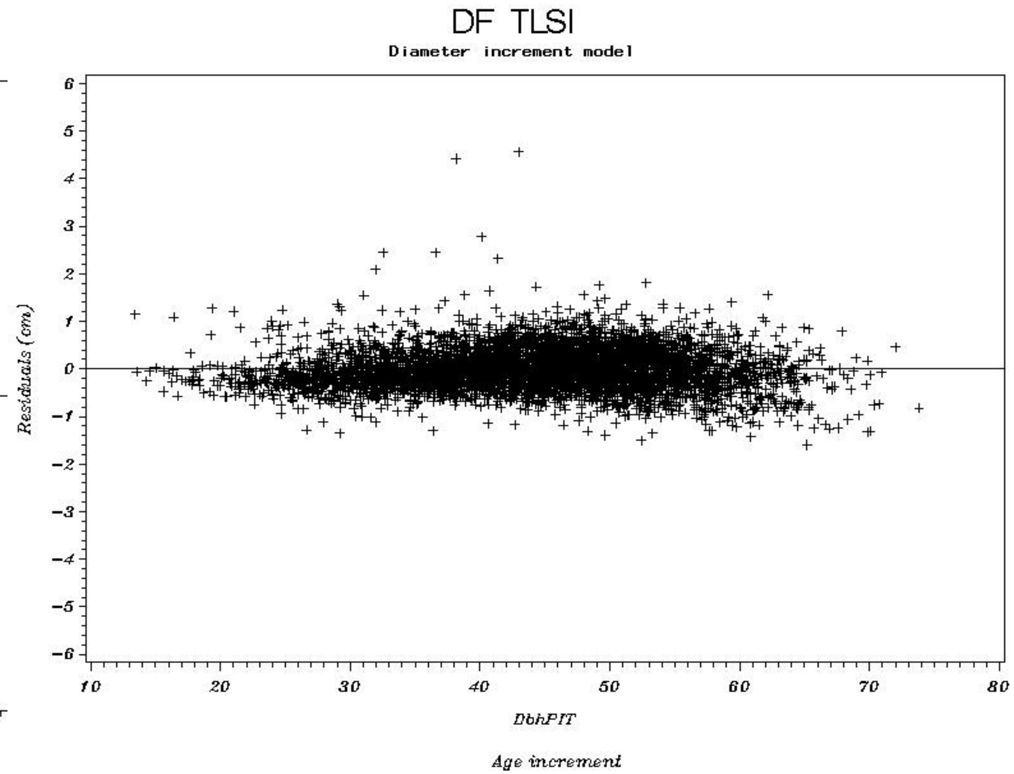
Residuals (cm)
Age (years)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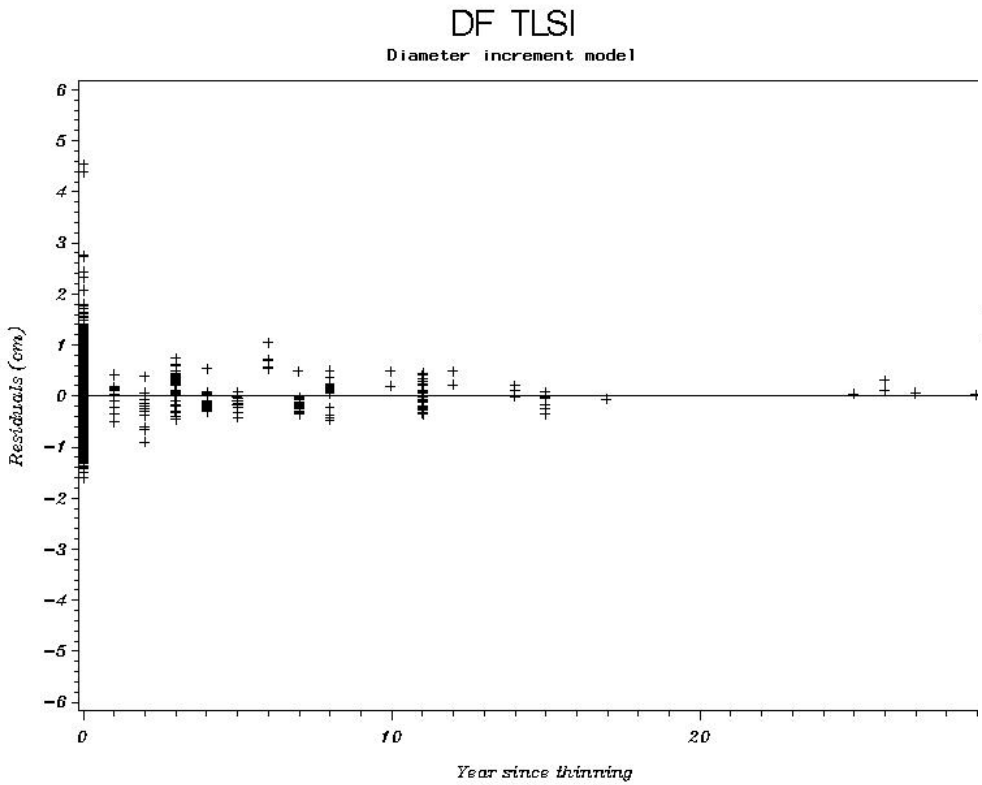
Residuals (cm)
DbhPIT
Age increment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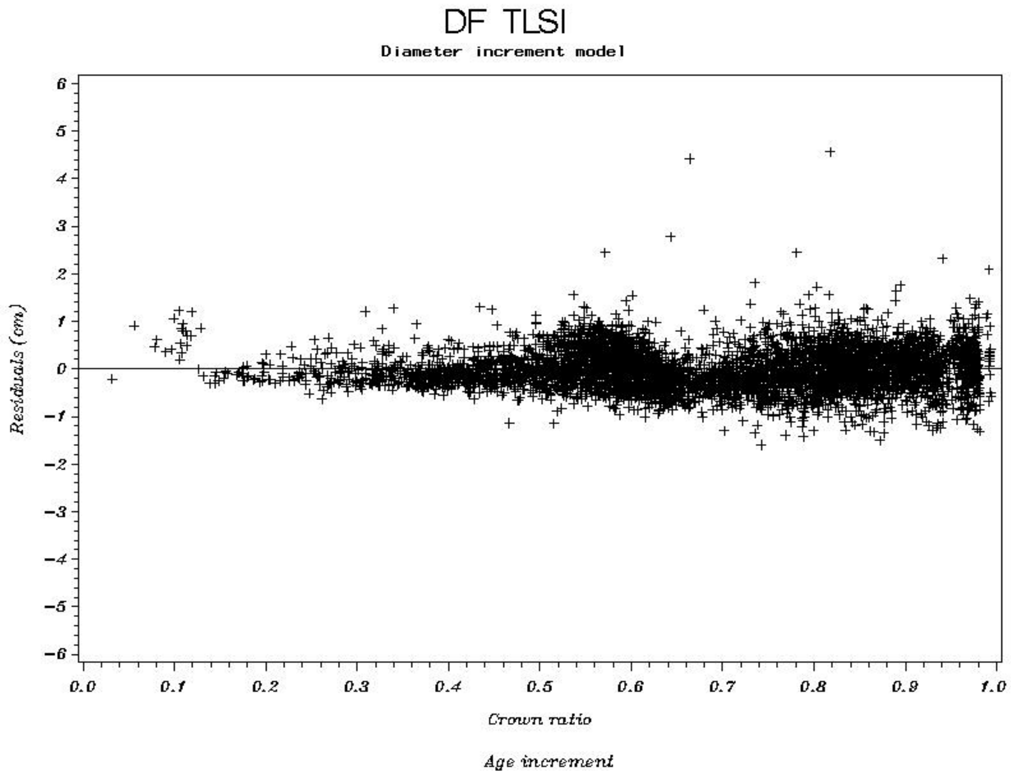
Diameter increment model
Residuals (cm)
Year since thinning
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
10
20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Diameter increment model
Residuals (cm)
Crown ratio
Age increment
6
5
4
3
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0
-1
-2
-3
-4
-5
-6
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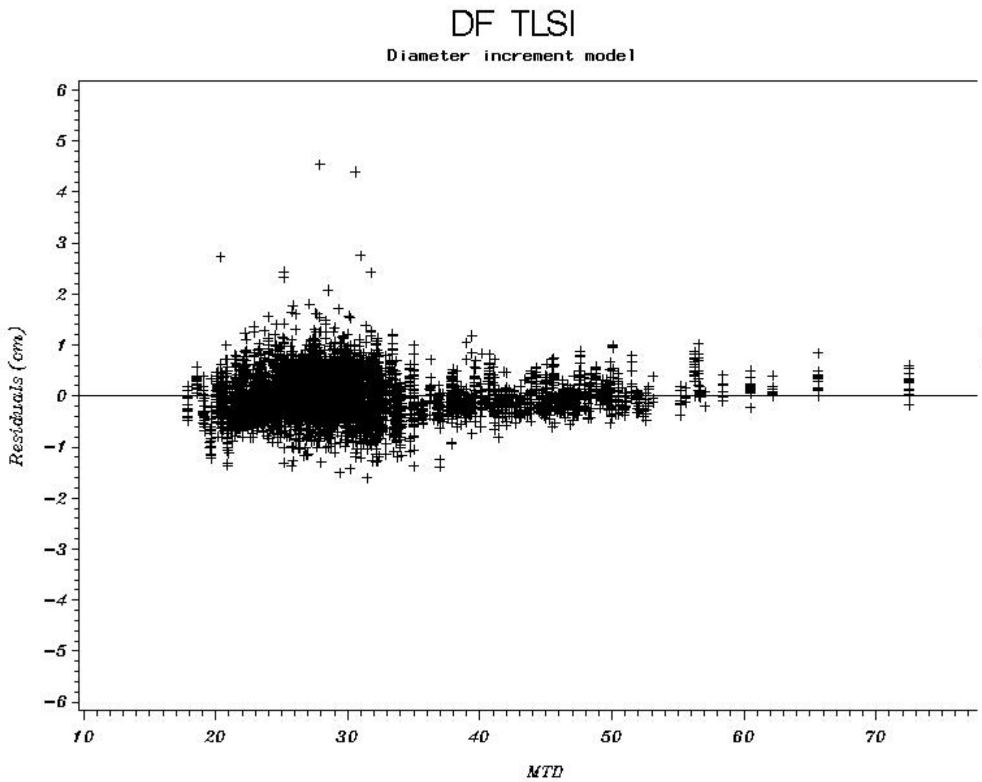
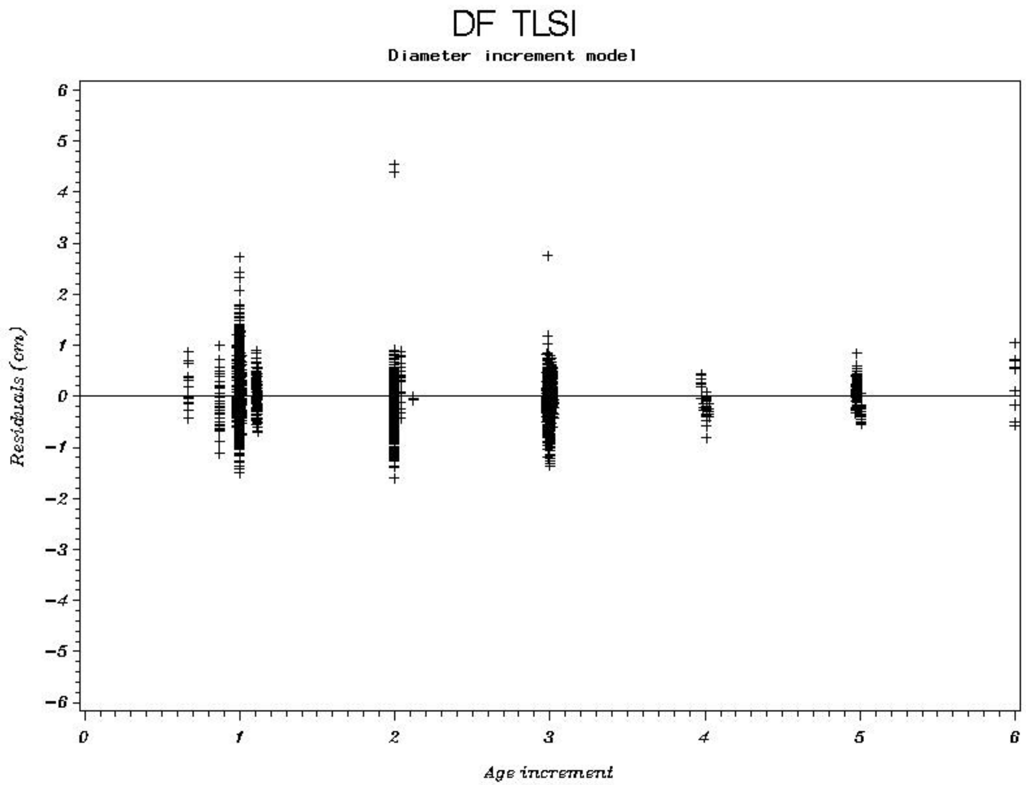
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0


DF TLSI
Diameter increment model
Residuals (cm)
MTD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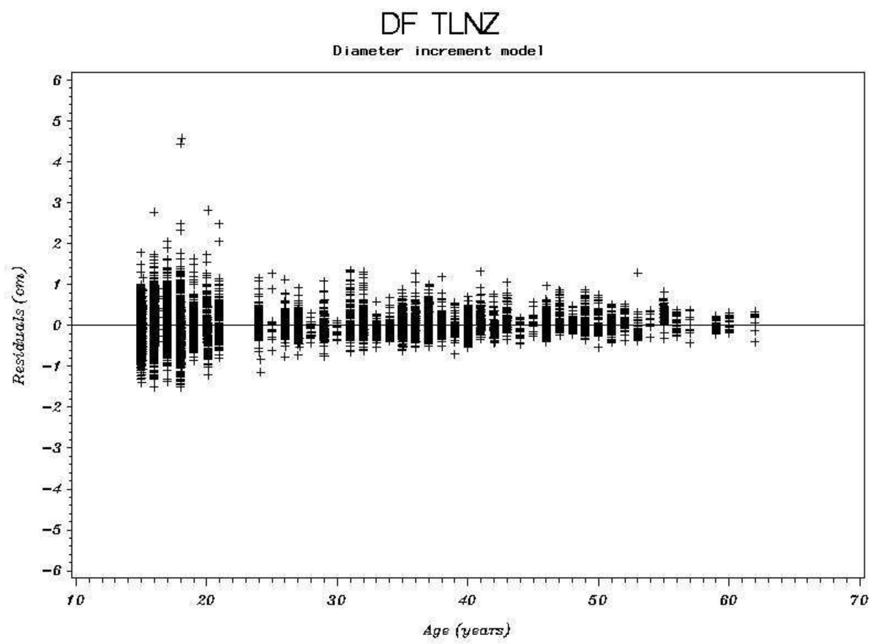
Diameter increment model
Residuals (cm)
Age increment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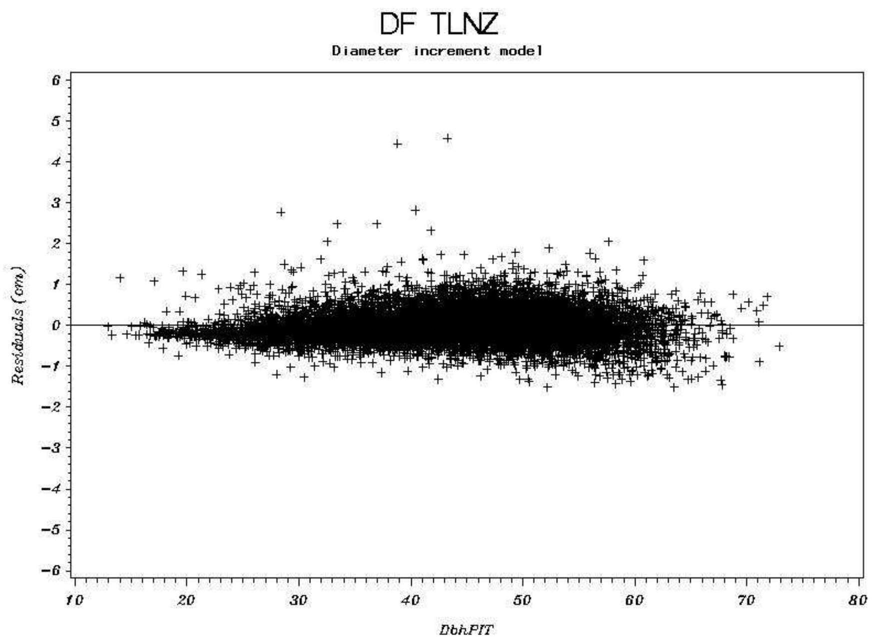
Diameter increment model
Residuals (cm)
Age (years)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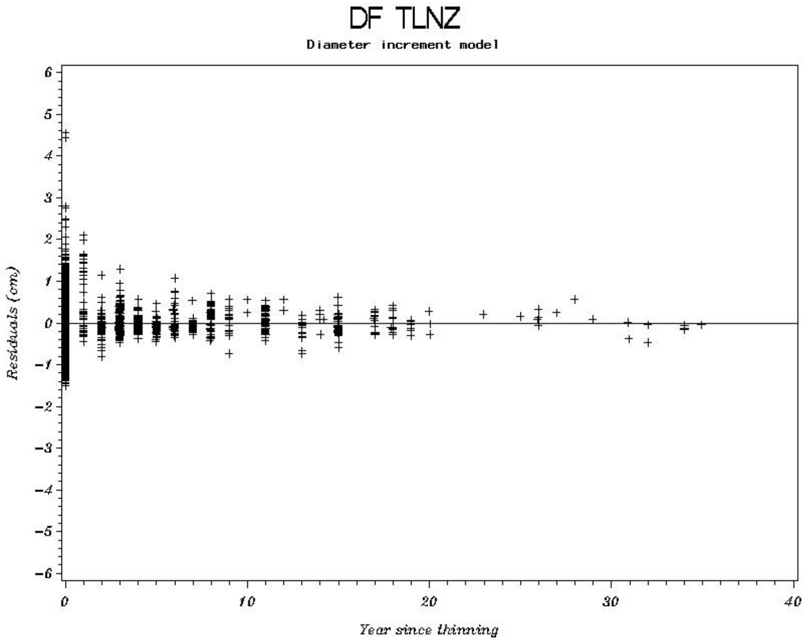
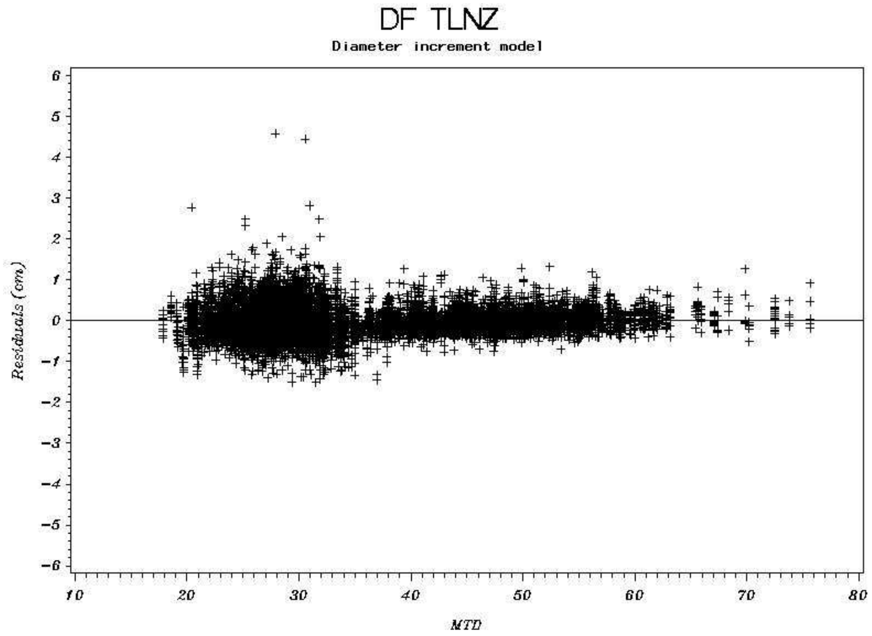
Diameter increment model
Residuals (cm)
DbhPIT


DF TLNZ
Diameter increment model
Residuals (cm)
Year since thinning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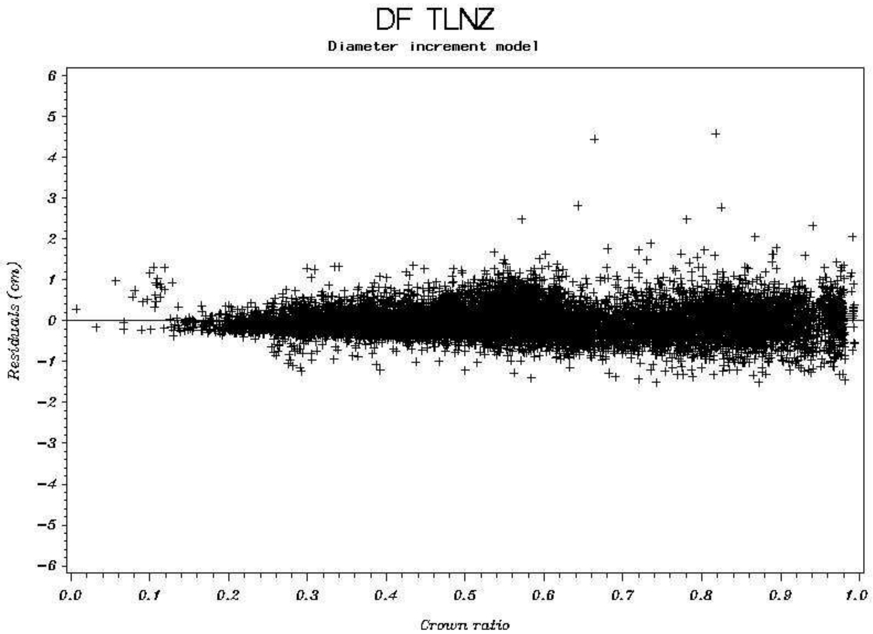
Residuals (cm)
MTD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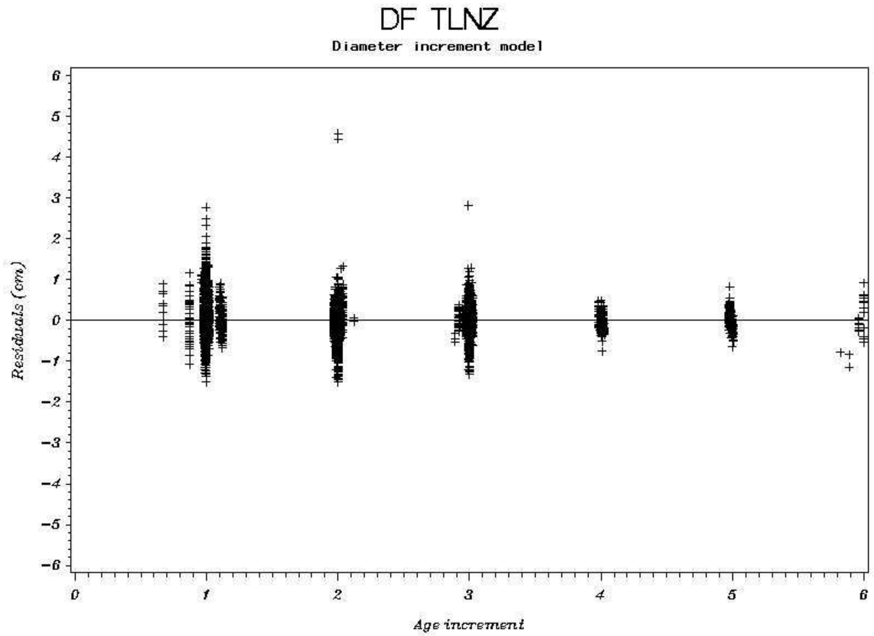
Diameter increment model
Residuals (cm)
Crown ratio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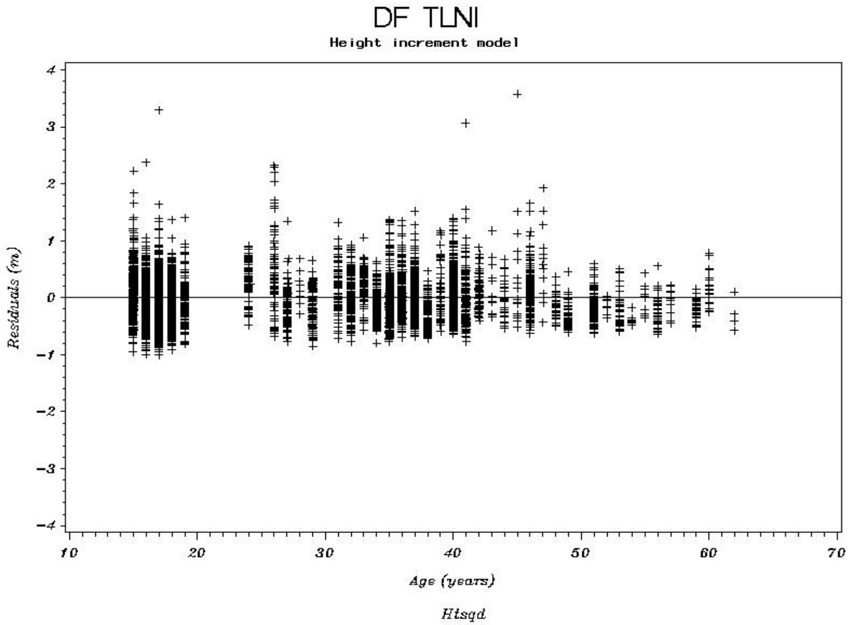
Diameter increment model
Residuals (cm)
Age increment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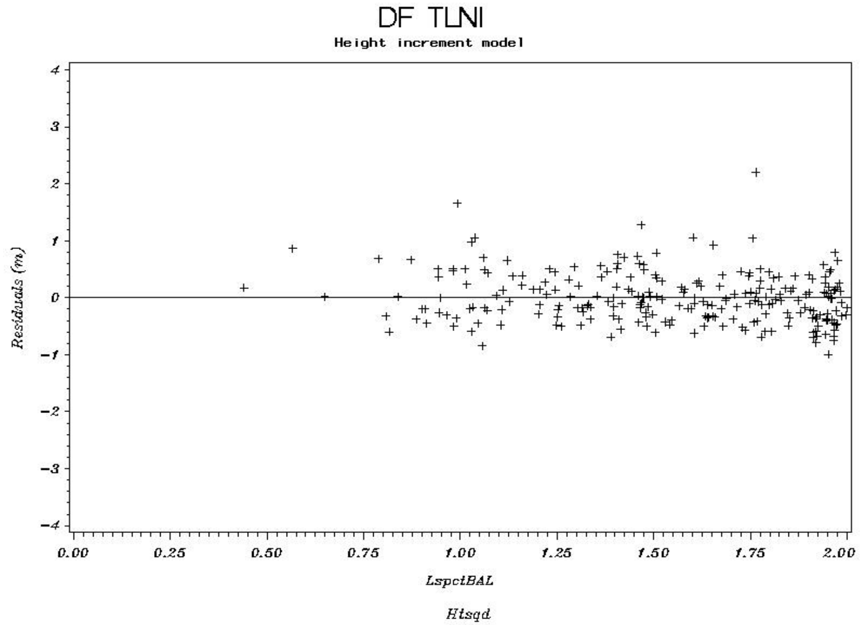
Height increment model
Residuals (m)
Age (years)
Htsqd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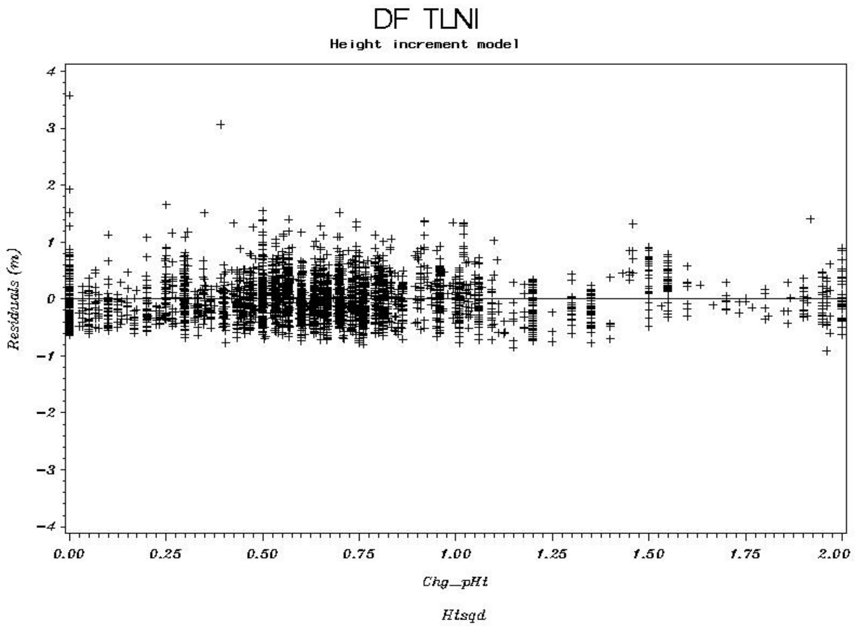
Residuals (m)
LspctBAL
Htsqd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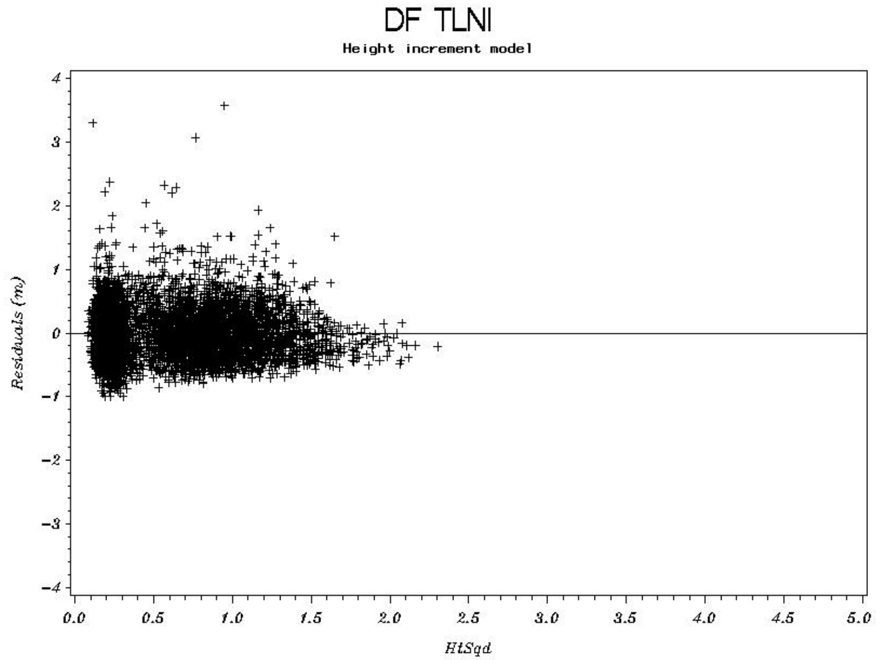
Height increment model
Residuals (m)
Chg_pHt
Htsqd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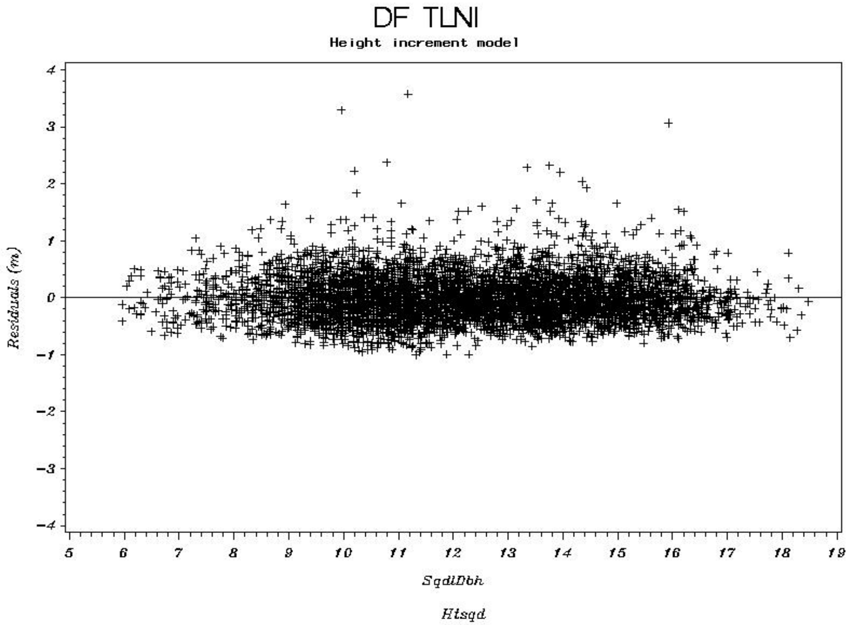
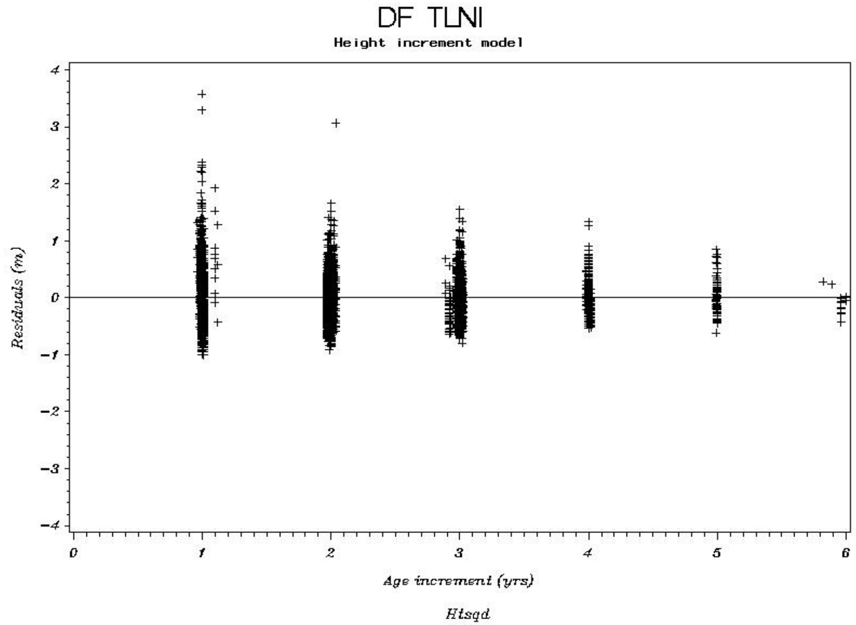
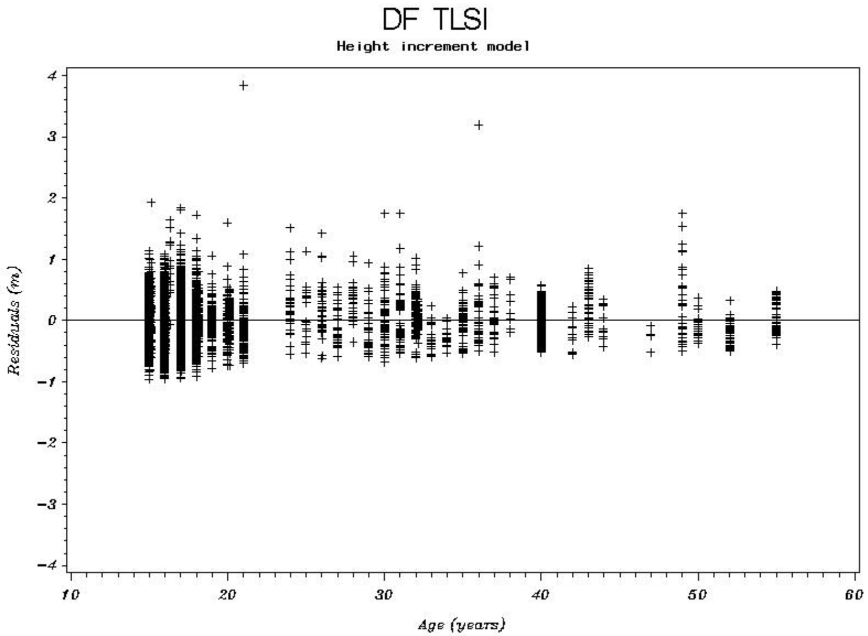
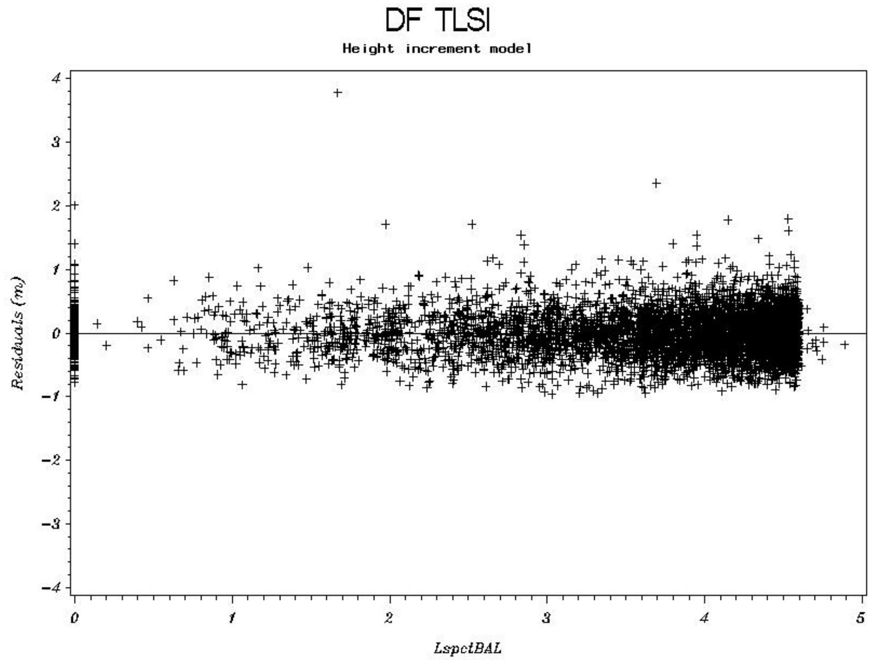
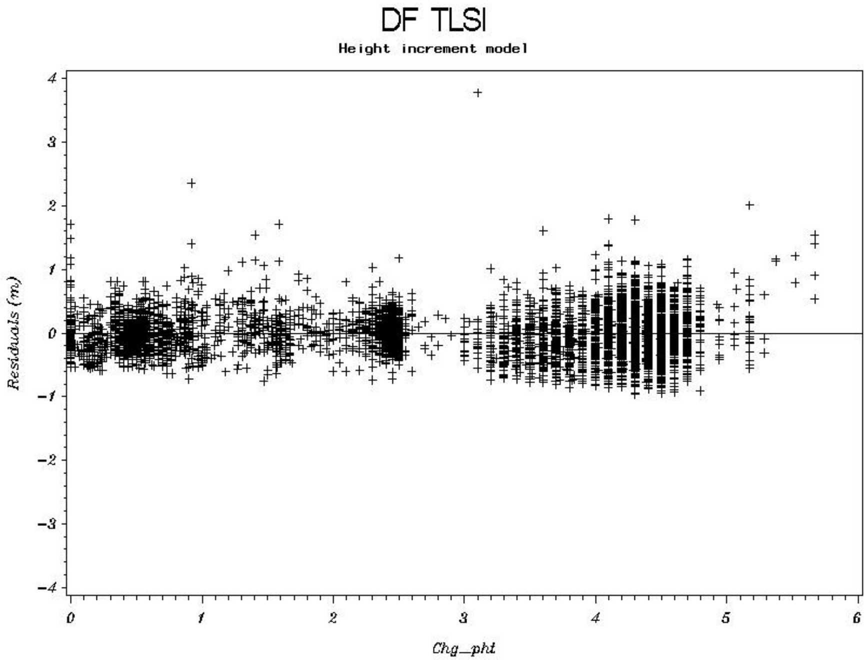
Height increment model
Residuals (m)
HtSqd

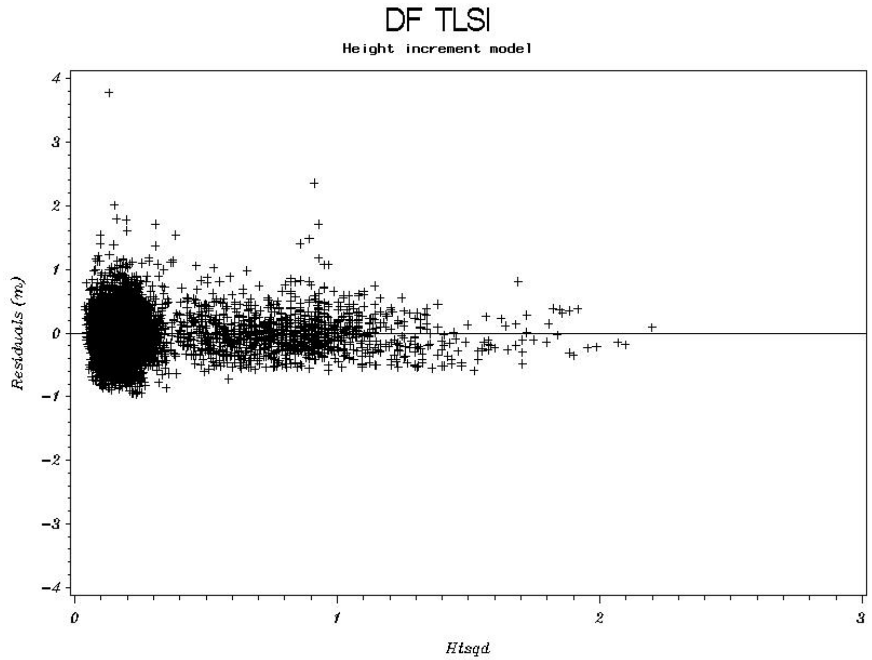

DF TLNI
Height increment model
Residuals (m)
SqdlDbh
Htsqd

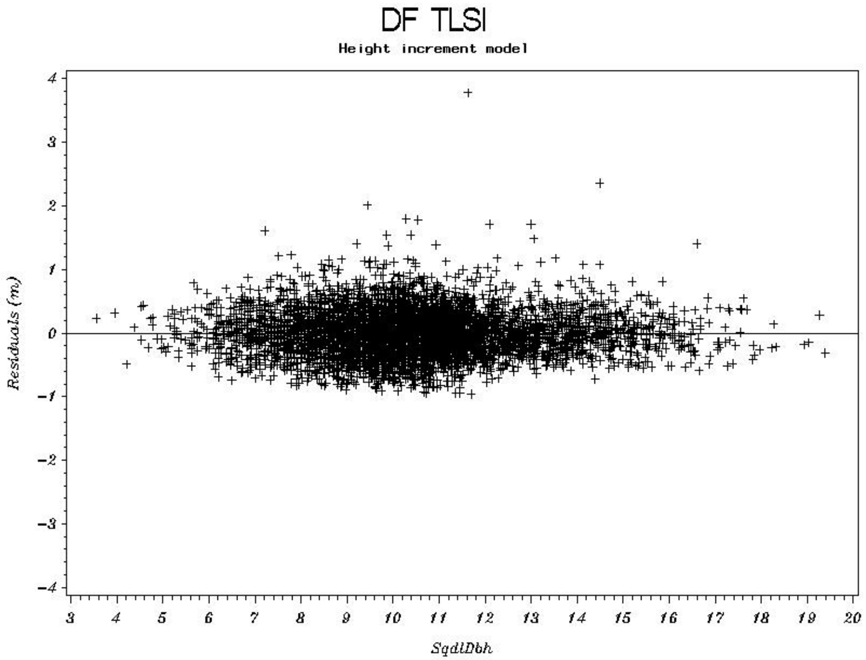

DF TLNI
Height increment model
Residuals (m)
Age increment (yrs)
Htsqd

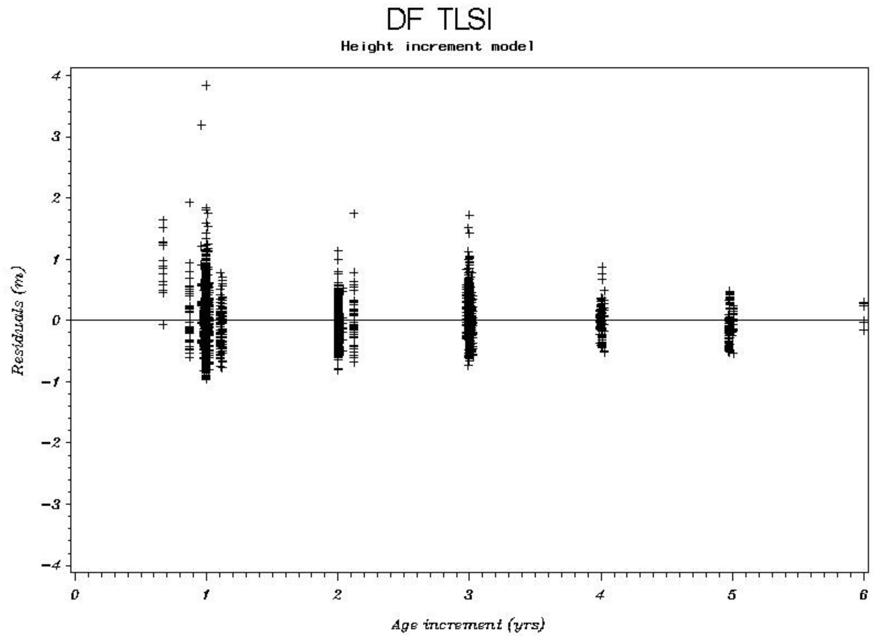

DF TLSI
Height increment model
Residuals (m)
Age (years)
4
3
2
1
0
-1
-2
-3
-4
10
20
30
40
50
60

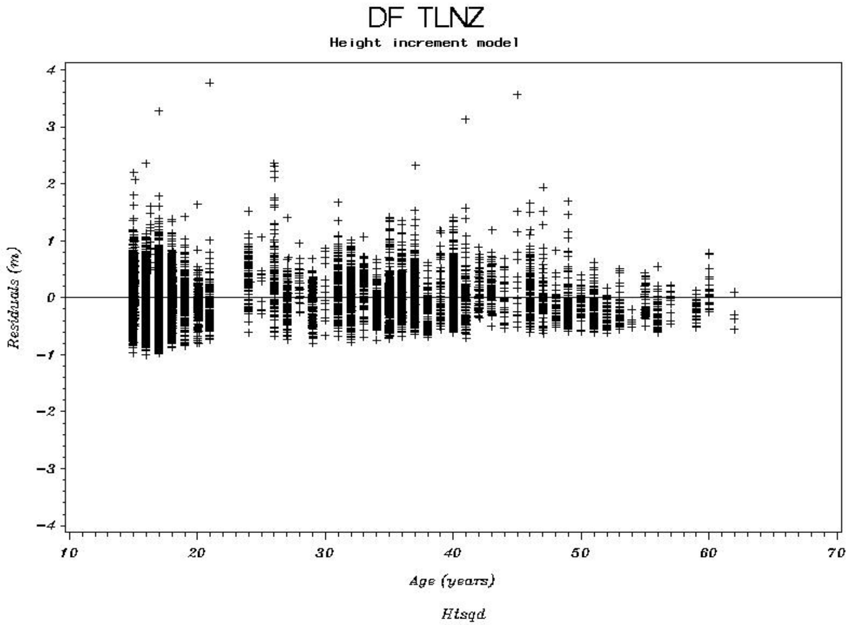

DF TLSI
Height increment model
Residuals (m)
LspctBAL
4
3
2
1
0
-1
-2
-3
-4
0
1
2
3
4
5

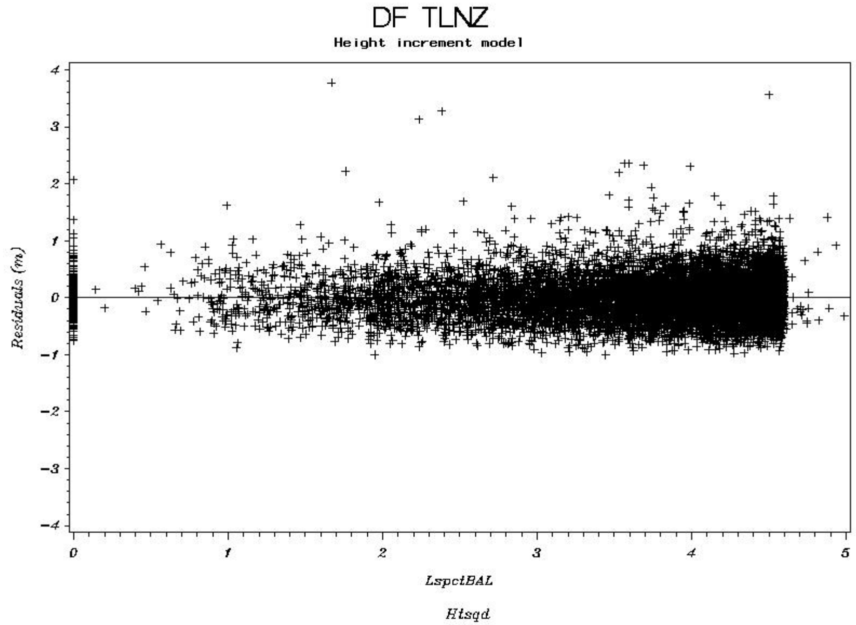

DF TLSI
Height increment model
Residuals (m)
Chg_pht

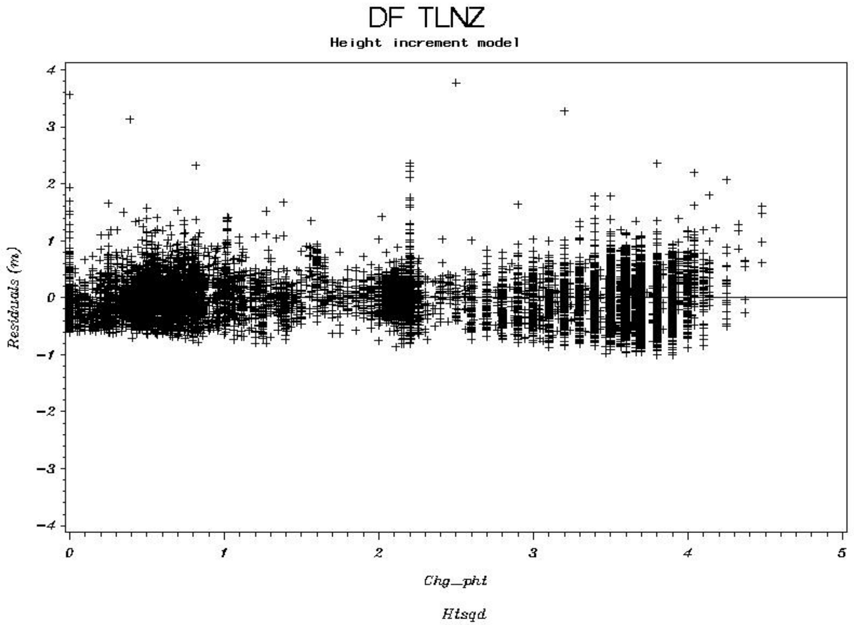

DF TLSI
Height increment model
Residuals (m)
Htsqd

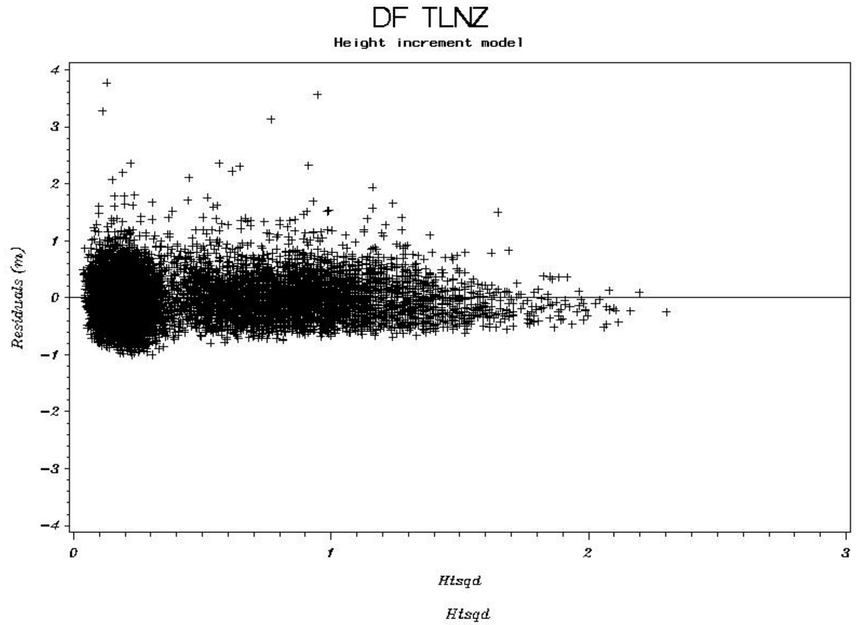

DF TLSI
Height increment model
Residuals (m)
SqdlDbh

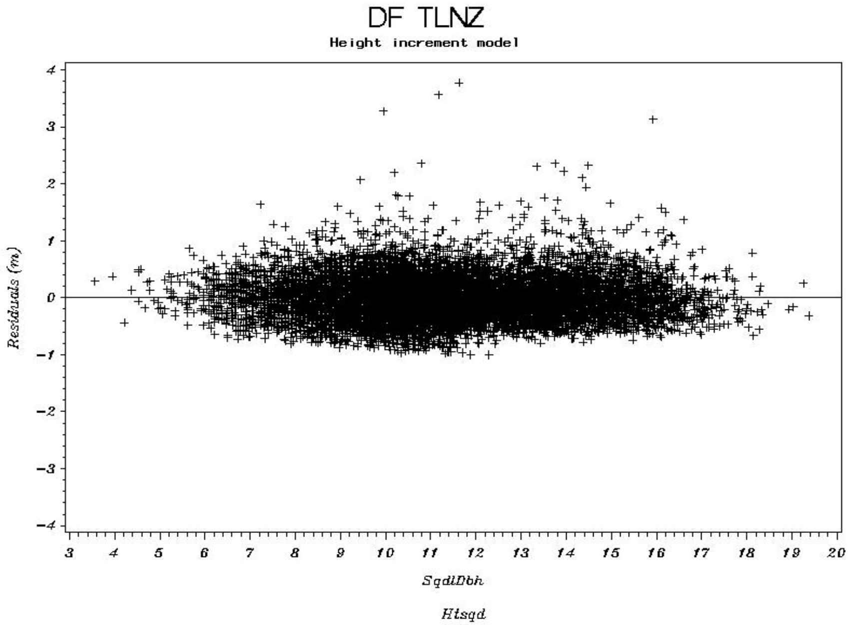

DF TLSI
Height increment model
Residuals (m)
Age increment (yrs)

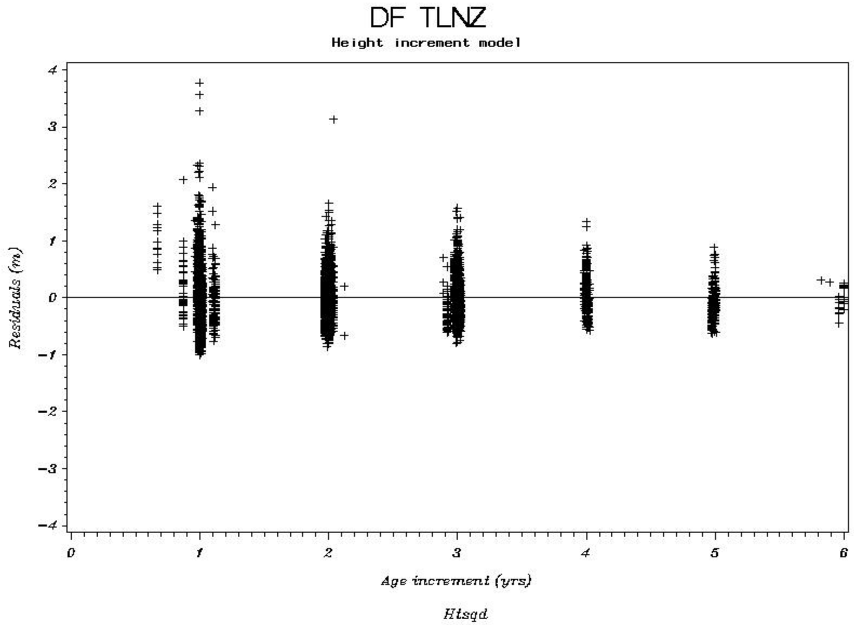

DF TLNZ
Height increment model
Residuals (m)
Age (years)
Htsqd


DF TLNZ
Height increment model
Residuals (m)
LspctBAL
Htsqd


DF TLNZ
Height increment model
Residuals (m)
Chg_pht
Htsqd


DF TLNZ
Height increment model
Residuals (m)
Htsqd
Htsqd


DF TLNZ
Height increment model
Residuals (m)
SqdlDbh
Htsqd


DF TLNZ
Height increment model
Residuals (m)
Age increment (yrs)
Htsqd

DISCUSSION

The following variables (or transformations, thereof) were useful across most of the modelling regions:

- DBHPIT,
- HPIT,
- chg_pht,
- SDIratio
- Cr_ratio and
- MTD.

These variables represent new approaches to index New Zealand radiata pine relative stand density and/or productivity potential. Another new and beneficial approach to growth prediction was to use a 'pre-estimate' of growth itself, DBHPIT/HPIT/chg_pht, in a growth equation. This approach incorporates a predicted pattern of dominant-tree height growth to aid in the height growth prediction of any subject tree.

For the most part, prediction variables relate to tree- or stand-level size/yield attributes. The sign of the coefficients for the explanatory variables in equation [2] conform with anticipated effects on diameter and height growth. For example, the negative effect on diameter growth attributable to increased competition (ie. SDIratio, MTD) while the positive effects attributable to DBHPIT and Cr_ratio. The combination of SDIratio and ysth variables reflect
the stand's intra-specific competition particularly with growing space available in the stand after thinning is applied. The coefficient for ysth was fixed at -0.0025 for DF TLNI due to smaller number of plots with thinning information available from the South Island. In the height increment model, LspctBAL, chg_pht and sqdldbh provide a positive contribution to height growth while Ht^2 has a negative contribution. Ht^2 relates to competition within the stand.

Poor R^2 for tree height increment model confirms previous finding in ITGM (Shula & Gordon , 2000). Even though all explanatory variables used in the models are highly significant, the models could only explain less than 16% of the height increment variation. Low R^2 indicates that the range in squared prediction error is usually greater than the range in squared observed departure from the mean value. Variation in explanatory variables also indicates that regional height increment models may be necessary.

TREE SURVIVAL MODELS

DATA

The current analyses used conventional growth data extracted from the Permanent Sample Plot (PSP) system according to the following acceptance criteria:

- ≥ 4 years old,
- remeasured at least once,
- plot size ≥ 0.04-ha,
- windthrow ≤ 2 trees per plot and mean dbh of windthrow < dbh_q, and
- from conventional growth monitoring plots (not nelder plots).

All plot and tree-level observations meeting the selection criteria were included in the regression analyses. The data used in the analysis is extensive as shown in Table 5 with equal number of PSPs in both the North Island (DF TLNI) and South Island (DF TLSI). A higher percentage of dead trees occurred in DF TLNI (15%) than DF TLSI (4%). Higher percentage of dead trees for DF TLNI possibly relate to warmer climate and hence higher existence of pathogen (eg. Swiss needle-cast) in the North Island. DF TLNZ model is the combined model using data from the North and South Islands.

Table 5. Number of observations, trees, and PSPs by region

Sample	DF TLNI	DF TLSI
No. Obs.	145914	91759
No. Trees	23914	20315
No. Dead Trees	3578	859
% Dead Trees	15	4
No. PSPs	343	325
No. PSPs with Dead	207	142
% PSPs with Dead	60	44

Table 6 presents measures of central tendencies (sample size, mean, standard deviation, minimum, maximum) for stand-level attributes for the datasets. Statistics were calculated at each age represented in a series of PSP measurements.

Table 7 presents measures of central tendencies (sample size, mean, standard deviation, minimum, maximum) for three tree-level attributes (dbh_i, BALdbh, and chg_pdbh) of 'live' and 'dead' trees from two datasets. Statistics were calculated at each age represented in a series of PSP measurements from the sample plots.

Compared with live trees, dead trees are characterised by smaller tree size (dbh_i), less diameter growth (chg_pdbh_i) and larger intra-specific competition ($BALdbh_i$). Nonetheless, some large trees die, as indicated by the range in maximum diameter.

NB: Negative values for chg_pdbh are an artifact of the prediction equation operating at the lower extreme of tree-size, and should be considered equivalent to zero.

Table 6. **Measures of central tendencies (derived using each age on a PSP) for stand-level attributes for each of the regional survival datasets.**

Attribute	DF TLNI (343 plots)	DF TLSI (325 plots)
Age (yrs)		
mean	27.31	20.61
std. dev.	11.40	10.98
minimum	9	7.02
maximum	71	66.04
SPH (s/ha)		
mean	1273.35	1227.84
std. dev.	610.44	572.70
minimum	119	148
maximum	2954	2700
BA (m^2/ha)		
mean	51.58	39.43
std. dev.	23.27	25.31
minimum	5.41	1.10
maximum	132.21	161.79
dbhq (cm)		
mean	24.80	20.95
std. dev.	9.64	8.58
minimum	8.90	4.10
maximum	59.20	69.40
SI (m)		
mean	33.95	29.93
std. dev.	3.32	3.03
minimum	17.20	18.80
maximum	42.30	40.70
SDI (sph)		
mean	1046.35	836.81
std. dev.	380.28	452.96
minimum	116	47
maximum	2260	2708

Interval (yrs)		
mean	1.89	1.87
std. dev.	1.31	1.10
minimum	0.77	0.77
maximum	19	12.19

Table 7. Measures of central tendencies (derived using each age on a PSP) for tree-level attributes of live and dead trees from each of the regional survival datasets.

Model	dbh_i (cm)		chg_pdbh_i (cm)		$BALdbh_i$ (cm)	
	live	dead	live	dead	live	dead
DF TLNI						
n	→		142336	3578	←	
mean	24.15	14.05	1.15	0.71	1.72	4.73
std. dev.	11.78	6.47	0.85	0.69	1.41	1.80
minimum	1	1	0.01	0.01	0	0
maximum	87.9	58.5	16.12	9.19	24.14	31.98
DF TLSI						
n	→		91844	850	←	
mean	20.60	15.56	1.87	1.37	1.29	5.25
std. dev.	9.55	8.83	0.96	0.74	1.26	4.35
minimum	0.4	0.5	0.12	0.11	0	0.09
maximum	80.2	53.3	11.28	4.33	32.11	64.15

METHODS

Background

The initial investigations (Lundgren and Gordon 1997, Shula 1997c) established the utility of using the logistic function to predict the probability of survival between 0 and 1 with variable time intervals between measurements. The current investigation utilised this modelling approach.

The current analyses used SAS (SAS Institute Inc. 1989) weighted, non-linear regression procedure, NLIN, (method=marquardt) to estimate parameter coefficients (α=0.05).

A generalised logistic function was fit:

$$y = \left\{ \frac{1}{\left(1 + \exp^{a_0 + a_1 x_1^{b1} + \ldots + a_n x_n^{bn}}\right)} \right\}^i \qquad [3]$$

where:

y = probability of survival over a period of "i" years,
i = variable time interval between measurements (years),
x_n = tree- and stand-level explanatory variables,
a_0, a_n = coefficients to be determined, and
b_1, b_n = coefficients (optional) to be included/determined.

The data for the dependent variable (y) is discrete (0 or 1), however in practice, equation [3] predicts the probability of survival as a continuous variable between 0 and 1.

To reduce the heterogeneity of residual variance, a variety of weighting schemes were investigated, including:

- the reciprocal of tree-size attributes (e.g., dbh), and
- iterative re-weighting using the reciprocal (or not) of the predicted.

Various criteria for judging equation goodness-of-fit were performed and compared. Discussion on the criteria and explanatory variables used can be found in the earlier part of this report.

Probability of Survival models
Two probability of survival models (DF TLNI and DF TLSI) were initially fitted for Douglas-fir in NZ. For the two models, the final number and selection of explanatory variables were similar (

Table 8). Mchgpdbh was used in DF TLNI instead of chgpdbh as it provided a better fit. The similar number and commonality of explanatory variables for DF TLNI and DF TLSI suggests that the development of a single equation (DF TLNZ), applicable to all NZ, could be justified.

Improvement in adjusted R^2 was not evident with the inclusion of additional explanatory variables, e.g., RD, SDI, reldbh and SI. The final selection of explanatory variables represents 3 principal attributes useful to predict the probability of survival:

- tree-size (ie. LogDbh),
- potential change in tree-size (ie. Chgpdbh, mchgpdbh), and
- relative tree-size (ie. BALdbh).

Fit Statistics and Parameter Coefficients

The adjusted R^2 values ranged from 9.6% to 19.2% (Table 9) which appear low. However, adjusted R^2 values are misleading due to the nature of the actual survival data (a discrete variable: 0 = dead or 1 = alive) versus the probability of survival (ps) prediction (a continuous variable: $0 < ps < 1$). Nonetheless, across regions, the relative ranking of adjusted R^2 values is informative. Furthermore, it is not possible to objectively determine percent-error of prediction because this requires subjective selection of a probability of survival (continuous between 0 and 1) to define either a ‘dead’ (0) or ‘live’ (1) condition.

Table 8. Region, parameters, and coefficients from the regression analyses using equation [3].

Model	Parameter	Coefficient (α=0.05)	Standard Error
DF TLNI	intercept	-2.4329	0.0829
	Log Dbh	0.4552	0.0225
	BALdbh	0.3466	0.0071
	mchgpdbh	-10.5773	0.1498
DF TLSI	intercept	-8.6560	0.1511
	Log Dbh	0.8585	0.0365
	BALdbh	0.6423	0.0096
	chgpdbh	-0.1538	0.0173
DF TLNZ	intercept	-5.4438	0.0626
	Log Dbh	0.0920	0.0169
	BALdbh	0.6166	0.0053
	chgpdbh	-0.4659	0.0140

All coefficients are statistically significant from zero at 95% level.

Table 9. Region, mean residual, adjusted R^2, and Furnival's Index from the regression analyses.

Model	**Mean Residual** (std. dev.)	**Adjusted R^2**	**Furnival Index** (weighted)
DF TLNI	0.0027 (0.1390)	19.15%	0.1391
DF TLSI	0.0040 (0.0905)	9.60%	0.0906
DF TLNZ	0.0079 (0.1261)	12.36%	0.1263

Residuals

Table 10. Statistics of residuals and CV

Model	**Mean Residual**		**Mean Predicted Probability of Survival**		**Coefficient of Variation (%)**	
	Dead	**Alive**	**Dead**	**Alive**	**Dead**	**Alive**
DF TLNI	-0.770	0.022	0.770	0.978	24.05	6.11
DF TLSI	-0.842	0.012	0.842	0.988	26.64	3.38
DF TLNZ	-0.815	0.023	0.815	0.977	22.96	5.11

Figures 37-38 present prediction residuals vs stand dbh_i for the DF TLNI and DF TLSI. The residuals were calculated as the actual (0 or 1) minus the predicted probability of survival (0.0 to 1.0). The following descriptions are provided to further interpret the pattern of residuals in Figures 37-38.

All positive residuals represent trees that were actually alive at the end of the prediction period; the respective predicted probability of survival (equation 1) is equivalent to (1 minus the value of the residual). For example, a residual of 1 equates to a predicted probability of survival of 0, while a residual of 0.2 equates to a predicted probability of survival of 0.8. Therefore, positive residuals close to 0 represent predicted probabilities of survival close to 1 (i.e., more likely to live) for trees that were actually live at time of prediction. Similarly, positive residuals close to 1 represent predicted probabilities of survival close to 0 (i.e., more likely to be dead) for trees that were actually live at time of prediction.

Conversely, all negative residuals represent trees that were actually dead at the end of the prediction period; the respective predicted probability of survival (from equation 1) is equivalent to 0 minus the value of the residual. For example, a residual of -1 equates to a predicted probability of survival of 1, while a residual of -0.2 equates to a predicted probability of survival of 0.2. Therefore, negative residuals close to 0 represent predicted probabilities of survival close to 0 (i.e., more likely to be dead) for trees that were actually dead at time of prediction. Alternatively, negative residuals close to -1 represent predicted probabilities of survival close to 1 (i.e., more likely to be live) for trees that were actually dead at time of prediction.

Figure 37. Residuals vs Dbh (DF TLNI)

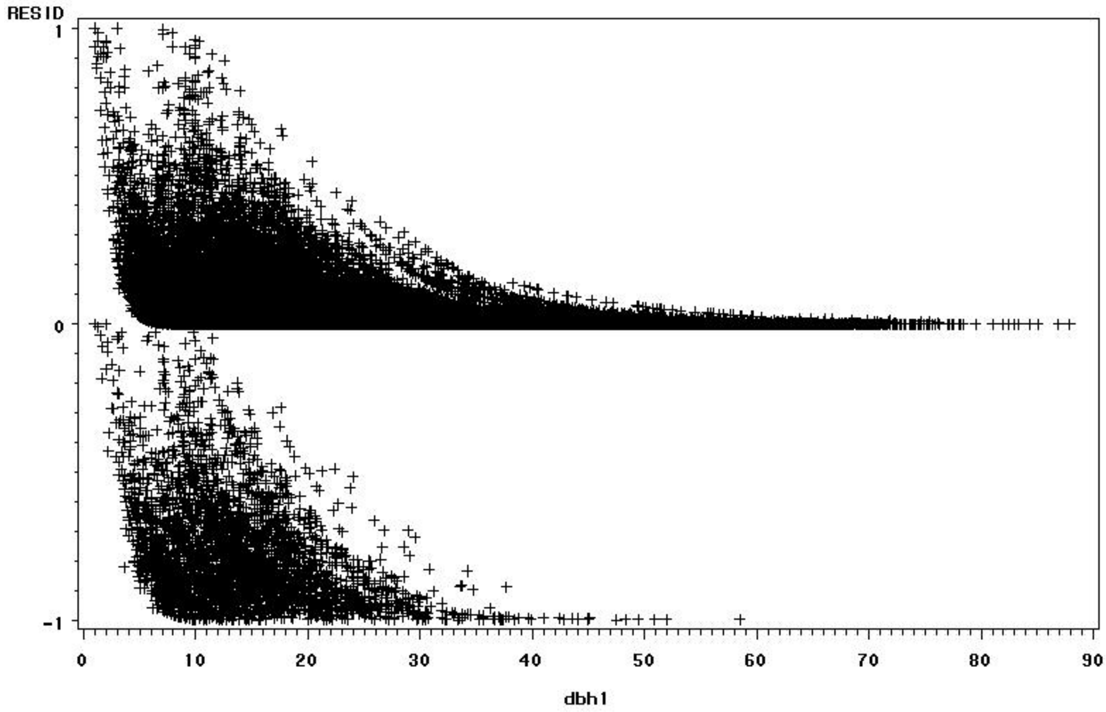
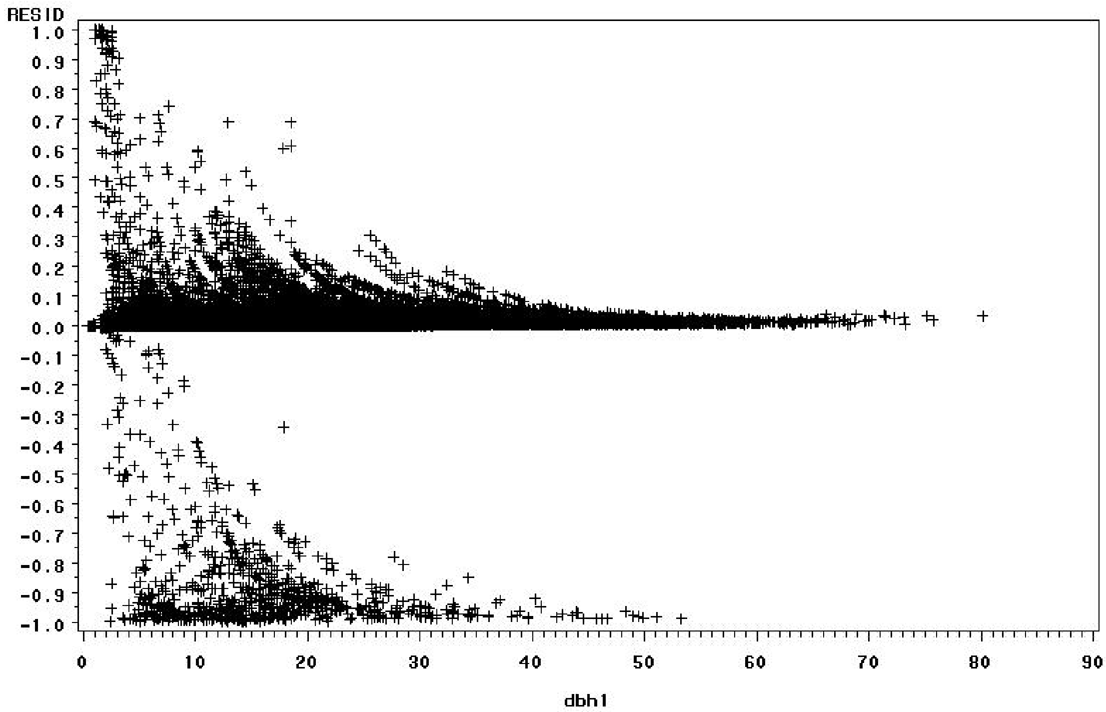


Figure 38. Residuals vs Dbh (DF TLSI)



Figures 37-38 enable the reader to identify various sets of predictions with respect to various degrees of probability of survival for trees that were actually dead or live at time of prediction. In this respect, the reader is able to stratify predicted probabilities of survival from equation [1] and to subjectively classify predictions as representative of 'dead' or 'live' tree conditions. For example, the bulk of residuals with $0 \leq$ residual value ≤ 0.2 (live trees), suggests that predicted probabilities of survival ≥ 0.8 might best represent 'live' trees. However, the bulk of residuals with $-1.0 \leq$ residual value ≤ -0.8 (dead trees), suggests that predicted probabilities ≥ 0.8 might just as well represent 'dead' trees. Therefore, ambiguity exists in the assignment of a 'dead' or 'live' condition based on a tree's predicted probability of survival.

Figures 39-40 present mean prediction residuals by actual mean relative diameter (reldbh). Residuals were calculated as previously described. Mean prediction residuals were calculated on the basis of reldbh groups with near equal sample size.

Figure 39. Residuals vs reldbh (DF TLNI)

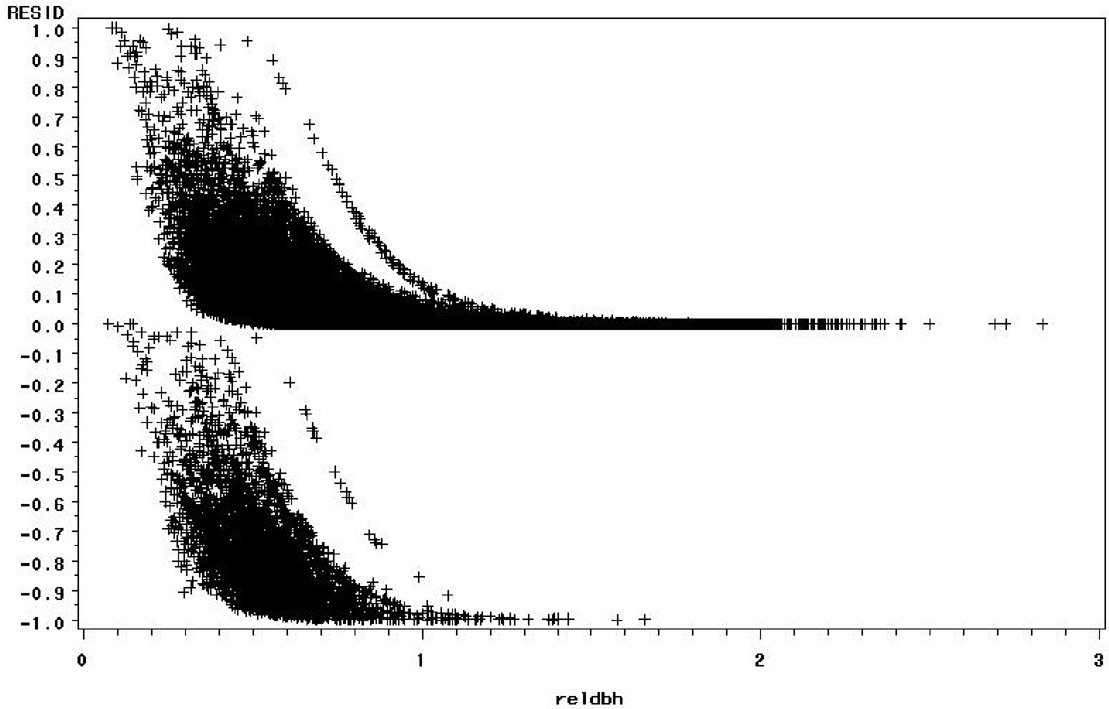
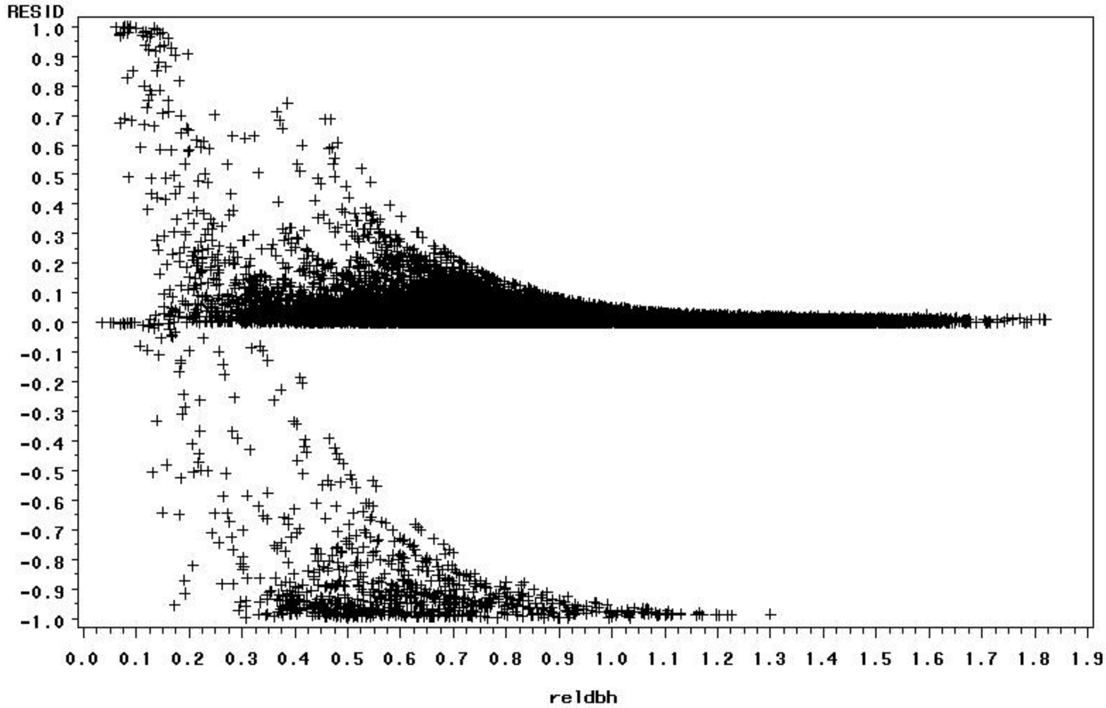


Figure 40. Residuals vs reldbh (DF TLSI)



Figures 39-40 indicate that, on average, prediction residuals are more centralised around zero (predictions approach the 'actual') as relative diameter increases, or as individual tree-size approaches and exceeds stand quadratic mean breast-height diameter. DF TLSI has more centralised mean prediction residuals than DF TLNI. There was higher proportion of dead and small diameter trees (relative dbh <1) for DF TLNI than DF TLSI.

Figures 41-42 present residuals by chg_pdbh, the 'pre-'estimate of diameter growth itself. This approach incorporates a predicted pattern of dominant-tree diameter growth to aid in the prediction of any subject tree's survival probability. Figures 41-42 have higher probability of survival for any trees with chg_pdbh>2.5 which means that higher "expected" diameter growth gives higher chance of tree survival. However this pattern applies in both dead and alive trees indicating that trees with a good prospect of diameter growth could still die. There is also higher proportion of trees with low probability of survival and low values of chg_pdbh in DF TLNI compared to DF TLSI.

Figure 41. Residuals vs chgpdbh (DF TLNI)

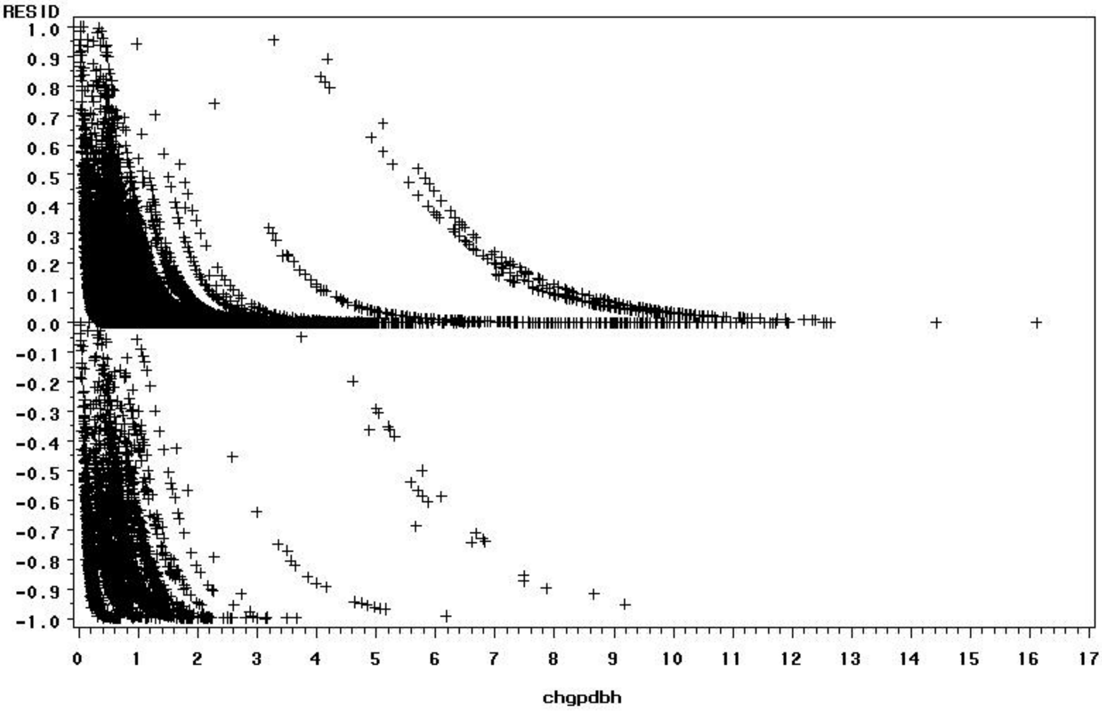
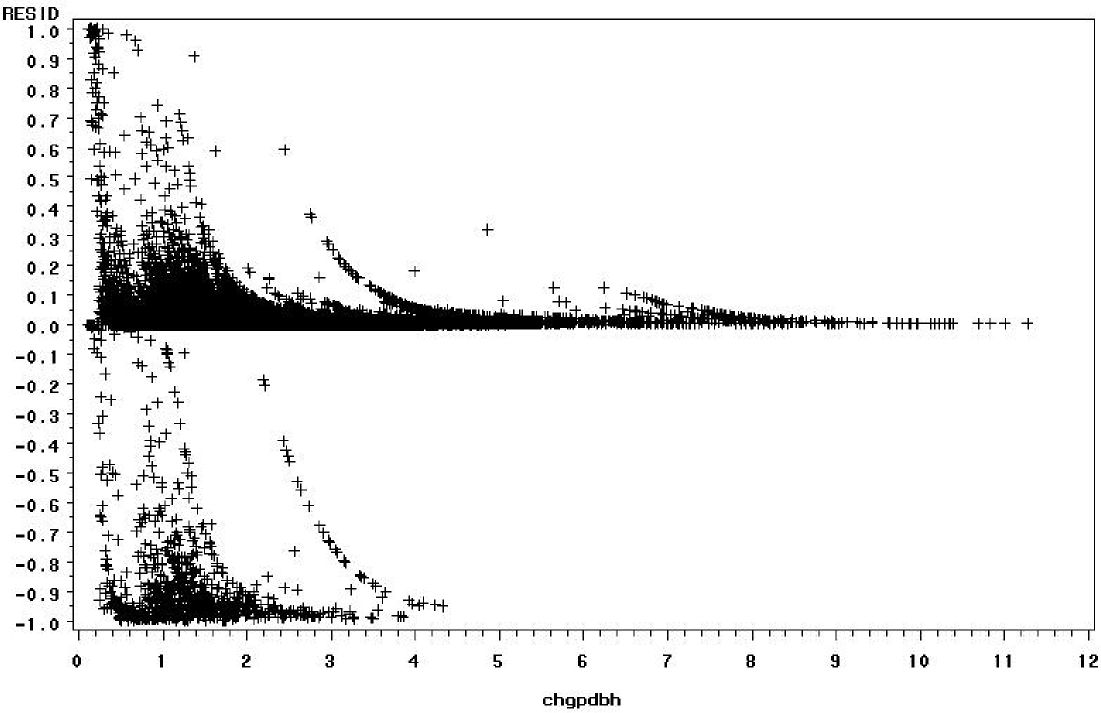


Figure 42. Residuals vs chgpdbh (DF TLSI)



Figures 43-44 present residuals by BALdbh, the within-plot tree competition growth indicator. This approach incorporates competition value of the subject tree diameter growth with respect to the plot's BA into the prediction of any subject tree's survival probability.

Figures 43-44 show trees with smaller BALdbh (ie. ratio of BAL to tree Dbh) have higher survival rate as larger diameter trees have lower ratio to the largest tree in the plot. Furthermore, bigger trees are expected to have higher probability to grow and survive than smaller size trees. However, it also clearly shows that big trees died too as shown in the large proportion of negative values residual for BALdbh < 10 with high probability of survival.

Figure 43. Residuals vs BALdbh (DF TLNI)

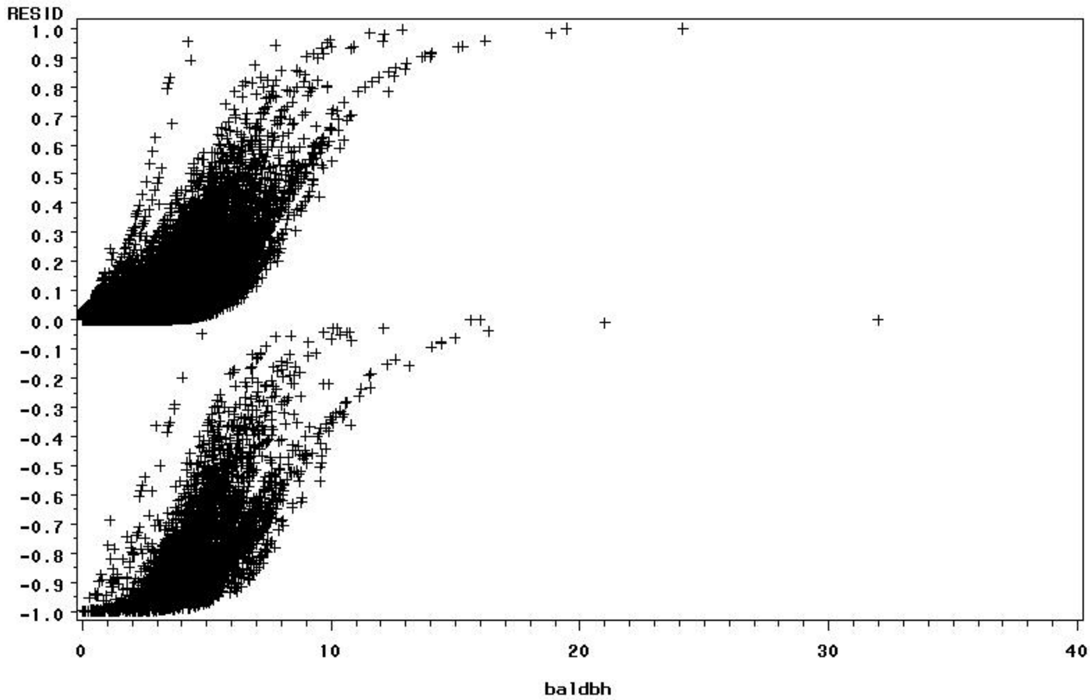
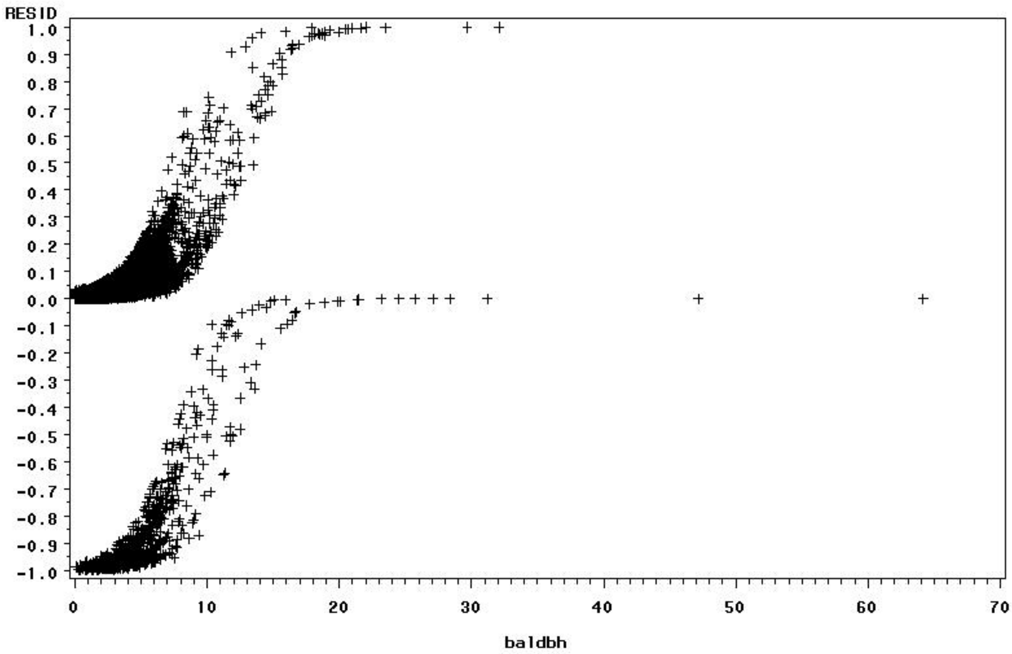


Figure 44. Residuals vs BALdbh (DF TLSI)



DISCUSSION

Explanatory variables. For the most part, prediction variables relating tree-level attributes (diameter, chg_pdbh, and BALdbh) were useful aides to predict the probability of survival at the tree-level. In all cases but one (chg_pdbh), the sign of the coefficients for the explanatory variables in equation [3] conform with anticipated effects on the predicted probability of survival. For example, the positive effects in the predicted probability of survival attributable to increased tree-size (ie. transformation of dbh, BALdbh). An anomaly, however, is the negative sign of the coefficient (significantly different from zero at 95%) for the explanatory variable, chg_pdbh. Intuitively, increased diameter growth corresponds with a greater probability of survival, however, the coefficient indicates a reduction in the predicted probability of survival, as potential growth increases. Explanations at-hand, include:

- an artefact of the multiple least squares statistical fitting procedure,
- a correspondence of greater diameter growth with younger, smaller diameter trees in more highly stocked plots (young trees grow faster than old trees), which are more predisposed to mortality than older, larger diameter trees.

The prediction of survival is difficult (as shown by the residual analyses and low adjusted R^2s), due largely to natural variation (both within island and between islands), as evidenced by the disparity in sample size for 'live' and 'dead' trees. Therefore, it is probably best to maintain specific regional equations.

Implementation. In an individual-tree growth simulator, equation [1] will predict the probability of survival of each tree in a tree-list. The predicted probability of survival will then be multiplied by the tree's expansion factor. With this approach, a tree's expansion factor will be progressively reduced with each time-step through the simulator. This implementation approach removes the dilemma in the assignment of a 'dead' or 'live' condition to 'a tree'. Rather, the probability of survival is assigned proportionally to a tree's expansion factor, such that, a proportion of trees represented by the expansion factor will be considered 'dead' or 'live'. This implementation approach suits the nature of the logistic equation to predict a probability of survival, whereby, e.g., a low probability of survival still imparts the potential to survive.

General Conclusion

The tree level diameter and height increment models together with probability of survival model for Douglas-fir in New Zealand, are considered ready for beta-testing in the new generation of individual-tree growth models and any ancillary applications (e.g., ITGM software). Validation of these models is pending.

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APPENDIX 1: STAND LIST FOR DINC AND HINC MODELS

Plot	Forest	SI	BA	MTH	SPH	Set
FR191/01/0	KANG	38.1	35.05	16.6	750	DF TLNI
FR191/011/0	KANG	41	38.99	19.3	738	DF TLNI
FR191/012/0	KANG	39.8	23.45	18.9	250	DF TLNI
FR191/014/0	KANG	39.9	19.67	19.5	250	DF TLNI
FR191/015/0	KANG	39.8	18.7	19.7	250	DF TLNI
FR191/016/0	KANG	39.8	32.19	19.1	500	DF TLNI
FR191/017/0	KANG	38.9	26.7	17	500	DF TLNI
FR191/018/0	KANG	40.5	36.56	19.7	500	DF TLNI
FR191/020/0	KANG	41	42.49	20	750	DF TLNI
FR191/022/0	KANG	39	25.36	18.6	250	DF TLNI
FR191/023/0	KANG	38.5	37.81	18.7	750	DF TLNI
FR191/024/0	KANG	39.9	33.92	19.3	500	DF TLNI
FR191/025/0	KANG	39.8	23.38	19.1	250	DF TLNI
FR191/03/0	KANG	39.7	33.81	19.3	500	DF TLNI
FR191/030/0	KANG	40.1	34.45	20	500	DF TLNI
FR191/031/0	KANG	39.4	30.89	19.4	500	DF TLNI
FR191/032/0	KANG	40.5	36.27	18.2	750	DF TLNI
FR191/033/0	KANG	39.9	41.95	19.4	750	DF TLNI
FR191/034/0	KANG	39.1	25.23	19	250	DF TLNI
FR191/035/0	KANG	38.4	18.91		250	DF TLNI
FR191/036/0	KANG	39.8	33.36	19.5	500	DF TLNI
FR191/038/0	KANG	39.9	23.07	19.4	250	DF TLNI
FR191/039/0	KANG	40.3	38.06	19.3	750	DF TLNI
FR191/041/0	KANG	40	19.95	19.8	250	DF TLNI
FR191/042/0	KANG	41.4	40.83	19.7	738	DF TLNI
FR191/043/0	KANG	39.3	38.13	18.1	500	DF TLNI
FR191/044/0	KANG	40.6	33.78	20.3	500	DF TLNI
FR191/045/0	KANG	39.2	34.84	18.2	500	DF TLNI
FR191/047/0	KANG	38.9	20.37		250	DF TLNI
FR191/048/0	KANG	40.3	34	20.1	500	DF TLNI
FR191/049/0	KANG	40.2	22.37	19.6	250	DF TLNI
FR191/05/0	KANG	39.5	14.86	18.3	250	DF TLNI
FR191/050/0	KANG	39.1	39.43	19.4	750	DF TLNI
FR191/052/0	KANG	40.8	32.55	20.1	500	DF TLNI
FR191/06/0	KANG	38.3	31.67	18.7	488	DF TLNI
FR191/08/0	KANG	39.8	25.12	17	500	DF TLNI
FR209/010/44	KANG	32.4	54.27	35.4	372	DF TLNI
FR209/012/34	KANG	34	66.5	33.7	517	DF TLNI
FR209/015/39	KANG	37.1	93.97	40.9	537	DF TLNI
FR209/020/27	KANG	35.5	104.1	38.7	1095	DF TLNI
FR209/021/45	KANG	37.4	67.1	40.9	455	DF TLNI
FR209/022/21	KANG	32.7	66.85	35.2	537	DF TLNI
FR209/023/7	KANG	35.5	60.45	38.7	455	DF TLNI
FR209/024/26	KANG	36	66.05	38.6	475	DF TLNI
FR209/025/17	KANG	32.3	53.94	35	496	DF TLNI
FR209/026/46	KANG	34.1	78.76	36.6	579	DF TLNI
FR209/027/21	KANG	31.4	45.48	34	310	DF TLNI

Plot	Forest	SI	BA	MTH	SPH	Set
FR209/029/11	KANG	33.3	83.29	35.8	599	DF TLNI
FR209/031/17	KANG	31.7	50.39	33.3	413	DF TLNI
FR209/032/41	KANG	24.3	21.91	25.1	269	DF TLNI
FR209/034/43	KANG	37.2	86.33	40.4	475	DF TLNI
FR209/038/41	KANG	28.1	24.13	30.6	310	DF TLNI
FR209/039/39	KANG	32.4	68.95	35	455	DF TLNI
FR209/04/15	KANG	35.4	57.1	37.6	475	DF TLNI
FR209/041/2	KANG	34	72	35.4	475	DF TLNI
FR209/05/45	KANG	37.1	82.9	40.1	517	DF TLNI
FR209/050/46	KANG	33.3	64.26	35.6	599	DF TLNI
FR209/052/44	KANG	33.9	91.74	36.9	579	DF TLNI
FR209/055/19	KANG	31.4	46.65	33.5	289	DF TLNI
FR209/059/34	KANG	33.7	74.49	35.4	455	DF TLNI
FR209/06/18	KANG	33.1	49.25	36.2	372	DF TLNI
FR209/060/16	KANG	34.2	66.21	36.1	455	DF TLNI
FR209/063/46	KANG	31.9	67.82	35.1	475	DF TLNI
FR209/064/11	KANG	35.3	88.61	38.6	558	DF TLNI
FR209/066/11	KANG	35.9	94.16	37.5	599	DF TLNI
FR209/067/18	KANG	33	74.85	35.1	496	DF TLNI
FR209/070/16	KANG	33.2	78.22	35.5	620	DF TLNI
FR209/074/41	KANG	26	29.65	28	393	DF TLNI
FR209/077/45	KANG	37.3	84.48	40	537	DF TLNI
FR209/078/21	KANG	32.9	61.69	34.6	496	DF TLNI
FR209/082/27	KANG	36	83.52	38.5	455	DF TLNI
FR209/084/15	KANG	31.2	57.93	34.3	331	DF TLNI
FR209/086/26	KANG	33.6	65.99	36	393	DF TLNI
FR209/087/32	KANG	33.5	71.31	36.4	517	DF TLNI
FR209/090/18	KANG	33.8	61.47	36.3	517	DF TLNI
FR209/093/20	KANG	34.4	69.94	36.7	517	DF TLNI
FR209/099/28	KANG	30.8	49.43	33.3	413	DF TLNI
FR212/01/0	KANG	35.1	50.97	16.4	1900	DF TLNI
FR212/010/0	KANG	35	18.67	16.1	510	DF TLNI
FR212/011/0	KANG	36.5	50.68	16.1	1890	DF TLNI
FR212/012/0	KANG	33.6	25.03	14.9	750	DF TLNI
FR212/014/0	KANG	34.6	17.26	16.5	520	DF TLNI
FR212/015/0	KANG	34.7	16.7	16	510	DF TLNI
FR212/016/0	KANG	35.2	24.14	15.7	820	DF TLNI
FR212/018/0	KANG	34.4	5.65	15.3	140	DF TLNI
FR212/02/0	KANG	34.8	21.87	16.3	750	DF TLNI
FR212/020/0	KANG	35.5	16.17	16.4	500	DF TLNI
FR212/021/0	KANG	33.6	24.08	14.8	490	DF TLNI
FR212/03/0	KANG	35.4	18.15	16.5	250	DF TLNI
FR212/04/0	KANG	36.2	19.63	17.1	490	DF TLNI
FR212/06/0	KANG	35	6.97	16	150	DF TLNI
FR212/08/0	KANG	36	24.92	16.6	750	DF TLNI
FR212/09/0	KANG	32	17.91	13.9	540	DF TLNI
FR244/012/0	KINL	35.5	102.48	39.9	640	DF TLNI
FR244/017/0	KINL	33.9	92.88	36.4	517	DF TLNI
FR244/020/0	KINL	32.8	73.16	34.4	537	DF TLNI
FR244/023/0	KINL	38.3	125.08	40.9	496	DF TLNI
FR244/026/0	KINL	37	89	40.3	517	DF TLNI

Plot	Forest	SI	BA	MTH	SPH	Set
FR244/027/0	KINL	33.9	94.39	35.6	599	DF TLNI
FR244/028/0	KINL	35.7	76.5	37.8	455	DF TLNI
FR244/029/0	KINL	35.9	106.9	39	537	DF TLNI
FR244/031/0	KINL	33	64.38	34.5	496	DF TLNI
FR244/04/0	KINL	42.3	125.59	44.7	537	DF TLNI
FR244/040/0	KINL	35.2	117.72	39.4	558	DF TLNI
FR244/042/0	KINL	37.1	98.46	40	558	DF TLNI
FR244/048/0	KINL	36	120.49	38.3	579	DF TLNI
FR244/053/0	KINL	32.5	64.57	35.8	579	DF TLNI
FR244/055/0	KINL	19.8	10.61	20.6	186	DF TLNI
FR244/058/0	KINL	35.6	107.97	38.2	537	DF TLNI
FR244/059/0	KINL	32.6	73.92	35.3	434	DF TLNI
FR244/060/0	KINL	37.4	75.97	39.1	496	DF TLNI
FR244/063/0	KINL	31.7	66.35	33.8	517	DF TLNI
FR244/066/0	KINL	32	68.06	33.7	517	DF TLNI
FR244/069/0	KINL	36	89.54	37.2	558	DF TLNI
RO1053/12/0	KANG	35.5	65.42	36.7	730	DF TLNI
RO1053/13/0	KANG	36.1	61.84	35.9	460	DF TLNI
RO1053/14/0	KANG	36.3	62.36	37.5	450	DF TLNI
RO1401/01/0	KANG	34.3	50.51	27.8	400	DF TLNI
RO1401/03/0	KANG	34.5	27.9	28.7	263	DF TLNI
RO1401/05/0	KANG	35.9	36.12	31.2	250	DF TLNI
RO1401/07/0	KANG	35.5	35.46	32.2	263	DF TLNI
RO1401/08/0	KANG	34.8	50.6	30.9	375	DF TLNI
RO1710/01/0	WIRI	34.1	80.03	35.5	520	DF TLNI
RO1710/02/0	WIRI	32.1	74.85	33.2	540	DF TLNI
RO20/01/0	KANG	32.6	57.06	39.3	272	DF TLNI
RO20/02/0	KANG	33.2	49.64	39	232	DF TLNI
RO20/03/0	KANG	33	83.2	39.1	781	DF TLNI
RO214/03/0	KANG	32.9	37.66		188	DF TLNI
RO214/04/0	KANG	33	42.3	24.9	420	DF TLNI
RO22/01/0	KANG	33.6	89.59	39.9	731	DF TLNI
RO22/02/0	KANG	34.4	59.07	39.5	267	DF TLNI
RO22/03/0	KANG	34.4	43.71	40.5	198	DF TLNI
RO23/01/0	KANG	35.3	50.44	46.6	148	DF TLNI
RO23/02/0	KANG	34.7	59.24	44.7	217	DF TLNI
RO24/02/0	KANG	36.3	85.58	40.1	741	DF TLNI
RO24/04/0	KANG	34.8	43.18	38.2	188	DF TLNI
RO240/01/0	FRIG	31	58.55	43.5	198	DF TLNI
RO38/01/0	KANG	35.3	83.5	28.4	1225	DF TLNI
RO38/02/0	KANG	34.1	44.13	42.5	148	DF TLNI
RO38/04/0	KANG	33.8	49.38	42.3	178	DF TLNI
RO483/00/0	KANG	29.4	46.75	39	178	DF TLNI
RO698/111/0	KANG	35.9	52.82	40.9	227	DF TLNI
RO698/112/0	KANG	34.7	59.13	39.5	237	DF TLNI
RO698/13/0	KANG	35.8	43.86	39.7	217	DF TLNI
RO698/210/0	KANG	35.7	62.25	40.5	346	DF TLNI
RO698/25/0	KANG	34	63.58	38.8	356	DF TLNI
RO698/29/0	KANG	36	64.29	42.4	356	DF TLNI

Plot	Forest	SI	BA	MTH	SPH	Set
RO698/314/0	KANG	35	71.07	39	455	DF TLNI
RO698/34/0	KANG	34	69.3	38	514	DF TLNI
RO698/42/0	KANG	36.2	75.98	37.1	662	DF TLNI
RO698/47/0	KANG	37.7	65.65	38.6	682	DF TLNI
RO698/51/0	KANG	35.8	81.87	39.3	939	DF TLNI
RO698/513/0	KANG	35.1	71.98	36.3	1038	DF TLNI
RO698/56/0	KANG	35.4	76.99	35.5	1038	DF TLNI
RO749/00/0	KANG	37	80.64	36.3	1190	DF TLNI
RO750/00/0	KANG	35.1	37.34	36.1	380	DF TLNI
RO771/02/0	KANG	34.4	43.93	35.6	188	DF TLNI
RO772/01/0	KANG	32.1	53.56	35.8	445	DF TLNI
RO772/02/0	KANG	32.2	44.52	36.3	346	DF TLNI
RO772/03/0	KANG	34.5	48.9	38.5	346	DF TLNI
RO775/114/0	KANG	35.9	72.07	33.8	950	DF TLNI
RO775/19/0	KANG	34.5	62.23	33.4	1013	DF TLNI
RO775/24/0	KANG	33	60.28	30.3	963	DF TLNI
RO775/320/0	KANG	33.4	64.97	33.1	813	DF TLNI
RO775/323/0	KANG	34.5	64.18	31.4	900	DF TLNI
RO775/35/0	KANG	32.7	61.61	30.6	875	DF TLNI
RO775/37/0	KANG	34.1	72.73	32.2	863	DF TLNI
RO775/417/0	KANG	35	27.25	31.3	263	DF TLNI
RO775/419/0	KANG	34.3	63.57	33	713	DF TLNI
RO775/42/0	KANG	32.6	56.13	31.8	663	DF TLNI
RO775/46/0	KANG	35.6	72.64	33.9	663	DF TLNI
RO775/522/0	KANG	32.1	49.53	30.5	363	DF TLNI
RO775/53/0	KANG	33	50	31.2	363	DF TLNI
RO775/611/0	KANG	32	47.94	30.1	250	DF TLNI
RO775/612/0	KANG	33.1	42.42	31.2	250	DF TLNI
RO775/616/0	KANG	35.5	46.11	34.2	250	DF TLNI
RO776/12/0	KANG	34.8	56.1	30.7	1213	DF TLNI
RO776/15/0	KANG	36.8	55.42	32.7	938	DF TLNI
RO776/24/0	KANG	32.7	57.83	31.6	888	DF TLNI
RO776/28/0	KANG	35.3	53.08	29.6	1063	DF TLNI
RO776/29/0	KANG	35	59.68	34.2	775	DF TLNI
RO776/313/0	KANG	36.6	59.58	34.4	663	DF TLNI
RO776/315/0	KANG	32	53.8	27	888	DF TLNI
RO776/412/0	KANG	34.8	54.38	33.3	650	DF TLNI
RO776/43/0	KANG	35.6	56.21	33.9	700	DF TLNI
RO776/46/0	KANG	34.6	55.83	33.2	638	DF TLNI
RO776/51/0	KANG	35.9	49.66	33.4	350	DF TLNI
RO776/510/0	KANG	34.2	50.32	33.6	363	DF TLNI
RO777/01/0	KANG	34.5	67.57	34.3	470	DF TLNI
RO777/02/0	KANG	34	46.11	35.7	340	DF TLNI
RO777/03/0	KANG	34.1	53.12	34.1	480	DF TLNI
RO778/02/0	KANG	37	68.58	39.2	820	DF TLNI
RO778/03/0	KANG	35.8	72.76	35.2	1090	DF TLNI
RO779/01/0	KANG	29.1	45.54	30.7	260	DF TLNI
RO779/02/0	KANG	31.8	39.11	34.9	160	DF TLNI
RO779/03/0	KANG	28.5	55.91	30.9	340	DF TLNI

Plot	Forest	SI	BA	MTH	SPH	Set
RO906/01/0	KANG	36	45.84	29.8	283	DF TLNI
RO906/04/0	KANG	35.3	54.8	29.2	550	DF TLNI
RO906/06/0	KANG	35.3	19.16	16.7	300	DF TLNI
RO906/07/0	KANG	36.5	54.01	29.7	417	DF TLNI
RO906/08/0	KANG	34.9	45.36	28.2	283	DF TLNI
RO971/01/0	WAKA	28.9	51.77	35.3	362	DF TLNI
RO971/03/0	WAKA	31.4	66.6	38.2	593	DF TLNI
RO971/04/0	WAKA	28.9	47.35	37.8	329	DF TLNI
RO971/05/0	WAKA	29.4	67.99	37.2	956	DF TLNI
RO971/07/0	WAKA	27	55.1	35.1	297	DF TLNI
RO971/09/0	WAKA	28.4	82.54	38.3	873	DF TLNI
WN57/01/0	KROI	31.4	135.72	38.1	1067	DF TLNI
CY112/01/0	HANM	30.3	35.3	35	188	DF TLSI
CY112/02/0	HANM	30.2	48.43	34.5	277	DF TLSI
CY112/03/0	HANM	29.5	94.94	28	1285	DF TLSI
CY112/04/0	HANM	30.5	58.05	28.4	514	DF TLSI
CY575/31/1	CRBU	27.3	89.2	25.6	680	DF TLSI
CY88/01/0	HANM	25.2	35.03	33.5	188	DF TLSI
CY88/02/0	HANM	24.9	32.66	33.4	208	DF TLSI
CY88/03/0	HANM	25.5	88.35	32.5	1117	DF TLSI
FR206/11/0	RIBB	29.2	40.39	17.2	500	DF TLSI
FR206/110/0	RIBB	30.4	46.05	17	738	DF TLSI
FR206/111/0	RIBB	29.8	29.52	17.2	250	DF TLSI
FR206/113/0	RIBB	30.6	36.53	17.8	500	DF TLSI
FR206/116/0	RIBB	30.1	17.26	17.3	250	DF TLSI
FR206/117/0	RIBB	31.1	34.12	17.9	488	DF TLSI
FR206/118/0	RIBB	30.4	36.24	17.9	500	DF TLSI
FR206/119/0	RIBB	31.3	45.29	18.2	738	DF TLSI
FR206/121/0	RIBB	30.3	23.94	17.9	250	DF TLSI
FR206/123/0	RIBB	30.2	42.99	17.5	500	DF TLSI
FR206/124/0	RIBB	30.2	46.29	18	738	DF TLSI
FR206/127/0	RIBB	30.7	20.79	18.4	250	DF TLSI
FR206/129/0	RIBB	30.8	45.74	18.1	725	DF TLSI
FR206/13/0	RIBB	29.3	48.91	17.2	750	DF TLSI
FR206/130/0	RIBB	30.9	38.4	17.8	500	DF TLSI
FR206/131/0	RIBB	31.1	26.85	17.9	250	DF TLSI
FR206/132/0	RIBB	31	21.4	18.3	250	DF TLSI
FR206/135/0	RIBB	30.7	35.59	18.2	488	DF TLSI
FR206/136/0	RIBB	32.1	49.64	19	750	DF TLSI
FR206/137/0	RIBB	32	50.43	18.8	750	DF TLSI
FR206/139/0	RIBB	31	20.76	18.3	238	DF TLSI
FR206/14/0	RIBB	29	19.82	16.6	238	DF TLSI
FR206/140/0	RIBB	31.6	41.3	18.3	500	DF TLSI
FR206/142/0	RIBB	29.6	24.93	16.9	250	DF TLSI
FR206/144/0	RIBB	30.1	19.44	17.3	250	DF TLSI
FR206/145/0	RIBB	30.1	47.42	17.1	750	DF TLSI
FR206/146/0	RIBB	30.4	45.61	17.7	750	DF TLSI
FR206/147/0	RIBB	30.6	37.84	17.8	488	DF TLSI
FR206/148/0	RIBB	30.5	18.39	17.5	250	DF TLSI

Plot	Forest	SI	BA	MTH	SPH	Set
FR206/150/0	RIBB	29.2	19.32	17.1	250	DF TLSI
FR206/151/0	RIBB	29.3	42.78	16.9	738	DF TLSI
FR206/152/0	RIBB	28.9	45.19	16.7	750	DF TLSI
FR206/153/0	RIBB	29.7	37.4	17.2	488	DF TLSI
FR206/154/0	RIBB	29.5	17.44	17.3	250	DF TLSI
FR206/155/0	RIBB	30.1	34.69	17.4	475	DF TLSI
FR206/156/0	RIBB	28.8	24.97	16.7	250	DF TLSI
FR206/157/0	RIBB	29.5	47.09	17.3	750	DF TLSI
FR206/158/0	RIBB	28.7	47.49	17.1	750	DF TLSI
FR206/159/0	RIBB	31.3	42.33	17.9	500	DF TLSI
FR206/16/0	RIBB	30.3	46.55	17	750	DF TLSI
FR206/17/0	RIBB	29.9	39.26	17.7	500	DF TLSI
FR206/18/0	RIBB	29.2	13.79	15.2	250	DF TLSI
FR206/212/0	RIBB	30.6	47.75	17.9	788	DF TLSI
FR206/214/0	RIBB	30.6	46.76	17.1	1175	DF TLSI
FR206/22/0	RIBB	31.2	49.78	18.4	763	DF TLSI
FR206/225/0	RIBB	30.2	52.71	17.9	1088	DF TLSI
FR206/228/0	RIBB	29.7	54.08	16.8	1338	DF TLSI
FR206/233/0	RIBB	31.1	68.2	18.3	1875	DF TLSI
FR206/234/0	RIBB	30.9	61.33	18.5	1413	DF TLSI
FR206/238/0	RIBB	31.8	68.38	18.6	1800	DF TLSI
FR206/241/0	RIBB	31	63.34	17.9	1500	DF TLSI
FR206/29/0	RIBB	30.4	48.75	17.2	688	DF TLSI
FR213/01/0	BLUE	29	25.75	13.1	500	DF TLSI
FR213/012/0	BLUE	26	26.72	12.5	800	DF TLSI
FR213/015/0	BLUE	26.5	37.39	11.8	1240	DF TLSI
FR213/03/0	BLUE	29.4	44.63	13	1510	DF TLSI
FR213/07/0	BLUE	28.1	41.22	12.3	1390	DF TLSI
FR224/0100/43	GDNE	34.1	76.12	35.3	617	DF TLSI
FR224/0101/27	GDNE	34.1	67.94	35.5	535	DF TLSI
FR224/0102/31	GDNE	33.3	60.28	34.6	638	DF TLSI
FR224/0104/25	GDNE	33.7	84.04	35.7	576	DF TLSI
FR224/0105/15	GDNE	31.2	71.29	32	597	DF TLSI
FR224/0106/38	GDNE	18.8	12.48	18.9	391	DF TLSI
FR224/0107/24	GDNE	30.6	54.08	32.4	597	DF TLSI
FR224/0108/5	GDNE	32.8	67.53	35	638	DF TLSI
FR224/0110/10	GDNE	30.2	56.56	31.4	597	DF TLSI
FR224/0111/4	GDNE	32.4	73.7	34.5	597	DF TLSI
FR224/0112/40	GDNE	23.1	23.16	23.5	432	DF TLSI
FR224/0113/26	GDNE	36.4	97.13	38.6	597	DF TLSI
FR224/0114/20	GDNE	34.5	81.17	36.4	617	DF TLSI
FR224/0115/32	GDNE	35.5	78.93	37.8	638	DF TLSI
FR224/0116/13	GDNE	32	64.49	34	617	DF TLSI
FR224/0117/22	GDNE	32.7	74.06	34.4	617	DF TLSI
FR224/0118/27	GDNE	33.8	83.97	36.2	658	DF TLSI
FR224/0119/35	GDNE	32.2	49.13	33.4	535	DF TLSI
FR224/0121/46	GDNE	31	67.23	32.6	638	DF TLSI
FR224/0122/9	GDNE	33.7	38.69	34.7	432	DF TLSI
FR224/0123/30	GDNE	31.2	61.1	32.6	597	DF TLSI

Plot	Forest	SI	BA	MTH	SPH	Set
FR224/0126/26	GDNE	33.1	72.91	34.4	720	DF TLSI
FR224/0127/46	GDNE	30.8	68.45	32.6	617	DF TLSI
FR224/0128/38	GDNE	22.5	22.38	22.9	453	DF TLSI
FR224/0129/39	GDNE	35.7	95.2	37.5	658	DF TLSI
FR224/0130/16	GDNE	34.1	67.93	34.9	576	DF TLSI
FR224/0131/39	GDNE	38.4	100.36	40.6	700	DF TLSI
FR224/0132/42	GDNE	28.4	60.93	29.5	617	DF TLSI
FR224/0133/3	GDNE	33	60.66	34.5	576	DF TLSI
FR224/0134/33	GDNE	33.3	67.39	35	576	DF TLSI
FR224/0136/19	GDNE	26.6	43.92	27.8	576	DF TLSI
FR224/0137/41	GDNE	23.5	27.67	25.2	453	DF TLSI
FR224/0140/23	GDNE	26.2	27.54	26.9	514	DF TLSI
FR224/0141/44	GDNE	32	69.98	33.6	617	DF TLSI
FR224/0142/22	GDNE	31.8	71.76	34.1	576	DF TLSI
FR224/0143/36	GDNE	30.7	48.3	31.7	514	DF TLSI
FR224/0144/41	GDNE	22.7	28.64	23.7	576	DF TLSI
FR224/0145/35	GDNE	29.8	60.4	31.4	617	DF TLSI
FR224/0147/16	GDNE	31.3	77.85	32.9	638	DF TLSI
FR224/0148/42	GDNE	28.6	56.53	29.8	638	DF TLSI
FR224/0149/30	GDNE	32.1	48.29	32.6	617	DF TLSI
FR224/043/18	GDNE	30.5	74.12	32.3	597	DF TLSI
FR224/044/23	GDNE	26.9	42.57	28.1	535	DF TLSI
FR224/045/15	GDNE	29	70.74	30.8	617	DF TLSI
FR224/046/13	GDNE	29.1	67	30.9	617	DF TLSI
FR224/047/28	GDNE	24.8	37.1	26.1	576	DF TLSI
FR224/048/39	GDNE	30.3	85.64	32	597	DF TLSI
FR224/049/38	GDNE	23.7	27.3	25.8	453	DF TLSI
FR224/050/35	GDNE	28.8	62.87	30.5	597	DF TLSI
FR224/051/42	GDNE	28.1	66	29.6	658	DF TLSI
FR224/052/31	GDNE	31.6	63.94	33.3	597	DF TLSI
FR224/053/17	GDNE	29.4	57.72	30.9	617	DF TLSI
FR224/054/19	GDNE	25.4	40.2	26.6	556	DF TLSI
FR224/055/7	GDNE	30.9	65.61	33.9	597	DF TLSI
FR224/056/37	GDNE	25.9	30.33	27.2	494	DF TLSI
FR224/057/4	GDNE	31.5	65.62	33.2	617	DF TLSI
FR224/058/46	GDNE	33.5	64.94	35.1	617	DF TLSI
FR224/060/2	GDNE	29.9	57.58	31.3	556	DF TLSI
FR224/061/44	GDNE	30.9	62.45	31.9	556	DF TLSI
FR224/063/9	GDNE	26.5	53.56	28.9	617	DF TLSI
FR224/064/33	GDNE	30.1	67.49	32	658	DF TLSI
FR224/065/26	GDNE	31	65.81	32.5	617	DF TLSI
FR224/066/5	GDNE	30.7	66.51	32.6	597	DF TLSI
FR224/067/30	GDNE	31.9	69.81	33.6	617	DF TLSI
FR224/068/6	GDNE	29.8	59.23	31.6	556	DF TLSI
FR224/074/21	GDNE	29.8	69.4	31.2	597	DF TLSI
FR224/075/25	GDNE	28.6	50.13	30.2	494	DF TLSI
FR224/076/45	GDNE	33.3	61.1	35.2	391	DF TLSI
FR224/077/27	GDNE	34.5	76.21	35.9	576	DF TLSI
FR224/078/43	GDNE	33.2	91.69	35	617	DF TLSI

Plot	Forest	SI	BA	MTH	SPH	Set
FR224/081/3	GDNE	31.2	64.56	32.8	638	DF TLSI
FR224/082/16	GDNE	32.7	69.18	34.7	638	DF TLSI
FR224/083/10	GDNE	30.7	63.64	32.2	597	DF TLSI
FR224/084/24	GDNE	30.3	59.1	32.3	597	DF TLSI
FR224/085/17	GDNE	33.9	66.62	34.8	576	DF TLSI
FR224/086/36	GDNE	31	60.54	32.1	617	DF TLSI
FR224/087/28	GDNE	26.3	38.25	28	556	DF TLSI
FR224/088/18	GDNE	30.8	65.96	31.9	597	DF TLSI
FR224/089/34	GDNE	33.4	69.77	36.4	597	DF TLSI
FR224/091/31	GDNE	33.6	66.56	36.7	617	DF TLSI
FR224/092/11	GDNE	33.7	66.49	36	597	DF TLSI
FR224/093/21	GDNE	34.2	76.75	36.3	617	DF TLSI
FR224/095/29	GDNE	31.1	53.47	32.5	617	DF TLSI
FR224/096/6	GDNE	31.7	65.15	33.7	597	DF TLSI
FR224/097/21	GDNE	34.7	79.19	36.4	638	DF TLSI
FR224/098/24	GDNE	28.3	49.08	29	514	DF TLSI
FR224/099/37	GDNE	25.2	23.53	26.5	473	DF TLSI
FR242/21/3	CRBU	26.5	74.29	17	1443	DF TLSI
FR242/22/2	CRBU	24.3	64	15.8	986	DF TLSI
FR242/23/1	CRBU	26	44.45	16.1	500	DF TLSI
FR242/24/2	CRBU	27.1	62.37	17.3	1000	DF TLSI
FR242/25/1	CRBU	26.8	42	17.8	500	DF TLSI
FR242/26/3	CRBU	24.9	77.88	16.3	1657	DF TLSI
FR242/27/1	CRBU	25.3	73.99	17	1725	DF TLSI
FR242/28/2	CRBU	25.7	58.87	16.2	1000	DF TLSI
FR242/29/3	CRBU	23.7	37.22	14.2	500	DF TLSI
FR245/01/0	HANM	33.8	22.27	19.3	500	DF TLSI
FR245/012/0	HANM	29.7	5.34	16.1	150	DF TLSI
FR245/013/0	HANM	30.5	26.27	16.7	790	DF TLSI
FR245/014/0	HANM	26	25.25	13.4	780	DF TLSI
FR245/015/0	HANM	30.4	26.33	16.9	500	DF TLSI
FR245/016/0	HANM	28.8	18.96	15.4	500	DF TLSI
FR245/03/0	HANM	33.6	35.25	19	1150	DF TLSI
FR245/04/0	HANM	34.9	26.64	19.7	500	DF TLSI
FR245/05/0	HANM	30.6	16.94	16.7	250	DF TLSI
FR245/06/0	HANM	34.2	10.62	19.9	150	DF TLSI
FR245/07/0	HANM	29.3	15.23	15.8	510	DF TLSI
FR245/08/0	HANM	33.1	36.67	18.9	1090	DF TLSI
FR245/09/0	HANM	31.8	42.82	17.4	1430	DF TLSI
FR246/010/0	BERK	31.9	61.47	16.6	1800	DF TLSI
FR246/014/0	BERK	23.6	54.37	13.2	1860	DF TLSI
FR246/015/0	BERK	26	19.16	14.8	250	DF TLSI
FR246/016/0	BERK	27.5	35.11	15.2	500	DF TLSI
FR246/02/0	BERK	25.9	35.34	14.2	740	DF TLSI
FR246/03/0	BERK	25.3	55.37	14.1	1850	DF TLSI
FR246/04/0	BERK	26.5	7.32	14.4	150	DF TLSI
FR246/05/0	BERK	30.5	28.37	17.1	500	DF TLSI
FR246/06/0	BERK	28	21.71	15.6	480	DF TLSI
FR246/07/0	BERK	28.2	36.14	15.5	820	DF TLSI

Plot	Forest	SI	BA	MTH	SPH	Set
FR277/01/0	CAST	34.7	58.68	15.4	1930	DF TLSI
FR277/013/0	CAST	33.8	30.38	14.6	500	DF TLSI
FR277/017/0	CAST	27.9	44.74	13.2	1700	DF TLSI
FR277/04/0	CAST	32	33.23	14.2	750	DF TLSI
FR277/08/0	CAST	30.4	14.52	12.8	250	DF TLSI
FR298/11/0	GLEF	35.1	39.19	18.3	783	DF TLSI
FR298/12/0	GLEF	33	35.16		633	DF TLSI
FR298/13/0	GLEF	35.7	54.91	18.9	1825	DF TLSI
FR298/14/0	GLEF	36.6	53.29	18.9	1575	DF TLSI
SD142/026/0	BLUE	36.1	72.74	31.1	850	DF TLSI
SD172/010/0	BLUE	33.7	85.46	29	910	DF TLSI
SD172/03/0	BLUE	29.9	87.94		990	DF TLSI
SD172/05/0	BLUE	31.5	73.22	26	1040	DF TLSI
SD172/07/0	BLUE	32.8	61.02	23.9	590	DF TLSI
SD172/08/0	BLUE	23.1	86.05	24.1	910	DF TLSI
SD37/01/0	BLUE	28.3	103.26	34.1	1229	DF TLSI
SD37/02/0	BLUE	25.9	51.15	26.1	559	DF TLSI
SD37/03/0	BLUE	27.1	44.39	34	227	DF TLSI
SD39/01/0	BLUE	31.1	55.73	37.2	375	DF TLSI
SD39/02/0	BLUE	29.4	106.28	33.8	1779	DF TLSI
SD39/03/0	BLUE	33.2	38.48	32.6	287	DF TLSI
SD39/04/0	BLUE	31.5	34.66	31.3	356	DF TLSI
SD44/01/0	BLUE	32.6	39.2	31.2	227	DF TLSI
SD44/02/0	BLUE	32.5	94.16	37.4	791	DF TLSI
SD44/03/0	BLUE	30.4	68.34	42.1	217	DF TLSI
SD708/02/0	NASB	23.4	13.08	15	517	DF TLSI
SD708/03/0	NASB	27.2	26.62	15.3	567	DF TLSI
SD708/04/0	NASB	22.5	35.07	20.2	550	DF TLSI
SD716/01/0	BLUE	34.1	65.88	26.4	1000	DF TLSI
SD716/02/0	BLUE	40.2	53.87	30.5	433	DF TLSI
SD716/03/0	BLUE	39.8	66.77	34.3	450	DF TLSI
SD716/05/0	BLUE	34.7	64.86	27.1	550	DF TLSI
SD717/01/0	BLUE	32.3	58.67	28.6	875	DF TLSI
SD717/02/0	BLUE	35.6	65.93	29.2	800	DF TLSI
SD717/03/0	BLUE	31	43.86	29.7	400	DF TLSI
SD717/04/0	BLUE	34.8	64.46	19.6	1325	DF TLSI
SD717/05/0	BLUE	32.4	68.31	18.9	1250	DF TLSI
SD717/06/0	BLUE	29.4	35.63		225	DF TLSI
SD717/07/0	BLUE	28.9	40.54	27.1	375	DF TLSI