FUTURE FORESTS RESEARCH

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Validation of the WQI microfibril angle Model

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TABLE OF CONTENTS

EXECUTIVE SUMMARY....3
BACKGROUND....4
METHODS....5
    Methods Used in the WQI Report....5
    Validation Method Used....5
RESULTS....7
    WQI Benchmark Study Results....7
CONCLUSION AND RECOMMENDATIONS....9
REFERENCES....10
ACKNOWLEDGEMENTS....10
APPENDICES....11

EXECUTIVE SUMMARY

The WQI microfibril angle model (henceforth referred to as ‘the model’) derived from the WQI ‘Benchmarking’ data (samples from a total of 150 trees from 17 sites of the 1978 Genetic Gains Trial) was tested on independent data from a silviculture and breeds trial at Shellocks.

Major findings were:

- When the model was re-fitted to the benchmarking data, reasonable agreement was found at most sites, but some departures from the model were evident at some site/disc height combinations in the benchmarking data.
- When the model was used to predict MFA at Shellocks, a lower coefficient of determination ($R^2 = 40\%,$ r.s.e. $= 4.24$) was obtained (cf. $R^2 = 75\%,$ r.s.e. $= 3.75$ in the WQI report), partly due to lower variability in the Shellocks data compared to the benchmarking data.. Substantial trends in residuals for MFA versus ring number were found, with extreme stockings showing greater departures, and intermediate stockings (similar to the benchmark trial on which the WQI model was based) showing a similar pattern but smaller departures.
- When a similar model was re-fitted to the Shellocks data, substantially different coefficients were obtained.
- Across breeds, similar trends in residuals were observed to the overall residuals, suggesting that most of the variability in departures from the model was due to silviculture.
- There was an increase in microfibril angle with decreasing stocking which was greater than predicted by the WQI model, reflected in higher than predicted MFA near the bark at low stockings and lower than predicted MFA near the pith at high stockings.
- The variables in the WQI model and the form of the functions do not explain the variation of MFA in general. The WQI models are descriptive of the average trends in a particular study, and should not be adopted without a better understanding of site and tree-level variability.
- The recommended approach for modelling microfibril angle (and other wood properties) in conjunction with growth models is to use the known generic patterns of radial and vertical variation, and include effects such as growth rate (e.g. thinning) and genotype only after confirmed with robust data and appropriate statistical models and tests. It is important to incorporate the various sources of random variation in the samples and models for valid inference and to provide realistic assessments of variability. This means incorporating and analysing variability in the form and/or coefficients of functions used. It is recommended that mixed non-linear or smoothing spline models be used for this purpose in future.

BACKGROUND

We were asked to validate the model for microfibril angle developed for WQI (henceforth referred to as 'the model') by University of Canterbury School of Forestry (WQI report No. Res 35 by E. Mason and H. Dzierzon). The models were derived from the WQI Benchmarking data (WQI report No. Res 34 by Cown *et al.* 2005; consisting of samples from 17 sites of the 1978 Genetic Gains Trial; with mostly 9–10 trees per site; and discs sampled at heights 0, 1.4, 5, 20m).

Microfibril angles were measured from disc samples for each ring. The sampling strategy was designed to confirm known trends and to document environmental effects.

The coefficients for the model are presented in Table 1 below.

Note: we obtained clarification on some of the variables in the model (E. Mason *pers. comm.*, D. Graham *pers. comm.*)

- The constant 1 was added to the disc heights before applying the Box-Cox transform (which would otherwise be $-\infty$ at disc height zero).
- "Mean temperature, specific year" was actually mean winter temperature.
- `Bray.P` is not Bray 1P but "Bray 2P, first extraction".

METHODS

Methods used in the WQI report:

Data: The data for the WQI model consists of microfibril angle data from 17 sites—the WQI 'National benchmarking study' (Mason and Dzierson 2007).

Models: The WQI model for MFA (WQI Res35: Table 15), is reproduced below in Table 1.

This model is a single linear model, with transformed co-variates, which ignores site, tree, and disc effects, and assumes that individual ring measurements are independent.

Note: The assumptions of the linear regression methodology are that model errors are independent, identically distributed random variables. *Such assumptions are extremely naive in the present context, and if violated all tests, inferences or predictions from the WQI model are invalid.* In particular the standard errors (errors in predictions of future data) may be greater than expected, and t- and p- values are misleading and exaggerate statistical significance. Our experience in Scion is that these assumptions do not hold, on the contrary there are strong within tree trends and differences between sites and genotypes for microfibril angle (Donaldson 1992; Donaldson 1995; Donaldson and Burdon 1995; Cown *et al.* 2004) and other wood properties that need to be understood. These trends and dependencies are apparent in the WQI and validation data (Cf. results section). Scion has developed statistical methods and software to model this variation (Ball 2003, 2004).

Model choice: There are many possible models that could be fitted and many were tried, although only the final selected models are documented in the report. In an attempt to avoid problems due to the nature of the model, significance levels were increased and a mixed model was also used (E. Mason *pers. comm.*), although specifics were not given.

Validation method used:

The model predictions were tested on independent data from a silviculture and breeds trial at Shellocks in Canterbury. The trial was established in 1991 and assessed shortly before clearfell in 2005. The Shellocks data comprised 4 breeds (GF 6, 14, 16, 25) used in combination with 3 initial spacings (250, 500 and 1000 spha) and 5 final crop spacings (100, 200, 400, 600, 1000 spha), and included pruned and unpruned plots in an unbalanced design matrix (not all combinations were included). Eighteen plots were sampled by felling 15 trees in each (270 stems in total) to yield stem and wood samples for analyses. Microfibril angle measurements were available on a total of 180 breast height discs (Cown *et al.* 2006). This dataset afforded the opportunity to examine how well the model predicts variation due to different silvicultural treatments.

We have examined various graphs of residuals from the model predictions at Shellocks.

We have re-fitted the model to Shellocks data and examined changes in coefficients from the original WQI model. Re-fitting the model enables us to see how much the model coefficients change and therefore gives an indication of whether one model fits all or whether different models are needed at different for different sites and silvicultures. Significant or major differences in coefficients indicate a limitation of the model, and would indicate that systematic model errors are likely to result in if the model is used for predictions on such sites. Examining the re-fitted model shows how well a model of similar form to the WQI model can handle the variation between silvicutural treatments at Shellocks.

Technical note: When re-fitting the model, since there was only a single value of `disc.height` and `Bray.P` within the Shellocks site, these terms could not be fitted. Instead the WQI model coefficients were used for these terms.

Height at time of growth (estimated from disc measurements in the WQI report) was estimated here from height-diameter relationships calibrated for the plots at Shellocks, and used to predict heights for individual rings from corresponding individual tree diameters.

Mean temperature was estimated by averaging maximum and minimum daily temperatures from NIWA climate daily series. Mean winter temperature was estimated as the mean of mean daily temperatures from April 1 to August 31.

RESULTS

WQI benchmark study results:

We had access to the 5-ring block data from the WQI benchmarking study (from the previous FFR spiral grain validation exercise), but not the individual ring data used for the WQI MFA model. Our first check was to re-fit the WQI model to the 5-ring block data, and examine the fit graphically.

When the model was re-fitted to this data a similar overall R^2 value was obtained (62%, compared with 75% in the WQI report). A graph of observed and predicted values is shown in Figure 1. Figure 1 is a 'trellis' graph, where each panel shows the graph for a given height site combination. Heights (0,1.4,5,20m) are labelled in the top of two boxes above each panel, while sites are labelled in the lower of the two boxes. Sites are numbers 1–17; corresponding forests and trial IDs are shown in Table 2. Each panel shows means and error-bars (2 times s.e.m.) for 5 ring blocks for a given height and site. Note quite good agreement at most sites but departures from the model at others, e.g. site 5,9,11,17 at height 0; site 7 heights 1.4, 5; site 16 height 1.4.

However, when the WQI model was used to predict MFA at Shellocks, the coefficient of determination reduced to $R^2 = 40\%$. When the same model was refitted to the Shellocks data we obtained $R^2 = 62\%$, but the coefficients were substantially different (Table 1). For example the intercept reduced from 47.8 to 42.2, suggesting an overall positive bias; the coefficient of `height.at.time.of.growth` changed from -7.4 in the WQI benchmarking trial to -15.9 at Shellocks; the coefficient of `winter.tmean`, changed from -0.6 to 1.0 (note: opposite sign), while the coefficient of radius reduced from -2.85 to virtually 0.

These changes in model coefficients between studies draw into question some of the interpretations for the reason for the effects in the WQI model such as radius being fundamentally important, reflecting mechanical effects of position within the stem; or a lower winter temperature meaning less latewood and therefore higher average MFA in a ring:

> "I think what's going on is that with a higher winter temperature the ring contains more latewood because more growth occurs during the winter, and latewood tends to have lower MFA.... The winter temperature effect is more likely to show up between sites. Although it's one of the weaker effects in the model, it is corroborated by findings from other studies, and we see a clear trend towards stiffer corewood on warmer sites." (E. Mason, pers. comm.)

These changes in model coefficients also mean that a single model in terms of these variables is not adequate, but that the relationships also change. Reasons for these changes are not yet understood.

Figures 2, 3, 4 show residuals from the WQI model predictions at Shellocks.

Figure 2 shows the residuals plotted against growth year. Note the trend: residuals increasing from -2 degrees (over-prediction) to a plateau of about +5 degrees (under-prediction) from 1999 onwards. Overlaid on the smooth trend were minor annual fluctuations that appeared to be about 1 or 2 degrees. Overall the WQI model is predicting a higher initial MFA at the pith and a greater decrease with increasing ring number from the pith than was observed at Shellocks.

Figure 3 shows the residuals plotted versus ring number from the bark by stocking and pruning. The same pattern (residuals decreasing when approaching the pith) is observed as in Figure 2 for each stocking/pruning combination. At 400spha the trend is less pronounced (residuals trending from about +3 to about 0), indicating the model fit is not too bad. At lower stockings (100, 200spha) residuals are higher at the bark and trend downwards more rapidly, while at higher stockings residuals are approximately the same at the bark as for 400spha, but trend more negative near the pith. Overall, this means that there is an increase in microfibril angle with decreasing stocking which is greater than predicted by the WQI model.

Figure 4 shows the residuals plotted versus ring number from the bark by seedlot. On average residuals trended from about +5 at the bark to about -2 (similar to the overall year trend in Figure 2). The pattern was similar across seedlots, suggesting that most of the variability in departures from the model was due to silviculture.

Observed and predicted means from the WQI model at Shellocks are shown by stocking and ring number from the pith in Table 3, and by seedlot and ring number from the pith in Table 4.

CONCLUSIONS and RECOMMENDATIONS

The WQI model gave good fits to the majority of site/height combinations in the WQI benchmarking study, but not in some of their site/height combinations. There were substantial trends in residuals from WQI model predictions for the Shellocks data, particularly for the extreme silvicultures (consistent with the known effect of thinning, R. Evans *pers. comm.*) indicating departures from the WQI model at Shellocks.

Therefore the relationships in the WQI model vary. The WQI model does not adequately predict the variation in MFA across sites and particularly silvicultural treatments.

Caution is needed when applying the WQI (or similar) model to a forest without validation on similar forests with similar silviculture.

It should be noted that the WQI model was constructed on the benchmarking data that did not include the range of silvicultural treatments, hence these results are not unexpected—we should not necessarily expect a model developed on the benchmarking data to accurately predict the variation at Shellocks, although it might if the covariates and form of the model faithfully reflected the true underlying causal factors.

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Table 1: Coefficients from the WQI model for ring mean MFA, compared with Shellocks refit

.

	WQI model (R^2=40%)			Shellocks refit (R^2=62%)	
	lambda	Estimate	Std. Error(*1)	Estimate	Std. Error(*1)
intercept	NA	47.76910	0.7809	42.200004	1.472172
ring width	0.7	0.86480	0.01688	0.730679	0.042185
radius	-0.1	-2.85950	0.0884	-0.001587	0.172470
disc.height	-0.3	-2.55830	0.1110	-2.55830(*2)	*
height.at.time.of.growth	-0.4	-7.43340	0.2367	-15.969512	0.793342
winter.tmean	NA	-0.62650	0.0674	1.047009	0.171165
bray.P	NA	-0.05757	0.006624	-0.05757(*2)	*

(*1) Standard errors not valid because non-independence of samples within trees is ignored in the linear model.
(*2) not refitted (not varying within site), WQI terms used as 'offset', i.e. WQI WQI model coefficient used.

Notes:
(1.) A constant, +1, was added to disc height before Box-Cox transform to avoid infinite values when variables approach 0 (E. Mason, pers. comm.).
(2.) R^2 values lower than for the WQI data, (R^2= 40%, for the original model or 62% if re-fitted with the same variables and transformations, but new coefficients, compared with 75% for the original model applied to the original data).
(3.) Comparable coefficients for ring width (0.73 for Shellocks compared with 0.86 for WQI), but not:
intercept: where the effect is lower by 5.5 (overall bias +5.5 for WQI model applied to Shellocks) than predicted;
radius (ring boundary): where the Shellocks effect is very small;
height at time of growth: where the Shellocks effect is twice as great;
winter mean temperature: where the Shellocks effect is larger but of opposite sign.
(4.) bray.P is Bray 2 P, first extraction (D. Graham pers. comm.).

Table 2: Forests and trial IDs for the 17 WQI benchmarking study sites.

SITEID	FOREST	TRIALID
1	Aupouri	AK772
2	Athenree	AK774
3	Ruatoria	RO1664/4
4	Kaingaroa	RO1664/3
5	Kaingaroa	RO2103/1
6	Mohaka	WN305
7	Lismore	WN306/2
8	Ngamu	WN306/1
9	Rabbit Is	NN405
10	Golden Do	NN405 (NN
11	Waimea	NN405/3
12	Ashley	CY421
13	Eyrewell	CY421
14	Waimate	CY421/1
15	Longwood	SD564/1
16	Rowallan	SD564/3
17	Blackmoun	SD564/4

Table 3: Observed and predicted means from the WQI model for MFA by stocking and ring number from the pith at Shellocks (disc height 1.4m).

```
> mfa.SP.pred.df
   pruning stocking pith.ring mfa.pred mfa.obs
1        P      100         0     39.1    37.5
2        P      100         1     34.4    35.0
3        P      100         2     31.4    33.4
4        P      100         3     29.1    32.9
5        P      100         4     27.9    32.8
6        P      100         5     26.4    33.1
7        P      100         6     24.8    32.1
8        P      100         7     24.8    32.2
9        P      100         8     23.1    31.2
10       P      100         9     22.1    30.7
11       P      100        10     21.7    30.9
12       P      100        11     17.7    28.5
13       P      100        12     16.3    27.3
29       P      200         0     38.8    37.9
30       P      200         1     34.6    36.2
31       P      200         2     31.5    34.0
32       P      200         3     29.2    33.2
33       P      200         4     26.6    32.2
34       P      200         5     25.7    30.5
35       P      200         6     24.0    29.7
36       P      200         7     23.1    29.1
37       P      200         8     23.4    29.0
38       P      200         9     21.3    27.3
39       P      200        10     21.1    26.8
40       P      200        11     20.1    25.5
41       P      200        12     15.8    24.2
43      UP      200         0     37.9    36.8
44      UP      200         1     33.5    34.1
45      UP      200         2     31.0    33.2
46      UP      200         3     28.2    32.0
47      UP      200         4     26.0    30.6
48      UP      200         5     25.7    29.9
49      UP      200         6     24.2    29.9
50      UP      200         7     23.1    29.5
51      UP      200         8     22.9    28.8
52      UP      200         9     20.8    27.3
53      UP      200        10     20.9    26.9
54      UP      200        11     19.2    26.7
55      UP      200        12     15.4    25.9
57       P      400         0     38.6    36.0
58       P      400         1     33.2    34.2
59       P      400         2     30.7    32.1
60       P      400         3     28.4    30.9
61       P      400         4     25.3    29.3
62       P      400         5     24.5    27.5
63       P      400         6     23.6    26.7
```

	pruning	stocking	pith.ring	mfa.pred	mfa.obs
64	P	400	7	22.1	25.8
65	P	400	8	22.5	25.5
66	P	400	9	20.5	23.5
67	P	400	10	19.9	23.3
68	P	400	11	20.1	22.3
69	P	400	12	15.4	20.5
71	UP	400	0	38.5	38.5
72	UP	400	1	33.5	35.4
73	UP	400	2	31.0	32.8
74	UP	400	3	28.7	31.8
75	UP	400	4	25.8	29.7
76	UP	400	5	25.5	28.3
77	UP	400	6	24.9	28.2
78	UP	400	7	22.7	27.4
79	UP	400	8	22.7	26.0
80	UP	400	9	20.9	24.6
81	UP	400	10	20.6	24.1
82	UP	400	11	19.6	22.4
83	UP	400	12	15.5	23.5
84	UP	400	13	14.8	24.1
99	UP	600	0	37.7	35.1
100	UP	600	1	34.1	33.6
101	UP	600	2	30.8	32.9
102	UP	600	3	27.7	31.9
103	UP	600	4	26.3	30.1
104	UP	600	5	25.4	29.2
105	UP	600	6	23.3	28.6
106	UP	600	7	23.0	27.4
107	UP	600	8	21.8	26.3
108	UP	600	9	20.6	24.8
109	UP	600	10	20.3	24.4
110	UP	600	11	17.2	24.6
111	UP	600	12	15.6	25.0
127	UP	1000	0	37.4	35.4
128	UP	1000	1	33.8	33.1
129	UP	1000	2	30.4	32.5
130	UP	1000	3	27.8	31.5
131	UP	1000	4	26.5	30.3
132	UP	1000	5	24.6	29.5
133	UP	1000	6	23.2	28.6
134	UP	1000	7	22.9	27.3
135	UP	1000	8	21.0	25.6
136	UP	1000	9	20.8	24.5
137	UP	1000	10	19.5	24.3
138	UP	1000	11	16.4	23.2
139	UP	1000	12	15.7	22.3

Table 4: Observed and predicted means from WQI model for MFA by seedlot and ring number from the pith at Shellocks (disc height 1.4m).

```
> mfa.seedlot.pred.df
   seedlot pith.ring mfa.pred mfa.obs
1     GF06         0     38.2    35.8
2     GF06         1     33.7    34.2
3     GF06         2     30.7    32.6
4     GF06         3     28.2    31.8
5     GF06         4     26.3    30.3
6     GF06         5     25.3    29.5
7     GF06         6     23.8    29.1
8     GF06         7     23.2    28.3
9     GF06         8     22.3    27.3
10    GF06         9     21.0    26.2
11    GF06        10     20.7    25.9
12    GF06        11     18.2    24.5
13    GF06        12     15.4    21.8
15    GF14         0     38.2    38.1
16    GF14         1     35.0    35.6
17    GF14         2     32.0    34.2
18    GF14         3     29.0    33.4
19    GF14         4     27.0    32.8
20    GF14         5     25.7    32.1
21    GF14         6     24.1    31.2
22    GF14         7     23.4    30.4
23    GF14         8     22.8    29.4
24    GF14         9     21.4    28.1
25    GF14        10     21.1    27.7
26    GF14        11     19.0    27.9
27    GF14        12     15.8    28.2
29    GF16         0     37.7    36.9
30    GF16         1     33.6    34.4
31    GF16         2     30.5    32.8
32    GF16         3     28.2    31.7
33    GF16         4     25.8    30.1
34    GF16         5     24.7    28.6
35    GF16         6     23.2    27.7
36    GF16         7     22.2    26.6
37    GF16         8     22.2    25.8
38    GF16         9     20.8    24.6
39    GF16        10     19.7    24.0
40    GF16        11     19.0    23.5
41    GF16        12     15.9    23.9
```

	seedlot	pith.ring	mfa.pred	mfa.obs
43	GF25	0	38.5	37.2
44	GF25	1	34.0	34.7
45	GF25	2	31.1	33.2
46	GF25	3	28.7	32.2
47	GF25	4	26.5	31.0
48	GF25	5	25.5	29.8
49	GF25	6	24.1	29.0
50	GF25	7	23.1	28.4
51	GF25	8	22.6	27.4
52	GF25	9	21.0	25.9
53	GF25	10	20.4	25.6
54	GF25	11	19.1	24.4
55	GF25	12	15.6	24.0
56	GF25	13	14.8	24.1

Fig 1: Observed and predicted MFA values for WQI site means (error bars = 2*SEM)

observed ——— predicted (WQI table 15) - - - - -

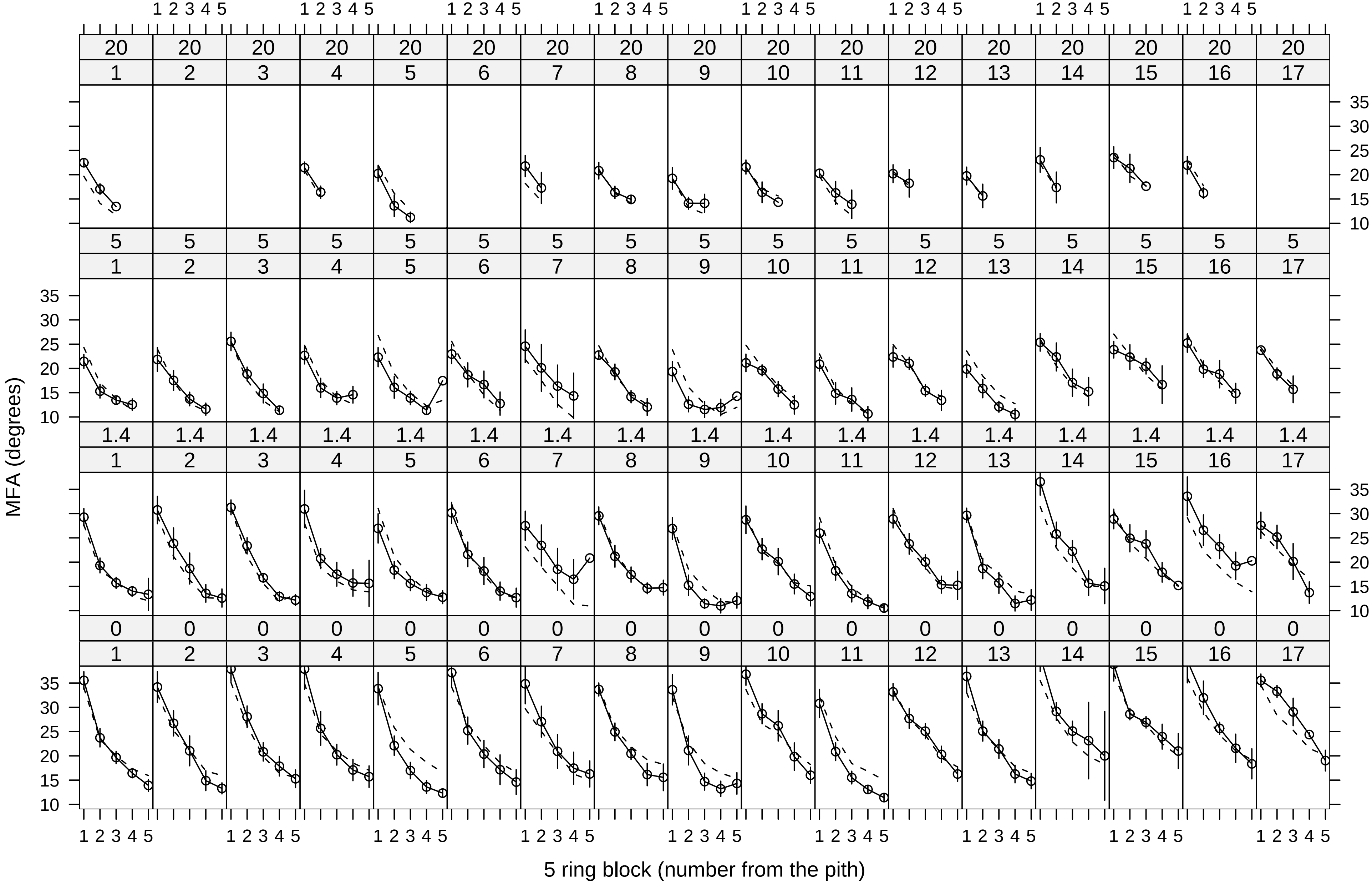

Fig 2: Residuals by growth year at Shellocks

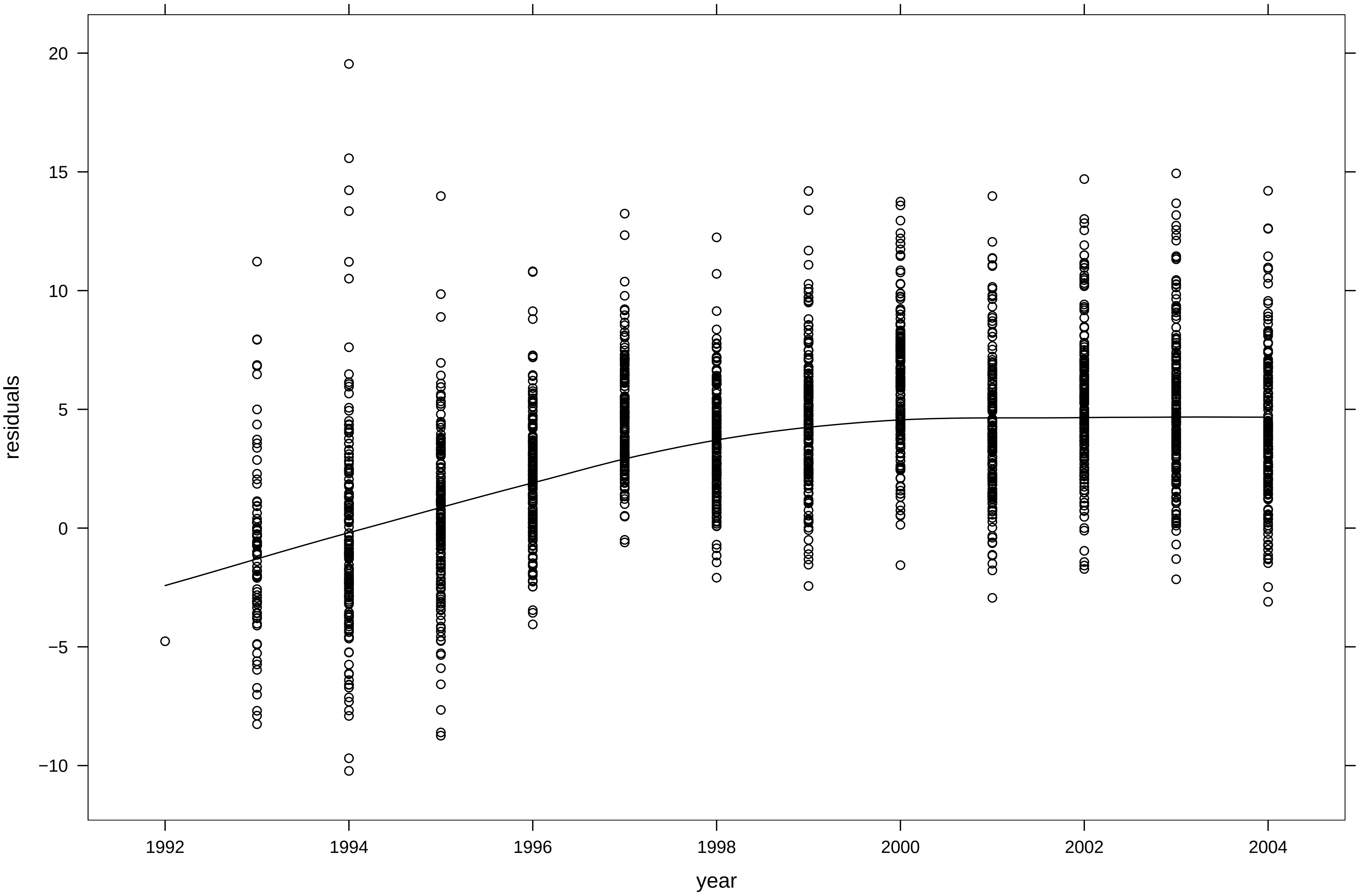

Fig 3: Residuals versus ring number from the bark by stocking and pruning

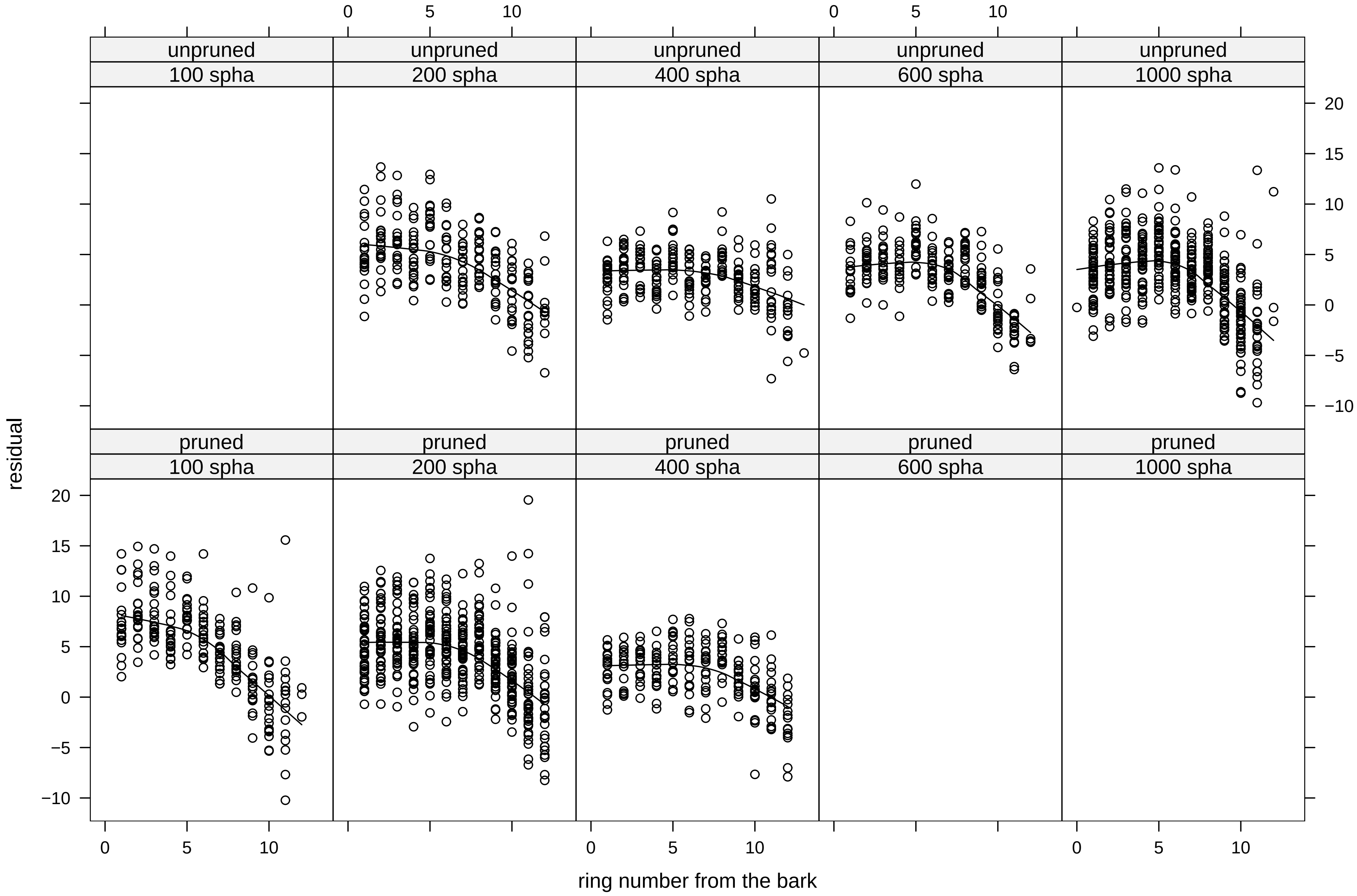

Fig 4: Residuals versus ring number from the bark by seedlot