AN INVESTIGATION INTO THE EFFECTS OF PHOSPHATE DEFICIENCY ON WOOD DENSITY IN RADIATA PINE

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INTRODUCTION

Phosphorus (P) and nitrogen (N) are by far the most common mineral deficiencies occurring in forest soils throughout the world and hence most fertiliser trials include applications of these nutrients either by themselves or in combination with other elements.

In New Zealand there has been much research in the past on the effect of fertiliser on wood properties of radiata pine. Cown (1977) summarised the findings of studies in the preceding 15-20 years from sites located in the (then) Auckland, Rotorua and Nelson Conservancies of the New Zealand Forest Service.

The conclusions from that review indicate that trees growing under conditions of nutrient deficiency exhibit slow radial growth, and wood properties differ from those found in healthy crops in the same region. Typically the wood density is higher and this is characterised by narrower growth rings with higher latewood percentages and longer tracheids.

When fertilisers are added, dramatic increases in radial growth can often result with some modification of the wood properties; the most important being a reduction in latewood percentage and hence a decrease of up to 10 or 15% in wood density. However it is important to bear in mind that post-treatment wood properties, although often significantly different from pre-treatment levels are usually similar to those in nearby healthy stands and thus do not represent a real loss in quality.

Cown's review indicates that although there is no evidence to suggest that different nutrients have a different influence on wood properties, the rate of growth itself is the important factor.

As part of the "Wood Quality of the Radiata Pine Resource" government funded programme, Objective 3 is concerned with quantifying the effects of site and silviculture on critical wood properties and utilisation potential. Within Objective 3, Sub-group 3.2 covers a range of studies to be completed in the next three years that will investigate the impact of P, boron and effluent irrigation levels on wood formation and quality using a wood densitometer system.

The work detailed in this report aims to describe the wood density variation from a P trial located at Riverhead Forest and add to previous research in this field. Past studies in the Auckland region have generally examined the effects of P and N applications and also some thinning treatments (Orman and Harris, 1963; Harris, 1966 and Cown, 1973). Results generally showed ring width increasing by up to 300%, wood density decreasing in the range of 10 to 15% and finally a reduction in tracheid length.

METHODS

From the available NZFRI phosphorus trials located throughout New Zealand, the Pelletised Rock Phosphate Trial at Cpt. 23 of Riverhead Forest (A734/ 2) was selected by the Soils Group of the Forest Technology Division as being most suitable for providing the material for this study. Riverhead soil type is mapped as Waikare clay loam and has a medium P retention (30-50%).

Briefly the trees were planted in 1974 and the trial established in 1978 when the trees were aged four years. From the 9 different treatment schedules, Treatment No. 7 consisting of one application of 150 kg P/ha applied as superphosphate, was selected to provide a comparison with Treatment No. 1 the control - having a naturally low soil P level. The only documented silviculture applied to the plot was a waste thinning to a residual stocking of 370spha in 1985 which occurred in conjunction with the compartment's normal programmed operation.

Approximately 30 representative trees (a minimum of 10 each from three replicates) were measured for DBHOB and an outerwood increment core containing the outer 10 rings removed for each of the two treatments. From the 30 trees an extra pith-to-bark increment core was removed on a subsample of 15 trees per treatment for densitometric analysis that met the required specifications ie. pith-to-bark series intact, rings orientated tangentially in the core, absence of compression wood and/or other defects.

In the laboratory the outer 10 growth ring section was cut from the outerwood cores and measured in length to provide a measure of growth rate prior to gravimetric basic density determination using the maximum moisture content procedure (Smith, 1954). The pith-to-bark cores were prepared for scanning according to established procedures (Harris and Hiscock, 1976). Briefly, this involves resin-extraction by refluxing with methanol in a Soxhlet apparatus for approximately 3 days and then reconditioning to 10% e.m.c. The cores are then precision machined to provide a tangential thickness of 1.5mm. The machined samples are then re-stabilised to 10% e.m.c prior to scanning.

The standard procedure for densitometric analysis was followed. Again in brief this involves:

1) Passing the machined sample between a radioactive source (Fe^{55}) and a scintillation counter. The source decays creating X-ray emissions at an extremely constant rate, therefore as the particle count rate varies over a set time this represents the varied amounts of absorption by the wood material, which is equated to wood density. This operation and the creation of a data file are carried out by the program FRI.EXE developed by the Institute of Geological and Nuclear Sciences based in Lower Hutt, Wellington.

2) The data are processed through an NZFRI program called IDAS (Integrated Densitometer Analysis System) written by Glen Marsom. This program is used to edit the individual sample raw data as produced by the FRI.EXE program. IDAS makes estimates of latewood and earlywood boundaries based on an input density cut-off level and also marks growth ring boundaries. These may be adjusted as required and any splits or hidden defects scanned by the densitometer may be edited out. Growth rings were analysed by a number of densitometric characteristics referred to as "ring components" (Cown and Clement, 1983). From the edited output, STATS (another NZFRI program) is used to give simple statistics by ring number from the pith for any number of cores required from each site or stand.

For the purposes of this study, the main areas of interest were:

1) comparison of growth rate and outerwood density (outer 10 growth rings) for trees growing under both P deficient soil conditions (control) and with a one off application of 150 kg P/ha applied as superphosphate; and

2) comparison of radial trends in basal area, earlywood and latewood density, and latewood percentage variation again between the control and treatment.

RESULTS AND DISCUSSION

DBHOB and Outer 10 Growth Ring Data:

Table 1 presents a summary of the mean DBHOB, the average growth rate of the outer 10 rings and the basic density of this outerwood portion by plot and treatment. Full details for individual trees are presented in Appendix 1. When discussing these outer wood results one must take into account the 18 years that have elapsed following P application and also the thinning treatment applied to the stand, including the trial 11 years prior to sampling. The thinning operation would have increased P levels from the subsequent decaying foliage. The responses discussed here are therefore predominantly being due to the thinning operation when the trees were aged 11 years. The densitometry results, which will be discussed later in this report, will present the overall effect of P application and also the thinning treatment by documenting the change in ring width and density components over the entire 18-year period.

Table 1 - Summary of DBHOB and Measured Outerwood Core Wood Properties

CONTROL					PHOSPHORUS TREATMENT				
Plot	No. of trees	DBH OB (cm)	Growth Rate (mm/ring)	Outerwood Density (kg/m3)	Plot	No. of trees	DBH OB (cm)	Growth Rate (mm/ring)	Outerwood Density (kg/m3)
1	10	38.5	5.3	498	1	10	42.8	6.4	460
5	10	37.4	5.6	478	2	10	39.7	5.7	480
9	12	34.1	5.5	486	5	10	39.7	5.1	472
Overall	32					30			
Mean		37.0	5.4	487			40.7	5.7	471
Min.		26.7	3.0	408			32.9	2.5	407
Max.		50.5	7.8	531			52.4	8.7	529

Average breast height diameter was approximately 10% lower in the control plots which averaged 37cm, ranging from 26.7cm to 50.5cm compared to 40.7cm for the P treatment trees which ranged from 32.9cm to 52.4cm. The average growth rate for the outer 10 rings for the control treatment averaged 5.4 mm/ring, which were approximately 5% lower than the 5.7mm/ring measured for the P treatment sample. One of the P treated trees (Tree 2 from Plot 5) recorded the lowest growth rate of 2.5mm/ring which has resulted in producing the lowest plot mean value of 5.1mm/ring for Plot 5. The DBH of 43.9cm recorded for this tree clearly shows that earlier growth rates were well in excess of the 2.5mm/ring measured for the outer 10 growth rings.

A minor reduction (<5%) in the outer 10-ring density was measured for the superphosphate treated plots when compared to control plots, 471kg/m^3 and 487kg/m^3 respectively. This small reduction in density is consistent with previous findings when the time delay following treatment and the later thinning operation is taken into consideration.

As mentioned previously dramatic increases in radial growth can often result in some modification of the wood properties following the application of fertiliser. A reduction in wood density of between 10% to 15% largely due to lower latewood percentages is one of the more expected changes (Cown, 1973). However, in the subsequent 3-5 years after fertiliser application, density-related properties have been shown to revert back to pre-treatment levels unless an additional treatment is applied. Cown and McConchie (1981) suggest that on some nutrient deficient sites the pre-treatment density levels may be abnormal and the observed response is simply an adjustment to "normal" levels.

In the national radiata pine wood properties survey, reported by Cown *et. al.* (1991), outerwood density values for 22 year-old trees grown in this region (designated high density) equated to 490kg/m^3 and compare favourably to results established in this study.

ANOVA analysis was carried out on the plot means for DBH, growth rate and outer 10-ring density. No significant differences (at the 5% level) between the control and P treated plots were observed for any of these properties, indicating the level of variation between trees, plots and treatments.

Densitometry:

The detailed output from the STATS program which calculated site averages for ring width, and ring density components for individual growth rings are given in Appendices 2 and 3 for the control and P treated plots respectively.

The earlywood/latewood density boundary was set at 500kg/m^3 as this has been the general standard for FRI densitometer studies on radiata pine. Opinion differs in opinion in the literature as to what the identifying factors for earlywood and latewood differentiation are, so the level was set simply to delineate growth ring boundaries and to give an approximate representation in width equal to that which appears visually on the actual samples. The width measurements recorded in the appendices represent the distances between these points and the growth ring boundaries. The mean basic densities and ring components for whole rings represent arithmetic averages calculated from all points scanned at 0.3mm intervals along the ring width.

Figure 1 presents the basal area increment (B.A.I.) for the control and P treatment plots for the entire growth period. The P plots show an accelerated growth period after the one-off application of superphosphate in the late 1970's and this response was observed up until the thinning operation in 1985. The thinning operation gave a considerable boost to B.A.I. for both the treated and control plots up until 1988 when similar growth rates were observed for both treatments. Between 1988 and 1991 B.A.I. reduces from a high of approximately 70cm^2 to approximately 40cm^2. From this point the treatment plots show improved B.A.I. over the control plots potentially due to the release of nutrients with the decay of thinnings and changes in canopy dynamics. Over the period from 1991 to 1995 B.A.I. is maintained at the 35 - 45cm^2 level.

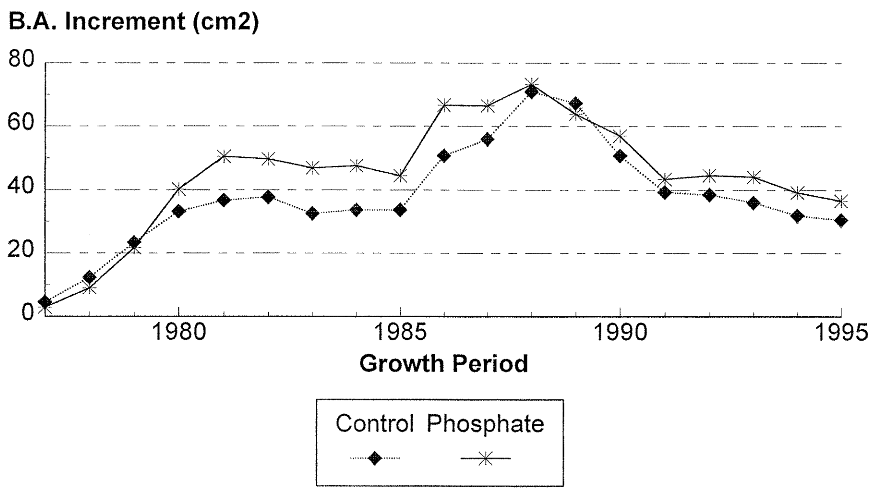

Figure 1 - Comparison of Basal Area Increment (cm^2/yr)

Figure 2 presents the densitometer summary chart data, which give the patterns of variation for ring, mean, earlywood minimum, and latewood maximum densities across the entire radius of the stem at breast height. These show very clearly the effect of the fertiliser treatment on density parameters. The thinning operation was not so obvious and the decline in density parameters relative to the control from 1987 on will be discussed in more detail later in this report.

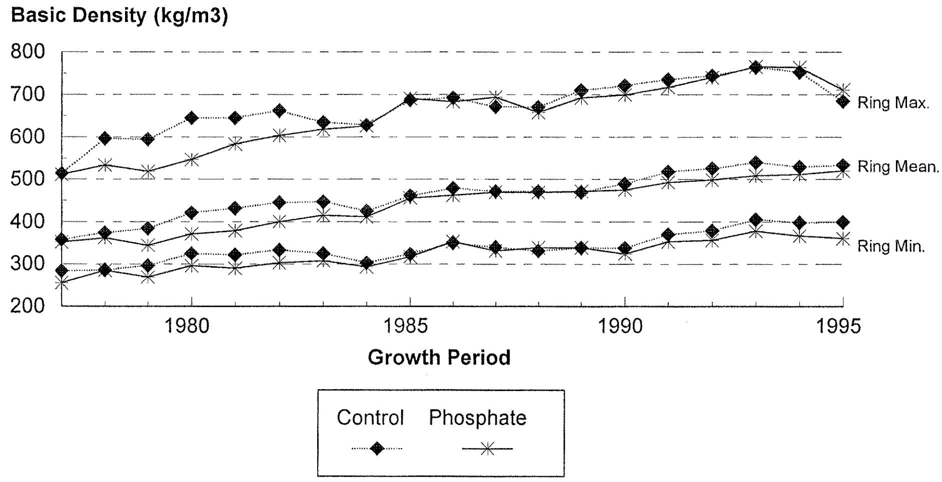

Figure 2 - Densitometric Radial Records

The application of P resulted in a 9% decline in ring mean density one year following application when compared to the control. Over the subsequent 4-5 years, density values for the P treatment plots gradually increase until they again approach the levels recorded for the control plots. Latewood maximum densities show the greatest response after treatment and this phenomenon has been observed in previous research, Cown and McConchie (1981).

Previous densitometric analysis for this forest includes data analysed from cores collected during the national radiata pine wood properties survey (Cown *et. al.*, 1991). McKinley and Young (1991) investigated a range of sites and ages from 9 locations in the Auckland region to provide a starting point for a series of studies investigating regional trends in New Zealand. Two Riverhead stands aged 16 years and 47 years representing "new" and "old crop" regimes respectively were analysed, and the ring mean density trends up to age 20 are presented in Figure 3 to provide a comparison with results from this study.

Despite a lack of stand records for the previous study, ring mean densities compare well. The "new crop" stand showed some evidence of a possible thinning treatment after ring 5 and produced ring mean density levels similar to that of the P treated plots in the current study. From that point density was shown to increase to levels more akin to the "old crop" stand. The ring mean density trend for the "old crop" stand shows a steady increase to ring 16 after which it was generally maintained at the 500 kg/m^3 level. This pattern conforms to the normal radial density trend (pith-to-bark) for radiata pine.

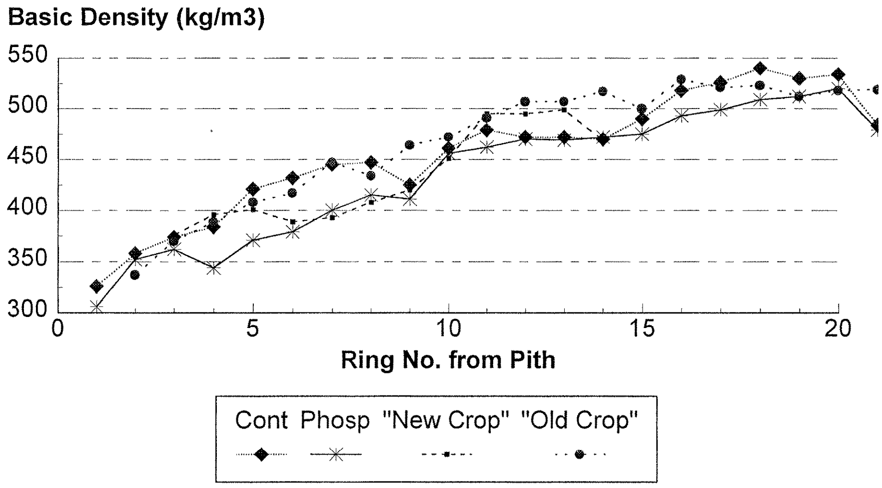

Figure 3 - Ring Mean Density

The control plots in the current study were producing similar density levels to the "old crop" stand with the exception of the thinning at ring 9 and the associated 5-year response period.

Using the standard densitometric definition for latewood percentage (>500kg/m^3) it was shown that ring mean density responses were closely related to variations in the amount of latewood present (Figure 4).

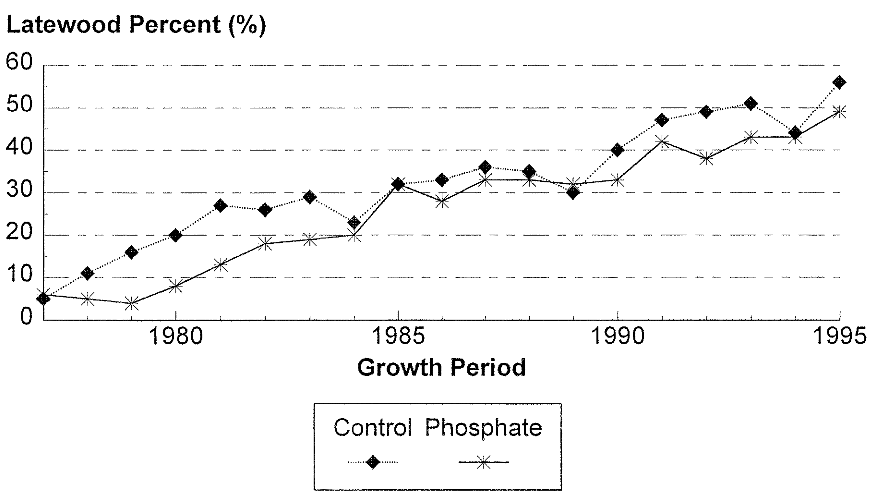

Figure 4 - Latewood Percentage

This close relationship has been well researched and documented along with the implications of fertiliser application affecting both properties (Cown, 1972). The high density of the phosphorus deficient sites can be largely attributed to the very high levels of latewood (also often associated with extremely poor growth rate). In this particular study the application of P in the late 1970's reduced latewood percent by 10-15% for approximately 5 years, up to the thinning in 1985. Levels were similar until 1992 when a small divergence between latewood percent for the two treatments was observed.

Two possible explanations which individually or combined may well impact on radial trends for the outer growth rings. These explanations are as follows:

- The release of nutrients following the decay of slash produced from the thinning operation. Previous research has sought to quantify the effect of nutrient uptake from slash resulting from pruning and thinning operations with variable results. This study suggests that a five-year delay has taken place prior to any noticeable effect on the growth rate and wood properties assessed. Prevailing weather conditions and soil type would have a major impact on the time delay between the production of slash and access to increased levels of nutrients (Skinner pers. comm).

- The second possible explanation could be due to the response of the understorey in the P plots. After the thinning operation the understorey would benefit from the reduced canopy enhancing growing conditions and therefore absorbing additional nutrients including the P applied. When the canopy closes for the second time the understorey would be shaded out with many plants dying and the decaying foliage from them releasing nutrients back to the soil. The enhanced nutrient availability to the radiata pine crop would again improve growing conditions which impact on the measured wood properties, increasing basal area and reducing density components when compared with the control plots (Skinner pers. comm).

CONCLUSIONS

- There was no significant difference in outerwood density and growth rate between the treatment and control plots following the assessment of the outerwood cores. This finding confirms that the impacts of fertiliser application (P) and silviculture (thinning) on wood and growth properties reduce in significance with increasing age following treatment, in line with previous research and the densitometric analysis carried out in this study.

- The application of P has shown a marked increase in B.A.I. and a reduction in mean ring density largely reflecting reduced latewood % and latewood maximum density.

- The response to P application with regard to growth rate and wood density diminished over the subsequent 4 to 5 years following treatment.

- Thinning produced a marked increase in B.A.I. for both the treatment and control plots for 3 years following the thinning operation. The impact on wood density and latewood properties however was considerably less than shown following the application of phosphate.

- Decay of thinnings and the decay of the understorey following canopy closure would conceivably release nutrients to the soil. This process could explain the slight increase in B.A.I. and decrease in mean ring density largely due to the reduction in latewood percent shown from approximately 1990 onwards.

- The concern over increasing proportions of juvenile wood with associated inferior wood properties suggests that a reduction in the application rate of fertiliser in these formative years may assist in improving overall wood quality at the end of the rotation. Once the stand has reached in excess of 10 years of age, for example and if necessary, fertiliser could be applied to maintain a high B.A.I. Results clearly indicate that the effects of fertiliser application and thinning diminish over time and hence repeat application may be cost effective in terms of volume production without compromising quality.

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Appendix 1 - DBHOB and Measured Outerwood Core Wood Properties

CONTROL							PHOSPHORUS TREATMENT @ 150 kg SUPERPHOSPHATE						
Plot	Tree No.	DBH OB (cm)	Length (mm)	No. Rings	Growth Rate (mm/ring)	Outerwood Density (kg/m^3)	Plot	Tree No.	DBH OB (cm)	Length (mm)	No. Rings	Growth Rate (mm/ring)	Outerwood Density (kg/m^3)
1	1	43.1	58	10	5.8	466	1	21	51.1	62	9	6.9	468
	2	39.4	38	10	3.8	473		22	42.3	82	10	8.2	494
	3	45.6	63	9	7.0	491		23	52.4	54	8	6.8	431
	4	28.4	30	10	3.0	524		24	38.7	53	10	5.3	489
	5	50.5	60	10	6.0	464		25	42.0	87	10	8.7	409
	6	29.8	53	10	5.3	531		26	44.2	78	10	7.8	462
	7	32.5	43	10	4.3	497		27	36.7	35	10	3.5	482
	8	38.5	57	10	5.7	521		28	39.2	54	10	5.4	463
	9	35.8	70	10	7.0	509		29	43.0	~	10	~	~
	10	41.2	46	10	4.6	503		30	38.0	49	10	4.9	446
	Mean	**38.5**	**52**	**10**	**5.3**	**498**		**Mean**	**42.8**	**62**	**10**	**6.4**	**460**
5	11	32.4	34	10	3.4	486	2	11	45.3	62	10	6.2	490
	12	42.8	63	10	6.3	490		12	36.4	53	10	5.3	407
	13	38.2	46	10	4.6	477		13	33.6	53	10	5.3	479
	14	45.5	65	10	6.5	497		14	39.5	59	10	5.9	505
	15	32.8	48	10	4.8	488		15	40.8	76	10	7.6	484
	16	29.7	62	10	6.2	438		16	40.4	52	10	5.2	461
	17	41.3	71	10	7.1	503		17	41.0	61	10	6.1	529
	18	41.1	46	10	4.6	408		18	44.8	65	10	6.5	471
	19	35.0	50	10	5.0	514		19	37.3	37	10	3.7	480
	20	35.2	74	10	7.4	483		20	37.7	47	10	4.7	496
	Mean	**37.4**	**56**	**10**	**5.6**	**478**		**Mean**	**39.7**	**57**	**10**	**5.7**	**480**
9	21	37.4	40	10	4.0	455	5	1	40.0	56	10	5.6	438
	22	47.0	67	10	6.7	509		2	43.9	25	10	2.5	422
	23	43.5	78	10	7.8	482		3	44.5	60	9	6.7	462
	24	37.1	56	10	5.6	471		4	32.9	45	10	4.5	468
	25	37.8	~	~	~	~		5	46.0	67	10	6.7	474
	26	26.7	44	10	4.4	492		6	36.5	44	10	4.4	466
	27	33.8	51	10	5.1	498		7	42.3	65	10	6.5	473
	28	31.3	46	10	4.6	480		8	38.2	54	10	5.4	477
	29	27.7	41	10	4.1	514		9	35.2	44	10	4.4	524
	30	34.5	69	10	6.9	489		10	37.2	45	10	4.5	512
	31	28.3	49	10	4.9	482							
	32	40.3	60	10	6.0	466							
	Mean	**34.1**	**55**	**10**	**5.5**	**486**		**Mean**	**39.7**	**51**	**10**	**5.1**	**472**

Appendix 2. Ring Properties - Control Plots

Year	Widths (mm)				%	Areas (cm^2)		Densities (kg/m^3)								N
	Outer Rad.	Ring	Early Wood	Late Wood	Late Wood	Incr.	Total	Ring mean	Ring mean	E/Wd mean	L/Wd mean	Unif.	Min.	Max.	Range	
1976	4	4	3.9	0.1	4	0.6	0.6	306	306	296	532	239	142	435	292	4
1977	9.5	7.5	6.7	0.4	6	2.9	3.1	352	344	341	527	188	255	511	256	8
1978	17.7	11.4	10.2	0.7	5	9	11.1	362	357	351	539	187	285	533	248	12
1979	29.8	14.6	13.8	0.6	4	21.7	31.2	344	349	336	529	192	269	518	249	14
1980	46.4	16.6	15.3	1.3	8	40.2	71.4	371	361	356	533	175	296	547	252	14
1981	61.4	15	13	2	13	50.5	121.9	379	368	352	544	192	290	583	293	14
1982	73.2	11.8	9.6	2.2	18	49.7	171.6	400	377	362	559	197	303	604	300	14
1983	82.8	9.6	7.8	1.8	19	46.9	218.5	415	385	377	563	186	308	618	310	14
1984	91.4	8.7	6.9	1.7	20	47.6	266	411	390	370	580	210	293	626	334	14
1985	98.8	7.3	5.1	2.3	32	44.5	310.5	456	399	383	604	221	317	691	373	14
1986	108.7	9.9	7.1	2.8	28	66.7	377.1	462	410	409	596	188	353	683	330	14
1987	117.7	9	5.9	3.2	33	66.5	443.6	470	419	397	613	217	331	694	363	14
1988	127	9.3	6.2	3.1	33	73.3	516.9	469	426	408	585	177	339	658	319	14
1989	134.6	7.6	5.1	2.4	32	63.9	580.8	472	431	406	616	210	339	692	353	14
1990	141	6.4	4.2	2.2	33	57	637.8	475	435	410	603	193	324	699	374	14
1991	145.7	4.7	2.8	1.9	42	43.4	681.2	493	439	404	618	213	353	717	364	14
1992	150.3	4.6	2.9	1.7	38	44.6	725.7	499	442	419	633	215	356	740	384	14
1993	154.7	4.4	2.6	1.8	43	44.1	769.9	509	446	416	632	216	378	766	387	14
1994	158.6	3.8	2.2	1.6	43	39.2	809	512	449	416	647	231	366	764	398	14
1995	162.1	3.5	1.8	1.7	49	36.6	845.6	520	452	414	627	212	361	711	350	14
1996	164.6	2.5	1.7	0.8	35	26.6	872.2	479	453	422	587	166	368	628	260	14

Appendix 3. Ring Properties - Phosphorus Plots

Year	Width (mm)				%	Area (cm^2)		Densities (kg/m^3)								N
	Outer Rad.	Ring	Early Wood	Late Wood	Late Wood	Incr.	Total	Ring mean	Ring mean	E/Wd mean	L/Wd mean	Unif.	Min.	Max.	Range	
1976	4.7	4.7	4.7			0.8	0.8	326	326	326			249	406	158	6
1977	11.9	9.9	8.6	0.5	5	4.5	4.9	358	353	348	539	174	284	514	230	14
1978	22.1	11.7	10.3	1.2	11	12.3	16.6	374	368	351	556	205	286	596	310	16
1979	34.9	12.8	10.7	2.1	16	23.4	40	384	377	351	549	199	296	594	298	16
1980	47.4	12.5	10	2.6	20	33.2	73.2	421	397	380	578	199	325	645	320	16
1981	58.2	10.8	7.9	2.9	27	36.7	109.9	432	408	378	573	195	322	645	323	16
1982	67.5	9.2	6.8	2.5	26	37.7	147.5	445	418	393	587	194	333	662	329	16
1983	74.5	7	5	2	29	32.5	180	447	423	397	563	166	325	634	309	16
1984	81.1	6.6	5.1	1.5	23	33.7	213.7	425	423	380	571	191	303	628	326	16
1985	87.3	6.2	4.2	2	32	33.7	247.5	461	428	390	609	219	324	687	364	16
1986	95.8	8.5	5.7	2.8	33	50.8	298.3	479	437	416	605	189	350	692	343	16
1987	104.4	8.6	5.5	3.1	36	56	354.3	472	442	403	592	189	340	671	331	16
1988	114.5	10.1	6.6	3.5	35	70.9	425.2	472	447	405	590	184	331	670	339	16
1989	123.2	8.8	6.1	2.7	30	67.3	492.5	470	450	405	620	215	339	710	371	16
1990	129.4	6.2	3.8	2.4	40	50.8	543.3	490	454	405	615	210	338	721	382	16
1991	134.1	4.6	2.5	2.2	47	39.3	582.6	518	458	413	639	226	370	736	366	16
1992	138.5	4.4	2.3	2.1	49	38.5	621.2	526	463	426	632	207	379	744	365	16
1993	142.4	3.9	2.1	1.8	51	36	657.1	540	467	432	644	238	405	765	361	16
1994	145.7	3.4	1.9	1.5	44	31.9	689.1	530	470	432	658	227	398	753	356	16
1995	148.8	3.1	1.4	1.7	56	30.5	719.6	534	473	431	613	182	400	684	285	16
1996	151.3	2.5	1.6	0.9	37	24.6	744.2	484	473	425	586	161	382	619	237	16