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EUCALYPTUS REGNANS NELDER GROWTH FROM AGE 4-15 YEARS

HEATHER McKENZIE & M.O. KIMBERLEY

NZ FOREST RESEARCH INSTITUTE

REPORT NO. 18 NOVEMBER 1993

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EXECUTIVE SUMMARY

A nelder trial representing equivalent square spacings over the range 91 s/ha to 4444 s/ha was planted at Kaingaroa Forest in 1978. It was part of an experiment that included a series of replicated block plantings at initial stockings of 625 s/ha, 1111s/ha and 2500s/ha.

An assessment of early mortality was carried out at age 4 years. Results indicated mortality was independent of stocking.

The block planting plots had little mortality before age 4, but by age 15 survival was about 65%. The survival in the nelder from age 4 to 15 years was 91 - 94 %.

Mean Top Height at age 15 years appeared to be unaffected by stocking and was similar in the nelders and block planting plots. However mean height decreased markedly with an increase in stocking.

Where comparison was possible, total stand volume in the nelder was higher than in the block plantings of equivalent stocking. There were no unthinned block planting plots at low or very high initial stocking with which to compare the nelder.

The nelder trial design depends on 100% survival initially and the early tree losses and consequent adjustments made in the analysis were not desirable. Splitting the nelder design of a circular layout into two semicircles may have also affected basal area and volume growth due to edge effect.

EUCALYPTUS REGNANS NELDER

- GROWTH FROM AGE 4-15 YEARS

INTRODUCTION

In the late 1970s FRI established a series of standard silvicultural trials to provide growth and yield information for the eucalypt species that were recommended in the N.Z. Forest Service Special Purpose Species Policy. An *E. regnans* experiment planted in 1978 included a series of replicated block plantings at initial stockings of 625 s/ha, 1111 s/ha and 2500s/ha adjacent to a nelder trial representing equivalent square stockings varying from 91 s/ha to 4444 s/ha. The blocks were subsequently subdivided into a series of regime trial plots (McKenzie, 1991).

Trial history

The site selected at Kaingaroa (Compartments 1209/1210) was classified as a high site index for *P. radiata*. It was also expected to be a good site for eucalypts. It had previously been occupied by 46 year old *P. radiata*. The site was sprayed with a mixture of amitrol, atrazine and simazine. Barerooted stock was raised from seed collected at Franklin, Tasmania and planted out in September. The trees were fertilised with 60g of urea shortly after planting. Early mortality occurred after the trees were successfully established and was unrelated to stocking.

Nelder Trial Design

The nelder design (Nelder, 1962) was selected to provide data on the basic relationship between initial spacing and individual tree characteristics and also because it included a wide range of stockings on a small area of land. Trees were planted in a series of concentric circles; the number of trees in a circle and the radius of each circle can be adjusted to produce the desired range of spacings. The growing space available to each tree is determined by the distance to the nearest eight neighbours and from this the equivalent square spacing and hence corresponding stocking on a hectare basis can be calculated. The range of spacings and equivalent stockings are shown in Table 1. Area constraints on the site led to the nelder being split into two semicircles which may have led to an edge effect for the highest stockings.

Disadvantages of the nelder trial design include not being able to impose thinning and pruning treatments and the effect of any establishment failure on the effective area occupied by neighbouring trees. A further constraint is that the "treatments" are not randomly allocated so that the effect of site on the inner circles, for example, is not known.

These drawbacks were taken into account to some extent when the trial was established by the use of the adjacent replicated block plantings, where thinning and pruning aspects were to be investigated. The untreated controls planted at 2 x 2 m (2500 s/ha) and 3 x 3 m (1111 s/ha) in the block planted plots were replicated three times giving two cross reference points with the nelder trial. In the nelder trial, the effect of mortality in the first year was expected to be virtually eliminated by planting pairs of trees at each planting spot. These were reduced to single trees at year 1.

METHOD

1. Field Measurement

Nelder Trial
At ages 4 to 9 years all heights and diameters were measured in all 15 arcs. At age 10 only a few arcs were measured. All arcs were measured from age 11 to 15 years but in arcs 1-11 a sample of heights was measured across the diameter range.

Block Planting Trial
Heights and diameters were measured each year from age 4 years in all plots. At age 4 all heights were measured, but from then on samples were measured; 30 trees per plot from ages 5 to 9 years and 15 trees per plot from ages 10 to 15 years.

2. Data Analysis

Nelder Trial
Despite planting two trees at each planting spot, very early mortality not related to competition between trees, occurred in both half nelders. The assessment at age 4 years was used to identify which trees had been successfully established and to take account of the effect of the early mortality on the trial design. Any trees that did not have all eight nearest neighbours surviving at this assessment were excluded from the analysis. Seven trees that were forked below 1.4 metres height were also excluded. The number of trees that were able to be included are shown in Table 1.

Table 1: Range of stockings represented in the *E. regnans* nelder and number of trees in sample.

Arc	Equivalent square spacing (m)	Stocking (s/ha)	Trees used in analysis (number) Nelder 1	Nelder 2
15	10.50	91	12	12
14	9.14	120	7	7
13	7.95	158	4	8
12	6.92	209	6	8
11	6.03	275	5	8
10	5.24	364	7	9
9	4.56	481	7	13
8	3.97	634	10	12
7	3.46	834	9	12
6	3.00	1111	12	16
5	2.62	1456	14	19
4	2.28	1923	19	19
3	1.98	2550	19	19
2	1.72	3380	17	22
1	1.50	4444	17	22

The following parameters were calculated: volume (m^3/ha), basal area (m^2/ha), and mean top height in (m). The mean height (m) was also calculated for each arc. Tree volume was calculated using the *E. regnans* volume function derived for Kinleith Forests (Hayward, 1987). In some arcs, because of the small number of trees included in the analysis, there were insufficient trees with heights measured to calculate a height on diameter regression. At age 15 years additional trees were included in the sample of height trees.

The nelder trial design may not give a true representation of mean top height because the area occupied by the trees in each arc decreases as stocking increases with the result that the number of trees used to calculate MTH decreases. However mean top height is a standard variable for comparing stands and was been included for comparison with other plots and stands. The mean height was also included to give another indication of the effect of spacing on height growth.

The data from each half nelder was examined and as there was a reasonably consistent result, except at the extremely high stockings, the data was combined.

The same procedure as that used for the *E. nitens* and *E. saligna* nelders (McKenzie and Kimberley, 1990; McKenzie et al, 1991) was used to smooth out any discrepancies across stockings. Smoothed curves were fitted through all stockings using spline functions. This was only carried out across stockings and not age on the assumption that seasonal variation in growth should not be obliterated.

Block Planting Trial

The data from the untreated control plots planted at 2x2 and 3x3 m was used to calculate means and standard errors calculated for the following parameters: volume (m^3/ha), basal area (m^2/ha), mean height (m) and mean top height (m) at ages 4 to 15 years.

RESULTS

Height

MTH was similar in the nelders and block planting plots (Figure 1, Table 2) with very little effect of stocking except at the lowest stocking. There was a similar alignment between the nelders and plots for mean height (Table 3). However mean height decreased markedly with an increase in stocking in the nelder and the mean height in the block planting plots was consistent with the nelder at corresponding stockings.

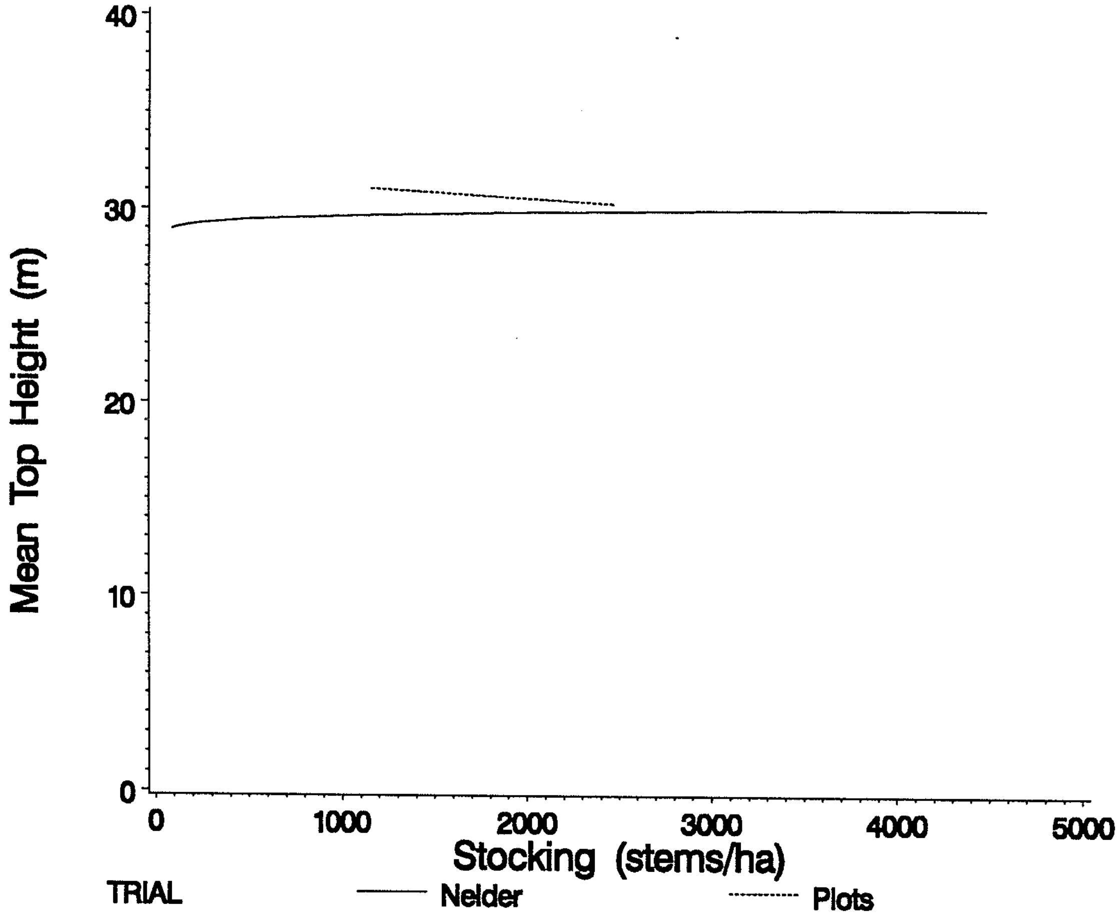

FIG. 1 - Mean Top Height at age 15 in the *E. regnans* nelder trial and adjacent block planting plots.

Basal area

Basal area was higher in the nelder (Figure 2). There is a large increase at the highest two stockings in the nelder

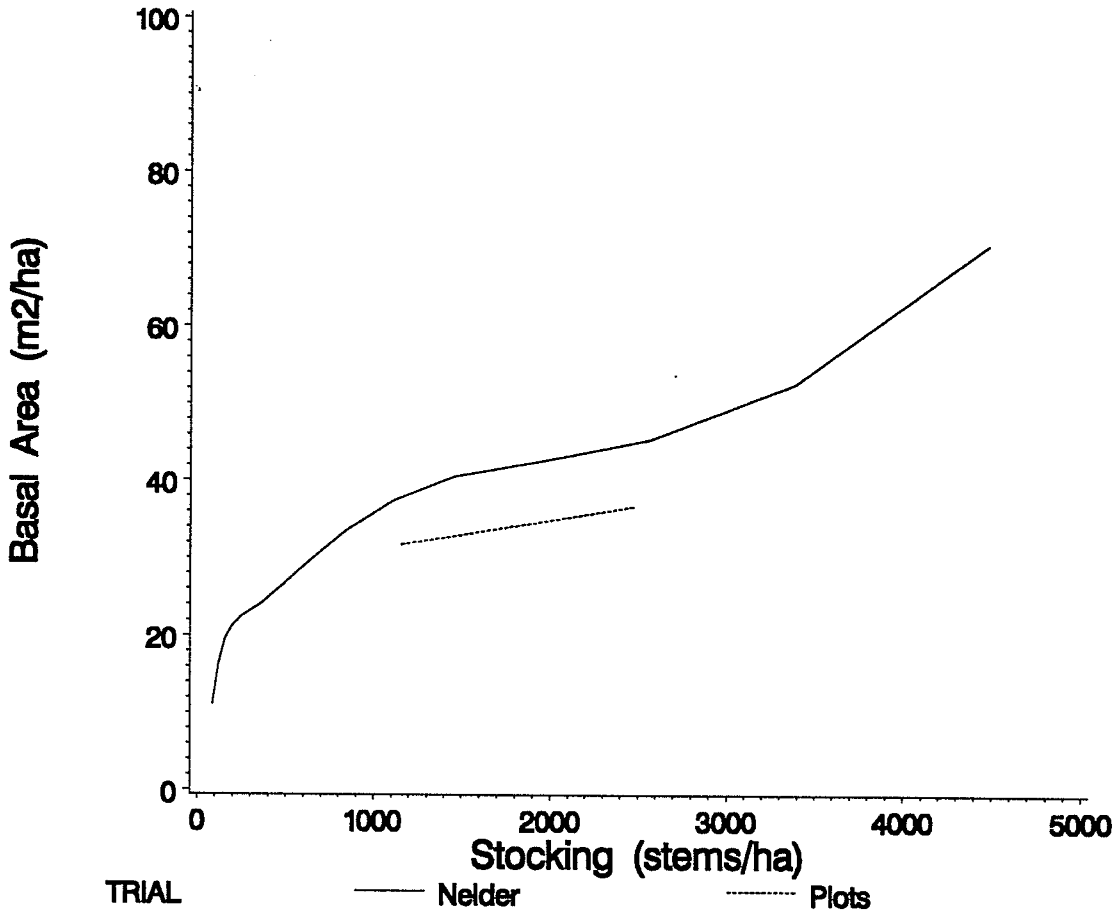

FIG 2: Basal area at age 15 in the E. regnans nelder trial and adjacent block planting plots

Survival

Survival was notably different in the nelder and block planting plots. The block planting plots had little mortality before age 4 years but by age 15 years survival was between 62 and 69% (Table 5). In the nelders the survival from age 4 to 15 years was 91 - 94 %.

Volume

In the nelder trial volume at age 15 ranged from 133 to 634 m^3/ha. At equivalent stockings it was lower in the block planting plots reflecting the lower basal area. (Table 6). MAI at age 15 years ranged from 8.9 m^3/ha/year to 42.3 m^3/ha/year and has clearly not peaked at any stocking (Table 7). Season appears to have had a marked effect on CAIs with trees at age 13 years, for example, having markedly less annual increment than the previous or subsequent years (Table 8). Large increments have occurred at age 15 in stockings up to 840 s/ha in the nelder. At greater stockings there were large volume increments at age 14 years. The block planting plots had a similar dip at age 13 years and an increase in each subsequent year, with age 15 years recording the highest CAI. The CAIs achieved at age 14 in the nelder and at age 15 in the block planting plots were very similar; the 1100 s/ha initial stocking achieving 37 and 39 m3/ha respectively and the 1500 s/ha achieving 44 and 45 m3/ha.

CONCLUSION

Mean Top Height was similar at corresponding stockings in both the nelder trial and block planting plots despite reservations about how it is derived for the nelders. The block planting plots are adjacent to the nelders and would be expected to have the same site quality. The consistency of MTH through the plots and nelder experiment, combined with the independence of MTH to stocking differences, supports the usefulness of MTH as an indicator of site quality for *E. regnans*.

Mortality was significantly different in the nelder plots compared to the block planting plots, which may account for the difference in basal area. The block planting plots had higher mortality and lower basal area compared to the nelder trial. Because of the variation in their initial estabishment, basal area results for the 2 trials may not be entirely compatible. However some of the stand parameters are similar; for example for corresponding stockings the highest CAIs of volume are virtually the same in the nelders and block planting plots, although occurring in different years; at age 14 years nelders and at age 15 years in the plots.

There were no unthinned block planting plots at low or very high initial stocking with which to compare the nelder.

The nelder trial design depends on 100% survival initially and the early tree losses and consequent adjustments made in the analysis were not desirable. Splitting the nelder design (a circular plot) into two semicircles may have also affected basal area and volume growth due to edge effect.

TABLES OF SMOOTHED NELDER DATA AND BLOCK PLANTING PLOT DATA

Table 2. Mean Top Height (m)

Age	Nelder Initial Stocking (sph) 90	120	160	210	275	365	480	635	840	1100	1460	1940	2570	3400	4490
4	8.8	8.9	9	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10	10.1	10.2
5	10.7	10.8	11	11	11.2	11.3	11.4	11.6	11.7	11.8	11.9	12	12.1	12.3	12.4
6	12.7	12.9	13	13.1	13.3	13.5	13.6	13.8	13.9	14.1	14.2	14.4	14.5	14.7	14.8
7	14.9	15	15.1	15.2	15.3	15.5	15.6	15.8	15.9	16	16.1	16.2	16.4	16.5	16.6
8	17.1	17.2	17.4	17.4	17.6	17.7	17.9	18	18.1	18.2	18.4	18.5	18.6	18.7	18.9
9	18	18.2	18.4	18.5	18.6	18.9	19	19.2	19.4	19.5	19.7	19.9	20	20.2	20.4
11	22.2	22.3	22.4	22.5	22.6	22.7	22.8	22.9	23	23.2	23.3	23.4	23.5	23.6	23.7
12	24.4	24.6	24.8	24.9	25.1	25.4	25.5	25.7	25.9	26.1	26.3	26.5	26.6	26.8	27
13	26.1	26.2	26.3	26.3	26.4	26.5	26.6	26.7	26.8	26.9	27	27.1	27.2	27.3	27.4
14	27.3	27.5	27.6	27.6	27.7	27.9	28	28.1	28.2	28.3	28.4	28.5	28.6	28.7	28.8
15	28.9	29	29.1	29.2	29.2	29.3	29.4	29.5	29.6	29.7	29.7	29.8	29.9	30	30.1

Age	Plots Initial Stocking (sph) 1160		2480	
	mean	s.e.	mean	s.e.
4	9.4	0.2	9.3	0.5
5	11.6	0.2	12.1	0.7
6	14	0.2	14.1	0.5
7	16.2	0.2	15.8	0.6
8	18.2	0.3	17.9	0.9
9	19.3	0.2	19.5	1
10	21.7	0.2	22.1	1.1
11	24.2	0.8	23.6	0.5
12	26.4	0.8	25.7	0.7
13	27.7	1.3	26.5	0.9
14	28.7	1	28.6	0.4
15	31.1	1.3	30.3	0.9

Table 3. Mean Height (m)

Age	Nelder Initial Stocking (sph)														
	90	120	160	210	275	365	480	635	840	1100	1460	1940	2570	3400	4490
4	8.3	8.3	8.3	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
5	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
6	12.3	12.4	12.4	12.4	12.4	12.5	12.5	12.5	12.5	12.5	12.6	12.6	12.6	12.6	12.7
7	14.5	14.4	14.4	14.4	14.3	14.3	14.3	14.2	14.2	14.1	14.1	14.1	14	14	14
8	16.8	16.7	16.6	16.6	16.5	16.4	16.3	16.2	16.1	16	15.9	15.8	15.7	15.6	15.6
9	18	17.9	17.8	17.7	17.6	17.5	17.4	17.3	17.2	17.1	17	16.9	16.8	16.7	16.6
11	22.1	21.8	21.6	21.4	21.2	20.8	20.6	20.3	20.1	19.8	19.6	19.3	19.1	18.8	18.6
12	24	23.8	23.5	23.3	23.1	22.8	22.5	22.3	22	21.8	21.6	21.3	21.1	20.8	20.6
13	26	25.5	25.1	24.9	24.5	23.9	23.5	23.1	22.7	22.3	21.9	21.5	21.1	20.7	20.3
14	27.7	27.1	26.7	26.4	26	25.3	24.9	24.4	24	23.5	23.1	22.7	22.2	21.7	21.3
15	29.4	28.9	28.4	28	27.5	26.8	26.3	25.8	25.3	24.8	24.3	23.8	23.3	22.8	22.3

Age	**Plots Initial Stocking (sph)**			
	1160		**2480**	
	mean	**s.e.**	**mean**	**s.e.**
4	7.9	0.2	7.1	0.7
5	9.9	0.2	9.2	0.7
6	11.8	0.2	10.8	0.7
7	13.6	0.2	12.4	0.6
8	15.3	0.2	13.8	0.8
9	16.3	0.2	15.1	0.8
10	18.3	0.2	16.7	0.7
11	19.8	0.5	17.9	0.6
12	21.4	0.2	19.7	0.7
13	22.9	0.6	20.5	0.8
14	24.3	0.5	21.7	0.7
15	25.8	0.6	23.2	1.1

Table 4. Basal Area (m^2/ha)

	Nelder														
	Initial Stocking (sph)														
Age	**90**	**120**	**160**	**210**	**275**	**365**	**480**	**635**	**840**	**1100**	**1460**	**1940**	**2570**	**3400**	**4490**
4	0.9	1.4	1.9	2.3	2.7	3.5	4.2	5	6.1	7.5	9.2	11.3	14.1	17.6	22.1
5	1.4	2.3	3.1	3.5	4.2	5.1	5.9	7	8.3	10	12.1	14.6	17.8	21.5	26.1
6	2.3	3.7	4.8	5.5	6.2	7.2	8.1	9.4	11	13.2	15.6	18.5	21.9	26	30.8
7	3.2	5.1	6.6	7.3	8.1	9.1	10.2	11.8	13.8	16.4	19.1	22.2	25.7	29.9	35.7
8	4	6.3	7.9	8.9	9.8	11	12.3	14.2	16.5	19.3	22.2	25.3	28.9	33.4	40.1
9	4.9	7.7	9.7	10.8	11.9	13.3	14.7	16.8	19.3	22.4	25.5	28.6	32.3	37.4	45.8
11	6.8	10.7	13.5	14.9	16.3	18	19.8	22.3	25.4	28.8	32.1	35	38.6	44.6	56.1
12	7.8	11.9	14.9	16.3	17.8	19.5	21.5	24.2	27.5	31.2	34.5	37.3	40.9	47.3	60.3
13	8.6	13.1	16.2	17.8	19.2	21.1	23.1	25.9	29.3	33	36.2	39	42.7	49.4	63.7
14	9.8	14.5	17.7	19.3	20.7	22.6	24.8	27.8	31.3	35.2	38.4	41	44.4	51.5	67.4
15	11	16.2	19.5	21	22.4	24.2	26.4	29.6	33.5	37.5	40.5	42.5	45.4	52.7	70.9

	Plots			
	Initial Stocking (sph)			
Age	**1160**		**2480**	
	mean	**s.e.**	**mean**	**s.e.**
4	6.3	0.4	8.5	2
5	9.4	0.7	12.1	2.5
6	12.4	0.9	15.5	2.5
7	15	1	18.7	2.5
8	17.7	1.2	21.6	2.5
9	20.5	1.1	24.9	2.1
10	22.8	0.9	27.8	1.8
11	25.3	1	30.4	1.6
12	27	1.2	32.1	1.6
13	28.3	1.2	33.7	1.5
14	29.9	1.3	35.9	1.5
15	31.8	1.5	36.7	1.6

Table 5. Survival Percentage

	Nelder														
	Initial Stocking (sph)														
Age	**90**	**120**	**160**	**210**	**275**	**365**	**480**	**635**	**840**	**1100**	**1460**	**1940**	**2570**	**3400**	**4490**
4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
5	98.9	98.3	98.7	98.7	98.6	98.8	98.8	98.7	98.8	98.8	98.9	98.9	99.0	99.0	99.0
6	97.7	97.5	98.1	98.2	98.2	98.2	98.3	98.3	98.3	98.5	98.5	98.5	98.6	98.7	98.7
7	97.7	97.5	97.5	97.7	97.4	97.7	97.7	97.8	98.0	98.0	98.1	98.1	98.2	98.3	98.3
8	96.6	96.7	96.8	96.6	97.0	97.1	97.3	97.3	97.4	97.5	97.6	97.7	97.8	97.9	97.9
9	95.4	95.8	96.2	96.1	96.2	96.6	96.7	96.7	96.9	96.9	97.1	97.2	97.3	97.4	97.5
11	94.3	94.2	94.3	94.5	94.9	95.2	95.4	95.4	95.7	95.9	96.0	96.1	96.3	96.4	96.5
12	93.1	93.3	93.7	94.0	94.1	94.4	94.6	94.8	95.0	95.2	95.3	95.5	95.7	95.9	96.0
13	92.0	92.5	93.0	93.0	93.3	93.6	94.0	94.2	94.4	94.5	94.7	94.9	95.1	95.3	95.5
14	92.0	91.7	92.4	92.4	92.5	93.0	93.1	93.4	93.7	93.9	94.1	94.3	94.5	94.7	94.9
15	90.8	90.8	91.1	91.4	91.7	92.2	92.3	92.6	92.9	93.2	93.4	93.7	93.9	94.1	94.3

	Plots			
	Initial Stocking (sph)			
	1160		**2480**	
Age	**mean**	**s.e.**	**mean**	**s.e.**
4	94.2	2.9	94.8	2.9
5	93.2	2.4	93.9	3
6	92.9	2.1	93.3	3.2
7	89.7	1.3	90.3	4.4
8	86.8	1.3	85.9	5.4
9	86.2	1.1	84.6	5.2
10	83	0.7	82.2	5.5
11	79.8	0.5	79.5	5.7
12	79.4	0.3	73.4	6
13	74.7	1.2	69.8	5.3
14	71.1	0	67.6	5.1
15	68.9	1.4	61.1	3.5

Table 6. Volume (m^3/ha)

Age	Nelder Initial Stocking (sph)														
	90	120	160	210	275	365	480	635	840	1100	1460	1940	2570	3400	4490
4	3	5	6	7	9	12	14	17	21	25	30	37	47	60	80
5	6	9	12	15	18	22	25	29	33	40	49	60	74	91	111
6	11	17	23	27	32	38	41	46	53	62	75	92	111	133	157
7	19	27	35	40	47	55	60	67	75	88	103	123	146	171	200
8	27	39	49	57	66	76	82	90	101	116	134	157	185	217	255
9	35	50	64	74	85	98	105	115	127	144	164	190	222	261	309
11	63	84	103	117	133	152	163	177	194	215	240	271	310	355	410
12	83	105	124	138	157	181	197	215	236	260	287	320	364	420	492
13	95	121	145	161	181	205	220	237	256	279	305	337	382	440	517
14	112	142	169	188	210	236	252	270	291	316	344	379	426	487	566
15	133	167	197	218	243	275	293	311	330	349	367	394	443	519	634

	Plots Initial Stocking (sph)			
	1160		2480	
Age	**mean**	**s.e.**	**mean**	**s.e.**
4	20	1	26	7
5	37	3	46	12
6	58	5	68	15
7	81	6	94	17
8	107	9	121	20
9	133	8	147	24
10	168	7	185	20
11	200	10	214	25
12	228	13	258	24
13	252	14	280	28
14	284	13	316	28
15	323	17	361	32

Table 7. Volume MAI (m^3/ha/yr)

Age	Nelder Initial Stocking (sph) 90	120	160	210	275	365	480	635	840	1100	1460	1940	2570	3400	4490
4	0.8	1.3	1.5	1.8	2.3	3.0	3.5	4.3	5.3	6.3	7.5	9.3	11.8	15.0	20.0
5	1.2	1.8	2.4	3.0	3.6	4.4	5.0	5.8	6.6	8.0	9.8	12.0	14.8	18.2	22.2
6	1.8	2.8	3.8	4.5	5.3	6.3	6.8	7.7	8.8	10.3	12.5	15.3	18.5	22.2	26.2
7	2.7	3.9	5.0	5.7	6.7	7.9	8.6	9.6	10.7	12.6	14.7	17.6	20.9	24.4	28.6
8	3.4	4.9	6.1	7.1	8.3	9.5	10.3	11.3	12.6	14.5	16.8	19.6	23.1	27.1	31.9
9	3.9	5.6	7.1	8.2	9.4	10.9	11.7	12.8	14.1	16.0	18.2	21.1	24.7	29.0	34.3
11	5.7	7.6	9.4	10.6	12.1	13.8	14.8	16.1	17.6	19.5	21.8	24.6	28.2	32.3	37.3
12	6.9	8.8	10.3	11.5	13.1	15.1	16.4	17.9	19.7	21.7	23.9	26.7	30.3	35.0	41.0
13	7.3	9.3	11.2	12.4	13.9	15.8	16.9	18.2	19.7	21.5	23.5	25.9	29.4	33.8	39.8
14	8.0	10.1	12.1	13.4	15.0	16.9	18.0	19.3	20.8	22.6	24.6	27.1	30.4	34.8	40.4
15	8.9	11.1	13.1	14.5	16.2	18.3	19.5	20.7	22.0	23.3	24.5	26.3	29.5	34.6	42.3

Table 8. Volume CAI (m^3/ha)

Age	Nelder Initial Stocking (sph) 90	120	160	210	275	365	480	635	840	1100	1460	1940	2570	3400	4490
5	3.0	4.0	6.0	8.0	9.0	10.0	11.0	12.0	12.0	15.0	19.0	23.0	27.0	31.0	31.0
6	5.0	8.0	11.0	12.0	14.0	16.0	16.0	17.0	20.0	22.0	26.0	32.0	37.0	42.0	46.0
7	8.0	10.0	12.0	13.0	15.0	17.0	19.0	21.0	22.0	26.0	28.0	31.0	35.0	38.0	43.0
8	8.0	12.0	14.0	17.0	19.0	21.0	22.0	23.0	26.0	28.0	31.0	34.0	39.0	46.0	55.0
9	8.0	11.0	15.0	17.0	19.0	22.0	23.0	25.0	26.0	28.0	30.0	33.0	37.0	44.0	54.0
11	14.0	17.0	19.5	21.5	24.0	27.0	29.0	31.0	33.5	35.5	38.0	40.5	44.0	47.0	50.5
12	20.0	21.0	21.0	21.0	24.0	29.0	34.0	38.0	42.0	45.0	47.0	49.0	54.0	65.0	82.0
13	12.0	16.0	21.0	23.0	24.0	24.0	23.0	22.0	20.0	19.0	18.0	17.0	18.0	20.0	25.0
14	17.0	21.0	24.0	27.0	29.0	31.0	32.0	33.0	35.0	37.0	39.0	42.0	44.0	47.0	49.0
15	21.0	25.0	28.0	30.0	33.0	39.0	41.0	41.0	39.0	33.0	23.0	15.0	17.0	32.0	68.0

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