Economics of Spacing, Respacing and Thinning

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ABSTRACT

An economic evaluation of a number of silvicultural treatments, which include spacing, respacing and thinning in Sitka spruce and coastal lodgepole pine is presented.

The results show, for the two prices assumed, that lower crop densities than those now practised lead to greater profitability if wood quality is not drastically reduced. The need for a detailed examination of the relationship between silvicultural treatment and wood quality is advocated. The evidence indicates that while lower than current crop densities lead to greater profitability, the optimum will depend upon the results from the suggested wood quality study.

1. INTRODUCTION

Considerable changes in silvicultural operations have occurred in the Republic of Ireland over the past decades. Espacement at establishment was increased from 1.5m in the 1950's to 2.0m in the 1970's. The trend in thinning has been to increase the intensity, with the adoption of mechanical or line thinning in the case of first thinning.

These changes were introduced as a response to the increasing cost of individual forest operations. Less emphasis was placed on the possibility that these changes could also increase revenue. The absence of yield estimates prevented an economic analysis of the overall financial effects of the treatments for the producers.

The trend towards wider spacing and heavier thinning is also evident in other countries. In New Zealand, Australia and South Africa extremely low crop densities are quite common in pine plantations. One silvicultural system implemented in New Zealand lowers the crop density from 1500 trees per ha at planting to 200 trees per ha at 11 metres top height. This particular regime was adopted as a result of intensive economic analysis (Sutton 1976). Such extreme treatments are not commonly practised in Europe. However, the results of many analyses have pointed towards lower crop densities. Wardle (1967) advocated spacing of 2.4 metres at planting for Sitka spruce. A more recent study of Sitka spruce in Northern Ireland (Kilpatrick et al 1980) indicates optimum density after respacing of 2000 trees per ha and a somewhat lower density at establishment. Bryndum (1976) indicated that net revenue from Norway spruce can be increased by increasing thinning intensity.

The results from a number of experiments established by the Forest and Wildlife Service (FWS) since 1960 has made possible an economic analysis of different silvicultural regimes under Irish conditions. These regimes include different initial spacings, respacing to different crop densities and a number of thinning type and intensity treatments.

2. Analysis Procedure

Net discounted revenue (NDR) or present worth of one rotation is used to make comparisons between treatments, despite its shortcomings as a valuation tool (Grainger 1976). In this study, however, the comparative rather than absolute values are of greater importance, so the failings inferent in NDR are not significant and do not affect the conclusions.

The estimation of NDR necessitates the isolation of all the costs and revenues for each treatment through the rotation.

The costs of conventional operations are based on those prevailing in the FWS in 1978. The cost of other operations are derived from work study estimates. Yield data come from two sources, from FWS experiments and from published yield tables.

The analysis is, of necessity, based on a number of assumptions. The sensitivity of the results to a number of these assumptions is also examimed. These include product price, and wood quality.

2.1 *Product price*

Two product price assumptions, termed "Price 1" and "Price 2" are shown in Table 1 in relation to both end use category and to mean diameter at breast height. 'Price 1' was arrived at by analysis of FWS sales for the year 1978. 'Price 2' differs from 'Price 1' only in the value placed on pulpwood. This 'Price 2' reflects the general trend towards a reduction in the price of pulpwood together with the relative stability of the sawlog price.

Table 1. Price assumptions IR £ (1978) by end use category.

Dimensions	Product		
	Large Sawlog	Small Sawlog	Pulp
	Volume 20cms top diameter Minimum length 3m	Volume 14 - ❮20cms Minimum length 3m	Remainder
Price 1	24.40	10.84	3.44
Price 2	24.40	10.84	1.50

Note: The prices shown are often presented in terms of the price per cubic metre received for trees classified by mean diameter. The two prices are presented in this fashion in the table below for the convenience of those more used to that method of presentation.

Price assumptions IR £ (1978) by diameter.

	Diameter at breast height (cms).							
	8	10	12	14	16	18	20	22
Price 1	3.44	3.72	4.45	5.7	7.69	9.79	12.7	14.59
Price 2	1.51	1.92	2.77	4.30	6.65	9.06	11.54	14.21

	DBH (cms)								
	24	26	28	30	32	34	36	38	40
Price 1	16.78	18.48	19.81	20.84	21.58	22.15	22.59	22.92	23.18
Price 2	16.50	18.27	19.66	20.72	21.49	22.08	22.53	22.87	23.14

2.2 *Wood quality*

The possible implementation of grading rules may influence the valuation of forest products. The adoption of lower crop densities can be expected to affect quality in a number of ways. Wider spacing and heavier thinning tends to increase ring width and so reduce strength of Sitka spruce (Phillips 1978). The density of this spruce material is also reduced (Gardiner and O'Sullivan 1978).

The effect on coastal lodgepole pine is not quite clear. In New Zealand, ring width is excluded as a parameter in grading rules for pines. The value of rejected material is also unclear. Moltesen and

Lynge (1980) estimated the value of rejected Norway spruce timber at 80% of the value of ungraded material. In this analysis the effect of a possible reduction in quality on the price of large sawlog has been quantified by a price reduction of 10% and 20% of this material to £10.84 per m^3. This price reduction due to the effect of low crop densities on wood quality is more pessimistic than estimated by Moltesen et al (1980). It is reasonable however, to expect that rejected material will at least obtain the same price as small sawlog.

2.3 *Scope of the Analysis*

Economic aspects of spacing, respacing and thinning are analysed in three stages.

Estimation of:

1. NDR for each treatment using 'Price 1' and assuming that treatment does not effect quality.
2. The effect on NDR of a reduction of the pulpwood price.
3. The effect of quality on NDR.

3. Economics of Spacing

The financial attractiveness of a range of spacings at establishment for the two major species planted in Irish forests — Sitka spruce and coastal lodgepole pine are considered.

3.1 *Yield Estimates*

The FWS experiments in Sitka spruce and lodgepole pine (coastal) cover five spacing treatments ranging from 1.2 to 3.6m square. These experiments indicate that during the early years of a stand's development, both basal area and volume increment are greater with narrow spacings, with these differences between the narrow and wider spacing decreasing with time. It is expected that the differences in total basal area and volume existing between the different spacings at the most recent measurement will not increase further over the remainder of the rotation (Lynch 1980). If basal area increment in a stand of wider spacing is equal to the basal area increment at narrower spacing then there are implications for diameter growth. The extent of the differences in volume and mean diameter between different spacings and those assumed for normal yield tables, (Hamilton and Christies 1971; FWS 1978 are shown in Table 2. If basal area increment remains constant for different spacings then one would expect diameter differences to increase between narrow and wide spacing. However, in order to be conservative it was assumed that the diameter differences are retained at the same level as shown in Table 2 throughout the rest of the rotation. Yield tables based on these assumptions are shown in Tables 3 and 4. Assortment tables (Hamilton and Christie 1971) were used to give a breakdown of the volume into the end use categories, with no check of the accuracy for wider spacings.

Allowances for losses due to roads, ride lines, gaps, fires and other causes were not considered. This approach has been taken because of the paucity of information on the scale of losses. It is likely however, that the losses will be more significant in wider spacings.

Table 2. Comparison of yield from FWS experiments at different espacements with normal yield tables.

	Spacing (metres)				
	1.2	1.8	2.4	3.0	3.6
Sitka spruce					
Age: top ht. 10.4m 15					
Volume difference (m^3/ha)	–5	39	–24	–43	–61
Diameter difference (cms)	–3.2	+.4	+1.6	+3.7	+5.0
Lodgepole pine (coastal)					
Age: Top ht. 6.5m 12					
Volume difference (m^3/ha)	13	0	–2	–12	–18
Diameter difference (cms)	–3.3	–1.4	0.7	1.5	2.1

Table 3. Provisional Yield Tables for different espacements for Sitka spruce, Yield Class 24.

Age	Yield					Cumulative
	Mean Diam.	Tot. Vol. 7	Large Sawlog	Small Sawlog	Pulp	Prod.
			1.2m spacing			
17	9.9	63		3	60	188
22	11.7	84		11	73	342
27	15.4	84	3	28	53	513
32	19.8	84	20	41	23	686
37	24.2	84	43	29	12	847
46	35.3	699	609	66	24	1098
			1.8m spacing			
18	14.3	87	1	24	62	260
23	15.9	84	5	34	45	419
28	19.8	84	20	41	23	593
33	24.3	84	43	29	12	763
38	28.7	84	62	16	6	922
46	38.9	719	658	43	18	1142
			2.4m spacing			
21	18.1	96	12	60	24	239
26	19.3	84	15	42	27	459
31	25.8	84	52	23	9	633
36	28.2	84	59	18	7	798
41	32.4	84	69	11	4	947
46	40.3	647	597	35	15	1079
			3.0m spacing			
24	23.2	124	56	47	21	371
29	24.0	84	43	29	12	546
34	28.5	84	62	16	6	697
39	32.8	84	70	10	4	852
46	42.2	684	640	640	31	1060
			3.6m spacing			
27	27.5	152	107	33	12	457
32	28.0	84	59	18	7	630
37	32.4	84	69	11	4	791
46	43.3	722	679	31	12	1042

Table 4. Provisional Yield Tables for different espacements for lodgepole pine (coastal), Yield Class 16.

Age	Yield					Cumulative Prod.
	Mean Diam.	Tot. Vol. 7	Large Sawlog	Small Sawlog	Pulp	
			1.2 spacing			
16	9.0	45		1	44	135
21	9.6	56		3	53	241
26	10.0	56		3	53	361
31	13.0	56		11	45	472
36	16.2	56	3	23	30	573
41	18.6	56	10	28	16	663
46	21.3	56	17	26	13	749
52	35.1	464	404	44	16	845
			1.8m spacing			
18	11.9	54		7	47	163
23	11.4	56		5	51	277
28	13.1	56		11	45	393
33	16.2	56	3	23	30	500
38	19.0	56	10	28	16	596
43	21.6	56	22	23	11	685
48	24.1	56	29	19	8	768
52	37.5	442	400	80	12	832
			2.4m spacing			
20	15.0	67	2	23	42	202
25	13.4	56		11	45	323
30	16.3	56	3	23	30	436
35	19.7	56	13	28	15	540
40	22.1	56	22	23	11	630
45	24.8	56	32	17	7	718
52	38.8	483	442	30	11	830
			3.0m spacing			
22	17.6	80	10	50	20	240
27	15.4	56	2	21	33	358
32	18.5	56	7	28	21	468
37	21.5	56	22	23	11	566
42	24.0	56	29	19	8	655
47	26.6	56	37	14	5	740
52	40.2	460	425	24	11	820
			3.6m spacing			
24	20.1	94	23	45	26	283
29	17.1	56	5	31	20	397
34	20.4	56	13	28	15	504
39	23.0	56	25	22	9	596
44	25.7	56	35	15	6	684
49	28.1	56	39	13	4	766
52	41.9	440	411	21	8	814

3.2 *Costs*

The costs have been differentiated into those for conventional crop management and for non-standard spacing. The former will not affect the comparisons between the different treatments and are therefore not tabulated. They have, however, been included in the calculations.

Spacing dependent costs (Table 5) show how the costs of non-standard spacings differ from the standard 1.8m spacing. Due to lack of information certain costs or savings which may be significant have not been included. These include savings in harvesting due to increased tree size which can be expected to increase with wider spacings.

Cleaning costs have been related to numbers and espacement of plants. No account has been taken of possible increased costs per tree with wider spacing. This is unlikely to be significant as canopy closure, even in the narrowest spacing, occurs a long time after the normal cleaning time.

No allowance was included for increased cost of plant replacement with wider spacings. The normal FWS convention is that plants are replaced only where 33% of the crop has failed. It is likely that losses of less than 33% would be significant in wider spacing. The rectangular (3 x 2m) spacing refers to the case where plough ribbons are 2m apart and the distance between plants on the ribbon is 3m. The spacing dependent costs are quite reduced in this case due to the asumptions of double mouldboard ploughing and systematic first thinnings. Single mouldboard ploughing is assumed in all cases except where spacing is 1.8 or 2m between rows. Line thinning is assumed only where the distance between rows is 2m or less. This systematic thinning leads to savings in brashing costs for these spacings. Pruning costs have been included for spacings from 2.4m for Sitka spruce and for all spacings for lodgepole pine (coastal).

3.3 *Results*

NDR values assuming Price 1 for thinned stands of Yield Classes 12 and 16 (Hamilton and Christie 1971) and for Yield Class 24 (FWS 1978) are shown in Fig. 1. The NDR values for coastal lodgepole pine Yield Class 16 are shown in Fig. 3. These estimates of NDR assume that costs for 1.8m crops apply for all spacings. It can be seen from Figures 1 and 3 that the NDR values increase with increasing spacing and that the results are consistent for interest rates from 2 to 10% and for both yield estimates.

Table 5. Spacing Dependent Costs (Irish £ per ha). (Net of 1.8m spacing costs)

Description	Spacing							
	.9x.9	1.2x1.2	1.4x1.4	1.8x1.8	2.4x2.4	3x2	3.0x3.0	3.6x3.6
Ploughing and planting (Yr. 0)	553	224	145	0	-85	—98	—127	—150
Cleaning Costs								
Yr. 2	92	40	25	0	-12	-12	-20	-22
Yr. 3	184	80	50	0	-24	-24	-40	-44
Brashing (Yr. of 1st thin)	289	137	96	0	116	54	53	19
High pruning								
Sitka spruce								
Stage 1 to 2.5m					100	100	100	100
Stage 2 to 5m					112	112	112	112
Lodgepole pine								
Stage 1 to 2.5m		89		131	109	109	129	149
Stage 2 to 5m		101		144	121	121	141	160

Table 6. NDR values Sitka spruce Yield Class 16. (IR £ per ha) (Based on BFC data)

Description	Spacing (m)						
	Price	Rate	.9x.9	1.4x1.4	1.8x1.8	2.4x2.4	3.0x2.0
No allowance for spacing dependent costs	P1	2	3046	3572	4058	4376	4376
No allowance for spacing dependent costs	P1	4	914	1151	1400	1592	1592
	P2	4	766	1018	1321	1550	1550
Corrected for costs	P1	4	-46	887	1400	1576	1640
	P2	4	-194	754	1321	1534	1598
10% of sawlog reduced in value from £24.40-£10.84	P1	4	—	—	—	1460	1524
20% of sawlog reduced in value	P1	4	—	—	—	1301	1365
No allowance	P1	6	11	121	253	381	381
for spacing	P1	8	-373	-321	-248	-155	—155
dependent costs	P1	10	-536	-511	-470	-396	-396

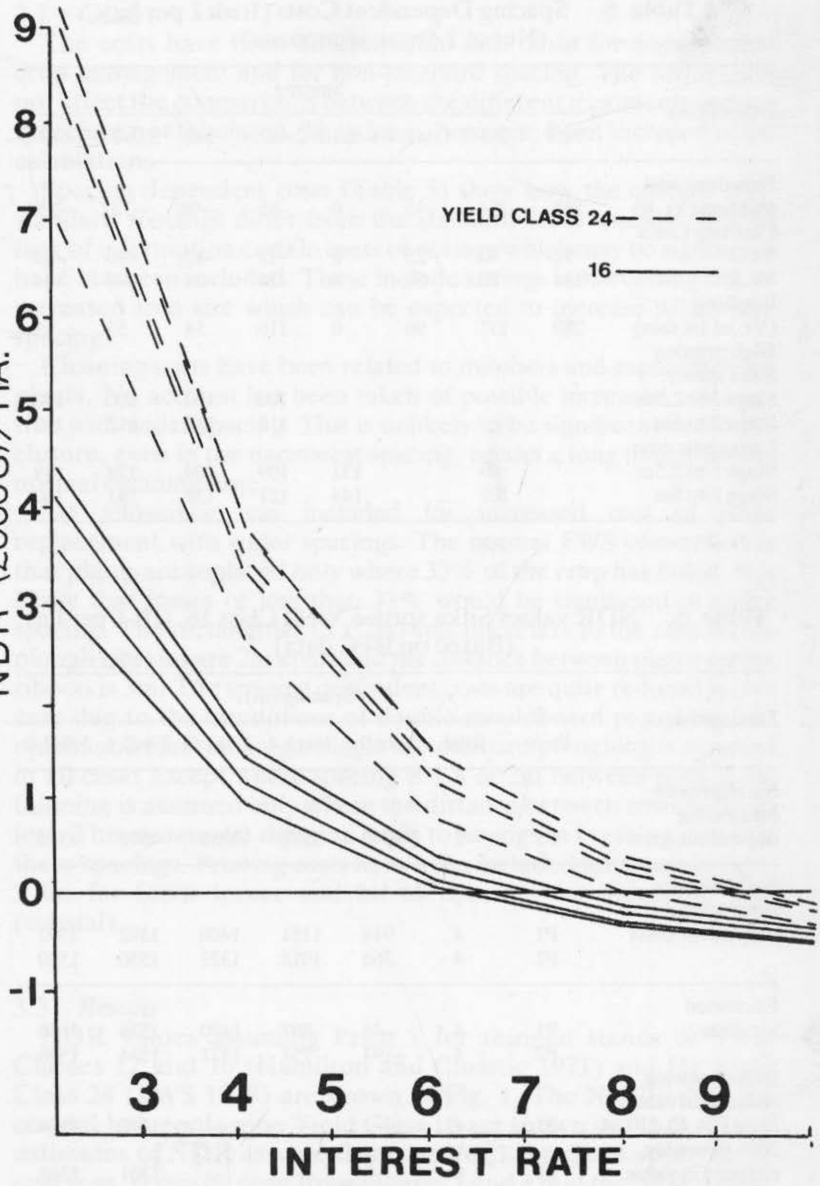

Fig. 1 Net discounted revenues for two yield classes of Sitka spruce for a range of spacings and interest rates. (No allowance taken for costs for different spacings).

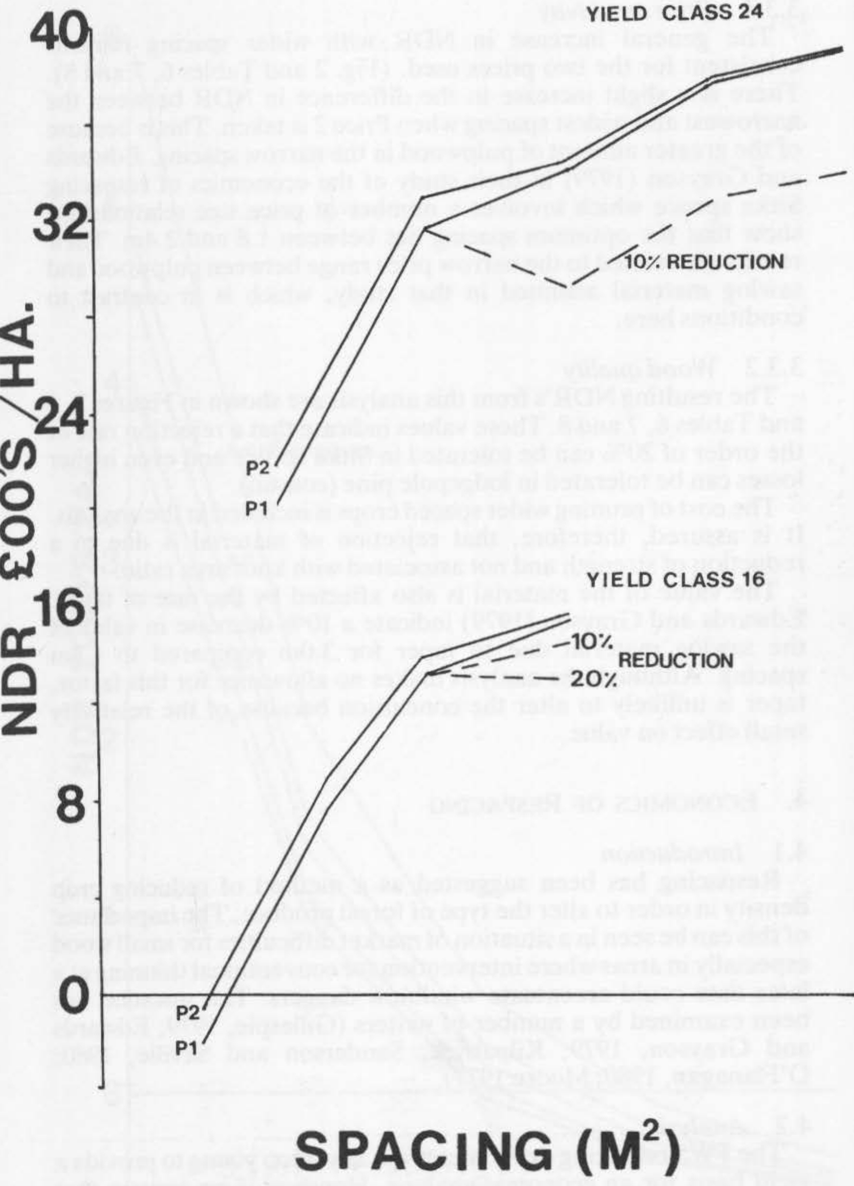

Fig. 2 **Net discounted revenues for two yield classes of Sitka spruce for a range of spacings and for two price size gradients. The effect of reduction of quality is also shown.**

3.3.1 *Price sensitivity*

The general increase in NDR with wider spacing remains consistent for the two prices used. (Fig. 2 and Tables 6, 7 and 8). There is a slight increase in the difference in NDR between the narrowest and widest spacing when Price 2 is taken. This is because of the greater amount of pulpwood in the narrow spacing. Edwards and Grayson (1979) in their study of the economics of respacing Sitka spruce which involves a number of price size relationships show that the optimum spacing lies between 1.8 and 2.4m. Their results are related to the narrow price range between pulpwood and sawlog material assumed in that study, which is in contrast to conditions here.

3.3.2 *Wood quality*

The resulting NDR's from this analysis are shown in Figures 2, 4 and Tables 6, 7 and 8. These values indicate that a rejection rate of the order of 20% can be tolerated in Sitka spruce and even higher losses can be tolerated in lodgepole pine (coastal).

The cost of pruning wider spaced crops is included in the analysis. It is assured, therefore, that rejection of material is due to a reduction of strength and not associated with knot area ratio.

The value of the material is also affected by the rate of taper. Edwards and Grayson (1979) indicate a 10% decrease in value of the sawlog material due to taper for 3.0m compared to 1.8m spacing. Although the analysis makes no allowance for this factor, taper is unlikely to alter the conclusion because of the relatively small effect on value.

4. Economics of Respacing

4.1 *Introduction*

Respacing has been suggested as a method of reducing crop density in order to alter the type of forest produce. The importance of this can be seen in a situation of market difficulties for small wood especially in areas where intervention for conventional thinning at a later date could accentuate windblow dangers. This question has been examined by a number of writers (Gillespie, 1979; Edwards and Grayson, 1979; Kilpatrick, Sanderson and Saville, 1980; O'Flanagan, 1980; Moore 1977).

4.2 *Analysis*

The FWS respacing experiments are as yet too young to provide a yield basis for an economic analysis. However if we assume that crops develop after respacing in the same way as those initially established at the same density then the NDR values already calculated for spacing in Tables 7 and 8 can be used to estimate

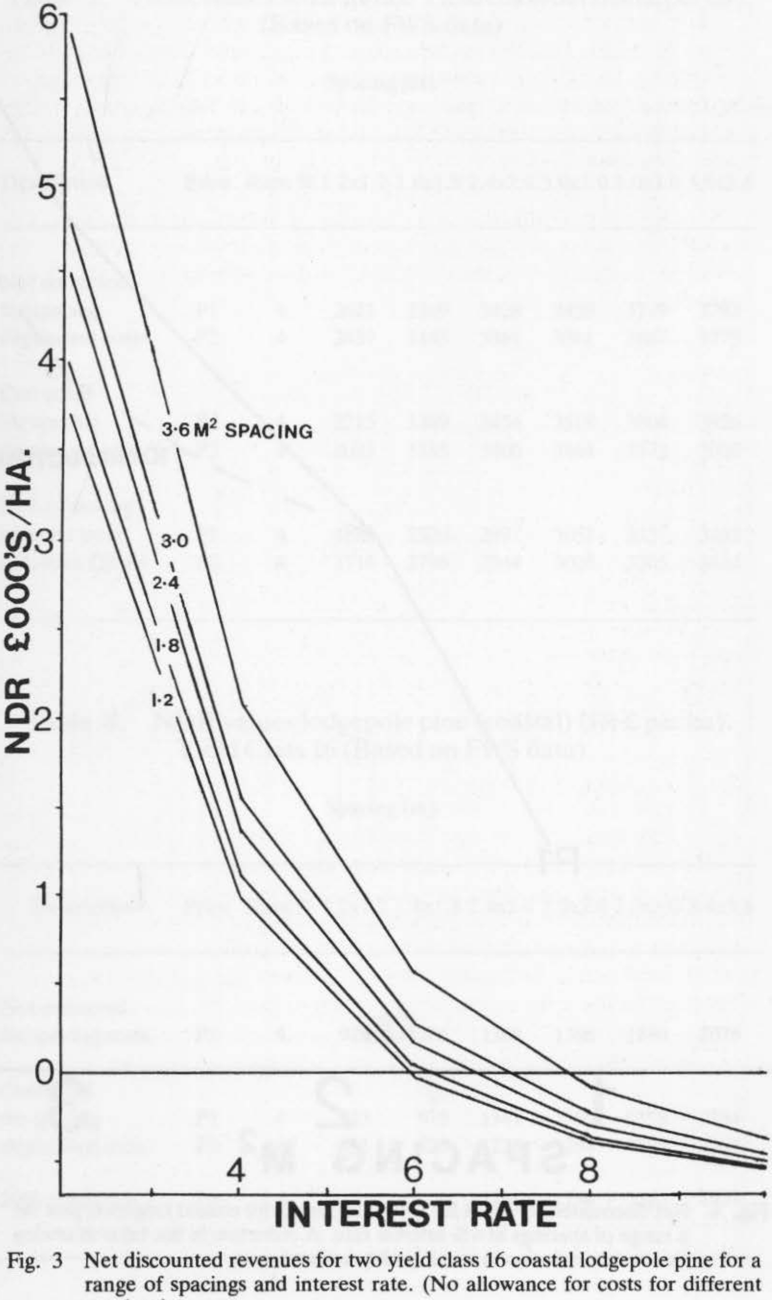

Fig. 3 Net discounted revenues for two yield class 16 coastal lodgepole pine for a range of spacings and interest rate. (No allowance for costs for different spacings).

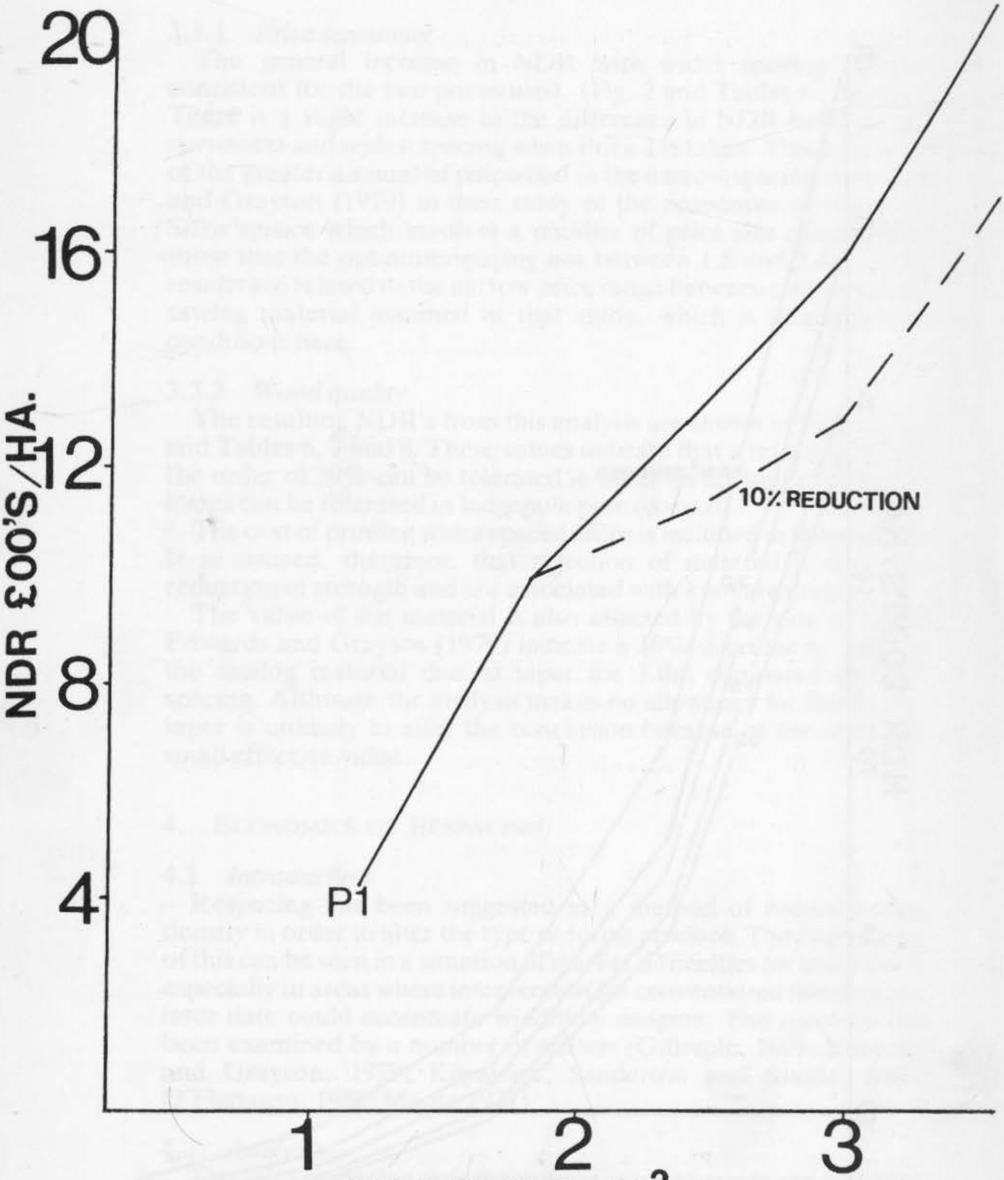

Fig. 4 Net discounted revenues for two yield class 16 for coastal lodgepole pine for a range of spacings at 4% interest rate. A reduction in the value of sawlog due to deterioration in wood quality is also shown.

Table 7. NDR values Sitka spruce Yield Class 24 (Irish £ per ha). (Based on FWS data)

			Spacing (m)					
Description	Price	Rate %	1.2x1.2	1.8x1.8	2.4x2.4	3.0x2.0	3.0x3.0	3.6x3.6
Not corrected								
for spacing	P1	4	2621	3309	3428	3428	3719	3793
dependent costs	P2	4	2439	3185	3361	3361	3687	3775
Corrected								
for spacing	P1	4	2215	3309	3454	3518	3804	3926
dependent costs	P2	4	2033	3185	3400	3464	3772	3908
20% of sawlog								
reduced from	P1	4	1898	2920	2997	3062	3337	3432
£24.40 to £10.84	P2	4	1716	2796	2944	3008	3305	3414

Table 8. NDR values lodgepole pine (coastal) (IR £ per ha). Yield Class 16 (Based on FWS data)

			Spacing (m)					
Description	Price	Rate %	1.2x1.2	1.8x1.8	2.4x2.4	3.0x2.0	3.0x3.0	3.6x3.6
Not corrected								
for spacing costs	P1	4	978	1106	1368	1368	1540	2076
Corrected								
for spacing	P1	4	513	973	1341	1389	1578	2134
dependent costs	P2	4	331	826	1236	1284	1505	2104
20% reduction	P1	4			1144	1144	1365	1837

the effects of respacing. Provided the respacing is carried out before serious competition has set in, then the assumption can be justified. Because of this assumption the quality effects can be expected to be alike for respacing and spacing. Therefore, taking the assumption already used in the spacing examination into consideration, NDR values increase up to a spacing of 3.6m for both Sitka spruce and lodgepole pine (coastal).

Table 9. Net discounted revenue (4%) (IR £ per ha)
Respacing from 1.8m spacing to wider spacings.

Sitka spruce		1.8	2.4	3.0	3.6
NDR value	Price 1	3309	3428	3719	3793
Cost of respacing discounted from year 10		0	57	83	98
NDR		3309	3371	3636	3695
Lodgepole pine (coastal)					
NDR value	Price 1	1106	1368	1546	2076
Cost of respacing		0	57	83	98
NDR of respaced crops		1106	1311	1463	1978

5. Economics of Thinning

The optimum economic thinning regime encompasses several different factors, which include thinning intensity, type and time of thinning. It is also related to the initial plant espacement. This study has, however been restricted to an examination of a limited number of thinning regimes. Those selected are thinning type and intensity in Sitka spruce and coastal lodgepole pine. Thinning intensity and thinning type are examined separately.

5.1 *Thinning intensity*

Thinning intensity refers to the average annual volume removed. Two thinning intensity experiments established by the FWS in 1964 form the basis for this study (Lynch 1980). The treatments in each of these experiments are of a low thinning type, with different volumes removed for each treatment. The treatments in each experiment are shown in Table 10 as a percentage of the total volume removed over the rotation to date.

Table 10. Thinning Intensity Treatments. Treatments expressed in % volume removed in thinnings.

Sitka spruce. Age 37. Top height 22 metres.			
Treatments	Light	Moderate	Heavy
% volume removed	9	26	42

Lodgepole pine (coastal). Age 27. Top height 15 metres.				
Treatments	Very light	Light	Moderate	Heavy
% volume removed	12	39	46	50

5.1.1 *Analysis*

The costs of each operation are assumed to be the same for each treatment. the differences between treatments will therefore be related to revenue only. Johnston et al (1967) indicated that this does not affect the conclusions significantly. The NDR values are shown in Table 11 for Sitka spruce and coastal lodgepole pine. The analysis follows the pattern established earlier, with NDR increasing with decreasing crop density for Sitka spruce. This is true for the two prices. The reduction in price of 20% of the large sawlog from £24.40 to £10.84 does not effect the conclusions.

For lodgepole pine (coastal) however, the NDR increases up to moderate intensity and then decreases for both prices and the quality assumption. These results for coastal lodgepole pine may be due to inaccurate yield projections as the experiment is only 27 years old. The diameter development that generally results with heavier thinning has not been totally converted into more valuable large sawlog material.

The results for Sitka spruce are similar to those from other studies. Bryndum (1976) indicated that NDR increases with increasing thinning intensity up to extreme treatments, where no deterioration in wood quality is assumed.

5.2 *Thinning type*

Type of thinning refers to the categories of trees removed in thinning and also the manner in which they are chosen. Traditionally the thinning practise has been of a selective type where individual trees have been chosen for removal. The objective of this selection has been the removal of the crooked and generally undesirable stems at the earliest age and so direct the increment on to the better stems. Economic pressure has brought about a change in first thinning to a more systematic type where lines rather than individual trees are removed. Subsequent thinnings have, however, continued to be of a selective type.

Table 11. Net discounted revenue (4%) (IR £ per ha) Thinning intensity experiments.

Sitka spruce	Treatments		
	Light	Moderate	Heavy
Price 1	1621	2194	2574
Price 2	1511	2062	2439
Reduction due to quality Price 2			2201

Lodgepole pine (coastal)	Treatments			
	Very light	Light	Moderate	Heavy
Price 1	333	510	721	600
Price 2	54	343	543	439
Reduction due to quality Price 2			391	287

5.2.1 *Analysis*

The results from FWS experiments suggest that no lasting loss in basal area increment occurs as a result of first line thinning up to 50% intensity (Lynch 1980). One experiment involving removal of 40% and 50% of the crop has been used to produce yield estimates. The yield from conventional treatment was used to compare the financial attractiveness of 40% and 50% line thinning with selective thinning of "marginal" intensity.

The NDR values increase up to the 50% removal and both mechanical types are more profitable than the "marginal" intensity as shown in Table 12. The savings in costs due to systematic thinning have not been included in these values. The inclusion of these costs can be expected to significantly increase the NDR values for mechanical thinning.

Table 12. Net discounted revenue (4%) (IR £ per ha). Thinning type experiment.

	Treatments		
	Management Table	40% removed in single line	50% in single line
Price 1	1542	1559	1593

Note: All costs have been assumed to be the same for each treatment.

6. Discussion

The results of this study indicate that lower crop densities than practiced at present lead to greater profitability. These results are dependent, like most economic analyses, on the future prices and costs. These are further confounded by the absence of reliable information on the relationship between wood quality and silvicultural treatment.

The proposed adoption of grading rules for Irish timber may greatly effect the optimum silvicultural treatment. The use of a visual grading system may dictate the acceptable ring width and so militate against low density and high yield class crops. It is important therefore that the grading rules will take consideration of the materials grown under Irish conditions. The use of mechanical stress grading seems less affected by ring width (Fitzsimons 1980) and as it is an objective way of measuring stress it seems more acceptable.

In coastal lodgepole pine the sawmill return will be affected by basal sweep and other stem deformities. As this will affect the valuation of the crops some estimation of the sawnwood output is necessary. These stem deformities point towards a respacing rather than wider spacing at planting.

The results of some recent studies, while recommending lower crop densities, do not advocate such low densities as this study. Kilpatrick et al (1980) recommend respacing where more than 2,000 trees per ha are present. Edwards and Grayson (1979) recommend respacing where the density is more than 3,000 and also indicate that the optimum planting distance lies between 1.8 and 2.4m. These studies are however based upon smaller price differentials between large sawlog and pulp than used in this study. The price of pulpwood in Ireland is at present depressed. An increase in the relative price of pulpwood can be expected to lower the optimum crop density from that indicated by this study.

The advantages of lower crop density are many for both the silviculturist and the processor. Larger tree sizes are more economical to handle. The management of stands is made easier by requiring less intervention for silvicultural thinning. The individual trees are more stable as height is not affected while diameters are increased. The percentage crown is greater in low tree density crops and so aids stability by lowering the centre of gravity of the individual tree.

In conclusion it can be said that lower crop densities offer many advantages. The actual density will however depend upon more definite information on wood quality. An improvement in the market situation for pulpwood may influence the optimum crop spacing. However the indications are that the espacement in Sitka spruce at establishment can profitably be increased above the present level. In coastal lodgepole pine the crop density should be reduced. This reduction could best be effected by respacing rather than wider spacing at planting.

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REFERENCES

BRADLEY, R.T., J. M. CHRISTIE and D. R. JOHNSTON. 1966. Forest management Tables. Booklet 16, For. Comm. London.

BRYNDUM, H. 1976. Preliminary results from some new Danish Thinning Experiments with Norway spruce on Fertile Soils. Proc. IUFRO Div. 4 meeting Edinburgh. Bull. 55 For. Comm. Lond. 22, 36.

EDWARDS, P. N. and A. J. GRAYSON. 1979. Respacing of Sitka spruce. Quart. J. For. 73: 205-208.

FOREST AND WILDLIFE SERVICE. 1978. Revised yield tables for coastal lodgepole pine. Res. Communication 16 unpublished.

FITZSIMONS, B. 1980. Forest and Wildlife Service internal report.

GARDINER, J. J. and P. O'SULLIVAN. 1978. The effect of wide espacement on wood density in Sitka spruce. Irish For. 35: 45-51.

GILLESPIE, J. 1979. Wood Markets and Silvicultural Practice. M.Sc. Thesis, Dept. of Stats., Dublin Univ.

GRAINGER, M. B. 1968. Problems affecting the use of Faustmann's formula as a valuation tool. N. Z. J. For. 13: 168-183.

JOHNSTON, D. R., A. J. GRAYSON and R. T. BRADLSY. 1967. Forest Planning. Faber and Faber.

KILPATRICK, D. J., J. M. SANDERSON and P. S. SAVILL.1980. The Baronscourt Sitka spruce Spacing Experiment.

LYNCH, T. J. 1980. Thinning and Spacing research in Sitka spruce and coastal lodgepole pine.

MOLONEY, B. 1980. Personal communication.

MOLTESEN, P. and T. MADSEN LYNGE. 1980. The influence of stress grading and thinning degree on the economics of Norway spruce. Dansk Skoyforenings Tidsskrift.

MOORE, D. G. 1976. The oceanic forest. Irish For. 33 (1); 4-15.

O'FLANAGAN, L. P. 1980. Lodgepole pine — silvicultural alternatives. In Growing Space in Coniferous Crops. (E. P. Farrell, ed.), 70-78.

PHILLIPS, H. 1978. Effects of Spacing, Pruning and Thinning on Wood Quality. FWS Internal Report.

QUINN, S. 1980. Personal communication.

SUTTON, W. R. J. 1976. New Zealand Experience with Radiata pine. Proc. IUFRO Div. 4 meeting Edinburgh. Bull 55 For. Comm. Lond. 55-61.

WARDLE, P. A. 1967. Spacing in Plantations. Forestry 40, 47-69.