# Growing Space in Coniferous Crops

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Society of Irish Foresters

GROWING SPACE IN CONIFEROUS CROPS Supplement to Irish Forestry, Volume 37, No. 2, 1980

# Growing Space in Coniferous Crops

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Belfield, March 1980.

Edited by

E. P. FARRELL

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Society of Irish Foresters

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The Society of Irish Foresters was founded in 1942 to advance and spread in Ireland the knowledge of forestry in all its aspects.

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(b) Indoor and field meetings on forestry topics

(c) Production of two issues annually of Society's journal "Irish Forestry"

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# Contents



*Cover: Permanent Sample thinning plot in Sitka spruce at Kinnity Forest.*

*(Photo: G. Gallagher)*

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# President's Address

Ladies and gentlemen, fellow members of the Society, it gives me great pleasure to welcome you to this the fourth symposium on forestry topics organised by the Society. Those which have preceded today's have been an outstanding success and have without doubt been the highlight of the Society's indoor programme. The previous three symposia ranged over a wide field dealing with such varying aspects as the silviculture of Sitka spruce, the marketing and utilisation of forest products and the problems of the second rotation. This year's symposium follows this wide ranging pattern and aims at examining in depth one of the critical aspects of present day forest management that of stand escapement.

This can be tackled at two levels, at planting for new crops or by respacement in older crops. Each has its own advantages and disadvantages and it is up to the forest manager to use whichever method will suit his needs. These will be governed by prevailing market conditions or by the ecological conditions under which the crops he is managing are growing. He has to be somewhat of a prophet to predict what market demands will be 50 years hence. Equally he has to be a sage to know how to reduce to a minimum the likely danges from the fickle Irish climate. Of the many options open to him only a very few or a combination of them will meet all the criteria which govern the growing of these crops. However, many of his problems may well be answered by research teams at home and abroad and by his own intuitive guesses. In this context we are indeed fortunate to have the services of five speakers who have spent a considerable amount of time working with the criteria which form the topic of this year's symposium — "Growing spruce in coniferous crops".

The papers to be presented cover every aspect from a wide ranging review of the topic by Dr. G. Gallagher through the various options of thinning and spacing for lodgepole pine by Mr. T. Lynch to two widely different management options, that of no thinning by Mr. J. Phillips and its diametrically opposed option for lodgepole pine — Silvicultural Alternatives by Mr. L. O'Flanagan.

Finally all of these options have been evaluated by Mr. D. O'Brien in his presentation on Economics of Spacing and Thinning. The success of this symposium will be assured by your involvement in the discussion periods.

John O'Driscoll, *President.*

# Crop Structure Studies in Ireland

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ABSTRACT

Information requirements on management techniques for fast growing exotic conifers planted in the State afforestation programme emphasised the need for crop structure research. Sample plot thinning series had been used for yield studies in Europe since the last century. More recently, statistically designed experiments have been established in many countries. Research in this field commenced at the end of the 1950's in the State Service. There are now over forty spacing and thinning experiments, the majority in Sitka spruce and coastal lodgepole pine. Some of the spacing experiments have now reached first thinning, and some thinning experiments are approaching rotation age. A data storage retrieval system has been developed to facilitate summary, analysis and comparison of plot measurement. In general results are consistent with research in countries within and outside of Europe. Cumulative volume production differences due to changes in growing space have less practical significance than those for diameter size, diameter and volume distribution. Volumes in the larger tree size categories increase considerably with increased spacing and thinning. This in turn influences profitability and quality. Economic criteria tend to favour increased growing space due to wider spacing and thinning though with the former, especially, serious consideration must be given to possible quality limitations which must be investigated further. Stand stability may be safeguarded by wider spacing, and put at risk by thinning but data are scanty. There are applications for crop structure research in extending stand management options and building models to judge them by, in terms of production, end-use and profitability. There is room for developing broader stand management strategies related to supply and demand and for constructing new forecasts. From present results a rough guide to decision making might be drawn up and improved as additional information becomes available.

## INTRODUCTION

Since its inception, over 60 years ago, State forestry in Ireland has developed distinctive characteristics in terms of sites and species planted, age structure, regional distribution and so on. The

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expansion of the planting programme from 7000 ha in the ten year period 1923-32 to 90,000 ha in 1963-72 is an indication of the increased harvests to be expected. Consideration of the processes which shape the produce is opportune.

Though Irish forestry was founded on exotic species and the best imported silvicultural techniques, regional and local conditions soon posed problems which required indigenous solutions. Not least in importance was the need to develop systems of stand management suited to the country, especially in relation to Sitka spruce and lodgepole pine. This required conceiving and testing methods to derive the maximum benefits from the new forests in terms of quantity, quality, consistency of produce and value for money invested, while safeguarding capital and increment.

## CROP STRUCTURE

Tree growing space has a far reaching influence on crop development. Within stand competitiveness or the lack of it, shapes the tree from an early stage. Crowns, stems and roots react to differences in growing space with consequent effects on timber production, quality, and crop stability. The time at which stands are shaped or modified also influences development in later years. The distribution of tree size and log size within trees effects financial return.

The term crop structure encompasses stand behaviour in relation to spacing at planting time, re-spacing and thinning. These aspects may be subdivided into amount and configuration of growing space and intensity, type and time of thinning.

## YIELD STUDIES

Studies in the field of crop structure have been carried out in Europe since the last century. As permanent sample plot measurement became the method for successive evaluation of forest growth and yield, information on the behaviour of stands and the trees comprising them increased. The great diversity found in forest crops required an approach which would reduce variation and thereby permit the comparison of specific silvicultural treatments, such as thinning. Consequently plot series, comprising a range of treatments were set up within uniform stands. Some of these, which have records going back to the beginning of the century have survived up to this decade. The most famous include the Norway spruce plots in the Thuringer Wald, Prussia. The Bavarian thinning series and the Dalby experiment in South Sweden (Assmann 1970, Carbonnier 1954).

The 1930's saw an expansion of research as the area of man-made forest grew. Spacing and thinning experiments were established in various countries. In Denmark, Bornbusch set up thinning experiments in Sitka and Norway spruce (Braathe 1957, Henrikssen 1961, Bryndum 1974). In Norway, Mork had designed a Norway spruce spacing experiment (Braastad 1970). Thinning and spacing series were laid down in Britain in a variety of species between the wars (Hummel 1959, Hamilton and Christie 1974) and at Bowmont, in Scotland MacDonald established a comprehensive Norway spruce thinning experiment (McDonald 1932, McKenzie 1962). Elsewhere O'Connor (1935) broke new ground with his correlated curve trend (CCT) southern pine and Eucalyptus spacing plots in South Africa.

The Bowmont and South Africa studies represented a significant development in crop structure research. The first involved the introduction of statistical techniques to thinning experiments as these plots were laid out in a latin square. The CCT plots introduced an ingenious concept of evaluating tree competition and greatly extended the scope of experiments. Incidently both studies still yield useful results (Hamilton 1976, Van Laar 1976).

From the 1950's onwards experimental work involving statistically or systematically designed experiments proliferated. Numbers of these have been reported on in recent years. Examples include Sitka spruce trials in Ireland and the U.K. (Gallagher 1969, 1976, Jack 1971, Hamilton 1976), Norway spruce in Scandinavia, (Braastad 1979, Bryndum 1978, Eriksson 1979) and Douglas fir in France (Bartoli 1971, Oswald and Pardé 1973). North American studies have concentrated mainly on their native pines, Douglas fir and White spruce (Bennet 1960, 1969, Evert 1970 and Reukema 1972), while in Australasia and South Africa, extensive studies have involved Monterey pine and the southern pines (Hawkins 1971, Shepherd and Forrest 1973, Cremer and Meredith 1976, Sutton 1976, Van Laar 1976).

## Research in Ireland

The development by Hummel and Christie (1957) of sets of yield tables for conifers in the U.K. meant that a ready source of tabular aids was available in Ireland for most species planted. There seemed little need therefore to duplicate the British sample plot programme which had been in operation since the 1920's (Forestry Commission 1928). However, in one significant respect forestry in Ireland took a different turn and this influenced thinking on crop structure. The performance of the coastal strain of lodgepole pine suggested that forestry based on this species could be viable on poor sites such as blanket peat and old red sandstone podsols (O Carroll 1962).

Until comparatively recently, little had been known about the growth and yield of coastal lodgepole pine, let alone its optimum silvicultural management. In its native habitat it had been regarded as a scrub species and its development as a commercial tree has been largely an Irish phenomenon (Forbes 1928, O'Driscoll 1964, 1979).

Crop structure studies began with this species when in the late 1950's the focus of research was on plantation establishment in the west of Ireland and a number of spacing experiments were established at Nephin Beg and Glenamoy in Co. Mayo (O Carroll 1958, Swan 1958). A recent inventory had also highlighted variation in lodgepole pine (O'Muirgheasa 1964) necessitating the construction of volume and yield tables for the coastal provenence (Joyce 1961, Joyce and Gallagher 1966). This was done through the assessment of felled trees and temporary sample plots. Data from individual plots were however, insufficient to determine what effects of crop management had on this variable and difficult to handle species. An experimental approach was therefore adopted in the early 1960's and extended to examine crop development in other conifers, Sitka spruce, Norway spruce, Douglas fir and Scots pine. Later Monterey pine and grand fir plots were added. Concurrently, studies in Sitka spruce were under way in Northern Ireland (Jack 1971).

While the establishment and early development of experiments has been described (Gallagher 1964, 1971) an overall view of progress seems timely to examine present and future options in the context of work done elsewhere.

## RESEARCH METHODS

### Development

The objectives of the experimental programme were simple; to apply a range of spacing and thinning treatments, to determine benefits and limitations under given conditions, to quantify effects and to demonstrate to management. The choice of approaches evolved with new information, individuals and ideas rather than through any basic plan. These have included single sample plots, standard statistically designed experiments, the CCT type approach and clinal systematic experiments.

### Experimental Details

Over 40 experiments have been established since 1958. While some have been lost, due to wind damage, most are still functional (Table 1) and are the source of growth and yield data.

Both spacing and thinning experiments are located on a variety of sites on western and upland peats, on old red sandstone podsols, on gleys, and on dry mineral soils. Thinning experiments are located

Table 1 FWS Crop Structure Experiments 1958-79.

| Variable | Species | No. of Expts. | Age present or at culmin | Reps. | No. Treat-ments | Range |
|---|---|---|---|---|---|---|
| Spacing at planting | Sitka spruce | 5ff | 6-19 | 2-4 | 5-13 | 0.2-4.0 m |
| | Norway spruce | 3ff | 15 | 3-4 | 3-15 | 1.2-3.6 m |
| | Lodgepole pine | 6 | 6-20 | 4 | 5 | 1.2-3.6 m |
| | Scots pine | 1 | 12 | 2 | 13 | 0.2-4.0 m |
| | Douglas fir | 3 | 11-15 | 2-4 | 5 | 1.2-3.6 m |
| | Grand fir | 1 | 15 | 3 | 5 | 1.2-3.6 m |
| Space/ alignment at planting | Sitka spruce | 2ff | 6-12 | 2-4 | 5-13 | 2.0-0.2x4.0 m |
| | Lodgepole pine | 1f | 6 | 4 | 5 | 2.0-2.0x4.0 m |
| | Scots pine | 1f | 12 | 2 | 13 | 2.0-0.2x4.0 m |
| Respacing at 8-10 yrs | Sitka spruce | 2 | 11 | 2-4 | 5 | 700-3000 SPH |
| | Lodgepole pine | | 11 | 4 | 5 | 700-3000 SPH |
| | Douglas fir | 1 | 23 | 3 | 5 | 1.8-3.6 m equivalent |
| Respacing 8 m top Ht. | Lodgepole pine | 3*** | 14-28 | 2-3 | 8 | 5000-700 SPH in 7 stages |
| Thinning intensity | Sitka spruce | 4 | 24-38 | 2-3 | 3-5 | 0-80% MAI removed |
| | Norway spruce | 2 | 36-38 | 2-3 | 4-5 | 0-60% MAI removed |
| | Lodgepole pine | 2* | 24-27 | 2 | 4 | 0-70% MAI removed |
| | Scots pine | 2* | -40 | 2 | 3-6 | 0-60% MAI removed |
| Thinning Type | Sitka spruce | 3* | 25-31 | 2-3 | 2-8 | Selection/ systematic |
| | Norway spruce | 2* | 21-38 | 2-3 | 4-6 | Selection/ systematic |
| Thinning intensity type | Sitka spruce | 3 | 16-18 | 3 | 5 | Selection/ systematic |

Notes: * Experiment written off. f Experiment featuring more than once.
The polar co-ordinate series included are not statistically replicated.

mainly in the more important forest areas in the east, in the south and south-east. There are also trials on the Kilkenny plateau, the Slieve Blooms and northern forests. Sample plots in a widely spaced private plantation in Leitrim have also provided useful data.

The claim by Marsh that O'Connor's CCT plots could answer most questions on stocking, growth and yield for southern pines (1957) was attractive. Two to three replicate, eight plot series were laid down in coastal lodgepole pine on three sites between 1962-65. Though the time of first thinning (or more properly re-spacing) was later than that advocated by the author of this method, i.e. before onset of any competition, useful results were achieved and some plots were maintained for over ten years. Wind damage proved an obstacle to the continuation of these large experiments and by 1974 they had been severely disrupted. However, they did provide material for a revised lodgepole pine yield table (FWS 1976).

Following the first spacing trials established on western peats, a more unified approach was adopted in the 1960's. After examination of information sources a 3 to 4 replicate, randomised complete block series was designed. This compromised between plot size and tree number, allowing bigger (up to .2 ha) plots for wider spacings. Ten experiments were established in five species on a range of sites. Six were devoted to lodgepole pine and Sitka spruce. In the absence of electronic data processing facilities at the time, treatments were spaced orthogonally for easier analysis. Two 'Nelder' systematic designs were added later, one of these in Sitka spruce. 'Spoke' arrangements with systematically changing growing space and plant alignment were used (Van Slyke 1964).

Since then these experiments have been complemented by a replicated Sitka spruce/lodgepole pine (coastal) growing space/alignment experiment and four respacing randomised blocks in the same species. Here plot size and plant number ensure equal numbers of trees for comparison. Again treatments, as defined by proportion of crop removed, were spaced orthogonally.

Thinning experiments are more varied and include a range of intensities, type and times. In general the factors are separated into different experiments where thinning intensities vary at uniform intervals and thinning types are regulated by the same intensity. The range of experiments is not completely satisfactory as conflicts between the number of treatments and number of replicates had not been fully worked out. Space limitation tended to confine replicates to a minimum while allowing a rather wide range of treatments and a consequent risk of these designs was missing plots causing difficulties in analysis. Differences in criteria used to define thinning intensity such as volume removed or remaining, basal area removed or remaining or increment removed combined with inherent stand variations also caused difficulties. Some of these problems are dealt with more satisfactorily in recent trials where larger uniform stands and a number of similarly designed experiments should allow clearer analysis.

Two thinning/fertilising factorial series were laid down in the early 1970's. A large number of thinning replications allowed a fairly sensitive analysis of this factor. A three experiment series has just been established to suppliment information on time, type and intensity of thinning.

## Data Collection

A standard type of data collection system has been developed which includes most pole stage experiments (Gallagher 1976, FWS 1978). This is a refinement of the code of sample plot procedure described by Hummel (1959). Sample plot records allow storage of experimental plot, single plot and individual tree data on computer tape in terms of tree numbers, diameter at breast height and tree location by co-ordinate, if required; for plot mapping. Measurement has been simplified in that lengths and diameters measured at arbitrary heights from ground level give a tree volume function.

$$V = 1/12\, L\, (d_1^2 + d_1 d_2 + d_2^2)$$

with $d_1$ and $d_2$ frustrum diameters and L its length. tree volume to required top diameters build up plot volumes through the volume basal area line

$$V_d = a + gX$$

all trees being measured for DBH. A sample printout is shown in Fig. 1.

## Treatments Applied

### *Spacing*

Distance between plants in square spacing from 1.2 to 3.6m has been the basis of 7 experiments in five species. Distance has been extended to 4.0m in a spacing/alignment experiment and to over 4.0m in almost square arrangement in 'Nelder' grids. Plant alignment varies from almost square spacing at 2.0m to less than 1.0m by 4.0m in these experiments (Table 1).

### *Respacing*

There are five experiments, one established in the early 1960's in Douglas fir and two each in Sitka spruce and lodgepole pine (coastal). These latter have been laid down within the last 5 years.

FOREST EXPNO BLOCK PLOT YR TREAT STATUS AREA

AVO 6401 1 2 1976 T3 2 MC 0.0405

| AGE | NO OF TREES | TOP HT | MEAN HT | TOP DIAM | MEAN DIAM | B.A. TOT | B.A. <7 | VOL TOTAL | VOL TO 7 | VOL TO 18 | VOL TO 24 | CROWN DIAM | CROWN % | TOP HT NUMBER | MEAN HT NUMBER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34 | 988 | 0.0 | 19.5 | 0.0 | 24.8 | 47.56 | 0.0 | 473.13 | 469.10 | 351.53 | 99.74 | 3.57 | 35.30 | 0 | 19 |

REGRESSION EQUATIONS
**********************

```
Y(TOT)= -0.01624 +  10.28633 * X
Y(7)  = -0.02152 +  10.31126 * X
Y(18) = -0.22191 +  12.00059 * X
Y(24) = -0.56313 +  13.79270 * X
```

ANALYSIS OF VOLUME TO 7 CMS REGRESSION EQUATION

```
VARIANCE=                          0.00215
VARIANCE OF INTERCEPT=             0.00230
VARIANCE OF COEFFICIENT =          0.84100
COEFFICIENT OF DETERMINATION =     0.94049
SUM(X-XBAR)**2 =                   0.00256
NUMBER OF OBS. =                   10
```

| TREE | DIAM B.H | BASAL AREA | VOL TO 7 | VOL TO 18 | VOL TO 24 | VOL TOTAL |
|---|---|---|---|---|---|---|
| 4 | 21.9 | 0.03766856 | 0.34195437 | 0.17048999 | 0.0 | 0.34635611 |
| 10 | 24.1 | 0.04561681 | 0.44434869 | 0.32908734 | 0.0 | 0.44944528 |
| 15 | 22.0 | 0.03801336 | 0.45481505 | 0.33514342 | 0.0 | 0.45755349 |
| v 23 | 33.6 | 0.08866851 | 0.94366628 | 0.88700404 | 0.74090767 | 0.94636458 |
| 31 | 22.8 | 0.04082823 | 0.41595734 | 0.30222357 | 0.0 | 0.42147345 |
| 39 | 29.6 | 0.06881360 | 0.61075823 | 0.51542399 | 0.31218251 | 0.61456073 |
| 44 | 20.9 | 0.03430705 | 0.31541747 | 0.15410299 | 0.0 | 0.31925705 |
| 50 | 23.3 | 0.04263858 | 0.41117948 | 0.27165029 | 0.0 | 0.41592031 |
| 58 | 25.9 | 0.05268541 | 0.51622733 | 0.42633544 | 0.18349234 | 0.52051924 |
| 63 | 24.9 | 0.04869558 | 0.46481389 | 0.36500078 | 0.0 | 0.46810224 |

MEAN HEIGHT TREE NUMBERS
***************************

```
4  8 10 12 15 17 23 27 31 36 39 41 44 48 50 54 58 61 63  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
```

VOLUME TREE NUMBERS
*************************

```
4 10 15 23 31 39 44 50 58 63  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
```

B.A. OF DEAD TREES = 0.0 PER PLOT

DBH TREE NUMBERS
*************************

```
4  5  8  9 10 11 12 14 15 16 17 19 23 26 27 29 31 34 36 38 39 40 41 42 44

46 48 49 50 52 54 56 58 59 61 62 63 65 66 67  0  0  0  0  0  0  0  0  0  0
```

END OF PLOT END OF PLOT END OF PLOT END OF PLOT END OF PLOT END OF PLOT END OF PLOT END OF PLOT END OF PLOT

Fig. 1 Sample Plot Printout.

Stocking differences of between 700 to 3000 SPH have been achieved by cutting out rows, rows and trees and trees 8 to 10 years after planting. A variant of these treatments has been included in the recent experiments to test the hypothesis that a crop of dominants (1000 SPH) and a ground cover of 'topped' trees would enhance production and quality (Moore 1976).

*Thinning*

CCT type respacing is included under this treatment as material removed was recorded for inclusion in cumulative volume production. the study was confined to lodgepole pine (coastal) and was to involve reducing a series of plots from > 5000 to 700 SPH in seven stages, commencing at 5-8m top height. One plot was left unthinned at each stage and after first reduction, thinning was determined by diameter differences between plots due thinning and an equivalent number of 'main crop' trees in unthinned plots. While these series are now written off because of wind damage one did survive untill fourth thinning comprising plots with a minimum stem number of 900 SPH.

The thinning intensities applied to Sitka spruce, Norway spruce, lodgepole pine and Scots pine plots have varied from no reduction to > 45% volume removed at first thinning and up to 80% periodic annual volume increment removed subsequently. One of the older trials in Sitka spruce at Avoca forest has now reached fourth thinning stage. A variety of thinning types have included single and multiple row thinnings, selection thinnings from above and below and combinations of these, mainly in Sitka spruce. Two IUFRO trials were established in the early '70's in Norway and Sitka spruce. The Norway spruce experiment is replicated in more than 10 European countries and incorporates different rack widths, systematic removal and varying times of first thinning (Abetz 1976). Combined three level thinning and fertiliser trials were also established in Sitka spruce and a recent series in this species examines time and intensity in more detail.

## ANALYSIS

Most experiments are designed for analysis of variance or co-variance, with regression to determine trends from varying treatment intensity. Systematic designs rely on regression only.

The nature of spacing and thinning experiments gives rise to differing problems. With spacing experiments set out, at, or not long after planting time, the apparent uniformity of site, plant selection and control of planting means that a wide range of treatments can be confined to apparently uniform areas. However there may be hidden variation as instanced in Table 2, where treatment results were significantly different but an unexpected factor caused a persistent anomaly. As similar experiments have been repeated in the same species on different sites, amalgamation of results will probably give more consistency.

Problems with thinning experiments have arisen, perhaps, from a desire to answer too many questions at once. Wide treatment ranges were ofter included at the expence of replication. In 11 out of 15 experiments replicates were confined to two. Difficulties arose here because of high within treatment variation and loss of plots through wind damage. Table 3 shows an improvement in significance of thinning intensity effects with increased replication.

Table 2. Analysis of Sitka Spruce Spacing at 11 Years (Doneraile).

| Treatments | Diameter at breast height (cm) | | | |
|---|---|---|---|---|
| | '63 | '65 | '71 | '74 |
| 1.2 m square | .24 | 0.81 | 4.38 | 7.1 |
| 1.8 m square | .30 | 1.06 | 6.43 | 10.1 |
| 2.4 m square | .25 | 0.76 | 5.40 | 9.3 |
| 3.0 m square | .27 | 0.83 | 6.32 | 10.5 |
| 3.6 m square | .27 | 0.87 | 6.83 | 11.5 |
| L.S.D. | .06** | .29** | 2.05** | 2.49** |

## RESULTS

Detailed results are not given but some discussion on the findings from examples of Forest and Wildlife Service (FWS) experiments, especially in Sitka spruce and lodgepole pine (coastal) in relation to work done elsewhere allow general comment on trends and inferences.

### Survival and Mortality

All FWS experiments suggest that there is little effect of respacing on survival and these conform with the findings elsewhere (Sjolte Jorgensen 1967, Low 1974, Low and Van Tol 1975).

Later on smaller trees are killed off through competition as stocking increases. Though most experiments are too young for meaningful results on total loss through mortality a survey of unthinned Sitka spruce (Gallagher 1972) indicates a potential loss at close spacings of up to 50% by stems and over 15% by basal area by 14m top height. This compares with 18% loss in 18 year Douglas fir, 60% stem loss in 44 year Scots pine and 25% loss in mature Norway spruce at close spacings (Anderson 1963, Wardle 1967, Oswald and Pardé 1973). American studies have recorded up to 40-50% stem losses in close spaced unthinned lodgepole pine, slash pine and ponderosa pine (Alexander 1960, Evert 1972, Keister, et al 1968). In Finland 25% volume loss occurred in unthinned Scots pine by rotation age (Mielikäinen 1979).

Table 3. Experimental results from 4 Sitka spruce Thinning Series.

| Experiment | Coolgreaney 1/63 | Avoca 1/64 | Kinnitty 3/68 | Muskerry 1/73 |
|---|---|---|---|---|
| Treatments | 2 | 3 | 5 | 3 |
| Replications | 2 | 2 | 3 | 6 |
| Diameter increment at breast height years 1-4 after first thinning (cm). | | | | |
| No thinning | | | 1.36 | 1.20 |
| Very light | | 1.60 | 1.45 | |
| Light | | | 2.27 | |
| Mod. heavy (Ecl) | | | | |
| Mod. heavy (Sel.) | 2.39 | 2.17 | 2.39 | |
| Mod. heavy (line) | 2.71 | | | 2.02 |
| Very heavy (line) | | | | 2.31 |
| Very heavy (Sel.) | | 2.67 | 2.72 | |
| Level of Significance % | 22.7 | 5.7 | 0.9 | <0.1 |

## Diameter and Volume Growth

*Spacing*

Figs. 2 and 3 compare FWS patterns in Sitka spruce and lodgepole pine experiments with numbers of other trials, some taken from the reviews of Sjolte Jorgensen (1967) and Evert (1972), and others more recent (Stiel and Berry 1973, Braastad 1970, 9, Kilpatrick et al 1980, Hamilton and Christie 1974). In general, similar trends are apparent. Crop stem diameters at breast height increase with increased spacing and differences are maintained over time, differentiation occurring from about 7 years depending on crop vigour. Diameters at wide spacing may increase to twice those closer grown, by canopy closure, in all treatments. Diameter distributions also change.

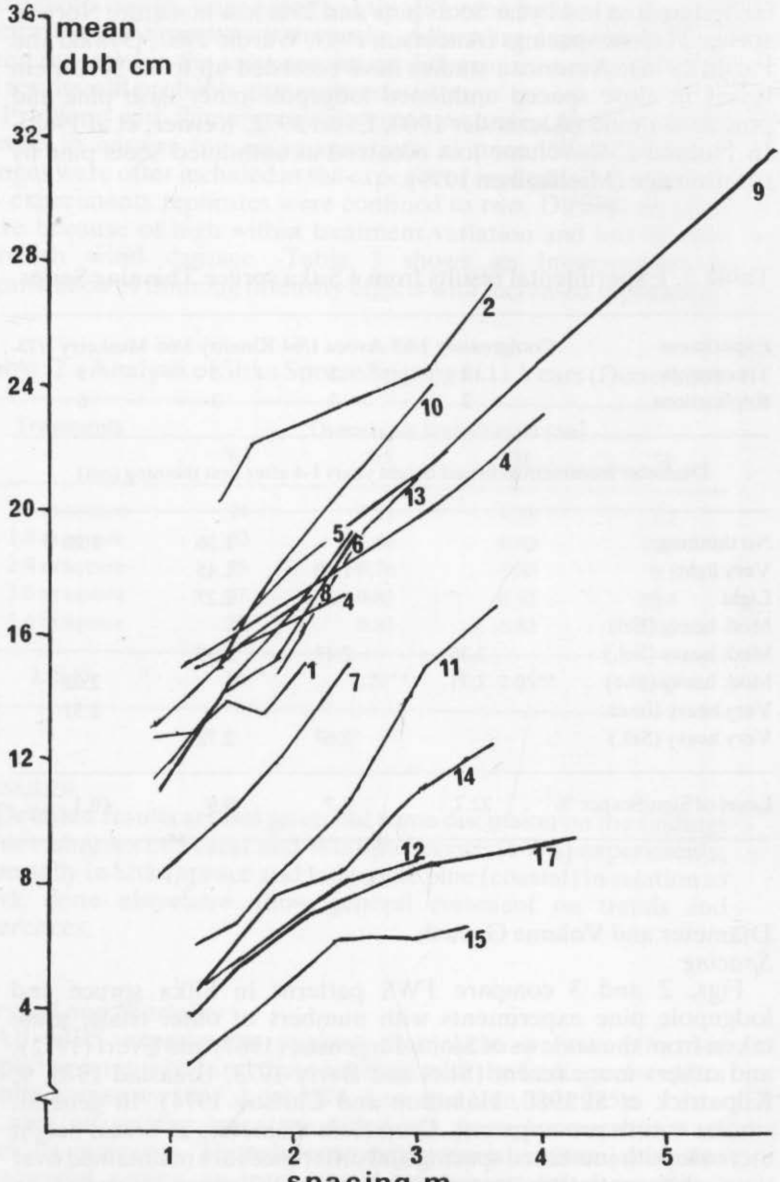


Fig. 2 Diameter growth in spacing experiments.
(For sources see Table 4)

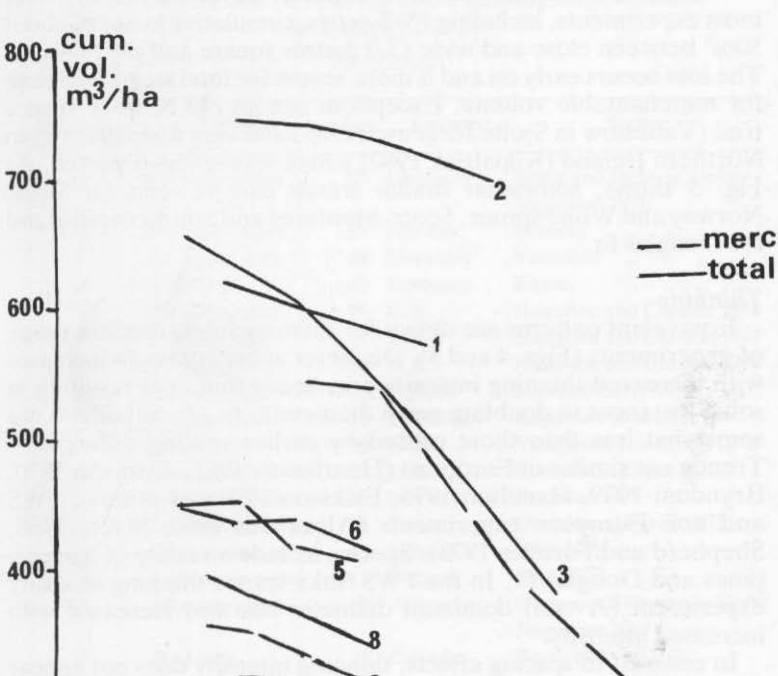


Fig. 3 Volume production in spacing experiments.
(For sources see Table 4)

Volume is less influenced then diameter development, but over most experiments, including FWS series, cumulative losses of about $50m^3$ between close and wide (3.0 metres square and over) occur. The loss occurs early on and is more severe for total stemwood than for merchantable volume. Exceptions are an old Norway spruce trial (Vaneslow in Sjolte Jorgensen 1967) and very wide spacings in Northern Ireland (Kilpatrick 1980) where severe loss occurred. As Fig. 3 shows, somewhat similar trends can be seen for Sitka, Norway and White spruce, Scots, Monterey and Southern pines and for Douglas fir.

*Thinning*

Equivalent patterns are shown for thinning intensities in a range of experiments (Figs. 4 and 5). Diameter at breast height increases with increased thinning intensity are; heavy thinnings resulting in some instances in doubling mean diameters. In general effects are somewhat less than those caused by earlier spacing differences. Trends are similar in European (Henriksson 1961, Assmann 1970, Bryndum 1979, Hamilton 1975, Eriksson 1979 and others), FWS and non European experiments (Alexander 1960, Myers 1958, Shepherd and Forester 1973). Species include a variety of spruces, pines and Douglas fir. In the FWS Sitka spruce thinning intensity experiment (Avoca) dominant diameter has also increased with increased intensity.

In contrast to spacing effects, thinning intensity does not appear to influence volume production consistently. In some series, (shown in Fig. 5), slight increases occur and in some the converse. The oldest series 90-100 year old Norway spruce in Bavaria (Assmann 1970) show a gain with light to moderately heavy thinning and a loss with moderately heavy thinning, a trend also suggested at Bowmont (Hamilton 1976). FWS experiments suggest small initial loss followed by recovery 2-3 years later. A wide range of thinning types indicate little effect on Sitka spruce volume production (Gallagher 1976). This was in contrast to results from Hamilton (1976) who found volume loss through low thinning.

Volume and Diameter Distributions

Changes in diameter and by inferences volume distribution because of varying crop structure treatments are important effects. Diameter distributions in FWS Sitka spruce and lodgepole experiments as between widest and narrowest spacings have become distinct by 11 years. A comparison is made with an 18 year Douglas fir trial (Oswald and Pardé) Fig. 6. Considerable early differentiation, at 10 years has also been shown for Monterey pine (Van Laar 1976). Jack (1971) used frequency distributions in 21 year Sitka spruce to confirm that both tree size and frequency of

Table 4. Details of Spacing and Thinning Experiments in Figures 2 to 5.

SPACING

| Graph No. | Species | Age | Country | Source |
|---|---|---|---|---|
| 1 | Norway spruce | 62 | Germany | Busse and Jachn in Sjolte Jorgensen 1976 |
| 2 | Norway spruce | 55 | Norway | Branseg ,, ,, ,, ,, |
| 3 | Norway spruce | 48 | Germany | Vaneslow ,, ,, ,, ,, |
| 4 | Scots pine | 48 | Germany | Kunze ,, ,, ,, ,, |
| 5* | Norway spruce | 37 | U.K. | Hamilton and Christie 1974 |
| 6* | Sitka spruce | 35 | U.K. | Hamilton and Christie 1974 |
| 7 | Scots pine | 35 | U.K. | Hamilton and Christie 1974 |
| 8 | White spruce | 35 | Canada | Stiel and Berry 1973 |
| 9* | Sitka spruce | 31 | N. Ireland | Kilpatrick et al 1980 |
| 10 | White pine | 30 | U.S. | Vimmerstedt in Evert 1972 |
| 11 | Douglas fir | 27 | U.S. | Eversole in Evert 1972 |
| 12 | Norway spruce | 28 | Norway | Braastad 1979 |
| 13* | Douglas fir | 18 | France | Oswald and Pardé 1973 |
| 14* | Sitka spruce | 15 | Ireland | FWS 1978 |
| 15* | Lodgepole pine | 11 | Ireland | FWS 1978 |
| 16 | Monterey pine | 15 | Australia | Cromer and Pawsey in Sjolte Jorgensen 1967 |
| 17 | Red pine | 9 | Canada | Beery in Evert 1972 |

THINNING

| Graph No. | Species | Age | Country | Source |
|---|---|---|---|---|
| 1 | Norway spruce | 102-85 | Germany | Assmann 1970 |
| 2 | Norway spruce | 90 | Sweden | Eriksson 1979 |
| 3* | Norway spruce | 64 | U.K. | Hamilton 1976 |
| 4 | Norway spruce | 55 | Denmark | Bryndum 1974 |
| 5 | Norway spruce | 53 | Denmark | Bryndum 1979 |
| 6 | Norway spruce | 43 | Sweden | Eriksson 1979 |
| 7 | Norway spruce | 42 | Denmark | Bryndum 1979 |
| 8* | Ponderosa pine | 52 | U.S. | Myers 1958 |
| 9 | Lodgepole pine | 87 | U.S. | Dahms 1971 |
| 10 | Lodgepole pine | 33-44 | U.S. | Alexander 1960 |
| 11 | Sitka spruce | 40 | Denmark | Henriksson 1961 |
| 12* | Sitka spruce | 29 | Ireland | FWS 1978 |
| 13* | Lodgepole pine | 26 | Ireland | FWS 1978 |
| 14 | Monterey pine | 23 | Australia | Shepherd and Forrest 1973 |
| 15 | Norway spruce | 40 | Finland | Vuokila 1975 |

* Volumes given as merchantable volume production (to 7-9cm top dm), others, total volume prod. Thinnings are allocated to 6 intensities in Figs. 4 & 5 from 'A' (no thinning) to 'F' (heaviest intensity) from source description.

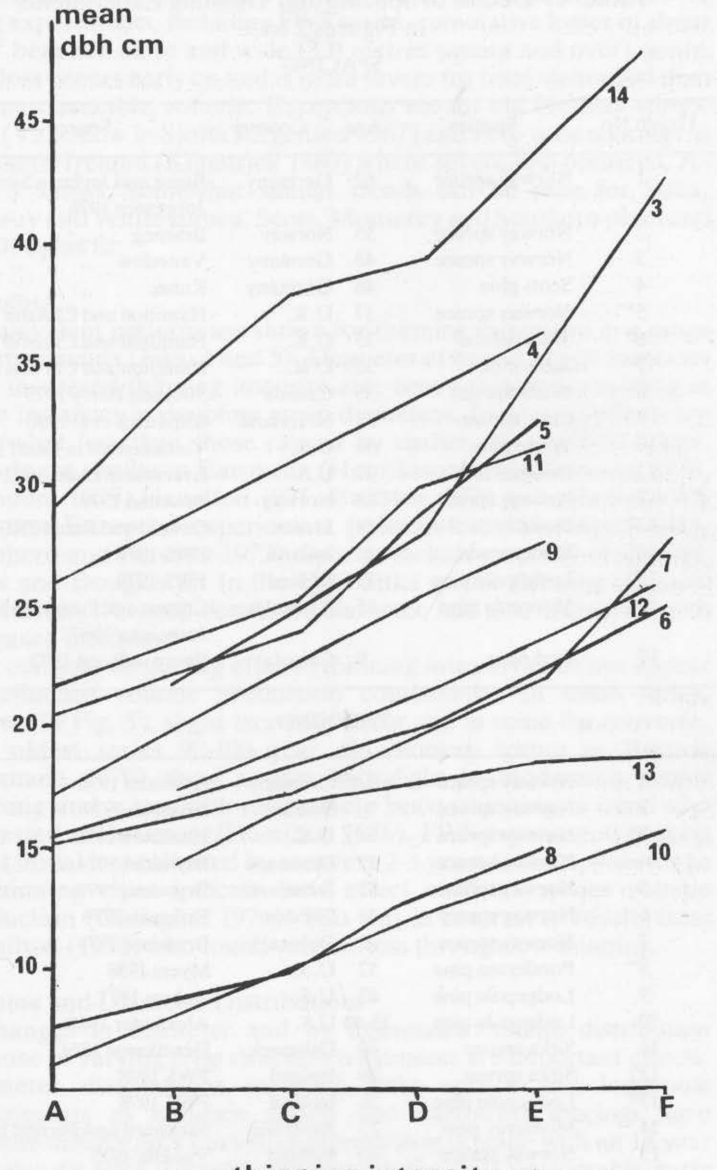


Fig. 4 Diameter growth in thinning experiments.
(For sources see Table 4)

larger trees increase with spacing. Henrikssen (1961) showed distribution peaking in 50 year old Sitka spruce at 30-35cm DBH in thinned plots compared with 20-25cm DBH in unthinned plots. Thinning type also induces changes in diameter distributions as evidenced from a second FWS experiment at Avoca some 6 years after first thinning, (Fig. 6).

Volume categories also change. At the Avoca (FWS) thinning intensity experiment most volume had been transferred on to the $>$20cm top diameter categories after more than 10 years of heavy thinning. Wardle (1967) showed distinctive volume category patterns occurring over time with spacing, where the slopes of total and merchantable volumes were negative with spacing, slopes became neutral to positive with increased top diameter volume category. Braathe (in Sjolte Jorgensen 1967) showed the transfer of volume from 20cm to 30cm DBH trees in older Norway spruce stands with spacings increasing from 1.2m to 3.0m.

This is also shown in mature pine stands in the U.S. where the volume of densely stocked stands is held in trees half the diameter of thinned stands (Dahms 1971). Thinning/spacing models in a variety of species in the U.K., U.S. and New Zealand show similar trends in diameter/volume development (Hamilton and Christie 1974, Feduccia and Mann 1976, James 1976, de Vries and Hildebrand 1978). This work is now underway in FWS studies (Lynch 1980).

## Stability

It is not possible to draw detailed conclusions from FWS experimental data though there are some pointers. No significant blow has as yet occurred in spacing experiments, though some have now exceeded 10m height. Abstracted information from two reports (Gallagher 1974, 76) shows that no thinning is least risky and that damage increases with intensity. Combinations of heavy row and selective thinning appear to have made stands susceptible in stands of over 12m top height (Table 5).

Though many other factors such as stand top height, soil, topography and climate must also be considered there is general confirmation of risk immediately following heavy thinning (Bradley 1969, Persson 1969, Hütte 1969).

## Wood Quality

Wood quality is not discussed in detail in this paper but some brief comments are given to complement discussion on the results already considered. The measurements taken in FWS experiments show that diameter growth and branch size increased significantly with increased spacing. Wider ring width and increased knot size must

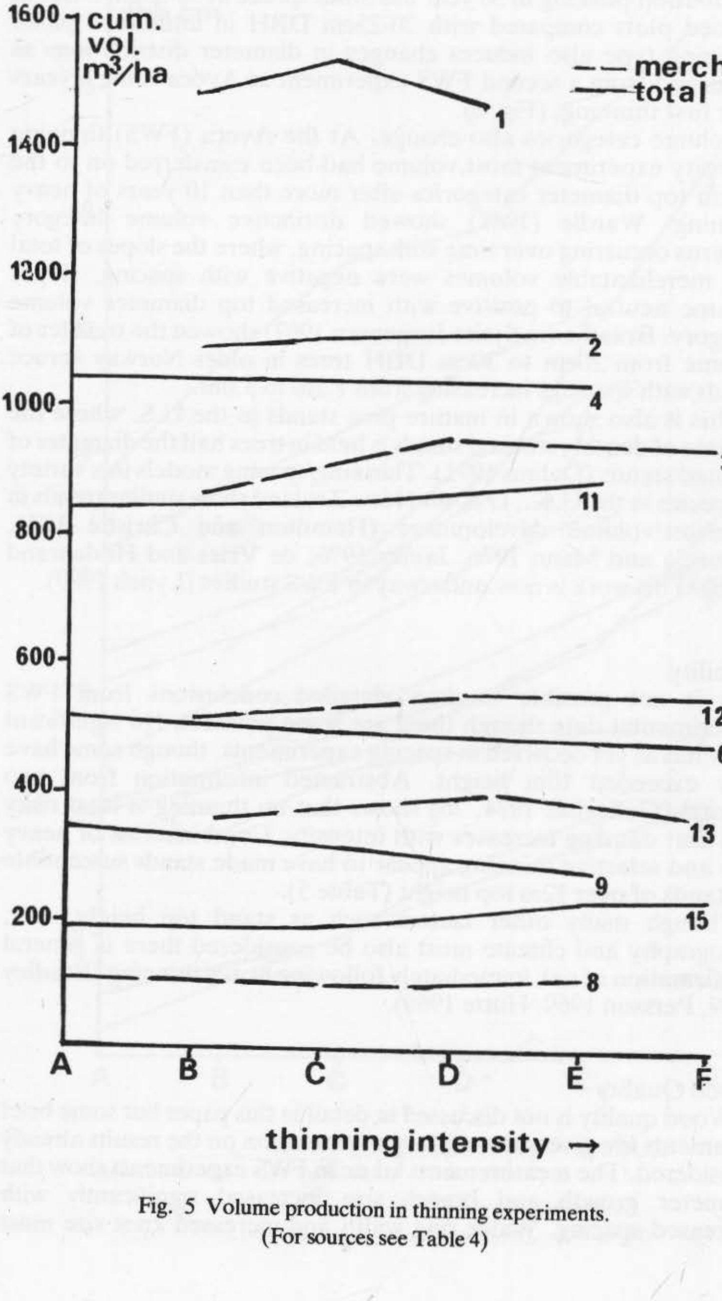


Fig. 5 Volume production in thinning experiments.
(For sources see Table 4)

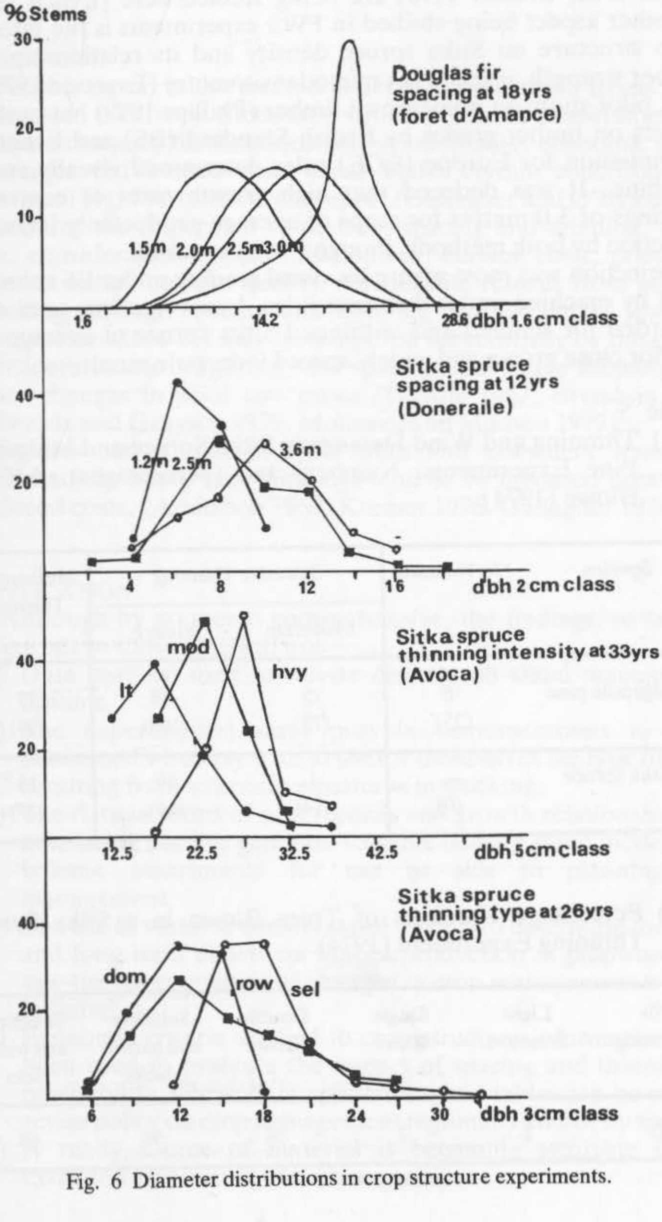


Fig. 6 Diameter distributions in crop structure experiments.

therefore have some effect on quality. These trends are universally evident, and together with other effects such as taper, branch/stem ratios, location of branches along the stem (Sjolte Jorgensen 1967, Evert 1972, Brazier 1976) are being studied here (Lynch 1980). Another aspect being studied in FWS experiments is the effect of crop structure on Sitka spruce density and its relationship with timber strength, using X ray microdensitometry (Evertsen 1979).

A pilot study on homegrown timber (Phillips 1979) has outlined effects on timber grades by British Standard (BS) and Economic Commission for Europe (ECE) rules determined visually and by machine. It was deduced that high growth rates or equivalent spacings of 3.0 metres for crops of average productivity increased rejection by both methods, though less by machine.

Rejection was most severe by visual grading under BS rules and least by machine under the same rules. Low rejections rates were recorded for thinned and unthinned Sitka spruce of average rate and for close grown and widely spaced lodgepole pine.

Table 5

(a) Thinning and Wind Damage in Sitka Spruce and Lodgepole Pine Experiments. Numbers and (percentages) of Trees Blown (1974).

| Species | No Thinning | Selective Thinning | | Mechanical Thinning |
|---|---|---|---|---|
| | | Moderate | Heavy | |
| Lodgepole pine | 6<br>(75) | 15<br>(75) | 18<br>(100) | 17<br>(94) |
| Sitka spruce | —<br>(0) | 1<br>(4) | 10<br>(66) | 15<br>(27) |

(b) Percentage Numbers of Trees Blown in a Sitka Spruce Thinning Experiment (1974).

| No Thinning | Light Selective | Single Rows | Double Rows | Selective and narrow racks | Selective and wide racks |
|---|---|---|---|---|---|
| 0 | 1 | 2 | 58 | 98 | 68 |

Somewhat similar results for Norway spruce have been recorded recently in Denmark (Moltesen and Madsen 1979) where the impact of very heavy thinning may be limiting.

### Economics

As this aspect is also treated in detail elsewhere (O'Brien 1980), discussion is cursory. Since crop structure affects diameter growth, volume category distributions and wood quality, economic effects of major importance must occur under certain conditions. An abstract (Fig. 7) from a recent report (Gallagher and O'Brien 1979) illustrates the impact on value from spacing and thinning, taking into consideration volume distribution, current costs, prices and interest rates, but not quality. Favourable returns from reduced stocking through spacing and thinning are not out of line with results elsewhere but may be tempered substantially by the quality considerations arising from wide spacings and heavy thinnings and from changes in price size ratios (Wardle 1967, Bryndum 1976, Edwards and Grayson 1979, Moltesen and Madsen 1979).

Studies carried out in FWS trials and elsewhere show that moderatedly heavy row thinnings tend to be favoured because of reduced costs, (Anderson 1969, Kramer 1976, Gallagher 1976).

## APPLICATION

Although by no means comprehensive, the findings, so far, are being put to some practical use.

(1) Data may be used to advise directly on stand management options.
(2) The experimental areas provide demonstrations to those concerned who may wish to see for themselves the type of crops resulting from alternative patterns in stocking.
(3) The data in terms of plot records and growth relationships are now being used to generate variable density stand models and volume assortments for use as sids to planning and management.
(4) The use of variable density stand models to determine the short and long term effects on timber production in pulpwood and saw-timber categories of changes in crop management is being initiated.
(5) Economic criteria applied to crop structure information have been used to evaluate the impact of spacing and thinning on profitability. These data applied to yield tables can be used to revise policy on crop management regionally and/or by species.
(6) A ready source of material is becoming available for an extended assessment of timber quality.

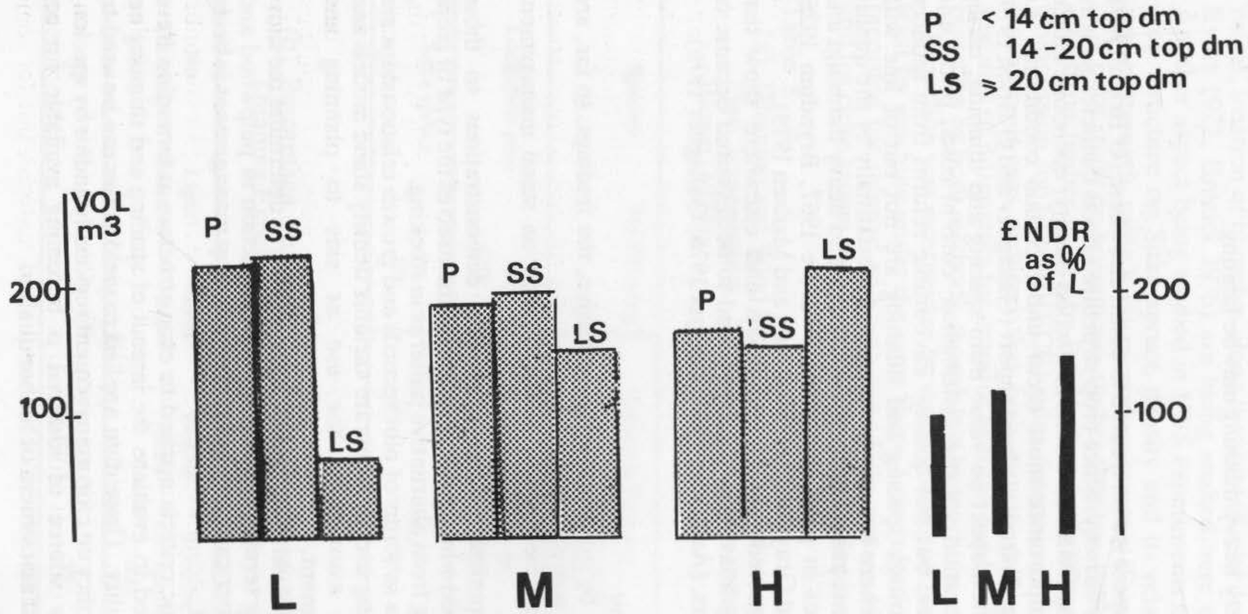


Fig. 7 Volume Assortments and Returns from Sitka spruce Thinning Intensities (29 yrs).

DISCUSSION

Up to now the crop structure research programme has provided a body of information where there was none before. Although this is still rather crude to apply, the experiments do give easy to use data for a wide range of crop conditions. While the evidence from our own experiments and work done abroad relates to most conifers, research here applies particularly to Sitka spruce and lodgepole pine.

The operation of an efficient data collection system means that additional information can be included each year and analysed without undue difficulty. The data collected since the mid 1970's will increase this base very considerably. As the quantitative effects of spacing and thinning become more established trends will be easier to determine and predict.

Results are in general, consistent with those from crop studies done elsewhere. The greatest effects are on diameter and diameter distribution, changes occurring soon after spacing, respacing or thinning. Volume is lost at spacings over 2.5m and probably immediately after thinning. Cumulative volume loss with wide spacings is permanent but decreases in relative importance with age, as this loss is in small sized assortments. With thinning the effect is less and there is probably recovery a few years after treatment. Total volume loss in merchantable timber may be in the order of 10% with wide spacings, and less due to heavy thinning regimes. The converse happens with larger size timber assortments and up to very low stocking densities, large proportions of the crop achieve sawlog sizes. These trends offer the possibility of greater flexibility in times, types and intensity of thinning while providing an easier way to handle log size.

Effects on quality, because of open growth, may be limiting, at least in the short term. While knottiness can be countered by green pruning wider ring width also results from less competition and this manifests itself in the timber grade. However, the effects on species are different and the precise nature of strength pattern within rings and between young rings and older rings has not yet been quantified. Also, the feasibility of extending structural specifications to a wider range of management practices may give more definitive information on the value of such crops.

Economic arguments for reduction in stocking, especially by thinning, are strong at present, with prices prevailing for saw timber sizes and difficulties in the pulp trade. Also, an emerging trend towards shorter rotations to capitalise earlier on past plantings provides added incentive to increase diameter growth by silvicultural means. However conditions do change and the long term timber patterns should be kept under review. Energy needs may also change the value of small sized material, but for some time to come we will need forests capable of efficient saw timber production and this is best achieved by thinning.

Our geographical position in a windy environment calls on ways to reduce risk, especially on wet sites and in relation to lodgepole pine. Late canopy openings must be avoided. This can only be achieved by wider initial spacing, respacing or early thinning. Here, the production of lower quality, larger sized material must be set against a high pulpwood content in the crop.

The results of crop structure research are to be seen against a background of practice in many countries, especially outside Europe, developing towards more open plantations than those grown under traditional methods, (Low and Van Tol 1973).

The question as to what should be the direction of future research is now posed. The short term goals include up-to-date analysis of crop structure experiments to develop a range of spacing/thinning options to suit by rotation length and end product requirements. Also it will be important to maintain experiments to as near rotation age as can be achieved to allow the calculation of relationships involving stand parameters which cover the life of the crop. Greater study on the behaviour of individual trees of various species for more detailed quantitative evaluation, such as biomass components and the effect of growing conditions on quality will also be required.

Longer term aims should include the construction of stand models for major species extended to the edges of the thinning/spacing/time spectrum. These could be incorporated into inventory forecasts to reflect the impact of a wide range of management strategies on production. Forecast information might be expressed in timber end use category, money or even biomass given appropriate conversion factors. Also a range of economic tests could be developed to compare options in terms of investment. An integrated programme of crop structure research should help to regulate future wood supplies in an orderly way.

Finally the results from crop structure research, so far obtained might be considered now in relation to planning the future management of plantations. Should such concepts, as those applied in New Zealand (Sutton 1976) be adopted here? Will future end use requirements push management in a particular direction? What are the likely consequences of change?

All the results, with the important exception of those relating to timber quality suggest material and financial benefits from increased tree growing space. There is also added management flexibility (Vuokila 1976, Gillespie 1979) in that the time for making and altering decisions is increased and risk taking may be reduced. Reservations not withstanding, the information received so far may help decision making in that answers can be given to some of the important questions that must be asked when chosing a management option. These relate to end use requirements, the importance of quality in relation to log size and price, site risks relating to thinning, growth rate (yield class) as a factor, and the likely assortments arising from a particular choice of management. Armed at least with some answers the likelihood of the best choice is improved.

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# Some Effects of a No-Thinning Regime on Forest Management

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SUMMARY

The Northern Ireland Forest Service has adopted a no-thinning policy for Sitka spruce on most areas of peat and gley soils due to experience of early windthrow following thinning both in Northern Ireland and elsewhere on such sites. The reasoning behind this decision is explained and its effects on such aspects of management as production timing, employment, road construction, recreation, conservation, landscape values and the work of the forester discussed.

## 1. INTRODUCTION

Before looking at the effects on management of a "no-thinning" regime it is perhaps necessary to explain why the Northern Ireland Forest Service does not intend to thin some 73% of its forest area. The thinking behind this decision is largely covered in a paper by Mackenzie (1976). The likelihood of windthrow is known to be related to a number of factors and in the paper a wind risk assessment was built up using data from 921 plots and took into consideration soil, slope, aspect, altitude, exposure (topex) and geology. This assessment showed that 14% of the plots were classified as being at very high risk and 54% at high risk.

### 1.2 *Exposure*

Further evidence of our exposure problems can be gleaned from a paper describing work on tatter flags by Savill (1974). Here the results of long term tatter flag experiments are given showing that on Ballintempo Forest, Co. Fermanagh, an area typical of much of our high elevation forest land in the west, the mean daily flag loss was 6.8cm$^2$ and at Beaghs in north Antrim the rate averaged 7.8cm$^2$. Even at much lower elevation, some 70m above sea level, at Castle Archdale, Co. Fermanagh the average daily loss was 6.6cm$^2$ (Jack and Savill 1973).

As a result of extensive work on tatter flags by the Forestry Commission in Scotland and northern England summarised by

Booth (1978) an exposure classification is suggested in which a means daily tatter rate of between 6.6 and 10.0cm$^2$ is regarded as "very exposed".

### 1.3 *Soil*

Shallow rooting increases the liability of a crop to windthrow and rooting depth is often restricted by wet soils (Savill 1976). Gleys and shallow peats are probably the worst in this respect. Deep peats, unless adequately drained, and we have not yet found a completely satisfactory method of doing this also often restrict rooting severely. There is some evidence that lodgepole pine, growing reasonably vigorously will effect considerable drying of deep peat, even to the extent of causing peat cracking in some cases, but there is no evidence that Sitka spruce can do so and most of our wet soils are planted with Sitka spruce. In Northern Ireland, 25% of the forests are on peaty gleys, 15% are on surface water gleys, 10% are on shallow peat and 26% on deep peat — a total of 76% of our forest area. Soil conditions therefore also point to a high risk of windthrow in Northern Ireland.

### 1.4 *Windthrow hazard classification*

A system of windthrow hazard classification has been developed by Booth (1977) in which he uses wind zones drawn from Meteorological Office and tatter flag information plus the factors of altitude, exposure (topex) and rooting related to soil type to classify sites into six hazard classes. For each class the top height at which the onset of windthrow is likely to occur is suggested. In Northern Ireland about three quarters of our woods fall into the three most severe hazard classes where windthrow begins between 10m and 16m top height. The windthrow considered here is that caused by our routine winter gales of 40 to 60kts, not by our occasional severe storms. From the papers mentioned above and our own experience frequent plough scores restrict rooting and increase the danger of windthrow. Many gleys were ploughed with single mouldboard ploughs at 1.8m intervals giving a high degree of root restriction.

## 2. THINNING/NO-THINNING

Thinning increases the risk of windthrow (Mackenzie 1974 and Booth 1977). Booth in fact suggests that one can achieve an extra 3m top height before the onset of windthrow by not thinning. The increase risk from thinning arises from two main causes: the general opening of the crop with the associated loss of mutual shelter and exposure of larger areas of individual crowns and by the cutting of the intense racking systems necessary for modern machinery and the damage to soil structure and tree roots caused by these machines.

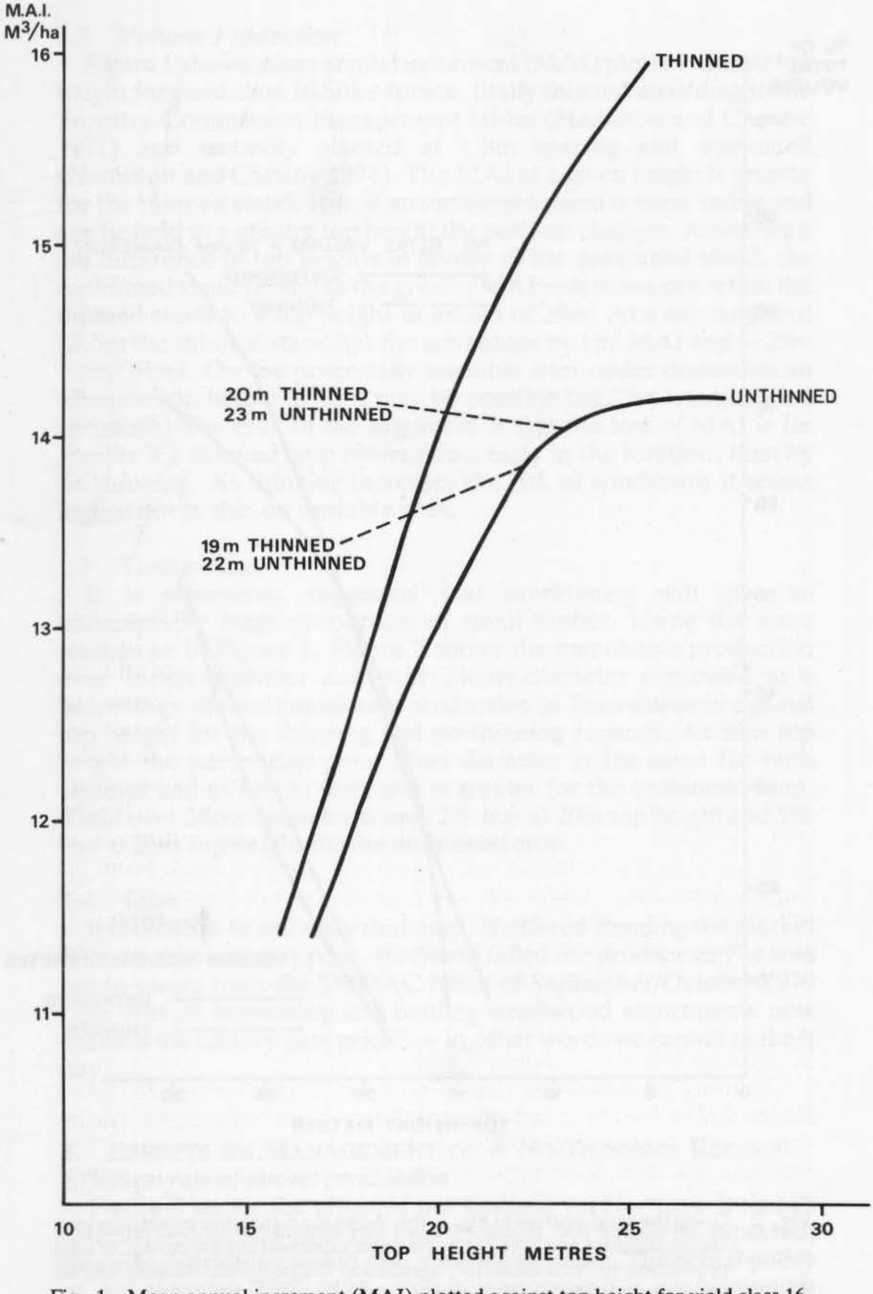


Fig. 1 Mean annual increment (MAI) plotted against top height for yield class 16 Sitka Spruce, firstly thinned according to the Forestry Commission management tables (Hamilton and Christie 1971) and secondly planted at 1.8m spacing and unthinned (Hamilton and Christie 1974).

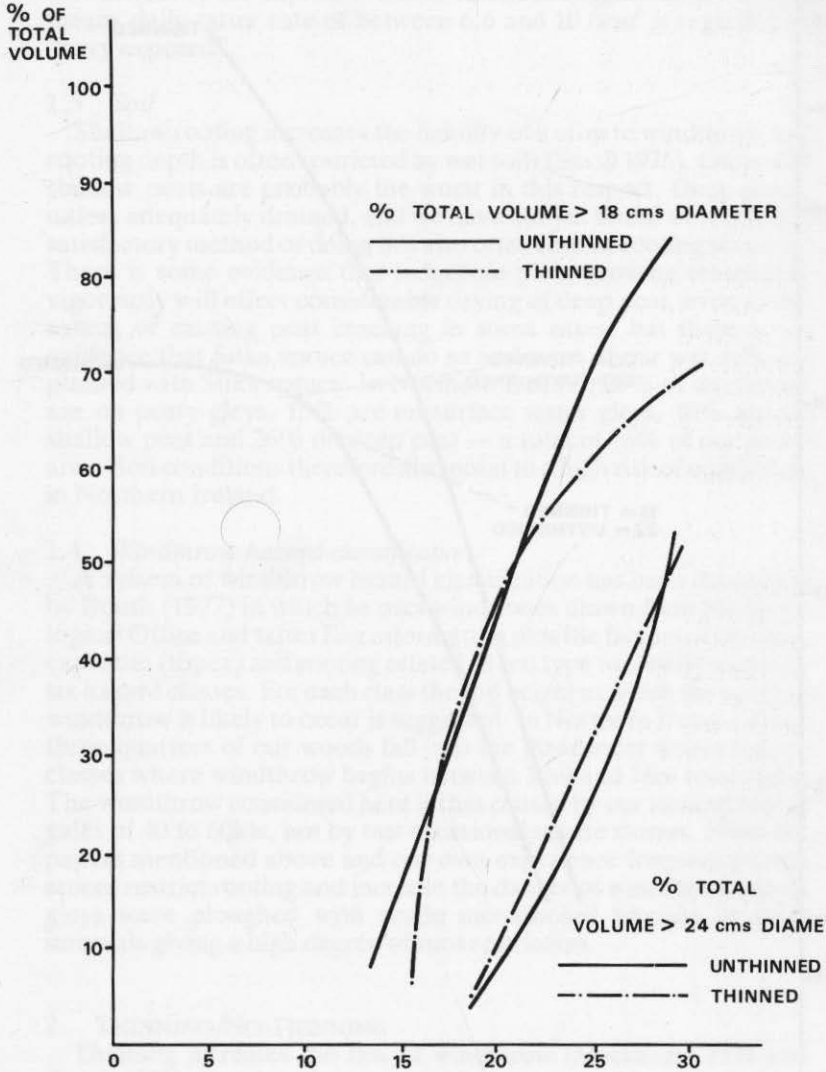


Fig. 2 Using the same sources as Fig. 1, this shows the cumulative production over 18cms diameter and over 24cms diameter expressed as a percentage of total production to 7cms diameter, against top height for the thinning and no thinning regimes.

2.2 *Volume Production*

Figure 1 shows mean annual increment (MAI) plotted against top height for yield class 16 Sitka spruce, firstly thinned according to the Forestry Commission management tables (Hamilton and Christie 1971) and secondly planted at 1.8m spacing and unthinned (Hamilton and Christie 1974). The MAI at a given height is greater for the thinned stand. But, if an unthinned stand is more stable and can be held to a greater top height the position changes. Assuming a 3m difference in top heights in favour of the unthinned stand, the unthinned stand produces the greater MAI unless one can retain the thinned stand to a top height in excess of 20m. At a top height of 22.5m the thinned stand has the advantage by $1m^3$ MAI and at 25m $1.5m^3$ MAI. On the potentially unstable sites under discussion an ultimate top height of 20m may be possible but 25m is unjustified optimism! The crux of the argument is that the loss of MAI is far greater if a thinned crop blows down early in the rotation, than by no thinning. As thinning increases the risk of windthrow it seems logical not to thin on unstable sites.

2.3 *Timber Sizes*

It is sometimes suggested that no-thinning will give an unacceptably large proportion of small timber. Using the same sources as in Figure 1, Figure 2 shows the cumulative production over 18cms diameter and over 24cms diameter expressed as a percentage of total cumulative production to 7cms diameter against top height for the thinning and no-thinning regimes. At 20m top height the percentage over 18cm diameter is the same for both regimes and as height increases is greater for the unthinned crop. Yield over 24cm diameter is only 2% less at 20m top height and 5% less at 25m top height for the unthinned crop.

2.4 *Sales*

It is difficult to sell early thinnings. If offered standing the market in Ireland is currently poor. If offered felled the produce can be sold but to quote from the SWOAC News of September/October 1979 "the cost of harvesting and hauling smallwood assortments now exceeds the factory gate price" — in other words we cannot make it pay.

3. EFFECTS ON MANAGEMENT OF A NO-THINNING REGIME

*Effect on rate of timber production*

Figure 3 shows the effect of not thinning on Northern Ireland's forecast production over the next 25 years. As would be expected, thinning everything would give a steady increase. The actual policy of not thinning 73% of the forest area depresses production by

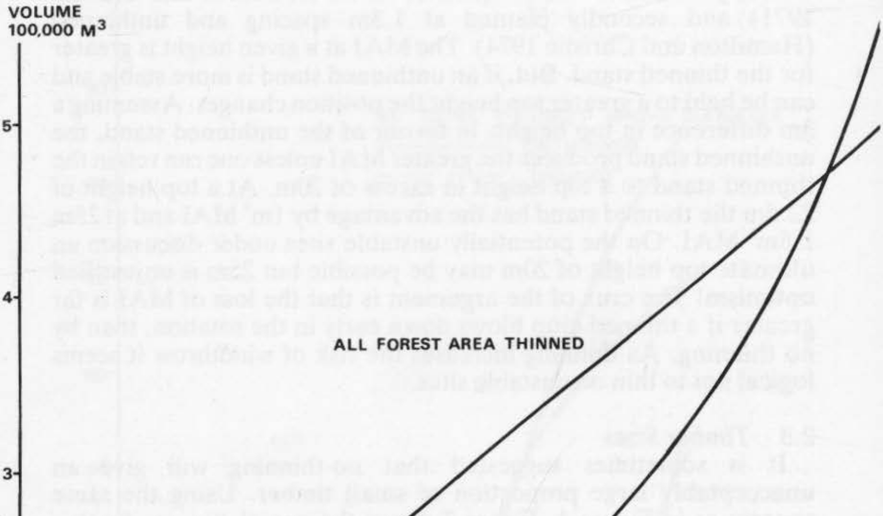


**Fig. 3** **Shows the production forecast for Northern Ireland in the actual situation of having a no thinning policy over 73% of the forest estate, compared with the production to be expected were the whole area to be thinned.**

between 50,000 and 100,000m$^3$ per annum from 1984 until the end of the century when production from this policy rises rapidly and exceeds that from a thinning regime. Such a rapid increase may be desirable as it allows a boost to supply new industry without having to resort to early felling or some such device likely to produce a loss of potential MAI.

There are of course concomitant dangers. By not thinning there is more timber on the ground. An indication of the extent of this is given in Figure 4 which shows the standing volumes which would occur over 16m top height assuming felling at 40 years of age and Yield Class 16 Sitka spruce thinned and unthinned. These criteria are applied to the age class structure of the Northern Ireland forest estate. This demonstrates that from 1980 to the end of the century there is some 70% more timber at risk from windthrow with the no-thinning regime compared to conventional thinning.

### 3.2 *Labour and Roads*

The prospect of an extensive windthrow in these circumstances could be made even more serious by two other factors. The first is the availability of trained labour to deal with such an emergency. In a thinning situation the higher annual production over the next 20 years would mean a reasonably large production labour force. In a no-thinning situation production and therefore the labour force is smaller. Figure 5 shows the likely extent of this difference which could amount to between 25% and 35% and could make the problem of tackling extensive windthrow more difficult. The second factor is the provision of forest roads. The economists always advise us to leave the construction of forest roads as late as possible to reduce interest charges. With thinning one has an extraction road network available in all areas of the crop at risk from windthrow. In a non-thinning situation the economists advice would tempt one to leave the construction of the extraction roads until immediately prior to clear felling. If one did so and was caught by extensive windthrow there would be no road network for extraction and no time to construct one before the timber deteriorated. To me, this is an unacceptable risk and I feel that even in a non-thinning situation one must ensure that crops at risk to windthrow are adequately roaded.

### 3.3 *Access*

Because unthinned plantations are normally unbrashed there is a problem of access to the woods. The importance of this problem and some of those mentioned later is not easy to assess in quantifiable terms. However because the plantations are impenetrable except along roads and compartment boundaries there is a danger that pockets of windthrow, outbreaks of disease,

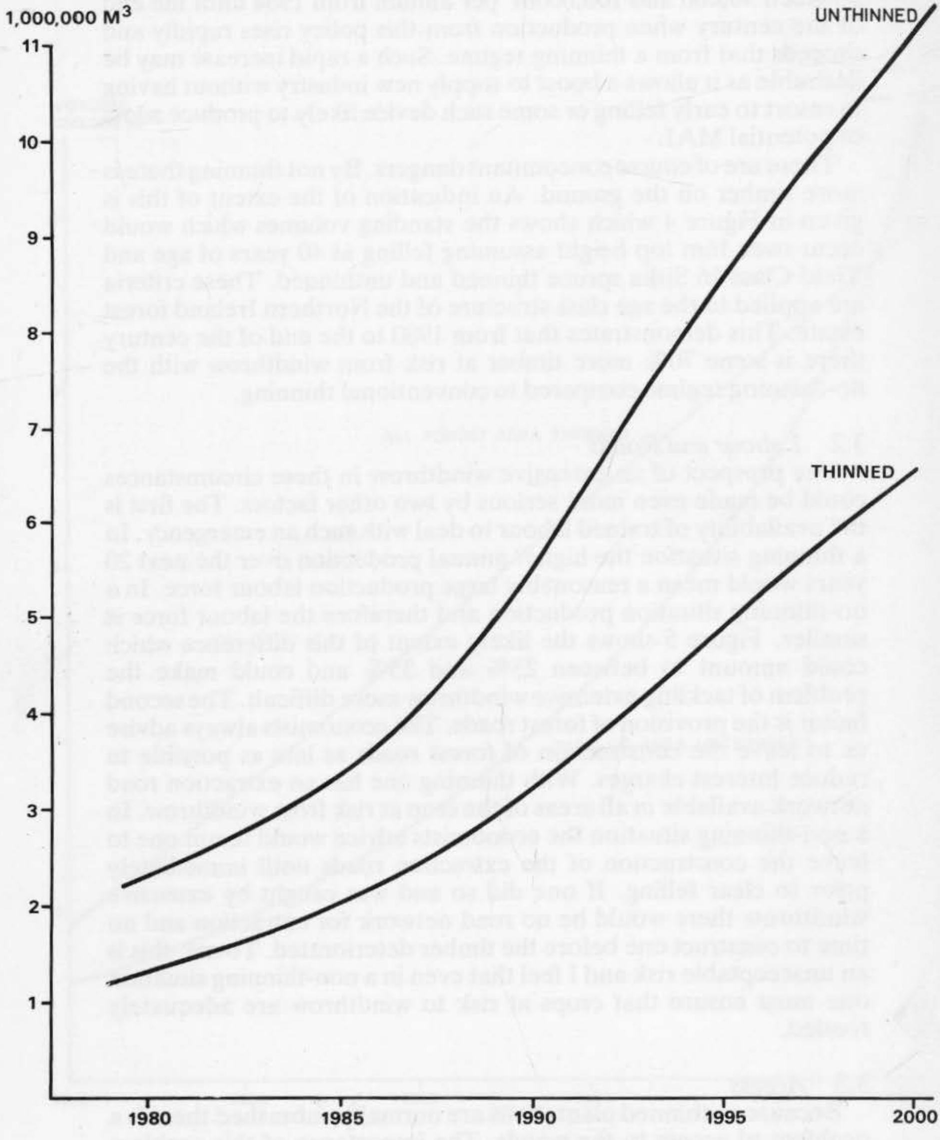


Fig. 4 Shows the standing volumes over 16m top height which occur given the area and age class structure of the Northern Ireland Forest Service estate, assuming that this were all composed of Sitka spruce yield class 16 and final felling was at 40 years of age.

areas of nutrient deficiency, blocked drains and other damage will not be noticed as quickly as would be desirable.

3.4 *Recreational Value*

While the public can have access to roads and rides they cannot walk through unbrashed woods nor can they even see into them. Walking along a closed sided green tunnel is not an interesting or attractive proposition. An unthinned spruce wood is not a pleasant environment to be in.

3.5 *Wildlife Conservation*

While I know of no work which is directly related to unthinned woods, an unthinned spruce plantation will have virtually no ground flora once the canopy closes. However unless a thinned crop is grown to 25m or more the flora is minimal anyway so the loss may not be great. I am not competent to suggest the effect on insects or minor soil fauna. The effect on birdlife is perhaps more predictable. In a recent paper on woodland song bird populations (Moss 1978), breeding song bird species diversity is shown to be related to foliage height diversity, i.e. the depth of the tree crowns and the presence of herb and shrub layers in addition to the tree canopy. If we only have a tree canopy layer, and a shallow one at that, the diversity of bird species will be less than in a normally thinned plantation.

If a no-thinning policy is adopted it therefore becomes all the more important to enhance the wildlife habitat value of the forest in other ways: by creating habitat diversity through leaving unplanted areas such as wide rides, stream sides and lake margins. Patches of natural scrub should be retained and tree species variety introduced using native species where possible.

3.6 *Landscape*

We are constantly being urged to make our plantations fit into, rather than obliterate natural landscape features. This involves the shaping of exterior and interior boundaries which can be done as well with no-thinning as with thinning regimes. It also frequently entails using species changes to emphasise landscape features, such as glens of hardwoods or areas of contrasting foliage colours from species such as larch. Many species cannot be satisfactorily grown without thinning and if they are surrounded by a matrix of unthinned spruce it will be difficult and probably uneconomic to give them the attention they require. The temptation will be to forget them to the detriment of their amenity value as well as the loss of their production potential.

3.7 *The Work of the Forester*

Many of us regard thinning as one of the most rewarding and

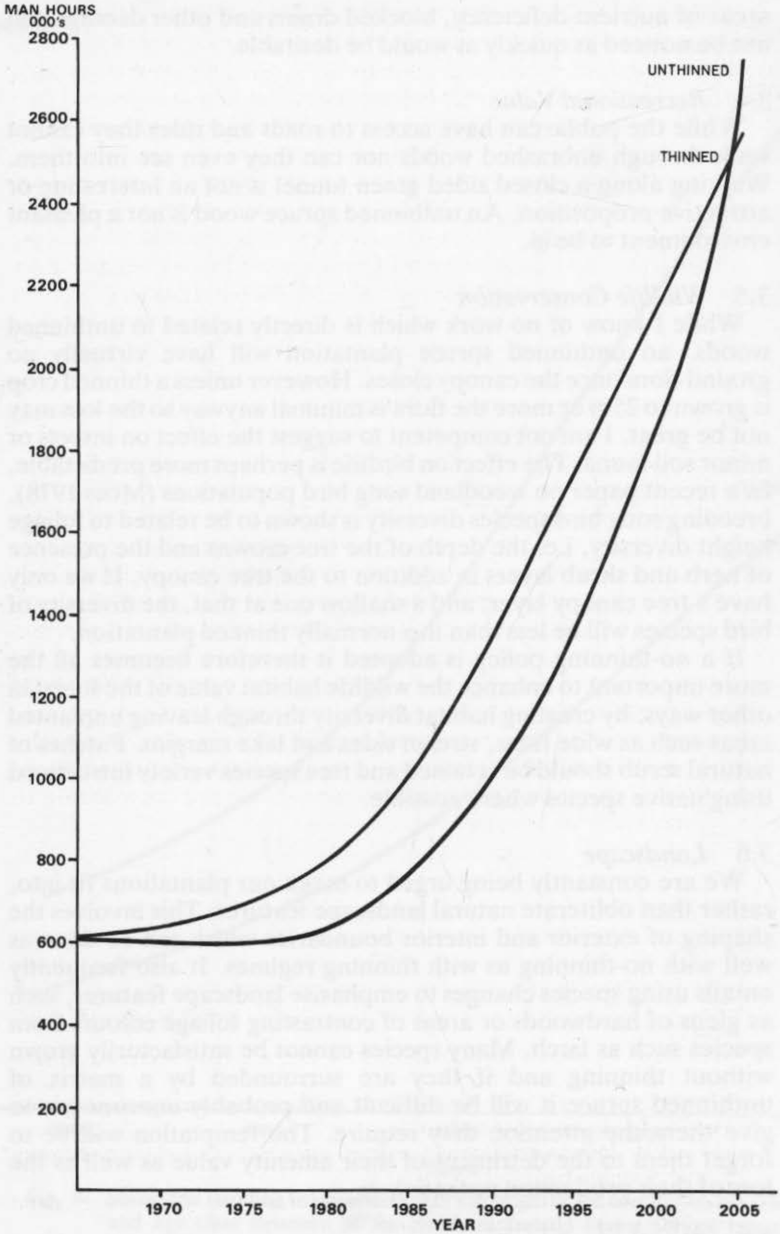


Fig. 5 **Shows the estimated labour requirements of the Northern Ireland Forest Service in a thinning and no thinning situation using historical day rate outputs.**

satisfying of tasks. It is a facet of tree culture we enjoy. To be denied the chance to carry it out and to be denied effective access to much of the woodland under our control does not help morale. Many foresters have regarded establishment as a necessary and somewhat tedious pre-requisite to what they see as our real raison d'étre — the production of timber. Faced with having to wait 40 years instead of 20 years before production starts, which means in many cases leaving the harvesting to our successors, we can feel cheated of seeing the results of our labours. There is often also a sneaking suspicion that in accepting no thinning we have taken the easy option to avoid a problem we should have tried harder to solve.

## 4. Current Trends

Here I am thinking only of Sitka spruce which will remain our principal commercial forest tree. I think sheer economic pressure will prevent a return to a thinning regime on peat and gley sites. Planting spacing has been widened to some 2,000 plants per hectare. We could opt to plant somewhat closer than this and accept respacing before canopy closure to get the benefits of quicker vegetation and a degree of selection. However opinions on the economics of respacing vary. Recently Edwards and Grayson (1979) have suggested that the economics are dubious if the original crop spacing lies between 1.8m and 2.4m as the majority of the recent plantations do. Against this Savill, from work in Northern Ireland suggests that at 1.8m spacing or 3,000 plants per hectare, respacing to 2,000 stems per hectare could be justified at least on the higher yield class sites. There are considerable areas in Northern Ireland of a suitable age for respacing and we are considering to what extent it should be carried out.

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# Thinning and Spacing Research in Sitka Spruce and Lodgepole Pine

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ABSTRACT

Thinning and spacing experimentation began in Ireland in the late 1950's. Some meaningful results are now available from these experiments. If spacing at planting is increased from 1.8 to 2.4m square in Sitka spruce a loss in production of about 4% is incurred. A loss of the same magnitude results from a thinning intensity which removes 80% of volume increment. Wider initial spacings or heavier thinning intensities than those conventionally practised give greater quantities of sawlog timber. A first thinning in spruce which removes alternate lines of trees does not depress increment. Rethinning after line thinning comprises a certain amount of unattractive material. There are implications for timber quality where wide spacing and heavy thinning are employed.

## 1. INTRODUCTION

The paper outlines the principle results from thinning and spacing experimentation in the Republic of Ireland. The question of spacing is dealt with first followed by that of thinning, subdivided into selective and systematic thinning types.

The first replicated spacing experiment was established in 1958; thinning research was initiated in 1962. Altogether, a total of 15 thinning and 17 spacing trials has been established in Sitka spruce (SS) and the various provenances of lodgepole pine (LP). Windblow has eliminated two of the thinning trials and caused varying degrees of damage to five others. One of the spacing trials in which the Lulu Island provenance of lodgepole pine was being studied failed to develop satisfactorily and yielded no meaningful results.

Scattered throughout the country are 59 permanent sample plots (44 in spruce, 15 in pine). These provide growth data for the production of yield models.

GROWING SPACE IN CONIFEROUS CROPS
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## 2. Spacing

Originally, spacing experiments were established at time of planting. A major disadvantage of this procedure was the time-lag involved before any meaningful results were forthcoming. More recently, the emphasis has changed to one of respacing in a crop which has successfully established itself. A necessary requirement for respacing is that competition between trees is not too advanced before the stocking is reduced.

Many of the earlier spacing experiments suffered various misfortunes. Three experiments contain either the Lulu Island or inland provenances of lodgepole pine; these had been initiated before only the Coastal provenance of this species became accepted for general planting. Other trials received a "spot" fertiliser treatment at planting in accordance with the management practice of the time. Consequently, plots with closer spaced plants received a higher concentration of nutrient. Some confusing and seemingly contradictory growth patterns have since been attributed to this practice. The imbalance in nutrient input was later corrected. Injudicious blocking, attacks of sawfly and aphid, frost and wind-damage have all influenced growth to a greater or lesser degree in some other experiments.

The concept of respacing adopted in recent years may eliminate many of the above draw-backs.

Spacing results discussed here come from two of the most informative older type experiments at Ballyhoura (SS) and Cloosh Valley (LPC) forests. The former is a high productive gleyed site, 130m above sea level fertilised with phosphate and potash nine years after planting. The pine experiment is on a western blanket peat site and 90m above sea level. "Spot" fertilisation at planting was equalised two years later with a broadcast application of phosphate. Planting in both trials is on a ploughed ribbon.

Both the pine and the spruce studied have a high production rating — Yield Class 16 and 24 respectively (Hamilton and Christie, 1971).

### 2.1. *Results of Different Spacings*

#### 2.1.1. *Survival*

Percentage survival up to canopy closure is not affected by spacing. From then on, it can be expected that competition between stems in the closer spacings will lead to a higher mortality rate at these espacements.

#### 2.1.2. *Height*

Both mean height and top height are greater at closer spacings at least in the early stages (Fig. 1). Differences in pine may, in part be due to the greater concentration of fertiliser in closely spaced plots due to spot application at planting. Mean height differences are statistically significant for both species. Differences in top height are significant for pine only.

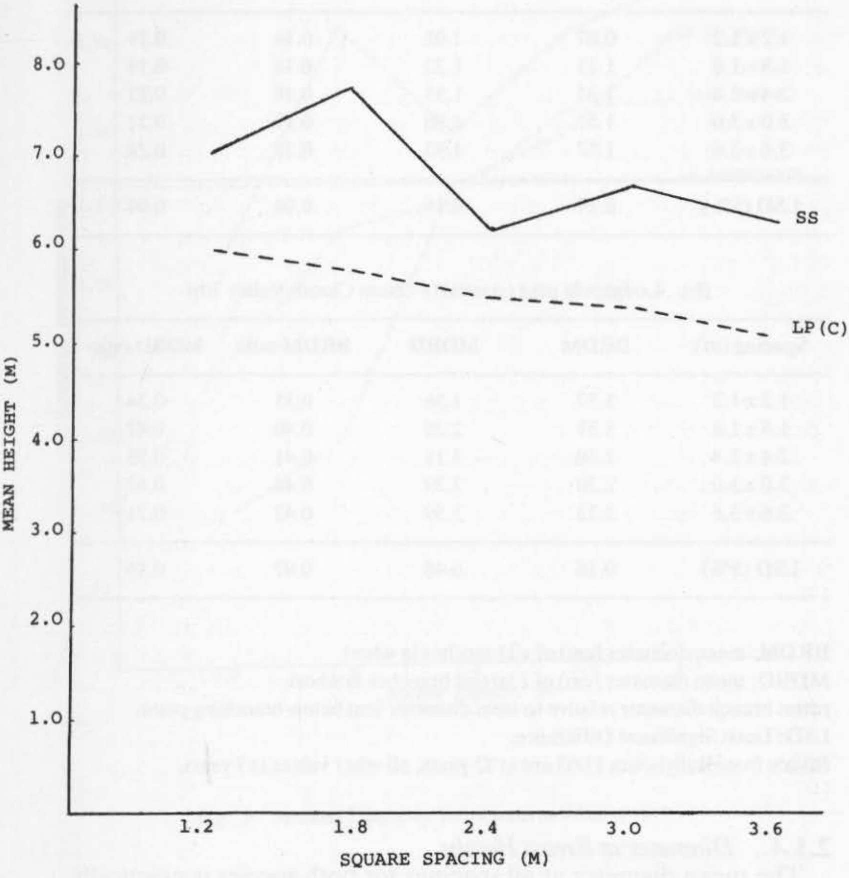


Fig. 1 Mean Height at 12 years.

### 2.1.3. *Branch Size*

Measured on the lowest live whorl, mean branch diameter increases with wider spacing for both spruce and pine. When the ratio of branch to stem diameter (measured 5cm beneath point of branching) is studied, an increase with wider spacing is also detected. (Table 1).

Table 1 Branch Diameter and Relative Branch Size.

(a) Sitka spruce — from Ballyhoura 11/63

| Spacing (m) | BRDM | MDBD | BRDM ratio | MDBD ratio |
|---|---|---|---|---|
| 1.2 x 1.2 | 0.87 | 1.01 | 0.14 | 0.19 |
| 1.8 x 1.8 | 1.15 | 1.32 | 0.14 | 0.18 |
| 2.4 x 2.4 | 1.31 | 1.55 | 0.18 | 0.22 |
| 3.0 x 3.0 | 1.51 | 1.86 | 0.17 | 0.22 |
| 3.6 x 3.6 | 1.57 | 1.93 | 0.18 | 0.24 |
| LSD (5%) | 0.19 | 0.16 | 0.04 | 0.04 |

(b) Lodgepole pine (coastal) — from Cloosh Valley 7/64

| Spacing (m) | BRDM | MDBD | BRDM ratio | MDBD ratio |
|---|---|---|---|---|
| 1.2 x 1.2 | 1.57 | 1.56 | 0.35 | 0.34 |
| 1.8 x 1.8 | 1.87 | 2.26 | 0.40 | 0.47 |
| 2.4 x 2.4 | 2.30 | 3.11 | 0.41 | 0.55 |
| 3.0 x 3.0 | 2.30 | 3.39 | 0.44 | 0.67 |
| 3.6 x 3.6 | 2.12 | 3.59 | 0.42 | 0.71 |
| LSD (5%) | 0.18 | 0.48 | 0.07 | 0.16 |

BRDM: mean diameter (cm) of all branches in whorl.
MDBD: mean diameter (cm) of 2 largest branches in whorl.
ratio: branch diameter relative to stem diameter 5cm below branching point.
LSD: Least Significant Difference.
Ratios from Ballyhoura 11/63 are at 12 years, all other values at 9 years.

### 2.1.4. *Diameter at Breast Height*

The mean diameter at all spacings for both species is practically the same at 6 years of age. With the onset of competition in the close spacings, differences become evident at 9 years so that by 15 years a difference of 5.4cm separates the widest from the narrowest spacing in LP (C) — the equivalent figure for SS is 8.2cm.

Annual diameter increments of 1.27cm result in exactly four rings per inch at the breast height point. Spacings wider than 2.3m square for high yield class spruce will give timber containing less than four rings per inch during the age 6 to 15 years. The equivalent spacing in high yield class pine is 2.8m square.

The pattern of diameter increment in spruce is shown in Fig. 2.

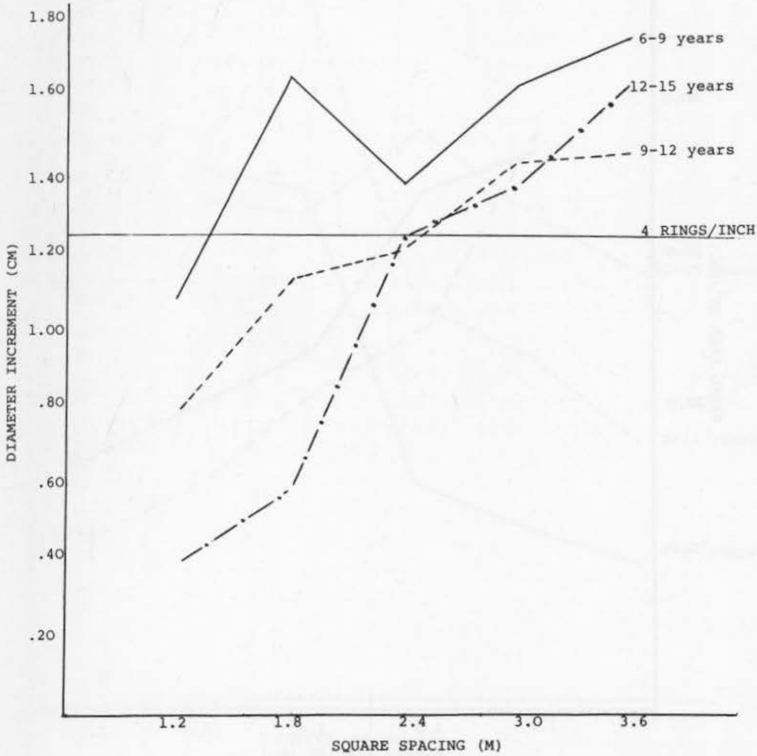


Fig. 2 Annual Diameter Increment in Sitka spruce.

2.1.5. *Basal Area*

Total production is depressed at wider spacings. (Fig. 3). Differences between 1.2 and 3.6m spacings at 15 years stand at $20m^2$/ha in SS and $27m^2$/ha in LP (C).

The graphs in Fig. 4 show a levelling off in basal area increment by the fifteenth year over all spacings. Presuming this equalisation in increment to be maintained, maximum production loss in basal area over the rotation should be in the region of 20 and $30m^2$/ha respectively for spruce and pine.

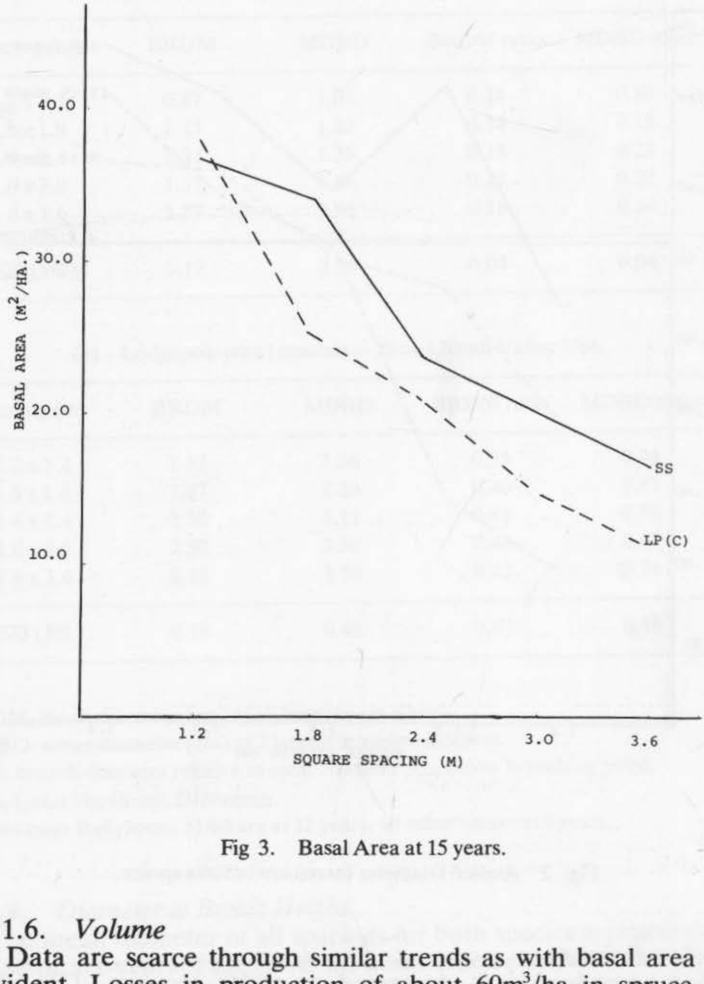


Fig 3. Basal Area at 15 years.

### 2.1.6. *Volume*

Data are scarce through similar trends as with basal area are evident. Losses in production of about 60m$^3$/ha in spruce are suggested as spacing increases from 1.2m to 3.6m square.

### 2.1.7. *Tree Form*

Wide spacings greatly affect the shape of the individual stem. When expressed as millimetres diameter for each metre length of stem, rate of taper in SS at 3.6m spacing is more than three times that at 1.2m at 15 years. (Table 2).

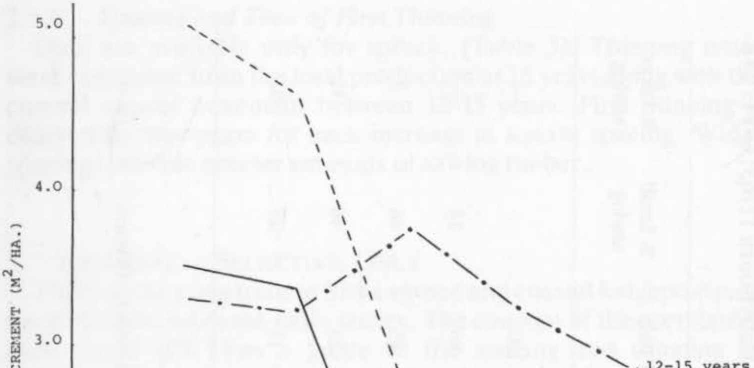


Fig. 4 Annual Basal Area Increment in Sitka spruce.

Table 2 Taper in Sitka spruce at 15 years (Ballyhoura 11/63).

| | Spacing (m) | | | | | |
|---|---|---|---|---|---|---|
| Factor | 1.2 x 1.2 | 1.8 x 1.8 | 2.4 x 2.4 | 3.0 x 3.0 | 3.6 x 3.6 | LSD (5%) |
| Length to 7cm top diameter | 4.2 | 6.1 | 5.5 | 5.8 | 6.1 | 1.9 |
| mm/m to 7cm | 7.3 | 10.3 | 15.4 | 19.6 | 24.2 | 2.9 |
| cm diam/cm length | 1:137 | 1:97 | 1:65 | 1:51 | 1:41 | |

Table 3. Pre-thinning Details of SS at Various Spacings. (Based on experiment Ballyhoura 11/63, GYC 24).

| Spacing (m) | Thin at (years) | Stems/ha | Top Ht. (m) | BA ($m^2$/ha) | DBH (cm) | Vol. 7 ($m^3$/ha) | % Pulp | % Small sawlog | % Large sawlog |
|---|---|---|---|---|---|---|---|---|---|
| 1.2x1.2 | 15 | 6911 | 10.0 | 36.8 | 8.3 | 129.7 | 100 | — | — |
| 1.8x1.8 | 17 | 3045 | 11.5 | 35.6 | 12.2 | 181.0 | 86 | 14 | — |
| 2.4x2.4 | 19 | 1714 | 13.5 | 38.6 | 16.9 | 198.4 | 45 | 46 | 9 |
| 3.0x3.0 | 21 | 1104 | 15.5 | 39.2 | 21.3 | 209.0 | 23 | 46 | 31 |
| 3.6x3.6 | 23 | 762 | 17.0 | 39.0 | 25.5 | 203.5 | 11 | 27 | 62 |

Top height figures are taken from Management Tables. (BFC Booklet 34).
Volume and basal area figures are derived from actual values at 15 years and current annual increment from 12-15 years.
Volume assortments are derived from Management Tables.
Pulp: 7 – <14cm top diameter.
Small sawlog: 14 – <20cm top diameter, minimum length 3m.
Large sawlog: >20cm top diameter, minimum length 3m.

2.1.8. *Spacing and Time of First Thinning*

Data are available only for spruce. (Table 3). Thinning times were computed from the total production at 15 years along with the current annual increment between 12-15 years. First thinning is delayed by two years for each increase in square spacing. Wider spacings provide greater amounts of sawlog timber.

## 3. Thinning — Selective Only

The first thinning trials in Sitka spruce and coastal lodgepole pine were established in the early sixties. The concept of the correlated-curve-trend (CCT)[1] as a guide to the spacing and thinning of lodgepole pine formed the basis for the establishment of three experiments in 1962. Two of these trials are now windblown and only a portion of the third remains.

An LP (C) thinning trial set down in the mid-1960's to study various intensities of selective thinning has also been severely damaged by wind. There remains today only one full experiment in this species as yet undamaged and in which different forms of line thinning are compared.

Early thinning experimentation in Sitka spruce was almost entirely concerned with studies of low, selective thinning though some less common treatments like eclectic and selection types were also included. Windblow has caused less damage to spruce trials. From a total of ten Sitka trials established, only three have suffered appreciable damage.

Many of the earlier thinning experiments suffered from insufficient replication in their design. Consequently, significance levels are low in variance analysis. More recently established trials contain up to four replications of each treatment.

Our most important experiment studying low, selective thinning is that at Avoca forest. (Table 4). It was laid down in 1963 to study a range of thinning intensities and to see at what intensity increment was lost. (Intensity of thinning refers to the quantity of timber removed per annum). To date, the crop has been thinned four times at 21, 25, 29 and 34 years of age. Light thinning has constituted little more than the removal of dead and suppressed trees, moderate thinning is closest to the normal management practice in this country

1 O'Connor and Craib developed the correlated-curve-trend guide to thinning in South Africa, based on experiments which consisted of a series of plots subjected to progressive reduction in number of stems before onset of competition over a period of years. One plot is left unthinned at each reduction. This gives a wide range of stocking at final crop, from free-grown to fully competing stems.

while the heavy intensity may be regarded as being more severe than would otherwise be accepted.

Some relevant details of the thinnings as well as of the present main crop are given in Table 5.

Table 4. Avoca 1/64.

| | |
|---|---|
| Description: | Thinning intensity experiment in Sitka spruce. |
| Location: | Compartmant 81032G. |
| Elevation: | Between 150-180m above sea level. |
| Aspect: | Sloping gently southward. |
| Exposure: | Unexposed. |
| Site: | Brown earth, formerly cultivated. |
| Species: | Sitka spruce, provenance 6/R/39, Washington (Manning). Age 2 + 2 years. |
| Planted: | 1943, pit-planted. |
| Initial Stocking: | 3,964 stems/ha. Spaced at 1.5 x 1.5m. |
| Treatment: | Three levels of intensity described as light, moderate and heavy. First thinning to a pre-determined basal area after thinning. |
| Thinning type: | Low, selective. |
| Experimental design: | Randomised block; 3 treatments, 2 replications. |
| Plot size: | .04 ha, with 5 metre surround. |

### 3.1. *Results of selective thinning*

#### 3.1.1. *Stems*

The average initial stocking for all plots was 3,964 stems/ha. After fourth thinning at 34 years, heavy thinning had reduced stocking to 543 stems/ha. the equivalent figures for moderate and light treatments were 1,074 and 2,136 stems/ha respectively.

#### 3.1.2. *Height*

The removal of more smaller stems with heavy thinning increases mean height. In 1979, sixteen years after first thinning mean height is greater by 1.8m with heavy thinning.

Top height is only slightly greater after heavy thinning (Table 5).

Table 5. Avoca 1/64: All thinnings and present main crop.

| Factor | Treatment Light | Moderate | Heavy |
|---|---|---|---|
| Four thinnings, vol. to 7cm ($m^3$/ha) | 66 | 200 | 308 |
| Percentage total volume removed | 9.3 | 26.4 | 42.3 |
| Percentage total basal area removed | 19.4 | 39.2 | 53.8 |
| Percentage yield class removed | 18.8 | 56.8 | 87.5 |
| Percentage stems removed | 51.9 | 73.9 | 83.6 |
| Main crop in 1979, standing | | | |
| volume ($m^3$/ha) | 647 | 558 | 421 |
| top height (m) | 21.8 | 22.0 | 22.4 |
| mean height (m) | 19.3 | 20.8 | 21.1 |
| mean diam. (cm) | 19.9 | 25.4 | 31.3 |

Table 6. Avoca 1/64: Basal Area.

| Treatment | Increment since first thinning ($m^2$/ha) | | | | | Cumlative BA in 1979 |
|---|---|---|---|---|---|---|
| | Yrs. 1-4 | Yrs. 5-8 | Yrs. 9-13 | Yrs. 13-16 | Yrs. 1-16 | ($m^2$/ha) |
| Light | 10.6(100) | 9.6(98) | 6.5(80) | 4.2(89) | 30.9(93) | 82.8(93) |
| Moderate | 10.6(100) | 9.8(100) | 8.1(100) | 4.7(100) | 33.2(100) | 89.1(100) |
| Heavy | 9.5(90) | 11.0(112) | 7.5(92) | 4.9(104) | 32.9(99) | 90.5(102) |

Differences are not statistically significant.
Brackets denote data as a percentage of moderate thinning.

### 3.1.3. *Diameter at Breast Height*

Heavier thinning intensities produce significantly greater diameter increment. The trend is more or less consistent over a 16 year period. (Fig. 5). All stems in the heavily thinned plots have a mean diameter of 20cm or greater with an overall mean of 31.3cm. (Fig. 6).

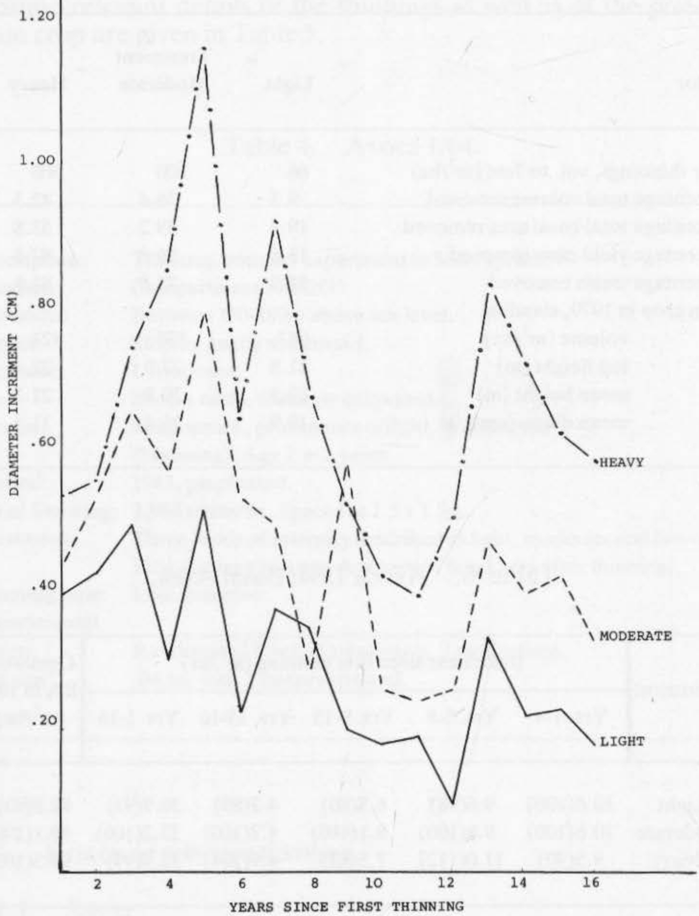


Fig. 5. Avoca 1/64: Mean Diameter Increment over 16 years.

### 3.1.4. *Basal Area*

During each of the three years after first thinning, increment was depressed with heavy thinning. Increment recovered in the fourth year, the recovery was maintained and initial losses were made up. (Gallagher 1969). Cumulative production — present main crop and all thinnings — at 37 years has fallen behind by nearly 10% in the lightly thinned plots (Table 6).

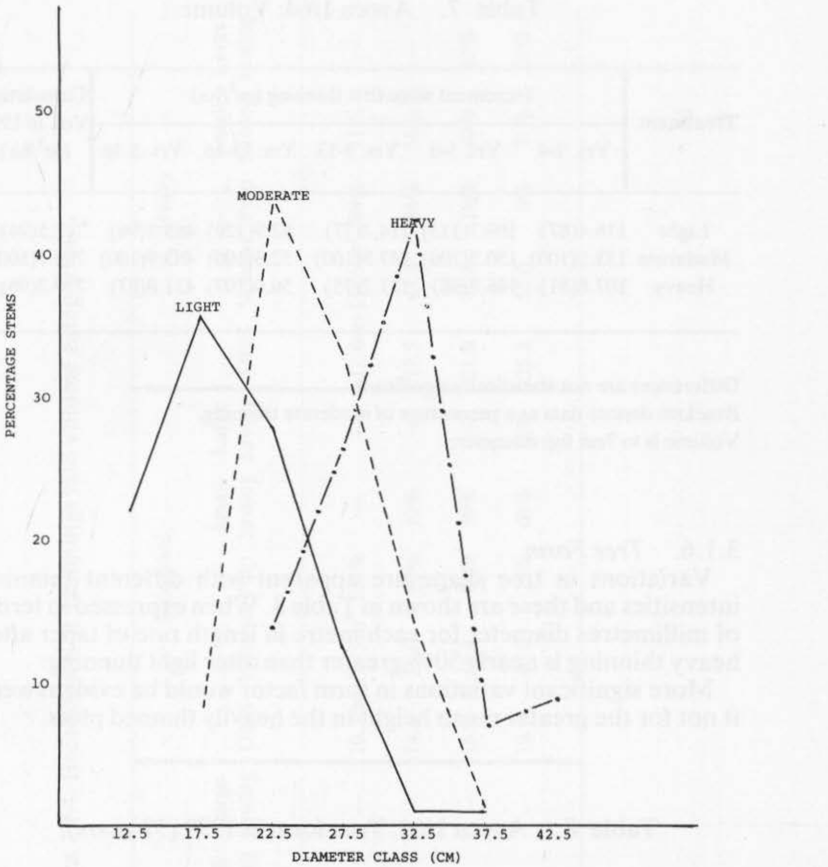


Fig. 6. Avoca 1/64: Diameter Distributions at 37 years.

### 3.1.5. *Volume*

The heavy thinning at Avoca removed 83% volume increment in four thinnings. The equivalent figure for the moderate treatment — and comparable with accepted practice — is 46%.

Increment trends differ somewhat from those of basal area. (Volume is to 7cm top diameter, basal area includes all stems). Heavy thinning depresses volume increment somewhat. A reduction in the region of 13% is incurred during the 16-year period after thinning commences when the heavy treatment is compared to the moderate. Cumulative production is down by about 4% or $30m^3$/ha. (Table 7).

Table 7. Avoca 1/64: Volume.

| Treatment | Increment since first thinning ($m^3$/ha) | | | | | Cumulative Vol. in 1979 ($m^3$/ha) |
|---|---|---|---|---|---|---|
| | Yrs. 1-4 | Yrs. 5-8 | Yrs. 9-13 | Yrs. 13-16 | Yrs. 1-16 | |
| Light | 116.4(87) | 169.7(113) | 114.3(77) | 62.9(120) | 463.3(96) | 713.5(94) |
| Moderate | 133.5(100) | 150.3(100) | 147.8(100) | 52.3(100) | 483.9(100) | 758.7(100) |
| Heavy | 107.8(81) | 146.8(98) | 111.2(75) | 56.0(107) | 421.8(87) | 729.2(96) |

Differences are not statistically significant.
Brackets denote data as a percentage of moderate thinning.
Volume is to 7cm top diameter.

### 3.1.6. *Tree Form*

Variations in tree shape are apparent with different thinning intensities and these are shown in Table 8. When expressed in terms of millimetres diameter for each metre in length rate of taper after heavy thinning is nearly 50% greater than after light thinning.

More significant variations in form factor would be evident were it not for the greater mean height in the heavily thinned plots.

Table 8. Avoca 1/64: Tree form in 1979 (37 years).

| Factor | Treatment Light | Moderate | Heavy | LSD (5%) |
|---|---|---|---|---|
| Form factor | .496 | .494 | .474 | — |
| mm/m to 14cm top diam. | 10.7 | 12.2 | 15.6 | 3.6 |
| cm diam/cm length to 14cm | 1:93 | 1:82 | 1:64 | — |
| length to 14cm top diam (m) | 10.0 | 13.6 | 15.4 | — |

$$\text{Form factor} = \frac{\text{Vol. to 7cm top diameter}}{\text{basal area x mean height}}$$

Table 9. Avoca 1/64: Breakdown of Thinnings into volume categories.

| Treatment | Light | | | | | Moderate | | | | | Heavy | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thinning | DBH | Volume | Pulp | Small Sawlog | Large Sawlog | DBH | Volume | Pulp | Small Sawlog | Large Sawlog | DBH | Volume | Pulp | Small Sawlog | Large Sawlog |
| First | 8.1cm | 23.1m$^3$ | 100% | — | — | 10.3cm | 77.9m$^3$ | 100% | — | — | 12.8cm | 136.9m$^3$ | 89% | 11% | — |
| Second | 10.9 | 13.8 | 100% | — | — | 14.4 | 33.0 | 90% | 10% | — | 17.5 | 43.5 | 44% | 56% | — |
| Third | 12.1 | 17.0 | 100% | — | — | 16.9 | 48.4 | 61% | 39% | — | 21.8 | 75.8 | 18% | 40% | 42% |
| Fourth | 13.3 | 12.2 | 100% | — | — | 19.1 | 40.9 | 25% | 68% | 7% | 25.3 | 52.0 | 8% | 31% | 61% |

3.1.7. *Volume Assortments*

The effects of increased thinning intensity and a greater diameter growth are reflected in the distribution of timber into different volume categories. Categories included here are large and small sawlog and pulpwood. Large sawlog is that portion of the stem from butt to 20cm top diameter (3m minimum length), small sawlog is from 20cm or butt to 14cm top diameter (3m minimum length) and pulpwood from 14cm or butt to 7cm top diameter.

At Avoca all the yield from the light treatment was pulpwood. Third and fourth heavy thinnings, on the other hand gave over 80% volume in the sawlog categories (Table 9).

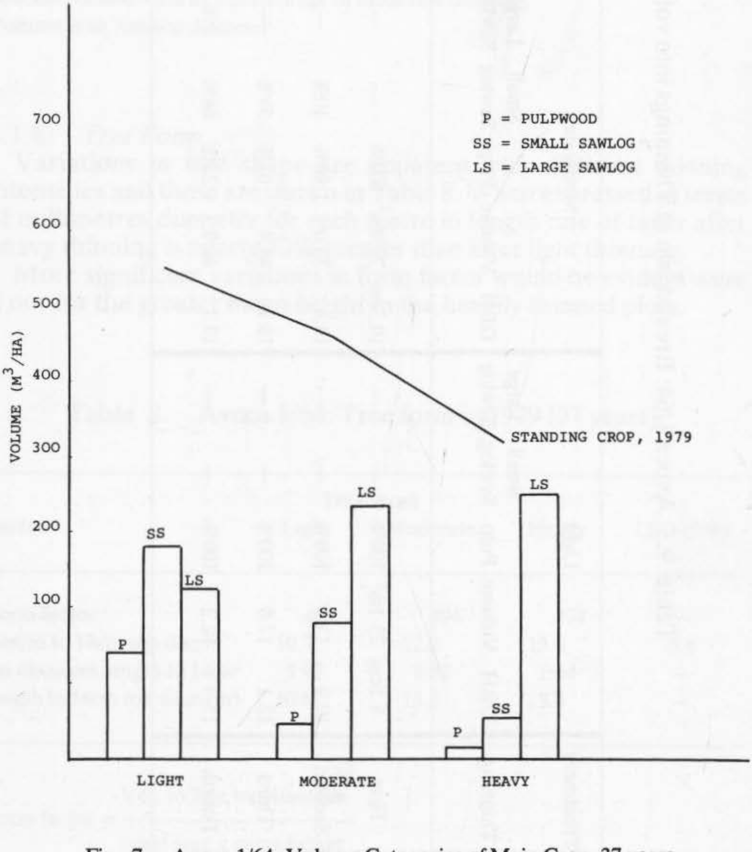


Fig. 7. Avoca 1/64: Volume Categories of Main Crop, 37 years.

In 1979, three years after fourth thinning the standing crop in the heavily thinned plots comprised more than 80% large sawlog. The total crop, including thinnings has produced more than half its volume as large sawlog under the heavy thinning regime and less than one-third with light thinning. (Fig. 7, 8).

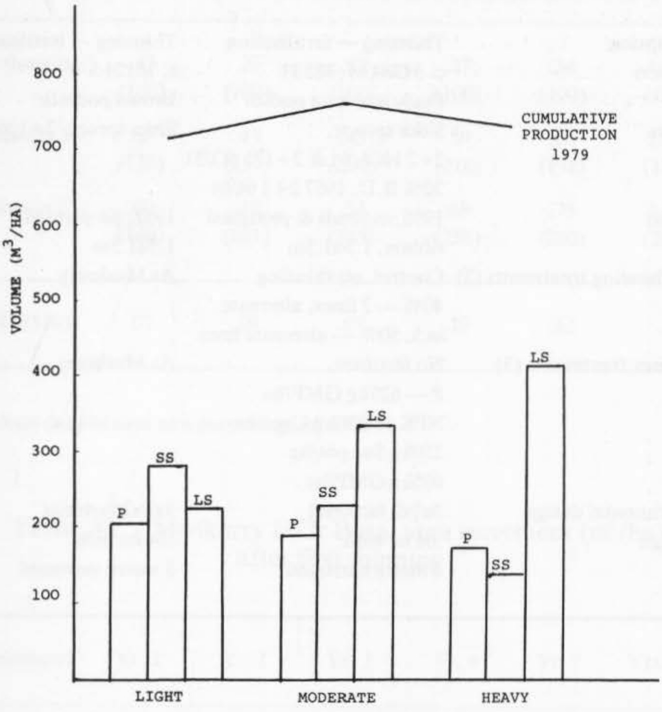


Fig. 8. Avoca 1/64: Volume Categories of Total Production, 37 years.

## 4. Thinning — Systematic or Line

Experimentation in line-thinning is relatively new to Ireland. One trial in Sitka spruce established in 1968 in Avoca forest (Gallagher 1970, 1976) has been extensively damaged by wind. In 1972, two thinning fertilisation trials were established in spruce. (Table 10). Since their experimental designs were identical, initial results from both trials were combined for analysis purposes. (O'Brien, Phillips, Lynch 1977). No effect of fertiliser was detected nor was there any interaction between fertiliser and thinning or fertiliser and site. Thinning alone was responsible for differences in growth rate.

Table 10. Two line — thinning experiments.

| | Muskerry 1/73 | Shillelagh 2/73 |
|---|---|---|
| Description | Thinning — fertilisation | Thinning — fertilisation |
| Location | c. 34384 M, 385 H | c. 16124 S |
| Soil | Peaty iron-pan podsol | Brown podsolic |
| Species | Sitka spruce, 2+2 HC6/51 & 2+1?1 6Q/51 20% B.U. 1957 2+1 6t/64 | Sitka spruce, 2+1, 6t/47 |
| Planted | 1956, mounds & ploughed ribbon, 1.5x1.5m | 1951, pit-planted 1.5x1.5m |
| First thinning treatments (3) | Control, no thinning 40% — 2 lines, alternate, in 5, 50% — alternate lines | As Muskerry |
| Fertiliser treatments (3) | No fertiliser, P — 625kg GMP/ha NPK — 250kg Urea/ha 250kg Sul.pot/ha 605kg GMP/ha | As Muskerry |
| Experimental design | 3x3x2 factorial | 3x3x2 factorial |
| Plot size | .04 ha with 5 metre surround | .04 ha with 5 metre surround |

For the purpose of this paper both experiments were re-analysed separately on the basis of three thinning treatments and six replications. Both trials have since been rethinned selectively. the site at Muskerry has a higher yield class than that at Shillelagh — 26 compared to 18.

## 4.1. *Results of line thinning*

### 4.1.1. *Diameter at Breast Height*

There is an immediate and positive response to line thinning (Table 11). Significance levels are high. Using the Least Significant Difference (LSD) technique, all three treatments are significantly different from each other when the five-year period is taken as a whole.

Table 11. Muskerry 1/73: Mean diameter increment (cm) after first thinning.

| Treatment | Yr. 1 | Yr. 2 | Yr. 3 | Yr. 4 | Yr. 5 | Yrs. 1-5 |
|---|---|---|---|---|---|---|
| No thinning | .43 | .27 | .22 | .27 | .34 | 1.53 |
| | (100) | (100) | (100) | (100) | (100) | (100) |
| 2 lines in 5 | .55 | .43 | .45 | .59 | .66 | 2.68 |
| | (128) | (159) | (204) | (218) | (194) | (175) |
| 1 line in 2 | .60 | .49 | .54 | .69 | .75 | 3.07 |
| | (140) | (181) | (245) | (256) | (220) | (201) |
| LSD (5%) | .07 | .09 | .07 | .10 | .12 | .30 |

Brackets denote data as a percentage of control.

Table 12. Muskerry 1/73: Basal area increment ($m^2$/ha) after first thinning

| Treatment | Yr. 1 | Yr. 2 | Yr. 3 | Yr. 4 | Yr. 5 | Yrs. 1-5 |
|---|---|---|---|---|---|---|
| No thinning | 3.91 | 2.47 | 2.08 | 2.56 | 3.36 | 14.38 |
| | (100) | (100) | (100) | (100) | (100) | (100) |
| 2 lines in 5 | 2.99 | 2.44 | 2.63 | 3.56 | 4.16 | 15.78 |
| | (76) | (99) | (126) | (139) | (124) | (110) |
| 1 line in 2 | 2.70 | 2.27 | 2.60 | 3.48 | 3.99 | 15.04 |
| | (69) | (92) | (125) | (136) | (119) | (104) |
| LSD (5%) | .48 | — | .41 | .66 | — | — |

Brackets denote data as a percentage of control.

4.1.2. *Basal Area*

Details of basal area increment are given in Table 12. Increment is less in the first two years relative to the no-thinning regime. A recovery is subsequently effected and during the overall five-year period, initial losses are made up.

Results are similar for the experiment at Shillelagh except that increment does not recover until the fourth year.

4.1.3. *Re-thinning after line-thinning*

A first line-thinning usually means the retention of some dead, suppressed and small stems in the main crop which are removed at second thinning. Some consequences of this are shown in Table 13. The mean tree from second thinning has hardly changed after a cycle of five years. Furthermore second thinning contains a sizeable number of small, dead stems which would most likely have been already removed had first thinning been selective.

Table 13. Shillelagh 2/73: Details of first and second thinnings (data per hectare).

| Thinning | Treatment | All Stems | Mean DBH | Stems <7cm | Stems Dead | Vol. to 7 | Mean Vol. |
|---|---|---|---|---|---|---|---|
| First | 1 line in 2 | 2,010 | 12.2cm | 110 | 30 | 119.8$m^3$ | .063$m^3$ |
| Second | 33% volume | 1,075 | 12.4cm | 70 | 75 | 75.6$m^3$ | .075$m^3$ |

5. Thinning of Lodgepole Pine (Coastal)

No specific details of thinning research in LP (C) are presented because of the paucity of data. Indications from a thinning experiment at Killavullen forest are that increasing intensities of thinning in pine have very similar effects on diameter growth as already reported for spruce. Basal area increment appears to be stimulated by thinning, a fact which is also borne out in the CCT trials.

Conclusions and Discussion

In The Forest and Wildlife Service at present recommended spacing at planting for Sitka spruce and coastal lodgepole pine is 2 meters square or 2,500 stems per hectare. Thinning policy follows the "marginal intensity" concept as described in Forest Management Tables (Hamilton and Christie 1971). First thinning, for the most part, removes every third line of trees. These practices have evolved from what were originally narrower spacings and lighter intensities. Experimental results presented here put the emphasis on the effects of even wider spacings and heavier thinnings than those presently practised.

The forest manager about to embark on a planting programme may enquire: "What happens if I plant at wider spacing, say 2.5m square?" Should he decide to do so he can expect a drop in cumulative production in the region of 4% where the species is Sitka spruce. A drop of somewhat greater magnitude will be incurred with coastal lodgepole pine. First thinning will be delayed by about two years, thereby reducing the number of thinnings and giving somewhat less thinning volume than at 2m spacing (a figure of about 7% less thinning volume in high yield class spruce might be expected). On the other hand, the extended spacing will give larger diameter trees at any given time.

Wider spacing gives the forest manager more flexibility when deciding on exactly when to thin. This is especially true with spruce. Because of the larger diameters obtainable, thinning may be earlier than normal in response to a specific demand. Such is the resilience of the species that the effects of early reduction in stocking should soon be overcome. Alternatively, should thinning be delayed by a number of years, competition between individual stems will not be as detrimental as in conventional spacing.

The possibility of a shorter rotation at wider spacing is feasible. As long as a normal thinning programme is carried out and having regard to the larger than average tree diameters, the attainment of an acceptable final crop containing appreciable amounts of sawlog should be possible some years earlier than otherwise.

Thinning to a marginal intensity as described in Management Tables will remove, on average about 45% volume increment during the thinning rotation. The recommended age of first thinning for Sitka spruce, Yield Class 22 is 18 years after which thinnings will be felled periodically for a further 18 years. this presumes a rotation of 38 years — maximum mean annual increment less 20% — and that final thinning takes place two years before the end of the rotation.

The heavy thinning treatment at Avoca has removed 308m$^3$ of merchantable volume or 83% of increment in four thinnings over a 13 year period. Stocking is now reduced to 540 stems per hectare with a mean diameter three years after fourth thinning of 31.3cm. On a shortened rotation this may be regarded as a final crop. This heavy thinning has reduced total production by 4% — a reduction similar to that which follows a widening of initial spacing by half a metre.

There are indications from the experiment at Avoca that volume increment begins to be irretrievably lost when more than 80% volume increment is removed in thinning though basal area production remains unaffected. Diameter increment is greatly stimulated by heavier thinning intensities, something which is reflected in the greater amounts of sawlog timber contained in the thinnings and in the final crop.

The precise nature of first thinning requires some comment. At Avoca, first thinning was low and selective, removing 45% of the standing volume or 65% of the stems. In the Forest and Wildlife Service, at present, the general practice at first thinning is to remove one-third of the crop in lines. Recent research evidence indicates that, in spruce at least this intensity may be increased so that alternate lines of trees are removed. There is no reason to believe that a thinning intensity of 80% volume increment over a similar period to that at Avoca and where first thinning removed every second or every third line would have anymore significant effect on crop growth than if all thinnings were purely selective.

An undesirable consequence of line thinning is the amount of "rubbish" which remains to be cut out at re-thinning. Such a situation may be relieved somewhat by removing all dead and badly suppressed trees as one operation in a first line thinning. Delaying first thinning further aggravates the situation as more trees will have died by the time thinning is felled.

This paper does not attempt to answer all questions relating to spacing and thinning of forest crops. The forest manager will need to consider other important questions before embarking on a particular spacing and/or thinning regime. He will need to be conscious of the threat of windblow following thinning. If he decides to increase spacing at planting will he be able to satisfactorily control weed growth? Wide spacing and heavy thinning will yield bigger timber but this must be extracted, transported and sold. What are the economic advantages of one silvicultural system relative to another? The whole question of timber quality is becoming more relevant. To what extent will the financial gains accruing from more sawlog timber be offset due to deterioration in quality? Results show that coarser branching, wider rings and more acute slope of grain are all "part and parcel" of wider spacings and heavier thinnings?

One silvicultural practice not dealt with in great detail is that of respacing or precommercial thinning. A forest manager may decide to play safe at planting and stick with conventional spacing. Then, when the crop is about ten years old and having decided on a course which will yield the greatest amount of sawlog timber he may either:

(a) respace to a pre-determined stocking which will require either none or at most one or two thinnings during the remainder of the rotation.

*or*

(b) maintain present stocking, first-thin early and heavily, every second line of trees say, remove three or four further thinnings to an intensity which does not exceed 80% volume increment down to a final crop of about 500 stems per hectare.

The ten-year period after planting provides a breathing space during which the forest manager can make up his mind what his long-term strategy should be. The second alternative may not be feasible if windblow is a definite threat. But it does give a supply of small as well as large timber which can be advantageous.

Close initial spacing may be the only realistic option for coastal lodgepole pine considering the poor form of the species. Indeed, respacing in pine should prove a very desirable silvicultural treatment if it removes the worst looking stems at an early age. Line thinning in lodgepole pine does nothing to improve the appearance of the stand so respacing in a closely spaced crop may be the most acceptable practice.

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# Lodgepole pine — Silvicultural Alternatives

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## BACKGROUND

Lodgepole pine is a very important constituent of the State forests in the Irish Republic. Three broad provenances are generally distinguished in the species planted here; coastal, Lulu Island and interior. These three provenances have quite different growth capacities and though all provenances have been planted since the twenties, various provenances have been fashionable in different periods, particularly interior in the late thirties while Lulu Island was generally planted in the fifties, though it must be remembered that coastal provenances were planted right through from the early twenties. Plantings from the mid sixties onwards have been almost completely coastal with the emphasis on south coastal provenances.

Table 1. Area of lodgepole in hectares from 1968. Inventory, by age, class and provenance in pure and mixed stands.

| Planting Year | Coastal | Lulu Island | Interior | Total |
|---|---|---|---|---|
| Pre 1923 | 15 | — | 1 | 16 |
| 1923-'27 | 66 | — | 4 | 70 |
| 1928-'32 | 248 | 2 | 83 | 333 |
| 1933-'37 | 913 | 5 | 110 | 1028 |
| 1938-'42 | 992 | 167 | 765 | 1924 |
| 1943-'47 | 1154 | 152 | 241 | 1547 |
| 1948-'52 | 1772 | 884 | 1114 | 3770 |
| 1953-'57 | 3101 | 5648 | 1037 | 9786 |
| Totals | 8261 | 6858 | 3355 | 18474 |

GROWING SPACE IN CONIFEROUS CROPS
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Signed: JIM DILLON

December, 1980

Table 2. Lodgepole pine as a percentage of total forest area pre 1958 and as a percentage of Planting programme 1958-1978.

| Planting | % | P/Year | % | P/Year | % |
|---|---|---|---|---|---|
| Pre 1923 | — | 1960 | 28.6 | 1970 | 23.9 |
| 1923-'27 | 2.7 | 1961 | 30.9 | 1971 | 20.6 |
| 1928-'32 | 6.7 | 1962 | 30.4 | 1972 | 21.0 |
| 1933-'37 | 10.7 | 1963 | 24.9 | 1973 | 21.6 |
| 1938-'42 | 16.4 | 1964 | 24.4 | 1974 | 23.5 |
| 1943-'47 | 20.2 | 1965 | 24.1 | 1975 | 28.7 |
| 1948-'52 | 23.3 | 1966 | 24.9 | 1976 | 32.6 |
| 1953-'57 | 34.7 | 1967 | 22.2 | 1977 | 34.7 |
| 1958 | 30.2 | 1968 | 24.3 | 1978 | 38.8 |
| 1959 | 26.4 | 1969 | 25.8 | | |

The weighted mean yield class for coastal lodgepole in the 1968 Inventory (1) was 113 hoppus feet per acre which is the equivalent of metric Yield Class 10 (2). This yield would be considered low by present day levels but many of these crops lacked fertilisation and ground preparation. The use of modern establishment techniques and more vigorous provenances during that last fifteen to twenty years has boosted average yield class considerably. This combined with the increasing usage of the species (see table 2) means that large areas are now in, or approaching thinning stage.

Lodgepole pine is confined to the poorer site types and these in turn are generally the more inaccessable, being often raised bogs or blanket peats. This means that roading is expensive and thus the cost of extraction of thinnings high. In the present climate of curtailed markets, the sale of such thinnings standing is difficult, particularly when more than sufficient spruce is available to satisfy demands for first and second thinnings. Under these circumstances other options should be considered.

## Silvicultural Alternatives

It is patent that various silvicultural alternatives exist but which one and what regime could be construed as the best option. It is difficult to forecast future timber demands but the following criteria could be acceptable guidelines.

(I) Optimum saw log volume per hectare.
(II) Shortest possible rotation.
(III) Clean, knot free boles.
(IV) Best financial return.

Bearing the above in mind but particularly accepting item IV for comparative purposes, a plantation of lodgepole in Lough Ennel Forest, Knockaville property, was studied. The following will give some idea of the plantation.

| | |
|---|---|
| Site Type: | Raised midland bog, deep peat with full cover of *Calluna vulgaris*. |
| Ground Prep.: | Ploughed prior to planting, ribbons about 2.0m apart with adequate network of drains. |
| Planting: | Carried out in 1970 with pure lodgepole pine at spacing of 2.00 x 1.5m approximately. |
| Area: | 100 hectares of which 30 are the subject of this investigation. |
| Yield Class: | The estimated yield class at 9 years of age was 18. |

An economic analysis was carried out on the following silvicultural regimes, which will be referred to as options.

OPTION A

This would be normal silvicultural practice as envisaged in lodgepole pine yield tables i.e. regular thinning from 18 years at 5 year intervals with clear felling at 50 years. Additionally, 400 stems per ha would be high pruned to 6m as in next option.

OPTION B

A respacement to 800 stems per ha at nine years of age is envisaged here. All stems would be high pruned to 6m in three stages as set out below.

| Age | Height m | Pruned height m |
|---|---|---|
| 9 | 4 | 2 |
| 14 | 8 | 4 |
| 17 | 11 | 6 |

The crop would be clear felled at 35 years.

OPTION C

This is a no thinning regime with three possible rotations:
C (I) — 30 years; C (II) — 40 years; C (III) — 50 years.

For the purpose of the economic comparison all costs to 8 years were disregarded and only costs from 9 years (1979) onwards were applied to the various alternatives. These costs can be found in the appendix. Most costs are standard values or based on actual work carried out at Lough Ennel Forest.

## Economic Analysis

The volume and size classes used in the projections were taken from the standard yield tables where possible, otherwise figures are taken from tables developed by Crop Structure Section, Research Branch, Forest and Wildlife Service, Bray, using early results from their experiments, (see acknowledgements). Such projections may have a high error factor, but as conservative estimates of diameter development were used, we do end up with guidelines for management decisions, where none existed heretofore. Price assumed and size category assortments used, can be found in appendix. All costs and revenues are at 1979 levels. It is assumed that costs and revenues will equally keep pace with inflation so valid comparisons can be made.

## Results

Table 3. Net Discounted Revenue (NDR) in £ per ha for one rotation.

| Interest | Option | | | | |
|---|---|---|---|---|---|
| Rate % | A | B | C (I) | C(II) | C(III) |
| 2 | 7263 | 6152 | 3124 | 5812 | 7330 |
| 4 | 3500 | 3607 | 2070 | 3169 | 3286 |
| 6 | 1738 | 2101 | 1380 | 1744 | 1489 |
| 8 | 891 | 1205 | 926 | 968 | 679 |
| 10 | 472 | 667 | 625 | 540 | 309 |
| Rotation Age | 50 | 35 | 30 | 40 | 50 |

Table 4. Order of Options from Table 3 figures.

| Interest | Option | | | | |
|---|---|---|---|---|---|
| Rate % | A | B | C (I) | C (II) | C (III) |
| 2 | 2 | 3 | 5 | 4 | 1 |
| 4 | 2 | 1 | 5 | 4 | 3 |
| 6 | 3 | 1 | 5 | 2 | 5 |
| 8 | 4 | 1 | 3 | 2 | 5 |
| 10 | 4 | 1 | 2 | 3 | 5 |

The use of different rotation ages makes the selection of the most profitable options difficult, particularly if one wishes to apply the results generally. One method of correcting each option for the various clear felling ages is to discount an infinite number of rotations in each category back to the present. The establishment costs (not included in tables 3 & 4) have to be alotted in such an exercise and for this standard costs were used for the various operations in deep peat sites.

Table 5. NDR value for infinite number of rotations.

| Interest | Option | | | | |
|---|---|---|---|---|---|
| Rate % | A | B | C (I) | C (II) | C (III) |
| 2 | 10999 | 11181 | 8676 | 10367 | 11066 |
| 4 | 4151 | 4778 | 3495 | 4132 | 3936 |
| 6 | 1770 | 2178 | 1483 | 1801 | 1521 |
| 8 | 881 | 1172 | 878 | 946 | 669 |
| 10 | 462 | 627 | 561 | 515 | 300 |

Table 6. Order of Options from Table 5 figures.

| Interest | Option | | | | |
|---|---|---|---|---|---|
| Rate % | A | B | C (I) | C (II) | C (III) |
| 2 | 3 | 1 | 5 | 4 | 2 |
| 4 | 2 | 1 | 5 | 3 | 4 |
| 6 | 3 | 1 | 5 | 2 | 4 |
| 8 | 3 | 1 | 4 | 2 | 5 |
| 10 | 4 | 1 | 2 | 3 | 5 |

## DISCUSSION

Table 4 shows that Option B is the best option for all interest rates except 2% while in Table 6 this option is consistently the best. The financially most rewarding regime is not always seen as of overriding concern in forest management decisions. Fortunately Option B scores well under the criteria mentioned earlier under "silvicultural alternatives": 79% of the timber is estimated to be in the large sawlog category, it is the second shortest rotation and the pruning regime outlined should give 6m of clean timber.

The carrying out of this regime at Knockaville, Lough Ennel Forest did not pose any particular problems (Fig. 1). The selection of the trees to be felled was left to a workman who was told to work along each line, picking the best tree in a group of three trees and fell the other two. If he is unable to find a good tree within a group of three he can occasionally extend the group to four or five. Where the stocking is about 2,500 stems per hectare this system gives a respacement to around 800 stems evenly distributed. The cost of this operation was 22 smh (standard man hours) per hectare or £58 at 1979 prices. Low pruning to two metres generally involves cutting about 5 whorls, which in the south coastal provenance we were dealing with meant branch diameters of 1 to 5 cm.

Both chainsaws and pruning saw methods were used the costs being 13 standard man hours per ha (£34) and 35 smh (£93) respectively. The chainsaw method requires both skill and dexterity and a lightweight saw is essential to avoid worker fatigue. The ground conditions were difficult due to the combination of furrows, ribbons and 1600 felled trees per hectare. The answer may well be

Fig. 1 Respaced 10 year old Lodgepole pine (Coastal) at Knockaville, Lough Owel Forest.

a shears such as the New Zealanders use. The costs of first and second lift in the high pruning regime advocated are in the appendix, together with roading, maintenance and other expenses envisaged.

The general system envisaged here is not disimilar from that advocated and practised by foresters in New Zealand for radiata pine,[3] though it must be remembered that the growth rates in New Zealand for radiata are far higher than anything possible for lodgepole here. There are also permutations in the system advocated such as taking a late thinning at say 30 or 33 years and having a longer rotation, thus producing a larger diameter log.

Windblow has not been mentioned and no experience is yet available of the effects of high winds on lodgepole in raised bogs. However it is reasonable to speculate that a system of respacement taken at a height of four metres must allow for a firmer root plate. Moore[4] in his system of Oceanic forestry applied to Sitka spruce postulates, and rightly so, that a system of respacing at an early age must improve stability.

The question of disease must arise, since quite a quantity of debris from the trees felled is left lying on the ground and doubts as to the hygenic status of green pruning may be present in some minds. A thinning to waste in lodgepole (planted 1963) carried out in Castlelost property in Lough Ennel forest in 1976 was checked by Research Branch, Bray in 1979 and found to have no pathogenic problems except *Stereum sanguinolentum* in some lop and top and *Fomes annosus* in some stumps.[5] These stumps had not been treated at the time of felling, and it is accepted that stump treatment with urea should be part of the respacement programme.

Green pruning experiments carried out by Gallagher[6] have not shown ny significant disease resulting from the practice and from personal observation lodgepole pruning wounds have calloused quickly. In fact the main problem would be an epidemic of the pine shoot moth *(Rhyacionia buoliana)* after respacements, since with no thinnings one has no chance to dispose of damaged trees.

## CONCLUSION

It is not possible to know the future but present evidence, combined with poor markets for thinnings and the inhospitable nature of deep peat as a medium to extract over, would merit serious thought to be given to the respacements and subsequent pruning of lodgepole pine crops as outlined in this paper.

ACKNOWLEDGEMENTS

Mr. Dermot O'Brien, Research Branch, Forest and Wildlife Service, Bray devised and carried out the financial analysis given in this paper while Mr. Paul Clinch, also of Research Branch, supplied the figures for Tables 1 and 2.

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## APPENDIX

The table below shows costs used. The figures are at 1979 levels and show rate per hectare.

| Operation | Standard Man Hours | Cost IR £ |
|---|---|---|
| Mark Thinnings | 10 | 26.50 |
| Mark Final Crop | 12 | 31.80 |
| Prune to 3m (400 stems/ha) | 15 | 39.75 |
| Prune 3 to 6m (400 stems/ha) | 38 | 100.70 |
| Major Road Repairs | 9 | 23.85 |
| Gravel 25 M3 at £2 | — | 50.00 |
| Respace to 800 stems/ha | 22 | 58.30 |
| Prune to 2m (chainsaw) 800 stems | 13 | 34.45 |
| Prune 2 to 4m (800 stems/ha) | 34 | 90.10 |
| Prune 4 to 6m (800 stems/ha) | 60 | 159.00 |
| Mark Final Crop (in option C) | 24 | 63.60 |
| Annual Maintenance/ha | — | 8.00 |

The different costs for the various Options were applied against the year in which they deemed to occur. Some costs were repetitive such as thinning in Option A and of course each option had major road repairs prior to harvesting.

## Production, Log Assortments and Money Values

### Option A

The normal yield tables (Res. Comm. No. 16) were used for volume and size categories for thinning and clear fellings.

### Option B

The volume and size categories used for this option were as follows.

| Age | Mean DBH (cms) | Total Vol. ($m^3$/ha) | Pulp ($m^3$) | Small Sawlog ($m^3$) | Large Sawlog ($m^3$) | Total Value (IR £/ha) |
|---|---|---|---|---|---|---|
| 35 | 31.3 | 522 | 28 | 80 | 414 | 11,011 |

### Option C

| Age | Mean DBH | Total Vol. | Pulp | Small Sawlog | Large Sawlog | Total Value |
|---|---|---|---|---|---|---|
| (I) 30 | 19.4 | 483 | 156 | 241 | 86 | 4944 |
| (II) 40 | 24.3 | 666 | 97 | 225 | 344 | 10980 |
| (III) 50 | 29.9 | 810 | 47 | 140 | 623 | 16790 |

The prices applied to the various categories were as follows:

| | | Price per ($m^3$) (IR £) |
|---|---|---|
| Small sawlog | 14-20cm top diameter for minimum log of 3m. | £10.84 |
| Large sawlog | 21cm and over top diameter for minimum log of 3m. | £24.40 |
| Pulp | Remainder to 7cm top diameter. | £1.50 |

# 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 | Large Sawlog | Small Sawlog | Pulp |
|---|---|---|---|
| | Volume 20cms top diameter<br>Minimum length 3m | Volume 14 - <20cms<br>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 | Price | Rate | Spacing (m) | | | | |
|---|---|---|---|---|---|---|---|
| | | | .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 |

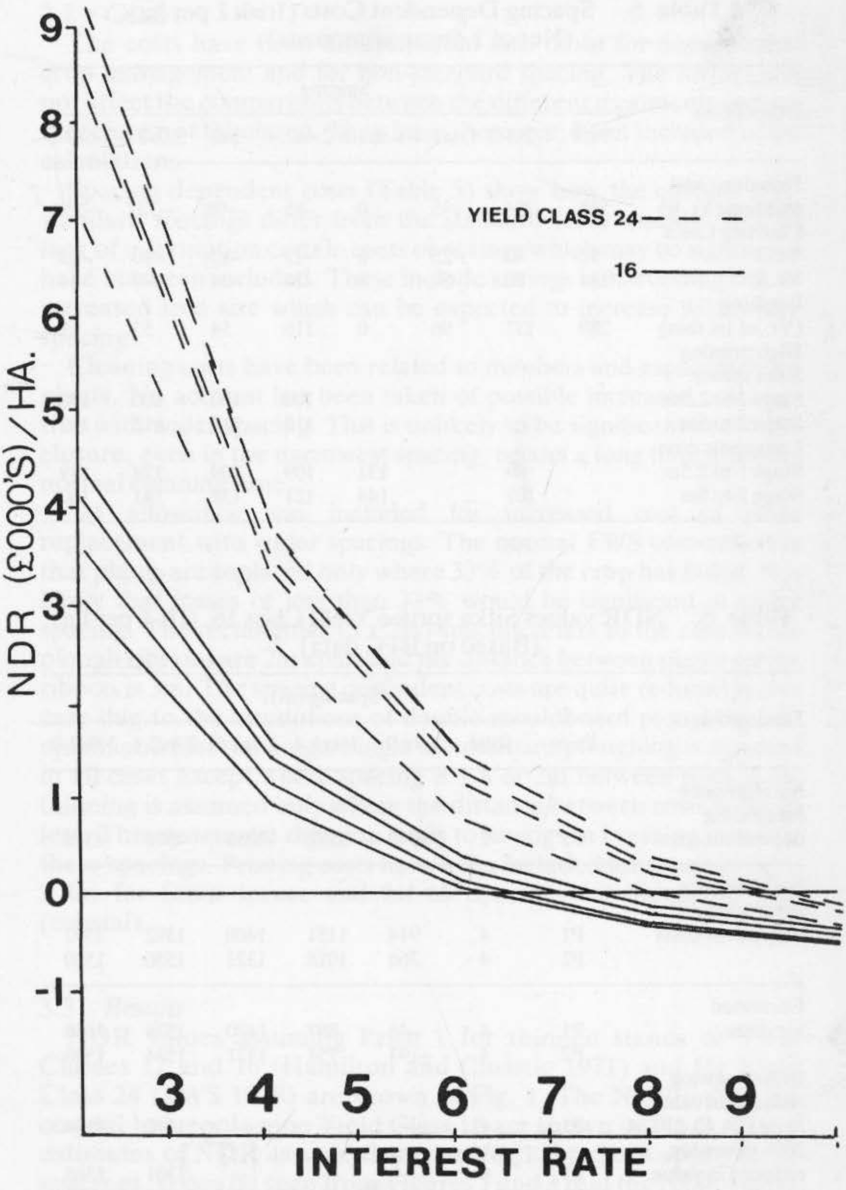


Fig. 1 Net discounted revenues for two yield classes of Sitka spruce for a range of spacings and interest rates. (No allowance taken for costs for different spacings).

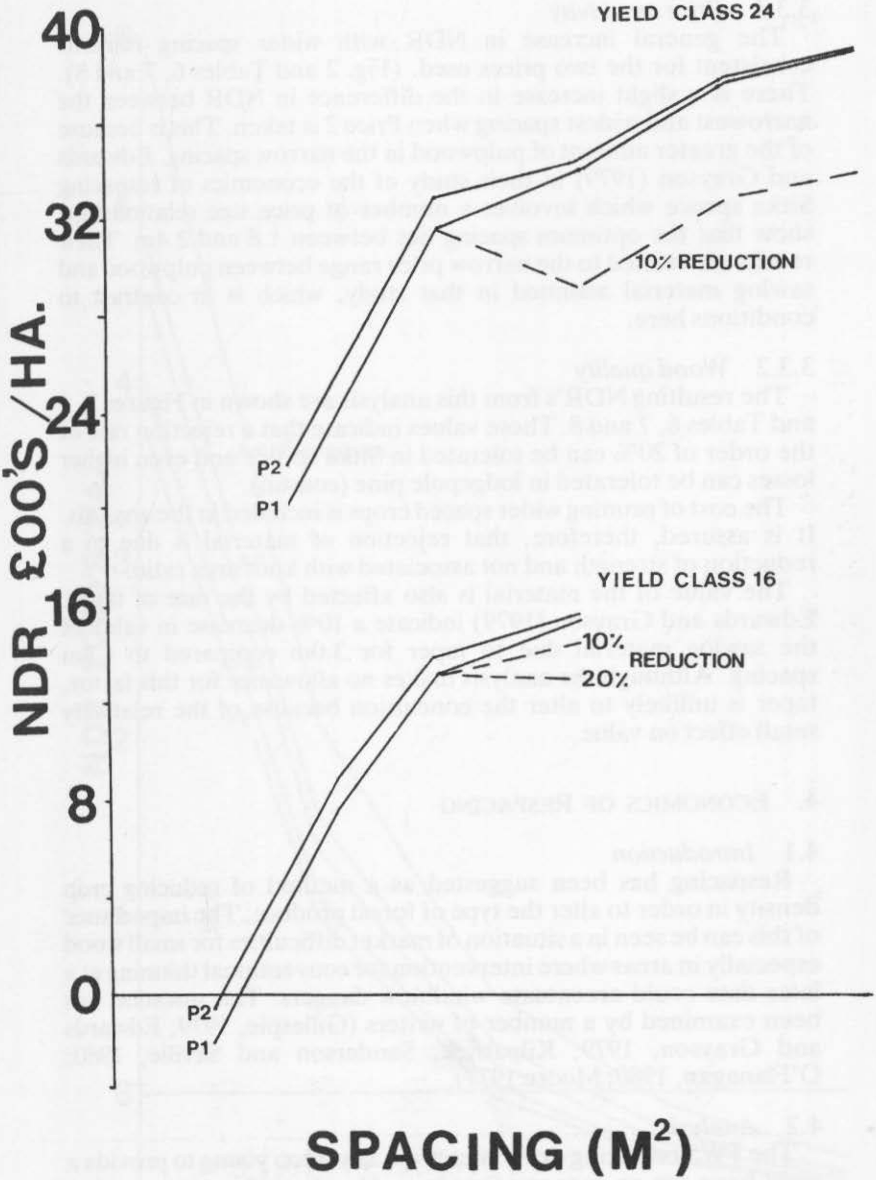


Fig. 2 **Net discounted revenues for two yield classes of Sitka spruce for a range of spacings and for two price size gradients. The effect of reduction of quality is also shown.**

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

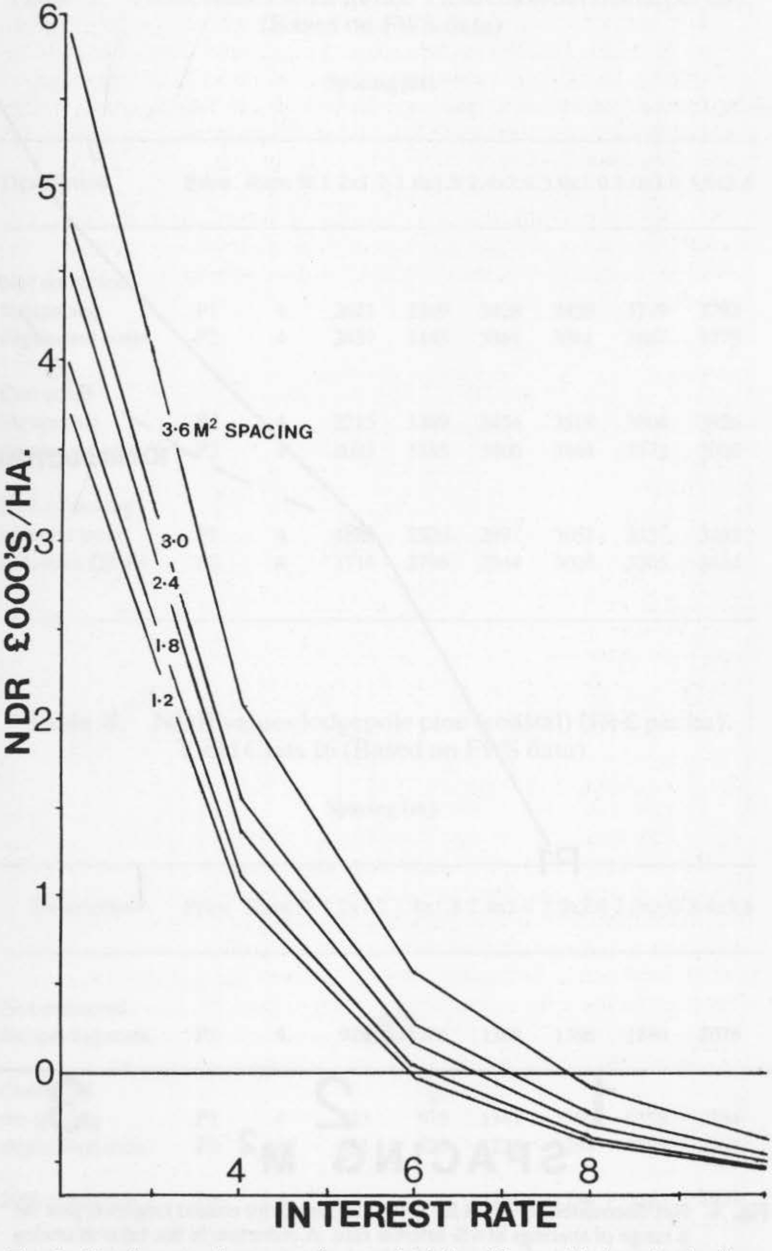


Fig. 3 Net discounted revenues for two yield class 16 coastal lodgepole pine for a range of spacings and interest rate. (No allowance for costs for different spacings).

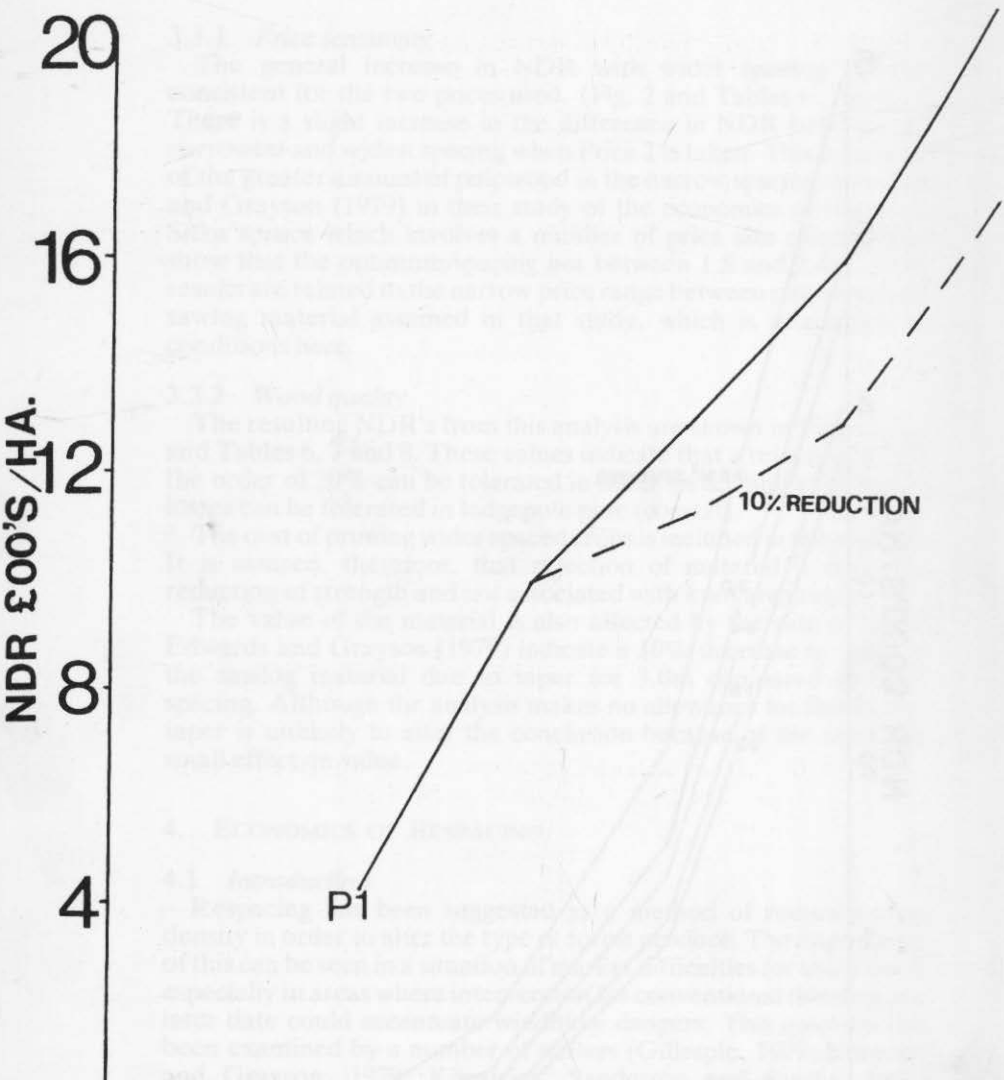


Fig. 4 Net discounted revenues for two yield class 16 for coastal lodgepole pine for a range of spacings at 4% interest rate. A reduction in the value of sawlog due to deterioration in wood quality is also shown.

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

| Description | Price | Rate % | Spacing (m) 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)

| Description | Price | Rate % | Spacing (m) 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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