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Line Thinning

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FRONT COVER Extraction by a Volvo 462 forwarder in a line thinning of Corsican pine at Thetford Forest, Norfolk *(27104)*.

LINE THINNING

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I INTRODUCTION

At the present time something in the region of 20 thousand hectares of coniferous plantations in Britain enter the stage of first thinning every year. This level of recruitment is increasing slightly and will remain at a relatively high level until the end of the century. The costs of harvesting first thinnings tend to be relatively high for a given volume of timber harvested, and means of reducing these high costs are continually being sought. In this connection the use of *line thinning* has rapidly increased over the last decade to the point where a substantial proportion of thinnings are now done in the form of line thinnings.

More evidence on the effects of line thinnings on both the crop and the site has become available during the last few years. Additional information on the suitability of different methods of working in line thinning is also now available. The purpose of this publication is to provide information on the various effects of line thinning as far as they are known, and to offer some guidance on methods of working. Aspects which are covered are the effects of line thinning on growth and yield, crop stability, risks of damage to site and crop, and on harvesting. The economic implications of these features are discussed.

Most of the information which is available on line thinning relates to Sitka spruce, which is by far the most common species in the areas reaching the stage of first thinning. Information on other species is much more limited. In this publication line thinnings are considered only in connection with first thinning.

II DESCRIPTION OF LINE THINNING

Thinning is the removal of a proportion of the trees in a crop in order to provide more growing space for the remaining trees and thereby enhance their diameter increment, but also to provide an intermediate yield of timber.

Thinnings may be either **selective** or **systematic.**

a. **Selective thinning** is one in which trees are removed or retained on their individual merits. For example, *low* thinning is a selective thinning in which trees from the lower canopy, i.e. sub-dominants and suppressed trees, are removed. *Crown* thinning is one in which trees are removed from the upper canopy, i.e. dominants and co-dominants.

   In practice most selective thinnings embrace elements of both types. The type of selective thinning most frequently employed in Commission plantations has been described as 'intermediate type' which is predominantly low but also involves the removal of some competing dominants and co-dominants.

b. **Systematic thinning** is a thinning in which trees are removed according to a predetermined system, which does not permit consideration of the merits of individual trees. (The term 'mechanical thinning' has occasionally been used as a synonym for systematic thinning but it is a term which in this context is deprecated).

Line thinning is a systematic thinning in which trees are removed in lines or in a series of inter-connecting lines. The principal forms of line thinning are as follows:

Row thinning. A line thinning in which the lines of trees removed follow the planting rows.

Strip (syn. corridor) thinning. A line thinning in which lines of trees are removed but where the lines do not necessarily follow the planting rows.

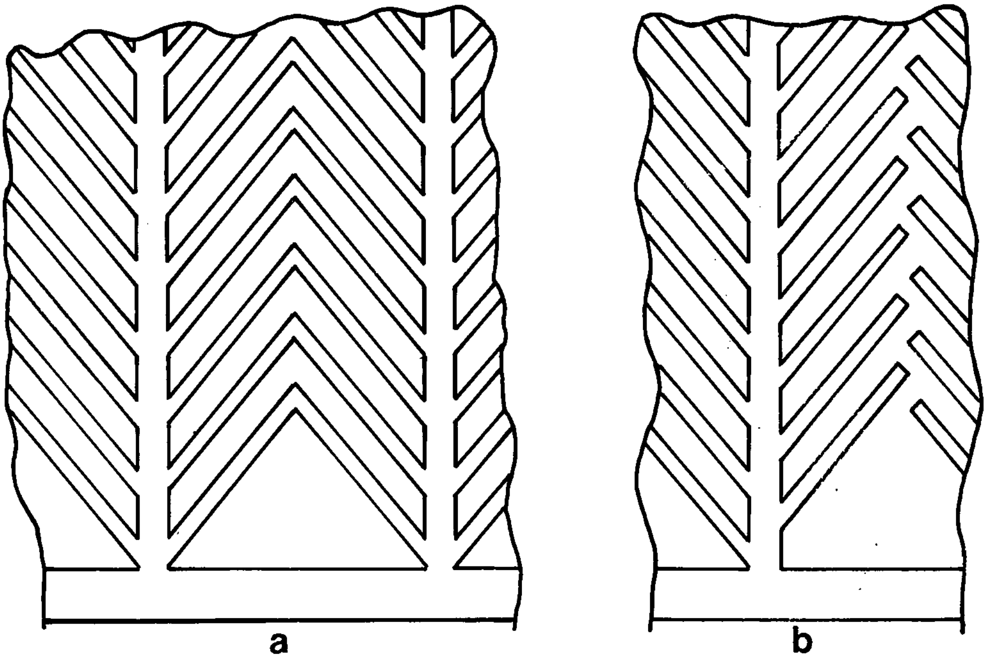

FIGURE 1 Line removal patterns for (a) chevron thinning, (b) staggered chevron thinning.

Chevron thinning. A line thinning in the form of a series of widely spaced, approximately parallel, lines (main racks), the intervening area being thinned by the removal of regularly spaced pairs of lines (side racks) originating opposite each other in the main rack and acutely angled to the main racks. (See Figure 1(a)).

Staggered chevron thinning. Similar to chevron thinning except that the side racks are not directly opposite but alternate. (See Figure 1(b)).

It is clearly not practicable to include in this publication a consideration of every possible pattern of line thinning. The choice is almost infinite. In practice however, only a few patterns have evolved as having distinct advantages in terms of their suitability for specific harvesting systems.

Two basic line thinning patterns will be considered. These are row thinning and chevron thinning. Patterns of single row thinning considered practicable are:

a. the removal of one row in every four,
b. the removal of one row in every three,
c. the removal of one row in every two.

In some situations where the original spacing between the planted rows is comparatively close, it may be necessary to remove two adjacent rows in order to create an adequate extraction or access lane. In terms of practical treatments involving the removal of two adjacent rows, the possibilities are:

d. the removal of two rows in every five and,
e. the removal of two rows in every four.

The removal of three adjacent rows is rarely justified and is not considered here. There are a number of possible variations to the basic patterns shown in Figure 1.

In the following chapters the various aspects of line thinning are compared with conventional selective thinnings and in this connection it has to be noted that in selective thinnings it is usually inevitable that a number of access racks (strips) are created within the stand.

III GROWTH AND YIELD

There are five thinning experiments in Forestry Commission woodlands which were designed to investigate the influence of line thinning on growth and yield. These experiments were recently analysed and have been described in some detail in a paper included in Forestry Commission Bulletin No. 55, *Aspects of Thinning*. The main findings of that paper are summarised here. Two of the experiments are in Sitka spruce, two in Corsican pine and one in Scots pine. One of the Corsican pine experiments which originated in 1943 is not replicated. The others are of relatively recent origin so that the effects of the treatments were observed over periods of only four to six years after thinning. All of the treatments employ variations of row thinning.

The first important feature to emerge from the review of the evidence was that responses to thinning were confined to the rows immediately adjacent to those removed. Practically no response was detected in other rows. In addition, the responses in the outside rows were greater as the number of adjacent rows removed increased. This has an important bearing on the practice of line thinning in that any thinning which leaves three or more adjacent rows unthinned denies a proportion of the crop any prospect of enhancing its diameter increment.

The second point to emerge was that a loss in volume production was associated with line thinning. This follows from the fact that some of the more efficient dominants and co-dominants are indiscriminately removed as a result of line thinning, and conversely a number of inefficient sub-dominants are retained, whereas with a selective thinning they would in most cases have been removed.

The third important feature was that the volume losses associated with line thinning increased with an increase in the number of adjacent rows removed. For example, the loss associated with the removal of two adjacent rows was considerably greater than the losses resulting from single row removal. The explanation in this case is that the gap created by the removal of two or more adjacent rows is such that the remaining trees are initially unable to utilise the additional growing space created.

While the different experiments have not been entirely consistent in quantifying the losses, it is possible, nonetheless, to interpret in broad terms the quantitative results of the experiments. Table 1 shows the volume production relative to conventional selective thinning which would result from a number of different patterns of row thinning in Corsican pine and Sitka spruce. These data represent the best information available to date and can be taken to apply up to the time at which canopy is closed and the site is again fully utilised. Further conventional selective thinnings should have no further influence on production. The volume losses given for Corsican pine can be assumed to be equally applicable to other pines. For other conifers, with the possible exception of larch, and although there is no substantiated evidence, it would seem not unreasonable to assume losses of the same order as indicated for Sitka spruce. These absolute losses can be taken to be virtually unaffected by yield class.

Table 1

Treatment	*Production relative to normal selective thinnings (cu m/ha)*	
	Corsican pine	*Sitka spruce*
Selective	0	0
1 row in 4 (25%)	−5	−6
1 row in 3 (33%)	−7	−8
1 row in 2 (50%)	−8	−10
2 rows in 5 (40%)	−10	−14
2 rows in 4 (50%)	−12	−18

It is of interest to consider the effects of patterns of line thinning other than row thinnings which are given above, and the one which is most relevant is chevron thinning. Although no information has been obtained from direct experimentation in this pattern of line thinning, the effects can be simulated from the information deduced from row thinning. Chevron thinning is essentially a combination of row thinning (main racks) and strip thinning (side racks). The losses in volume associated with the thinning of the main racks are deduced according to the number of rows removed and according also to the spacing of the main racks. The volume losses associated with the side racks is related to the minimum width of these side racks and to the spacing between them. A typical example of chevron thinning would be to have the main racks created by the removal of one row in every twenty, with side racks at 45° to the main rack and with a minimum width of 2 m, and spaced at 8 m intervals in the main rack. In Sitka spruce, the expected volume loss with this pattern would be approximately 6–8 cu m per ha. Where the main racks were created by the removal of two adjacent rows the volume loss would be approximately 2 cu m greater per hectare. This assumes an original plant spacing of about 1·8 × 1·8 m. Similar thinning in a more widely spaced plantation would result in greater losses.

Where combinations of line and selective thinnings are used there will be a loss in volume associated with the line thinning element, and this will broadly be related to the proportion of the area affected by the line thinning.

In a comparison of line and selective thinnings of the same weight, i.e. the same volume per hectare removed, and given that the selective thinnings are predominantly low, the average diameter of the trees removed will be less than with line thinning, although more trees will be removed in the process. The result is that the average diameter of the main crop after line thinning is less than after selective low thinning, and this feature persists throughout the life of the crop, assuming that further selective thinnings are broadly similar in each case.

Yield models have been prepared by the Forestry Commission's Research and Development Division to show the total effect of line thinnings in terms of both volume production and diameter growth for a range of species and yield classes. The models have been used in Part VII which considers economic aspects. They will be published in the near future and will be available from the Publications Officer at address on page 26.

IV CROP STABILITY

The incidence of wind damage in a plantation is, in the first instance, dependent on the occurrence of high wind speeds and their frequency. The stability of the crop is dependent on the crop structure and on site conditions, both of which are influenced by thinning.

Crop structure

Wind damage may be induced by both:

a. the steady pressure resulting from a high mean wind speed and,
b. the irregular force of gusts which cause shaking of the trees.

If the crop structure is such that less wind is allowed to penetrate the crop so that the mean wind speed is reduced, then less damage will occur. If branch contact is kept at a maximum, thereby restricting tree movement, the incidence of damage caused by gusting can be reduced.

It follows, therefore, that minimal damage may be expected with an unthinned crop where the dense, relatively smooth, canopy allows little wind penetration and where the closed canopy allows little movement of individual trees. The effect of thinning is to increase the air movement within the stand and, by altering the roughness of the canopy to induce wind flow patterns which cause gusting. At the same time the removal of trees decreases branch contact between remaining trees and consequently permits more tree movement. The importance of these effects is dependent on the weight of the thinning and the type or pattern of thinning. For example, a strict low thinning of average intensity will leave an evenly spaced main crop with an upper canopy surface largely unbroken, so that a high degree of branch contact is maintained. On the other hand, where line thinning is used, trees of all canopy classes are removed and regularly spaced breaks are created throughout the upper canopy. In these circumstances, the wind may penetrate to the full depth of the crop, increasing the mean wind speed within the stand. In addition, the roughness created in the upper canopy results in wind flow patterns that produce more frequent, shorter gusts. Branch contact is markedly reduced and so a greater movement of individual trees is permitted. The net result is to place the crop at a much greater risk than with selective low thinning.

The depth of penetration of the wind is related to the size of the gap created parallel to the wind direction. It follows therefore that the removal of two rows rather than one will result in higher mean wind speeds within the crop. The same effect will be the result of larger gaps brought about by rack junctions within a crop, or rack outlets onto roads. So long as the gaps in the crop remain, the crop is at a greater risk. The highest risk occurs immediately after thinning, but declines as the canopy closes.

Soil moisture

Where the canopy is complete, some 20 to 30 per cent of the rain falling on a stand is intercepted by the canopy and never reaches the ground. The effect of thinning is to permit a higher proportion of rainfall to reach ground level. In this connection, it is probable that a line thinning allows more water to reach the soil than does a selective low thinning of the same weight. In addition, there is a slight reduction in the amount of water which is taken up by the crop in line thinning where some of the more vigorous trees have been removed. Evaporation resulting from an increase in the air movement through the crop fails to compensate for the increase in throughfall and lower uptake. Once again the larger the gaps created, the longer it takes the canopy to close and reach peak interception. The resultant increase in soil moisture in a line thinned crop can have detrimental effects on the crop stability in soils where rooting depth is limited. Surplus of soil moisture acts in two ways. In places where drainage is impeded by clay soils, ironpans or indurated layers, the surplus water generally lacks oxygen and the finer root system may be destroyed, thus reducing the root contact with the soil. Secondly, in addition to reducing the physical strength of the soil, particularly on soils with high clay content, the water can act as a lubricant to the lateral movement of trees once they begin to rock. Excess moisture above the mineral layers in a peaty gley soil increases the possibility of peat layers shearing away from the mineral layers when under stress from a rocking tree crop. In conclusion, with certain soil types, line thinning by increasing soil wetness may decrease the crop stability relative to selective low thinning.

Ploughing

Most crops approaching the production stage have been established on closely spaced, single-furrow ploughing. This tends to induce root development parallel to the furrows and so in relative terms, stability at right angles to the ploughing direction is reduced. The importance of branch contact in this direction is obvious. The effect of row thinning is to impair stability in the most vulnerable direction, thereby increasing the risk of wind damage.

Observed wind damage.

Observations of wind damage have been made by the Forestry Commission in experiments specifically designed to investigate this aspect of thinning. Information has also been collected from surveys of wind damage in specific forests or where records of damage have been maintained. In addition, experience in other countries has been considered.

First, experimental evidence has shown that line thinning has resulted in some two to four times the damage per hectare experienced in areas thinned selectively at about the same intensity. The relative damage varies greatly between sites and this is mainly explained by variations in important site factors.

Secondly, it has been observed that as the crop gets taller, the hazards associated with it increase, so that where first thinning is delayed the risk of damage is greater.

The third feature to emerge from these observations concerns the size of trees blown. In unthinned plantations a high percentage of dominant trees tend to be windthrown. With selective low thinning there is a greater range in sizes of trees thrown, but again larger trees tend to predominate. With line thinning the trees are distributed equally among all sizes of trees.

Fourthly, where soils are exceptionally wet, greater wind damage has been observed. Finally, and perhaps of greatest importance, there is little question that the starting points for damage are points where gaps have been created in the canopy. Typical examples are:

a. in extraction racks in selectively thinned stands,
b. at junctions of racks particularly where two racks join the main rack at the same point, as in chevron thinning,
c. where racks join roads and,
d. in stands adjoining areas which have been clear felled.

Conclusion

Line thinning results in a less stable crop than does selective thinning mainly as a result of its detrimental effects on the structure of the canopy. The importance of this is very dependent on site conditions. Thus, on a high elevation site which is severely exposed, with regular high wind speeds, and where soil type impedes drainage and markedly restricts rooting, it would be unwise to contemplate line thinning. On the other hand, on sheltered, low elevation sites where wind speeds are comparatively low and where the soil is free draining allowing unrestricted rooting depth, the effect of impaired stability could be discounted and line thinning used.

Where site conditions fall between the extremes represented by the above examples it becomes more difficult to decide whether or not to use line thinning. A system of classifying the windthrow hazard of a particular site is outlined in Appendix A. This, in conjunction with the economic analysis described in Part VII, can be used to assist decision making.

V RISKS OF DAMAGE TO STAND AND SITE

Extraction damage

If the same system of harvesting were used in both selective and line thinnings, it could reasonably be argued that the amount of damage in a crop would be reduced by line thinning, mainly because the produce is concentrated in what is by definition the extraction route. In particular, with row thinning, maximum space is created per unit volume removed in thinning and consequently the possibilities of causing damage to adjacent trees are minimised. This is less true with chevron patterns where trees at the junction of main racks and side racks tend to suffer a higher incidence of damage, but for any particular harvesting system, this damage in total is not likely to exceed that which can be expected with selective thinning.

Line thinning, however, facilitates the use of large, heavy, harvesting machines which may not be feasible with selective thinning, so that a higher incidence of damage can be expected where these machines are employed. Damage may be through direct injuries to the tree which may ultimately affect the timber quality, or as a result of decay fungi gaining access to the trees through the damaged tissues.

Direct damage

With large skidders, or forwarders, damage to adjacent trees can be expected from safety frames, bolsters, bunks, or cranes. In addition, the effects of wheels or tracks on heavy machines may be to cause considerable root damage, although the critical factor here is ground pressure per unit area rather than gross weight. The damage is obviously related to the number of passes made through any one lane or rack. The retention of the brash on the extraction route has a moderating influence on the damage which would otherwise occur.

Fungal infections

Two fungi which create problems following harvesting operations are *Stereum sanguinolentum* and *Polyporus stipticus.* Both are vigorous, decay-forming fungi and can usually be expected to infect a proportion of the extraction wounds. However, as with the case of direct damage to trees, this problem is related more to the choice of harvesting machinery than to the thinning. The species is important in that Norway spruce, Sitka spruce and larch are most susceptible species (in that order), while pine and Douglas fir seem to suffer negligible damage. Decay arises much more frequently from stem than from root scars, and is more serious where the wood tissue is fractured than where the bark is removed without breaking the wood tissue.

Protection of stumps against infection by *Fomes annosus* is provided by the application of either urea or a solution containing the competing fungus *Peniophora gigantea.* In the case of urea, any subsequent damage to stump in the process of extraction may remove the protection which urea provides. In row thinning, the chances of this happening are marginally higher than with selective thinning in that the vulnerable stumps are frequently central to the extraction route. With other forms of line thinning this problem is not likely to be of any more significance than in selective thinning. The problem also becomes of less significance as the period elapsing between felling and extraction increases.

Effects on soil

Some forms of line thinning may cause greater exposure of the ground surface than would be the case with selective thinnings. It has been mentioned in Part IV that this may cause a higher proportion of rainfall to reach the soil and consequently increase the moisture content of the soil, which may in turn affect the soil structure and the ease with which it is compacted. It is unlikely, given the relatively short exposure period, that any serious leaching of nutrients will occur, nor can the minor effects on the humus layer be expected to be of any real importance in practice.

Once again the main concern with line thinning, insofar as soil properties are concerned, rests not so much with the thinning but with the means of harvesting. Heavy machines may cause compaction and soil breakage which is, in effect, the tearing of the humus layer. The degree to which these effects arise depends on the number of machine passes and the ground pressure of the machine. In most parts of Britain, soil breakage is no serious problem but some soils may be damaged by compaction, the most vulnerable being those in high rainfall areas which are also finely textured; i.e. contain more than 30 per cent clay, silt, and fine sand. Such soils in low rainfall areas may be compacted if traversed when wet. It is not yet known what the effect of compaction is on the subsequent growth of the crop, but what evidence there is suggests that it cannot be dismissed entirely. There are also notable differences between species according to the root characteristics. for example, spruce is invariably affected more than pine.

Damage by snow and ice

Ice and snow damage is generally of minor importance in this country, although snow damage can be of some importance in some localities, Pine, particularly heavy-crowned, South Coastal provenances of Lodgepole pine, appear to be at greater risk than spruce. Experience in other countries has shown that line thinned crops suffer greater damage than unthinned or selectively thinned crops. There is not yet enough evidence in this country to establish probabilities of damage in terms of locality or thinning type, but forest managers will, to some extent, be able to judge the importance of snow or ice damage on the basis of previous experience.

Visual effects of line thinning

In woodlands which are prominent in the landscape most forms of line thinning are visible, owing to the creation of regular patterns of thinned lines. The effects are most apparent in row thinning and become more evident as the number of adjacent rows removed increases. Cutting the lines obliquely to the contours reduces their impact, particularly where it is possible to make slight variations in angle and spacing; but opportunities for so doing may be limited by considerations of operator safety and damage to the remaining crop. Chevron, and in particular staggered chevron thinnings, tend to give an irregular edge to the thinned rows which reduces the visual impact. Since line thinning is likely to be followed by selective thinning for second and subsequent thinnings the visual effect may not be prolonged, especially in fast growing crops. Nevertheless, careful consideration should be given to the visual effects of the use of line thinning in highly sensitive landscapes.

VI HARVESTING

To a large extent, the choice of harvesting system dictates the patterns of line thinning which are possible. Certain patterns of line thinning can, however, accommodate quite different harvesting systems.

The choice of harvesting system will be dependent on a number of factors, notably terrain, but also on the end-product of the harvesting operation and the availability of machines. The thinning patterns which will accommodate four different, but commonly used, harvesting systems are considered below.

a. *Pole length harvesting by ground skidder.* Row, strip or chevron patterns of line thinning can be used with ground skidding systems.
b. *Shortwood harvesting by forwarder.* The same options are open to this form of harvesting as in a.
c. *Pole length harvesting by cable crane.* The only pattern of line thinning which has proved economic for cable crane extraction is some form of chevron or staggered chevron pattern. Most other forms of line thinning have proved to be inefficient in terms of the volume available for each set-up of the system.
d. *Shortwood harvesting by cable crane.* As for pole length harvesting by cable crane.

Pole length harvesting by ground skidder

Layout

The simplest pattern is row thinning and in many cases it will usually be possible to use single row removal. This, however, depends on the spacing in the plantation and on the size of the machine. Close spacing, or a large machine, may require the removal of two adjacent rows. Strip thinning may be used where the direction of the planted rows proves unsuitable for extraction. It is worth noting that strip thinning requires a greater number of trees to be felled per unit length of rack in order to achieve the same minimum rack width. A suitable chevron pattern would be to have main racks between 20 and 40 m apart, side racks at intervals of 7·5–10 m in the main rack and at angles of 35–45° to the main rack. The minimum width of side rack would be about 2 m.

Of the above mentioned patterns, row thinning tends to be least flexible and in the longer term may prove, in certain circumstances, a disadvantage. It has already been stated that double row removal increases the risk of windthrow and leads to a greater loss of increment. These factors, particularly on less stable sites, will tend to favour the removal of every second or third row. It is prudent, however, to consider the method of extraction to be employed at subsequent thinnings. If, for example, it is expected that forwarders are to be used, the rack width which may be adequate for a ground skidder may prove inadequate for a larger machine.

Where every third row has been removed at first thinning using a small ground skidder, access for a larger forwarder at the second thinning may only be gained by one of two undesirable alternatives. The first would be to remove one of the two remaining rows which would almost certainly do unacceptable damage to the long term potential of the crop. The second possibility would be to cut new access racks angled across the rows, which might again be deterimental to the crop, might also present physical difficulties, and would defeat

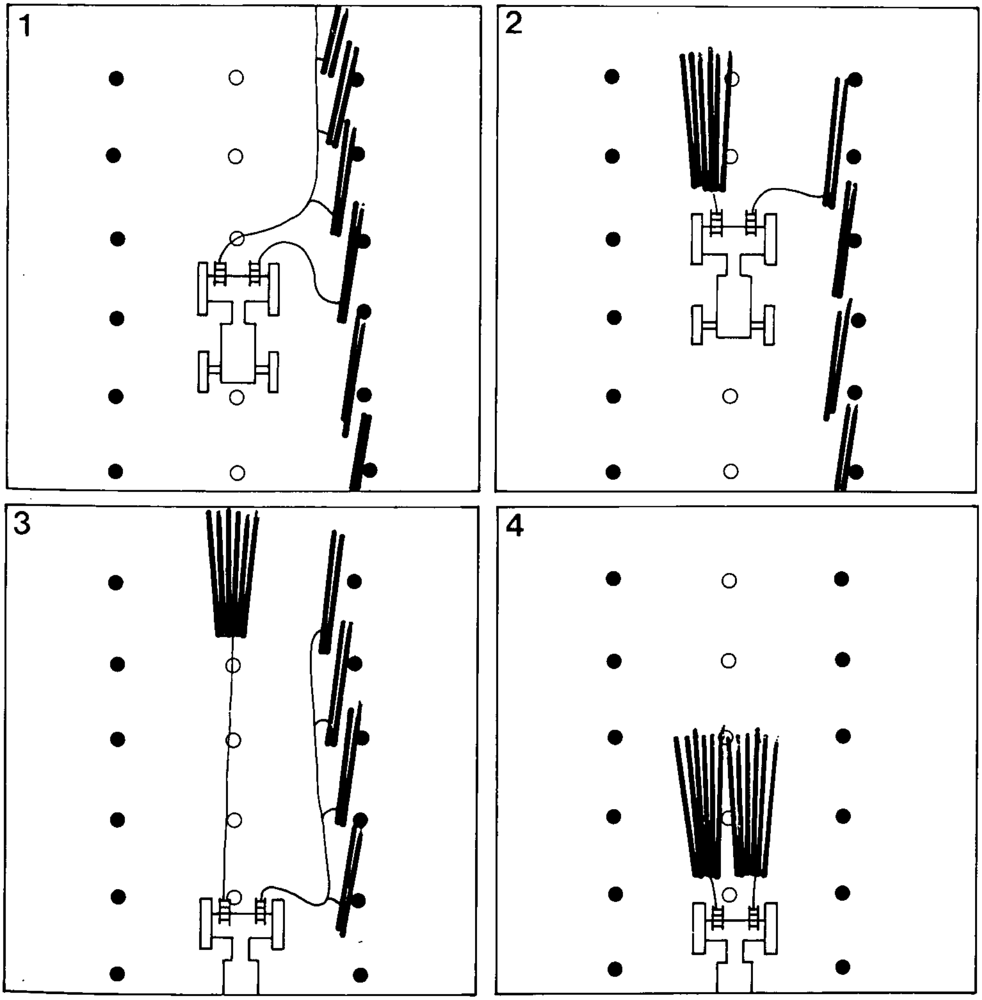

FIGURE 2 Single row thinning: sequence of extraction by ground skidder.

one of the objectives of the first thinning, the provision of access.

Felling

Normally, in felling for pole length extraction, small poles are extracted tip first and so felling should be done to facilitate this. With single row thinning, trees should be felled as close as possible to one side of the rack so that during snedding the brash falls to that side and the top is cut off and piled also on the same side, although on soft ground it may assist extraction if the brash is spread across the rack. The tip of the pole should then be removed to the opposite side of the rack. The pole is then turned and snedding is completed. It is helpful to stack smaller poles, of less than, say, 0·05 cu m by bringing their tips together, making chokering easier.

In double row thinning a similar method should be used for each row felled so that the brash and tops are piled on either side of the rack and the pole tips are clearly visible in the centre. Poles from each row should be brought together but not mixed with poles from the other row, and with tips positioned between the two felled rows. This prevents log jam during extraction.

For chevron thinning, main rack trees should be felled as appropriate for single or double row thinning. Side rack trees should be felled and presented in a manner similar to single row thinning with the brash being piled on the side of the rack nearest the direction of extraction. On steep slopes brash should be piled on the lower side of the rack. The brash acts as a cushion between the poles being extracted and the remaining trees. Congestion caused by the poles and the brash at the rack junctions may be reduced by felling and extracting main rack trees before side rack trees are felled.

Extraction

There is considerable variation in the types of machinery and equipment currently used for extraction in Britain. Load sizes also vary and depend upon the type of machine in use and the operating conditions. Single row thinning means collecting a full load from a relatively long length of rack and is consequntly more costly than other forms of line thinning. With a grapple skidder poles are extracted butt first. With winch skidders, preferably fitted with a double drum winch, tip–first extraction is recommended. It is helpful to estimate, in the first instance, the number of poles required to make up an optimum load. The tractor should then be driven in to the rack passing half this estimated number of poles. As shown in Figure 2, these poles should then be chokered to one winch rope (making half the load) and winched in to the tractor. The tractor proceeds along the rack passing the second half of the load with both ropes running free. This part of the load is chokered and both ropes winched to the tractor. The use of polypropylene rope chokers and detachable choker hooks is recommended. With double row thinnings the above procedure can also be used though it is usual to choker both halves of the load from the same part of the rack. Because of the extra space a larger tractor could be used and the average load increased accordingly.

In chevron thinnings, if the main racks are extracted before the side racks are felled, the extraction sequence would be as for row thinning and the side racks would be extracted later with one winch rope for each side rack. There is a marginal improvement in output with this system.

Shortwood harvesting by forwarder

Layout

In the case of chevron thinning, main racks should be only 15–20 m apart depending upon the size of trees and the product mix. The critical factor here is the weight of each piece and the distance it may be carried in order to produce a grapple load accessible to the forwarder. This distance should not average more than 5 metres. The angle of side racks in this case is much less critical and indeed can be a right angle, in this way minimising the carrying distance to the main rack.

Felling

Felling and snedding operations for shortwood extraction are similar to pole length working except that in this case poles are cross-cut at stump and stacked. All the billets should be laid the same way and the stacks should lie at right angles to the rack avoiding the base of standing, dominant trees so as to avoid unnecessary damage by the forwarder grab. All stacks should be free from brash and can be up to about 0·5 cu m in size, but the size depends on the type of produce and the capacity of the grab. Different products should be stacked separately. Billets which are too heavy to carry should be dragged or winched if possible to within reach of the forwarder grab (or cable crane).

Extraction
As in selective thinning the forwarder is confined to the main rack. It should travel into the wood along an empty rack and gather its load on its way out along another rack. Alternatively it may be possible, when using certain forwarders now available, to reverse directly into and along the rack. Full use of cross racks should be made wherever possible. Different products should not be mixed on one load unless separated by bolsters on the machine in order to prevent difficulties in unloading and sorting at the landing.

Pole length harvesting by cable crane

Layout
Main racks require to be a minimum of 3 m wide and must be straight. For uphill extraction main racks should be 40 m apart with side racks up to 30 m long at an angle of 35–40°. For downhill extraction main racks should be closer, up to 35 m apart with side racks up to 24 m long at similar angles.

Felling
Felling for pole length extraction by cable crane is similar to that described above for ground skidder using chevron thinning patterns. There is no advantage in this case in felling and extracting main racks before felling side racks.

Extraction
Average load in chevron thinning can usually be in the region of 0·4 cu m to 0·6 cu m which is larger than might be expected with selective thinning using the same extraction system. It is best to use only a single or double tag line. Some form of pre-chokering of suitable tag lines is desirable for efficient working, before the carriage returns for the next load.

Shortwood harvesting by cable crane

Layout
Main racks should be about 24 m apart. The angles of the side racks of the chevron are less important with shortwood harvesting. On sloping areas where timber has to be extracted to a road at a lower level, chevron patterns must be inverted so that the side-racks lead slightly upwards across the slope to the main-rack. This is necessary to overcome a problem of load 'snagging' which would occur in situations where the side-racks lead downwards across the slope. It is possible to use a form of row thinning with shortwood extraction using one row as a main rack with short interconnecting racks at right angles. It should be noted that rack layout for shortwood harvesting is sometimes incompatible with that required for pole length harvesting and so it is not a simple matter to change from using one system at one thinning to the other system at a later thinning.

Felling
The requirements are similar to those for forwarder working, described above, except that stacks should be presented on a bearer for ease of chokering and pointing in the direction giving easiest access to the rack.

Extraction
Average loads of pulpwood should be about 0·35 cu m. The use of tag-lines will reduce terminal time. Sawlog loads can be maximised using hooks and polypropylene chokers.

Costs

Apart from savings in brashing costs, the only advantage of line thinning compared with selective thinning is that harvesting costs are lower. So far as felling is concerned, there is a small reduction in the 'take-down' time which produces a small cost saving. The magnitude of this saving depends very much on the species, the mean tree size and site conditions, and it is not possible to provide data on this which is generally applicable.

In fact, comparison between felling costs in line thinned and selectively thinned stands, where other conditions are the same, is often unrealistic in that brashing is unnecessary for line thinning but essential to some degree for selective thinning. Comparisons of felling costs of line thinning in unbrashed crops with selective thinning in brashed crops show that there is relatively little difference between the two. Such differences as do exist usually tend to favour line thinning, but as they are insignificant no account is taken of them in the economic analysis in Part VII.

Differences in extraction costs are reasonably well established. Of course, in this case also, the influence of the method of extraction, the mean tree size, the volume removed per hectare and the site conditions all cause very substantial variations in unit costs. Insofar as it is possible to generalise, extraction costs of single row thinning, where pole length extraction by ground skidder is employed, is in the region of £1 per cubic metre (1979 costs) less than that of selective thinning. The difference is marginally greater where double row or chevron thinning is used. In the case of cable cranes, whether shortwood or pole length, the differences are slightly less and can be expected to be in the region of £0.7 to £0.8 per cubic metre. On the other hand, there is little difference in the cost of extraction of shortwood using a forwarder between chevron thinning and selective thinning (of equal weight). With single row removal where it is possible to employ a forwarder the extraction costs can be expected to be greater than with selective thinning, on account of the lower volume of produce for a given distance travelled by the machine.

VII ECONOMIC ASPECTS

In deciding whether to use line thinning or selective thinning, it is advisable first to consider the various factors involved in each situation, to quantify their effect in economic terms so far as this is possible, and thereafter to compare the net benefits of the two alternatives.

It is only necessary to consider those items of costs which are different in each of the options. Items which are common to all the options can therefore be ignored. The major quantifiable differences, in costs and revenues, between line thinning and selective thinning are as follows:

a. differences in costs of brashing and marking thinnings.
b. differences in discounted revenue arising from differences in volume production and average tree size.
c. differences in harvesting costs.

These costs and returns occur at different times and, in order to make comparisons, it is necessary to discount or compound these values to a common date, in this case the age of first thinning. A discount rate of 5 per cent per annum, which is the test discount rate used by the Forestry Commission, has been used in the example which follows. Values are given in terms of £(1979). Table 2 below shows the discounted or compounded costs of brashing and marking a selectively thinned and a line thinned crop of Sitka spruce. In this example the line thinning is done by the removal of every third row. It is also assumed that by the third thinning, the costs of marking are similar for both crops. The discounted costs of brashing and marking in spruce are shown to be £82/ha more for selective thinning than for line thinning.

The volume production losses associated with line thinning were considered in Part III but the effect on the discounted revenue depends not only on the volume but also on the average tree size. Since the average size of trees removed in a line thinning is greater than that removed from a conventional selective thinning the revenue obtained is greater. Conversely at later thinnings and felling the average size of tree and hence revenue will be greater in a crop which was selectively thinned at first thinning. Yield models for a variety of species and yield classes have been produced incorporating differences in volume production and average tree size for a range of line thinning patterns and for selective thinning. The total effect on revenue is obtained by using an appropriate price/size relationship which converts the timber yields into a set of revenues which can then be discounted to a common point in time using the selected discount rate, and summed to produce a total discounted revenue. As the appraisal is sensitive to the values ascribed to first thinnings, these are considered separately. The first step is to calculate the net revenue produced from the volume

Table 2 Brashing and marking costs

		Selective thinning		Line thinning	
Operation	*Year relative to age of 1st thinning*	*Cost £/ha*	*Discounted/ compounded to age of 1st thinning*	*Cost £/ha*	*Discounted/ compounded to age of 1st thinning*
Brashing	−1	60	63		
Marking 1st thinning	0	15	15		
Marking 2nd thinning	+5	15	12	10	8
Total discounted costs			90		8

Table 3 Difference in net revenue from first thinning

Sitka spruce yield class	10	12	14	16
Age of 1st thinning	26	24	22	21
Line thinning				
Volume* removed (cu m/ha)	33	36	38	42
dbh (cm)	12·0	12·3	12·5	12·9
Surplus price (£/cu m)	4·3	4·6	4·7	5·0
Revenue (£/ha)	142	166	179	210
Selective thinning				
Volume* removed (cu m/ha)	30	36	42	48
dbh (cm)	9·7	10·0	10·2	10·6
Surplus price (£/cu m)	0·9	1·9	2·2	2·6
Revenue (£/ha)	27	68	92	125
Difference in revenue (£/ha)	+115	+ 98	+ 87	+ 85
Difference in harvesting costs assuming saving of £1/cu m by line thinning (£/ha)	+ 33	+ 36	+ 38	+ 42
Total difference in net revenue (£/ha)	+148	+134	+125	+127

*To allow for unproductive areas, this volume is 15 per cent less than that appropriate for a fully stocked stand.

removed and on average tree size, expressed here as diameter at breast height (dbh). The 'surplus price' per cubic metre is the sale price of the timber less the cost of harvesting which is taken to be that appropriate to selective thinnings. The harvesting cost also includes labour 'oncost' which covers holidays, sickness, and wet time. Next, adjustment is made for the difference in harvesting costs (Table 3) between line thinning and selective thinning.

Table 4 Revenue excluding first thinning, discounted to age of first thinning

Sitka spruce yield class	10	12	14	16
Line thinning (£/ha)	1063	1316	1565	1853
Selective thinning (£/ha)	1131	1396	1641	1931
Difference	−68	−80	−76	−78

Table 5 Net benefit from line thinning

Sitka spruce yield class		10	12	14	16
Savings in brashing and marking costs	(£/ha)	+ 82	+ 82	+ 82	+ 82
Net revenue from 1st thinning	(£/ha)	+148	+134	+125	+127
Revenue excluding first thinning	(£/ha)	− 68	− 80	− 76	− 78
Total net benefit from line thinning	(£/ha)	+162	+136	+131	+131

Table 4 shows the difference in net discounted revenue of second and subsequent thinning and final felling in line thinned and selectively thinned crops. It has been assumed that a second and subsequent thinning the difference in harvesting costs between an initially line thinned (unbrashed) crop and a selectively thinned (brashed) crop will be negligible. For more extreme forms of line thinning the revenue will be further reduced. Bringing all these differences together the net benefit from line thinning is shown in Table 5.

It can be seen from these figures that there is a considerable net saving to be gained from line thinning over the range of yield classes shown above. However, no allowance has been made for the less quantifiable disadvantages of line thinning, namely, landscape considerations, damage to stand and soil and most important, the effect on stability. Where windthrow is a major hazard then there is an increased risk of the rotation length being shortened and a greater possibility of additional costs being incurred and in harvesting windthrown trees. Precise information on the degree to which line thinning increases the risk of windthrow is not yet available, but as a rough rule of thumb it has been estimated that when comparing line and selective thinnings the discounted revenue for a line thinned crop should be reduced by about 2 per cent for the most stable site, i.e. Windthrow Hazard Class I (see Appendix A), and a further 2 per cent for each increase in Windthrow Hazard Class. With more extreme forms of thinning, for example double row removal, multiples of 3 per cent are more appropriate.

Thus for a Sitka spruce crop of Yield Class 12 on a site of Windthrow Hazard Class V, the discounted revenue of the line thinned crop should be reduced by 10 per cent. The total discounted revenue of the thinning is made up of the following:

a. Net revenue of crop excluding first thinning £1316/ha
b. Net revenue of first thinning £166/ha
c. Additional revenue from savings in harvesting £36/ha

Total £1518/ha

Since 10 per cent of this total (£152/ha) exceeds the other benefits of line thinning £136/ha) then in this situation it would be advisable to adopt selective thinning.

VIII CONCLUSIONS

Line thinning has both advantages and disadvantages when compared with selective thinning. The advantages result from cheaper harvesting and from savings in the cost of brashing. The main disadvantages arise from losses in volume production and from reduced stand stability. In any particular situation, the use of line thinning will be appropriate if the advantages outweigh the disadvantages.

On some sites which are recognised as being extremely susceptible to windthrow, e.g. Windthrow Hazard Class V or VI, then line thinning should not be contemplated. It is usually the case on sites which are wind firm, i.e. Windthrow Hazard Class I, that line thinning will yield net benefits and will therefore usually be adopted. On sites which are not in these categories the decision will depend on more than this single factor and it is advisable therefore to assess rather more carefully both the favourable and unfavourable aspects of using line thinning in a particular crop.

The first stage is to decide on the pattern of line thinning to be compared with selective thinning. This will in turn depend on the harvesting system employed. Terrain will be the main determining factor if a choice of equipment exists. Cable cranes will usually be employed on slopes greater than about 40 per cent (22°). Ground skidders or forwarders will normally be selected for lesser slopes but other factors such as roughness and wetness may influence the choice on marginal slopes.

The only recommended pattern of line thinning for cable crane operations is a chevron pattern. Detailed recommendations are given in Part VI. Chevron, row, or strip thinning patterns may be used with ground skidders and in economic terms there appears to be no marked advantage of one over another. Since there is usually little difference in costs of harvesting between line thinning and selective thinning with forwarder extraction, it follows that selective thinning (with, of course, necessary racks) will usually be favoured in this case. Where line thinning is used with forwarder extraction, the best pattern will be a form of chevron as described in Part VI.

Two further points should be borne in mind when considering the pattern to be used. The first, as noted in Part VI, is the need to consider the method of extraction which may be used at subsequent thinnings and consequently to avoid using a pattern which may have immediate advantages with the equipment currently available but which might prove disadvantageous with different equipment. The second point arises where the machinery employed requires two or more adjacent rows to be removed in row thinning or where an extreme form of chevron thinning is used. In these cases the volume increment losses are greater and the risk of windthrow is increased.

Having selected the most suitable line thinning pattern, the decision on whether or not to use it should be determined by carrying out an appraisal of the alternatives of line thinning and selective thinning so far as available information permits, and along the lines suggested in Part VII.

It is beyond the scope of this leaflet to provide all the information necessary to carry out a detailed economic appraisal in every situation where line thinning is considered possible. In any case there are gaps in the knowledge of the effects of line thinning which preclude that possibility. Nonetheless, it is possible to make a reasonable evaluation of the alternatives of line and selective thinning in conditions other than described in the specific example given in Part VII. That example refers to Sitka spruce. Certain items in the calculation will vary according to species. Brashing costs, for example will be rather different in other species. The differences in revenues between line and selectively thinned crops given in the example will be broadly appropriate for most commercial species. Regarding the susceptibility of different species to windthrow, it is probably fair to assume that on the more stable sites, species is of little consequence. On sites of high windthrow hazard, differences can be expected between Sitka spruce and Lodgepole pine. The latter is more windfirm on deep peat, the former more so on shallow peats and peaty gleys. These differences can be accommodated by using a Windthrow Hazard Class one higher or lower, than otherwise indicated.

Some factors are not easily quantified and the importance attached to them is a matter of judgement. A good example is the visual effects of line thinning. In highly sensitive landscapes, this must be given careful consideration in appraising the alternatives of line and selective thinning.

In conclusion, line thinning can prove to be a troublesome technique on inappropriate sites, but if used with the correct pattern in the right situation it can prove rewarding.

APPENDIX A

WINDTHROW HAZARD CLASSIFICATION

The windthrow hazard of a site is a measure of the susceptibility of a stand on that site to windthrow by gales of regular occurrence. The classification is related to endemic damage and not to catastrophic damage caused by winds over Beaufort force 9, as for example the January gales of 1968 and 1976. The hazard class of a site is estimated on a point system, scoring for four site-related factors, and summing the points. They are:

a. *Wind Zone* (Figure 3 on page 20). The zonation has been derived from an analysis of tatter flag results for Scotland and the North of England, and extended to the rest of the country using extreme wind values from the Meteorological Office Climatological Memorandum Number 50A.

Wind zone	2	3	4	5	6	7
Score	11·0	9·5	7·5	2·5	0·5	0

b. *Elevation above sea level (m)* Windthrow hazard increases with elevation. The effect does not, however, appear to be linear; altitude having only a limited effect up to about 170 m but thereafter a rapidly increasing effect up to altitudes of about 400 m.

Elevation m	0–60	61–140	141–190	191–225	226–255	256–285	286–315	316–360	361–405	406–465	466–540	541+
Score	Nil	0·5	1	2	3	4	5	6	7	8	9	10

c. *Exposure* Exposure is always difficult to assess. Subjective assessments are suspect and 'Topex' is probably the best method of obtaining an objective assessment in the field. It is a method of estimating exposure by using relative elevation. An assessment for a particular locality is made by measuring the angle of inclination of the horizon (skyline) at the eight major points of the compass and adding the eight angles to give a 'Topex' value. The lower the value the higher the exposure. When looking out to sea 0° should be used, i.e. 0° = fully exposed.

Topex Total°	0–9	10–15	16–17	18–19	20–22	23–24	25–27	28–40	41–70	71–100	101+
Score	10	9	8	7	6	5	4	3	2	1	0

Where Topex maps are available the following scores should be used —

	Topex Total	*Score*
Severely exposed	(0–10)	10
Very exposed	(11–30)	7
Moderately exposed	(31–60)	3
Moderately sheltered	(61–100)	1
Very sheltered	(101+)	0

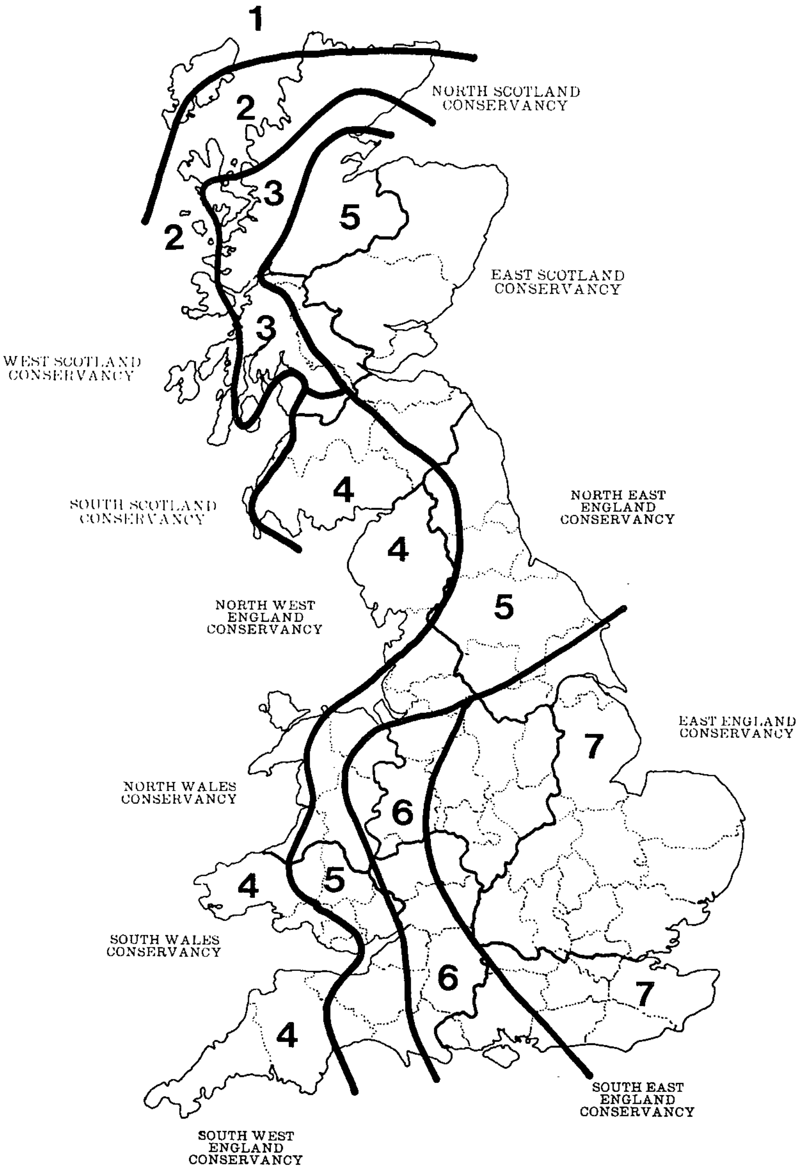

FIGURE 3 Map of Wind Zones in relation to Conservancy and Local Authority boundaries.

In the absence of Topex values, subjective assessment should allow for topography only, without regard for local climate which is already covered by the scores for 'Wind Zone' and 'Elevation'.

d. *Soil Type* The stabilising effect of the soil, especially through rooting depth, is equivalent in importance to each of the climatic factors.

Rooting and soil type	*Score*
Rooting unrestricted; trees rooting substantially to 45+ cm; soils usually free-draining, e.g. brown earths, intergrades to ironpan soils	0
Rooting restricted, but some evidence of substantial root penetration in excess of 25 cm, e.g. deep peats (45 cm); loamy gleys	5
Rooting very restricted. Clay gleys — with or without peat, e.g. surface water gleys. Peaty gleys.	10

Unless there is clear evidence to the contrary, soils subject to waterlogging should always be scored as 10.

Soil complexes
When soil maps are available and scoring is being carried out on a compartment basis, several soil types may be present in one compartment. A mean score should be used, weighted subjectively by the area of each soil type present. Soil Survey of Scotland maps in some instances use series names for complexes; it is then necessary to ascertain the soil types and proportions involved, e.g. Galloway area, Minnoch series consists of 25 per cent ironpan; 25 per cent surface water gleys, peaty gleys; 50 per cent deep peat; score 7·5.

Windthrow Hazard

The individual scores for (a) to (d) are added together and reference to the following table indicates the hazard class. Top heights at the onset of windthrow refer to regularly and selectively thinned spruce stands, planted either without ploughing or on ground ploughed with adjacent furrows generally 2 m or more apart.

Hazard class	*Score range*	*Top height (m) at onset of windthrow*
I	8·0	25
II	8·0 – 13·5	22
III	14·0 – 19·0	19
IV	19·5 – 24·5	16
V	25·0 – 30·0	13
VI	30·5 +	10

APPENDIX B

STANDING SALES

The volume of the marked trees in selective thinnings is normally assessed by the tariff system of measurement (Forestry Commission Booklet No 36 or No 39). This requires easy access in order to mark the trees, which in turn implies the need for a sufficient amount of brashing. In line thinning the pattern can be defined adequately without any marking. As is evident in Part VII, the fact that brashing need not be done in line thinning is a very strong factor in favour of its adoption in practice.

Although to some extent dependent on the pattern of line thinnings used, it is possible to assess the volume of a line thinning using a modification of normal tariffing procedures. This usually means sampling a number of the marked lines, thereby minimising the degree of brashing that is required for access. Brashing may be avoided entirely however if some method of felled measurement is adopted. Methods of measurement which will be appropriate according to the quantity and the nature of the products are given in Forestry Commission Booklet No 39. The only difficulty in this situation is in providing enough supervision in order to ensure that all timber removed from the area is measured beforehand.

APPENDIX C

THINNING CONTROL

1. The objects of thinning control are broadly:
a. to maintain volume production
b. to obtain maximum profitability
c. to ensure a regular supply of material from thinnings — insofar as these objectives are compatible with one another.

Failure to control thinnings can result in:
a. over-cutting, which in turn leads to a loss in volume production
b. under-cutting, i.e. overstocking, which depresses the mean diameter and hence the value increment
c. an erratic flow of timber to the consumer.

The principles of thinning control are outlined in Forestry Commission Booklet No. 34 *(Forest Management Tables)* and will be published as a prefix to the Yield Models mentioned on page 6. In addition, Forestry Commission Booklet No. 32 *(Thinning Control in British Woodlands)* considers the practical aspects of control in some detail. This appendix is specifically concerned with thinning control when various forms of line thinning are used.

2. The thinning intensity recommended for Forestry Commission plantations is defined in terms of an *annual* thinning yield. This is calculated as 70 per cent of the Yield Class of the crop, and applies throughout the thinning period which is described for each Yield Class of each species in Forestry Commission Booklets Nos. 32 and 34. Thus a stand of Sitka spruce, YC 16 will have an annual thinning yield of $16 \times 70/100 = 11{\cdot}2$ cu m/ha starting at age 21 and continuing at this level until virtually the last thinning prior to clear felling.

3. The volume to be removed at one thinning (the thinning yield) is normally the product of the annual thinning yield and the proposed cycle. So that for SS YC 16, if the proposed thinning cycle is 5 years then the thinning yield will be $5 \times 11{\cdot}2 = 56$ cu m/ha. The cycle can be varied within reasonable limits without any detrimental effects on the crop. The manager therefore has a choice of either removing a large volume on a long cycle or removing a smaller volume on a shorter cycle. If the **cycle** is of greatest importance then this can be fixed and the thinning yield adjusted accordingly. Conversely, the manager can fix the **thinning yield** and adjust the cycle if the size of the thinning yield is considered to be of greater importance.

4. With selective thinnings it is perhaps more usual to fix the cycle and adjust the thinning yield. In line thinnings, however, it is not always practicable to control the thinning intensity by making precise adjustments to the thinning yield in the same way. (Para 11 below). Furthermore, the harvesting method may impose sizeable constraints on the possibilities of varying the thinning yield, if maximum efficiency of harvesting is desired. In line thinnings therefore it is much more convenient to control the thinning intensity by *adjusting the thinning cycle.*

5. Conditions will undoubtedly arise, however, where the cycle indicated for a fixed thinning yield may result in other management difficulties. Should these prove to be of critical importance then inevitably the possibilities of modifying the thinning yield have to be examined.

6. There are three points to be borne in mind in considering the question of yield and cycle:
a. *Production losses*

A line thinned stand may take longer to attain the necessary level of stocking required before a further thinning is justifiable than would be the case with a selective thinning. This might mean a delay of one year or, in more extreme cases, two years. (The threshold levels of basal area stocking are given in Table 4 of Forestry Commission Booklet 34).

b. *Delayed Thinning*
It is now fairly common for first thinnings to be delayed. A delay of say, three years, means that an additional three years cut is available in addition to the normal thinning yield. If only part of this is removed in the thinning then the remaining portion of the additional available cut will have the effect of advancing the time at which the threshold level of basal area stocking is achieved. Hence, a second thinning may be justified after a shorter cycle than would otherwise be the case.

c. *Second Thinning*
It is sometimes possible to undertake a second thinning after a period of years which is at odds with the planned cycle. If intervention occurs before the current cycle has elapsed then the thinning yield must be reduced. The converse is also true. This practice is one which should be avoided if possible, in particular where the second thinning occurs *before* the planned cycle has elapsed.

Control with a fixed cycle

7. Since line thinnings are neutral, i.e. the average size of the trees removed is the same as that of the trees remaining, it is often simpler to establish the average volume per hectare of the stand before thinning and calculate the volume removed as a percentage of that volume — either through area or numbers of trees.

8. Whilst in some cases the average volume stocking can be taken from the Normal Yield Tables (Forestry Commission Booklet No. 34) it is usually better to check the volume on the ground. Where stands are brashed then a quick estimate of the volume may be obtained using Procedure 9 in Forestry Commission Booklet No. 39 *(Forest Mensuration Handbook)*. Alternatively, where the stand has not been brashed it may prove more convenient to estimate the average number of trees per hectare by means of sample plots and establish the mean volume per tree by the methods outlined in Procedure 10 in the same booklet.

9. The scope for modifying the thinning yield, given a fixed cycle, is most restricted in the case of row thinnings. For example, if it is desired to thin by removing single rows only, then the possibilities are: removal of every 4th row (25 per cent), every 3rd row (33 per cent) or every 2nd row (50 per cent). Obviously it is not possible to remove, say, 45 per cent or 29 per cent by means of single row thinning. With chevron patterns of thinning the possibilities of adjusting the thinning yield are rather greater. Examples of two fairly common situations are given below.

Row thinning

10. The various steps required in deriving an appropriate thinning pattern, for a fixed cycle, are given below. A worked example is included in brackets after each paragraph and assumes first thinning in Sitka spruce Yield Class 16.

a. Decide the cycle which is required (6 years).
b. Assess the average volume per hectare of the crop before thinning (Para 8) (150 cu m/ha).
c. Calculate the volume at normal Management Table intensity which should be removed for the given cycle and Yield Class (Table 1, Forestry Commission Booklet 34) ($6 \times 11{\cdot}2 = 67.2$ cu m/ha).
d. Express the thinning yield required (67·2 cu m/ha) as a percentage of the average volume per hectare before thinning (150 cu m/ha). i.e. ($(67{\cdot}2/150) \times 100 = 44{\cdot}8$ per cent).

e. Choose a row removal pattern appropriate to the calculated thinning percentage. (Using the figures given, the nearest equivalent for a single row removal pattern would be to remove every second row (50 per cent) with the possible alternative of removing every third row (33 per cent).

f. If the percentage resulting from the chosen row removal pattern exceeds (or is less than) the required percentage, then, assuming that there is no possibility of altering the cycle, the thinning yield at the next thinning must be reduced (or increased) or the row removal pattern reconsidered. (In the example the removal of every second row would normally mean extending the planned thinning cycle by about 2 years, which includes an allowance for loss of volume production. The alternative is to take a reduced cut after the planned cycle of 6 years. A safer course would be to remove every third row. This would suggest a five year cycle as being appropriate, or removing an additional year's cut after the planned cycle of 6 years).

Chevron thinning

11. In the various steps given below, the worked example is again taken to be Sitka spruce YC 16 with a planned thinning cycle of 6 years. Volume per hectare before thinning is taken to be 150 cu m/ha. Additional assumptions are that main racks lie parallel to the rows and are created by the removal of every 20th row.

a. b. c. and d. are as for row thinning.

e. Decide the spacing between main racks, and number of rows (whether 1 or 2) to be removed. (Every 20th row removed to create main racks).

f. From the target percentage (44·8 per cent) deduct the volume percentage removed by creating the main racks (i.e. 1 in 20 rows: 44·8 per cent − 5 per cent = 39·8 per cent). (If the main racks are not parallel to the rows then the percentage volume removed is in effect the minimum rack width expressed as a percentage of the distance between racks).

g. The remaining required volume must be removed from side racks. Since the remaining fully stocked portion of the stand is less than the *total area* (in the example 95 per cent) then the proportion of the *fully stocked* area to be removed should be calculated thus: (39·8/95) × 100 = 41·9 per cent.

h. Control of the thinning yield is exercised through varying either the side rack width, the angle of the side rack to the main racks, or the distance between side racks, so that the required percentage of the fully stocked area is removed. Given two of these three factors, the third can be found as follows:

$d = r \times f/p$ $\qquad$ $r = d \times p/f$ $\qquad$ $f = d \times p/r$

where p is the proportion of the fully stocked area required to be removed from side racks (see g. above),
d is the distance between side racks,
r is the minimum rack width and
f is a factor which varies according to the angle of the side rack with the main rack:

Angle	30°	35°	40°	45°	50°	55°
Factor 'f'	200	174	156	141	130	122

EXAMPLE

Given a minimum rack width of 2 m, and an angle of 40° between main rack and side racks, then the distance between side racks is:

$$\frac{2 \times 156}{41{\cdot}9} = 7{\cdot}45 \text{ m}$$

12. One of the hazards of modifying the thinning yield to accommodate a fixed cycle is that some efficiency may be lost. This may be in terms of constraints imposed on harvesting methods. Or it might be that the crop is inadequately thinned. Where, as a result of an attempt to vary the thinning yield, some undesirable features become evident then the basic assumption about the inflexibility of the cycle must be re-examined.

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FURTHER READING

The following aids to woodland management are available from HMSO shops listed on the back cover or from the Forestry Commission at the address on p.26.

Bulletin 14	—	Forestry Practice
Booklet 26	—	Volume Ready Reckoner for Round Timber
Booklet 30	—	Metric Conversion Tables and Factors for Forestry
Booklet 31	—	Top Diameter Sawlog Tables
Booklet 32	—	Thinning Control in British Woodlands
Booklet 36	—	Timber Measurement for Standing Sales
Booklet 39	—	Forest Mensuration Handbook
Booklet 45	—	Standard Time Table and Output Guides
Leaflet 75	—	Harvesting Windthrown Trees

Other titles are listed in HMSO Sectional List 31 and the Forestry Commission Catalogue of Publications.

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