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BULLETIN No. 35

PRUNING CONIFERS
for the Production of Quality Timber

By D. W. HENMAN, B.SC.

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EDINBURGH

HER MAJESTY'S STATIONERY OFFICE

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FOREWORD

The possibility of improving the quality of timber by the pruning of growing trees has attracted the attention of British foresters since the seventeenth century. Since the publication in 1806, of William Pontey's *The Forest Pruner*, numerous papers have been published on this subject. But until recent years there was little planned research or experiment.

In 1931 the Commission's Research Branch began a series of trials on the pruning of various conifers, which is still continuing. This work inevitably needs a long spell of years to yield final results, but it was apparent, by 1961, that enough had been learnt to justify the publication of an interim assessment.

This present Bulletin, by Mr. D. W. Henman, one of the Commission's research officers, describes the experimental work done, outlines the results to date, and suggests their possible applications in the management of forest crops.

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PART III. IMPLICATIONS AND APPLICATIONS OF THE RESULTS

INTRODUCTION

Experimental pruning of conifer crops was begun by the Forestry Commission in 1931 and the results of the experiments have been assessed up to date, but the final assessment, that of the pruned timber, still lies in the future.

The main purpose of this Bulletin is to indicate the extent of the experimental work done so far and to present its results; but in view of the practical interest at present being shown in the subject in Britain an appraisal is included of the aims of pruning, and the experimental results are used, as far as possible, to make provisional recommendations for forest practice.

The foreign literature has been surveyed, but as it is often difficult to relate to British conditions it has been drawn on in making the recommendations only when information from home sources is inadequate. Where the British results disagree markedly with Continental experience, this is indicated.

PART I
BACKGROUND TO THE EXPERIMENTS

Chapter 1
FOREST PRUNING

Definition

Pruning as a forest management operation is defined in the British Commonwealth Forest Terminology (1953) as the removal of live or dead branches or multiple leaders from standing trees for the improvement of the tree or its timber.

The Objects of Forest Pruning

The above definition excludes branch removal to facilitate access to stands (brashing), but within the definition the operation may have a variety of objects, of which the following are the most common:

(i) Improvement of appearance. This results incidentally from pruning for other purposes, but may also be the sole objective, e.g. in amenity woodlands or along roadsides, where dead or broken branches are considered unsightly.

(ii) Correction of the form of the stem, by early singling of forks.

(iii) Removal of dead, broken or diseased branches to prevent entry of rot to the stem.

(iv) Production of poles free of surface irregularities, sometimes with a superficial layer of knot-free timber.

(v) Removal of dead branches to prevent the occurrence of dead knots in the timber.

(vi) Production of knot-free timber.

The first three of the above objects are of little importance in commercial forestry; the fourth has considerable application in the rather limited field of transmission pole production; the last two are of prime importance in the production of quality timber. Except for the rather slight effect of branch removal on the form of poles, the importance of pruning in the last three objects listed above lies in the elimination of knots from the timber.

The Morphology of Tree Stems and the Formation of Knots

During normal development, the main branches of a tree arise as lateral buds on the leading shoot. Their pith and woody fibres are confluent with those of the stem, and as the tree grows this continuity is maintained in the wood laid on each year by both stem and branches. The fibres of the stem-wood which do not pass into the branches are deflected in the vicinity of the branches, as illustrated by Paterson (1938). When the stem is converted by sawing, slicing or peeling, the embedded branches are exposed as knots in the timber, with the deflected stem fibres giving sloping grain in the vicinity of the knots. Such knots, with their fibres completely intergrown with those of the surrounding wood, are termed live knots (British Commonwealth Forest Terminology, 1957). Should a branch die, the continuity of fibres ceases and further growth of the stem-wood envelopes the branch without fusing with it, forming dead knots (black knots), which frequently become loose on seasoning. As the dead branch decays and decayed wood is enclosed by the stem, unsound knots, softer than the surrounding timber, are formed. For much of its life, therefore, a tree has live or dead branches ramifying through its stem from pith to bark; and timber cut from the stem will be more or less knotty, with a varying proportion of unsound knots, depending on the number, size and time of death of its branches.

Natural and Artificial Pruning

In the later years of a tree's life the decaying branches fall off and the source of knot formation is removed, but this is an irregular and uncertain process and one which is unlikely to be complete over the whole lower bole of the maincrop trees in a stand even after the lapse of 50–60 years. Thus, for Britain, Mackenzie (1950) reported that branches in a 48-year-old Douglas fir stand in Inverness-shire still showed as persistent stumps, and Earl (1950) described a 58-year-old Corsican pine stand in Sussex as having whorls of sound, dead branches from 5 feet upwards to the live crown at 60 feet. Similar examples are common throughout the country, while Romell (1940) and Mollenhauer (1938) report similar conditions in Northern Europe and North America respectively. (See also Plate 7.)

Artificial pruning, on the other hand, can remove both dead and live branches completely from any length of stem in one operation. If this is done by cutting flush with the bark, there will be a period during which the stem-wood occludes the short stub, after which the fibres are able to run without interruption or distortion over the whole surface of the pruned length, and subsequent growth will form timber free of knots and their associated defects.

Timber Quality, Knots and Artificial Pruning

Quality in timber has a number of components. A comprehensive expression of these is provided by grading rules, whereby each piece of timber is classified prior to sale or use. A great number of grading rules have been compiled in different countries and in almost every case the best grades are the "Clear" subdivisions of the top qualities, i.e. those free from knots, thus emphasising the importance of knottiness among the characteristics which affect timber quality. Even within the knotty grades, the size and condition of the knots strongly influence the classification of the timber. Appendix C reproduces the table of permissible defects and characteristics of different grades from the Grading Rules issued by the Forest Products Research Laboratory of Great Britain. (See page 55.)

Except in a few special cases, such as that of "knotty pine" for panelling, the presence of knots lowers the quality, and hence the market value, of timber. The following are the chief ways in which this reduction occurs:

(i) Through the effect on the strength properties, by interruption of the direction of the grain. The localised cross-grain, with steep slopes around the knot, has more influence in this respect than has the knot itself. The effect may still be important after pruning, since grain distortion sometimes extends beyond the knot after the removal of the branch which formed it. In designing timber structures, higher safety factors are required in knotty than in clear material.

(ii) Through the effect on the machining properties of the timber. Part of the knot may break away; an otherwise straight-grained piece of timber may become cross-grained in the vicinity of the knot, causing the fibres to "pick up"; cutting edges, particularly of planer cutters, are dulled by knots and form bands of roughened surface on the dressed timber.

(iii) Through the effect on finishing properties. Irregularities in the timber surface and bleeding of resin may both result from knots.

(iv) Pulping processes are slowed down by knots, as is the hand peeling of pulp wood.

(v) Knots have some effect on the seasoning properties of timber, causing local distortion and small splits in their vicinity.

(vi) Holes arising from loose knots are objectionable, especially in timber used for panelling, cladding or screening.

(vii) Through the effect on appearance. Although this cannot be expressed quantitatively it is probably of considerable psychological importance, because of the association of knots with the physical defects mentioned above.

Of the characteristics of timber quality listed in the Grading Rules (Appendix C, page 55), the two most easily influenced by forestry practices are the rate of diameter growth (rings per inch) and the presence, condition and size of knots. Both can be controlled to some extent by thinning, but the elimination of branches is an uncertain and long-term process under any type or grade of thinning and the conditions which favour it are likely to be opposed to those for economic growth-rate. Artificial pruning is therefore essential to the production of quality timber, unless rotations are to be extended uneconomically. In terms of the British Grading Rules quality improvement through pruning may mean upgrading to Grade I Clear, in cases where the other features of the timber qualify it for Grade I, or to Grade II where other features prevent it from making Grade I but only the condition or size of the knots would exclude it from Grade II. Grading distinctions are, of course, open to revision under changing conditions of utilisation and marketing.

The Structure of the Pruned Stem

The growth of timber on the bole of a tree after pruning flush with the bark forms, in effect, a shell of knot-free timber over a central knotty core whose size and shape are approximately the same as the over-bark size and shape of the tree at the time of pruning. The knotty core in a single pruned length may thus be imagined as a truncated cone with its greatest diameter at ground level. Above this length, knotty timber occupies the whole of the stem, and after several years' growth a vertical section of the pruned tree would show an outward "step" of the knotty core at the pruning limit, extending to the bark. If at this stage a further length of stem is pruned, a second truncated cone of knotty wood will be left within an extended knot-free shell. And successive prunings at intervals of a few years will produce a total knotty core composed of several such cones, one above the other, surrounded by a clear shell and the whole capped by the branch-bearing top length. This is shown diagrammatically in Plate 1; the taper of the various pruned lengths is, of course, exaggerated in the picture.

The concepts of knotty core and knot-free shell of a pruned log have been lucidly explained by

Craib (1939) and further illustrated by Zehetmayr (1954 (*a*)). During the conversion of a pruned log, knot-free timber is removed by successive cuts from the outside until at some point the knotty core is reached; this thickest part of the knotty core thus determines the effective diameter of the core in the whole log. In a single pruned length it normally occurs at the base; in a log comprising more than one pruned length it occurs at the base of the thickest length, which is not necessarily the first length pruned, depending on the pruning regime used. Bends in the stem, swellings at the whorls, protruding branch stubs and other faults may considerably increase the effective diameter of the knotty core as usually measured (i.e. over-bark between branch whorls).

Chapter 2

A BRIEF HISTORY OF PRUNING IN BRITAIN

The pruning of forest trees was an established practice at least three centuries ago. Evelyn, in his *Sylva* (1664) defined it as "all purgation of trees from what is superfluous" and gave a list of the "necessary furniture" for the job, including hatchet, bill, handsaw, knife and broad chisel and mallet, with notes on their use. He distinguished between the needs of trees being grown for timber and for other purposes such as shade, fuel or fodder such as mast, and suggested that trees grown for timber should not have their crowns cut at all, thus putting the operation outside the present-day definition of forest pruning. Although he did not advocate branch removal for the improvement of the timber he recognised that deterioration of timber could result from bad pruning, claiming that indiscriminate chopping made the trees "full of knots, boils, cankers and deform'd bunches, to their utter destruction", and that unskilled and lazy workers left long stubs instead of cutting close to the bole, thereby inducing rot and spoiling the timber. His instructions were directed mainly to the growing of oak, a practice in which the irregular shapes and rather large dimensions of the timbers used in buildings and ships of the day put at a discount the need to eliminate knots. As regards conifers, Evelyn considered that they should be disbranched only with great caution, and emphasised the need to prune early to avoid large wounds.

In contrast to the disregard for knottiness in oak shown by Evelyn in the 17th century, foresters in Scotland a hundred years later were well aware of the degradation of softwood timber quality caused by knots, as is shown in correspondence to the "Edinburgh Weekly Amusement" between 1771 and 1773, quoted by Richardson (1959). There, widely spaced trees were said to require pruning, otherwise the wood would be full of knots in every part, as well as fast-grown and tapering.

Continental writers on forest pruning have referred to periods of fashion which the operation has enjoyed, interspersed with periods of discredit (Mayer-Wegelin, 1936). So far as can be judged from the literature, the subject was of considerable interest to foresters in Britain during the mid-19th century, especially during the period from 1830 to 1880, though M'Corquodale (1884) stated that pruning in the English Crown Forests was abandoned in the 1850's. The above period does not correspond to either of the main Central European "waves", but is more likely to have developed with the surge of large-scale planting on private estates during the 19th century, similar to the one which inspired Evelyn's writing two centuries earlier. The opinions of the time were expressed through such publications as Loudon's "Gardener's Magazine", "The Gardener's Chronicle", "The Quarterly Journal of Agriculture" and the "Transactions" of the English and Scottish Arboricultural societies. The forestry textbooks of the period also gave attention to the subject, for instance Pontey's "Forest Pruner" (1806), Cruikshank's "Practical Planter" (1830) and James Brown's "The Forester" (1861).

Most of the pruning prior to this period had been applied to hardwoods, chiefly oak, but the introduction of many exotic tree species led to experimentation with both hardwoods and conifers, and to a corresponding amount of dissension about the applicability of pruning to the different species. The number of coniferous species which would withstand pruning was considered by some to be very limited. Pontey (1806) saw no harm in pruning conifers, but Cruikshank (1830) did not recommend it except in treating cases of exceptional accidental damage to the tree, while Philip (1863) condemned it for spruce but condoned the pruning of dead branches on Scots pine.

Finger disbudding was advocated as a way of repressing double leaders or aggressive laterals; or, if the branch was too large for this, it should be cut back by one-third of its length, not against the trunk.

Gavin Cree, in various publications from 1828 to 1842, declared that branches should not be removed close to the stem in young trees; he claimed that this introduced rot in larch.

While, at that time, a distinction was drawn between pruning forest trees for ornament and pruning for timber, the precise effect on the timber which pruning was desired to have was not always clearly stated. It is apparent that knottiness (at least in the case of live knots) did not figure so largely in the determination of timber quality then as it does today, while the effect of branches, and of their removal, on the development of a tree was imperfectly understood. It may be that the gardener's experience with shrubs and fruit trees still influenced the forester's thinking. Wide-spreading and numerous branches were by some thought to reduce height growth—even to the production of dwarf or shrub form—and the increased diameter growth of such branches was taken to indicate a consequent loss of growth to the stem (Anon., 1863).

The pruning of branches was thus considered primarily a means of correcting the habit or form of the tree and of directing its increment towards the enlargement of the stem, or, in the case of oak, of producing the shapes required for ships' timbers; and it usually took the form of lopping or shortening of lateral branches, though considerable controversy raged as to whether pruning did or did not improve height or girth growth or stem straightness. The elimination of knots, or other direct improvement of the timber, was not often specifically mentioned, though it may have been implied by remarks such as Cruikshank's (1830) ". . . the object of pruning is to render the stem of the tree as tall and clean as possible". Robert Monteath (1836), referring to the green pruning of conifers, wrote in his "Forester's Guide and Profitable Planter", "No species of fir tree whatever should be pruned . . .," and quoted cases of much bleeding and no height growth for five or six years after pruning; but he went on to say that dry-pruning is very important to prevent black and loose knots and should be done close to the bole before the branch starts to rot. Robert Philip (1863) paid careful attention to the effects of close spacing and of pruning on the size of the branches, and consequently of the knots. In these cases timber quality was the explicit aim of pruning.

A. C. Forbes (1895) was acutely aware of the role played by knots in down-grading home-grown pine and spruce timber relative to that imported from Northern Europe, but he sought to remedy the fault by close spacing and no thinning for the first 50 years of growth, making no mention of pruning as a means of eliminating the knots.

By the turn of the century a much more reasoned attitude to both the purpose and the execution of pruning showed in the British literature, often due to writers with continental training or experience. Thus Schlich's classic "Manual of Forestry" (1904) included a section on pruning, and Sargent published a translation of des Cars' work which in turn was based on earlier work, also in France, by de Courval (Cars, 1902). By this time a certain amount of actual experimental work on pruning was being carried out on the Continent, such as that by Hartig (1872), whereas practical interest in the subject appears to have waned in Britain.

Pruning came again to the forefront in Britain at the beginning of the 1930's, probably as a development of the increased interest in afforestation which followed the passing of the Forestry Act ten years earlier and also as post-war thought became free to turn to the refinements of timber production. In the literature, this is reflected by, for instance, Lord Phillimore's plea (1930) for discussion on pruning in the professional journals and by the interest shown in the subject in succeeding years. In the work of the Forestry Commission, pruning became an established project in the programme of the Research Branch in 1931. In private forestry, papers in the journals, such as those by Ackers (1933), Anderson (1936), Critchley (1936) and others showed that British foresters had been actively concerned both mentally and practically with problems of pruning for some years.

The practice received another set-back during the second World War, when quantity production and labour shortage overshadowed other aspects of forestry, but it is now the subject of widespread interest in both private and state forestry.

Chapter 3

THE DEVELOPMENT OF FORESTRY COMMISSION RESEARCH ON PRUNING

Up to the time of the Commission's formation in 1919 little had been published on the basic objectives and principles of forest pruning, as distinct from accounts of individual pruning operations (see Chapter 2); so in 1931 a systematic investigation was begun by W. H. Guillebaud into the economic and silvicultural implications of, and the tools and methods necessary for, the establishment of practical regimes of pruning suitable for British conditions. In that year experiments were laid down in replicated plots in the Forest of Dean to investigate the effect of different severities of pruning on the increment of Douglas fir, *Pseudotsuga taxifolia* (Poir.) Rehder, Norway spruce, *Picea abies* (L) Karst., European larch, *Larix decidua* Mill. and Corsican pine, *Pinus nigra* var. *calabrica* (Loud.) Schneid. The results of these experiments are presented in Part II.

In 1932 an investigation was carried out in the Forest of Dean, the New Forest and in Alice Holt Forest, into tools, costs and methods of working for the pruning of oak and several coniferous species, and the results were published the following year (Guillebaud, 1933).

At about the same time, small, unreplicated experiments were laid down within or associated with Sample Plots, for example in Western hemlock, *Tsuga heterophylla* (Raf.) Sarg., on Murthly Estate, Perthshire in 1932, and in Norway spruce in Bowmont Forest, Roxburgh Estate, Roxburgh, in 1935. Their purpose was to supplement the information from other experiments, but careful initial records were not always followed up.

Observations on and early assessments of these experiments gave a better appreciation of the problems of pruning and in 1934 Guillebaud summarised these problems in the form of a Pruning Project Plan (unpublished). In this he pointed out that the smaller the tree when first pruned the greater the quantity of knot-free timber produced in a given rotation, and he advocated the first pruning of plantations at a much younger stage than was normal for first thinning. This would involve the pruning of live branches, and further information was required on the effects of green pruning on the growth of the trees and on the formation of clear timber. He also recognised that any subsequent prunings should be done before the diameter of the stem in each next length to be pruned exceeded that in the first length when it was pruned, in order that the knotty core did not become thicker in the upper part of the pruned bole. On these basic considerations he drew up a scheme of study, the first object of which was to prune to obtain clear timber from trees with knotty cores which nowhere exceeded 3–4 inches in diameter. The second was to observe any tendency by the tree to form abnormal wood over the scars of green-pruned branches or to develop rot at the site of pruning. The third object was to study the effect of different degrees of green pruning upon the rate of growth of the trees.

The work was planned jointly with the Forest Products Research Laboratory, and part of the second object was investigated and reported on by the laboratory after two years (Donald, 1936). The first and third objects were incorporated in pruning experiments, two of which were begun at Thetford, Norfolk and Rendlesham, Suffolk in 1935 but prematurely destroyed by windthrow, and one at Edensmuir, Fife, in 1937, the results of which are presented in Part II.

The Edensmuir experiment, on Scots pine, *Pinus sylvestris* L., formed the basis for five more experiments in Scotland, begun in 1938 and 1939; two on Norway spruce, at Drummond Hill, Perthshire and Inverliever, Argyll, two on Douglas fir, at Monaughty, Moray, and Inverliever and one on Sitka spruce, *Picea sitchensis* (Bong.) Carr., at Inverliever. These included, besides the original objects, investigations into season of pruning, interval between successive prunings and the effect of different types of thinning. Ten years after the first Edensmuir experiment was started, the same treatments were repeated in an adjacent part of the same stand, demonstrating the effect of beginning pruning at a greater age.

At the time when these more detailed experiments were being laid down it was considered that the findings of the early (1931) trials in the Forest of Dean justified a report on which field-scale pruning operations could be based. This was published as Forestry Commission Leaflet No. 22, *Pruning in Young Plantations* (1937, now out of print). Any general adoption of its recommendations was soon checked by war-time restrictions, but many of the principles on which they were based are applicable to present day conditions. The early indications from the 1936–1947 group of experiments in Scottish forests formed the basis of recommendations for practical pruning published by Zehetmayr in 1954. The results of both groups are considered in detail in Part II.

Because of unfavourable reports by European foresters, more precise information was required on the effect of green-pruning the spruces, both Norway and Sitka, from the point of view of pathological dangers; so in 1938, groups of five trees were green-pruned at 30 localities throughout the country. These were felled in 1945 and dissected by the Forest Products Research Laboratory to examine rate of healing, effect on clear wood development and the incidence of rot. The main results of this investigation, abstracted from F.P.R.L.'s unpublished (1952) report, are included in Part II.

Pruning experiments with objects other than the production of clean timber have been carried out from time to time. In 1937 a timing trial was made at Glentress Forest, Peebles-shire, to compare the cost of removing the branches from young Norway spruce thinnings before and after felling (pruning v. snedding). This was extended two years later to Douglas fir at Bennan, Cairn Edward Forest, Kirkcudbrightshire, and to Scots pine at Tentsmuir Forest, Fife, to compare on a larger scale the cost of pruning different numbers of trees per acre and the effects of such prunings on the costs of subsequent operations. No assessments of individual pruned trees were made, from which the effects of pruning on growth might be determined. The effect on bark-peeling costs has been reported for the Douglas fir (Zehetmayr, 1952) and for the Scots pine (Henman, 1962). Doubts about the validity of further results, arising from difficulties in other timing and costing studies (Zehetmayr, 1954 (*b*)), terminated the study of these experiments with respect to their original objects; they are now maintained to provide pruned timber for testing.

In 1947–1949 a series of experiments was begun in which the main factor was bud-pruning. This subject, reported by Zehetmayr and Farquhar (1956) and Henman (1961), is outside the scope of the present paper, but the experiments included an intense branch-pruning treatment the results of which are given in Part II.

Pruning has also been applied in a series of experiments begun in 1950 and 1951, in which selected trees in conifer crops have been kept free from the crown competition of their neighbours since the time of planting. A proportion of these isolated trees has been pruned to avoid large knots in the timber, and their growth is being compared with that of unpruned trees. The main results are not yet published; early results of the pruning are included in Part II.

In a recently-started thinning experiment at the Forest of Ae, Dumfriesshire, part of each thinning treatment has been selectively pruned and part left unpruned. Results from this experiment are not yet available.

The most recent of the Forestry Commission pruning experiments was started at Durris Forest, Kincardineshire, in 1958. In this, the severity of the prunings applied is being controlled by the diameter of the stem instead of by the height of the tree or the condition of its crown as in previous experiments. Results are not yet available.

Pruning enters into other Forestry Commission research work in connection with spacing and thinning experiments. In nearly thirty experiments throughout Britain, crops which were planted at different spacings and in which it is intended to maintain these differences by heavier thinning in the wider spacings, have had the wider-spaced stands pruned to prevent excessive knot development in the timber. The pruning regime applied in these cases was developed by Zehetmayr from the early results of the pruning experiments described here. The spacing experiments do not, however, provide comparisons between similar pruned and unpruned crops, by which the effects of pruning can be critically judged.

PART II
THE EXPERIMENTS

Chapter 4
GENERAL DESCRIPTION OF THE EXPERIMENTS

The number and variety of experiments from which information on pruning is available were indicated in the previous chapter. The experiments were commenced over a span of twenty years during which successive experiments were based on an increasing amount of experience, and were developed by different workers in different parts of the country. In consequence there are many differences in layout, prescription and conduct between the experiments. To describe each one individually would be tedious, and, in the case of the results, less instructive than dealing with each aspect of pruning jointly for all experiments. Details of each experimental site and of the treatments prescribed are therefore condensed in Appendix A. The eleven main experiments, four begun in the Forest of Dean in 1931 and seven in Scottish forests in 1936–47, do however have many features of purpose and design in common, and merit a brief comprehensive description; this is supplemented by the data in Table 1.

The crops selected for these eleven main experiments were of average or good quality, ranging in age from fourteen to twenty-five years; that is, crops in the early pole stage. Most of the stands had received no thinning up to the time the experiments were started, so would have carried between 1,000 and 1,500 stems per acre, rather more in the Norway spruce at Drummond Hill which had been planted at about 4,840 stems per acre (3 ft. × 3 ft. spacing). A proportion only of the trees in each stand was selected for pruning, the number ranging from 200 to 580 per acre in different experiments. The treatments were applied within plots of $\frac{1}{40}$ to $\frac{1}{10}$ acre in area and each range of treatments was replicated two to four times. In addition to unpruned controls, from three to six different treatments were compared in various experiments. Most of these treatments were different severities* of pruning, but types of thinning and seasons of the year for pruning were also compared in some experiments and, where more than one pruning was applied, the pruning cycle varied from four to nine years, giving differing pruning intensities. Final pruned heights of between 25 and 35 feet were achieved in varying numbers of operations. Pruning was done by hand saw, using ladders where necessary and any required stem dimensions were measured at the time of pruning.

The final results of the pruning phase of these experiments are summarised in this paper, since it is considered that all effects on the growth-rate, etc. of the crop, resulting directly from pruning, will by now have been expressed. The experiments themselves are by no means completed, however, the crops being as yet only middle-aged and the pruned trees not of saw-log size. Most are being continued by means of less frequent assessments to provide information on the final yield and quality of the pruned timber, though some have had to be closed prematurely, for instance the three at Inverliever Forest which suffered severe windthrow in 1957.

The object of pruning in the experiments described here was the production of knot-free saw timber. Pruning for other purposes, such as the production of poles, has not so far been dealt with experimentally, except where these purposes were incidental to the main object.

In presenting the results of the main experiments distinction will occasionally be made between the earlier and the later groups, which will be referred to as the 1931 (Dean) group and the 1936–47 (Scottish) group respectively. In addition, the 1947–50 (bud-pruning) group and the 1950–51 (free growth) group (see Chapter 3) receive particular attention.

To avoid repetition of experiment serial numbers the individual experiments are referred to by the name of the forest and the species. The two at Edensmuir forest, which are both in Scots pine, are distinguished by the suffixes "early pruning" and "late pruning", according to the stage at which pruning was started.

In all experiments a proportion only of the trees in each stand was selected for study. These are referred to as "selected trees" and include both "pruned trees" and similar unpruned "control trees".

* See Appendix B, page 54, for definition of terms.

TABLE 1 GENERAL DATA FOR THE 1931 (DEAN) AND 1936–47 (SCOTTISH) EXPERIMENTS

Species (1)	*Forest* (2)	*Year of planting* (3)	*Net area of the experiment* *(acres)* (4)	*Description at time of first pruning*: *Age* *(years)* (5)	*Quality Class* (6)	*Number of trees pruned per acre* (7)	*Mean height of pruned trees* *(feet)* (8)	*Mean b.h. girth/diameter of pruned trees* *(inches)* (9) *girth*	*diam.*	*Number of prunings made* (10)	*Total length of stem pruned* *(feet)* (11)
Norway spruce	Drummond Hill	1913	2.8	25	I–II	480	33	13	4	3	30
	Inverliever	1915	2.1	24	I–II	290	34	17	5¼	2	30
	Dean	1906	0.3	25	I	580	47	18½	50	1	27–36
Douglas fir	Monaughty	1924	2.8	14	II–III	310	26	13½	4¼	3–4	30
	Inverliever	1924	2.8	14	II–III	200	31	15	40	2–3	30
	Dean	1908	0.4	23	III	435	48	21	6½	1	6
Scots pine	Edensmuir (early pruning)	1923	1.0	14	II	250	16	10	3¼	4	26
	Edensmuir (late pruning)	1923	1.0	24	II	250	30	15	40	3	26
Corsican pine	Dean	1910	0.4	21	I	550	36	18½	50	1	18–24
Sitka spruce	Inverliever	1924	2.8	14	II	280	27	13½	4¼	2–3	30
European larch	Dean	1908	0.4	23	II–III	510	38	16	5	1	24

Chapter 5

THE EXPRESSION OF PRUNING INTENSITY

Definition

The amount of live crown carried by a tree is clearly a major factor determining its rate of growth (in diameter if not in height) relative to that of its neighbours in the stand; and the most easily measured characteristic of live crown quantity is its length.

In each canopy class of a stand, the crown lengths of the trees tend to adjust themselves to the prevailing conditions of height and stocking density, and the diameter growth of the trees is affected accordingly, as may be seen in any series of comparative thinning plots. If the crown length of a tree is reduced by pruning, its growth-rate can be expected to decrease in response to the smaller amount of live crown remaining, and it will be possible to compare the increment of trees whose crown lengths are normal for the prevailing stand conditions with that of trees of the same canopy class whose crowns have been reduced to some fraction of normal length. In other words, the effect of pruning on growth will be related to the amount of crown left on the trees, and this is probably the most logical way in which to consider the problem. In practice, however, the act of pruning tends to direct attention towards the amount of crown which is removed, rather than towards that which is left, and it is from this negative angle that the majority of the past pruning experiments were prescribed and have been evaluated.

In terms of this approach to the determination of pruning, the effect on the subsequent growth of the pruned trees depends directly on two factors; first, the extent to which live branches are removed from the tree on one occasion, and second, whether and at what interval more than one such pruning is applied. The first of these is here defined as the *severity* of the individual pruning operation and the combination of severity with repetition of a pruning operation comprises the *intensity* of a series of pruning operations. Thus a number of severe reductions of crown carried out on a short pruning cycle constitutes a pruning regime of high intensity, and at the opposite extreme, moderate removals of crown on a long cycle is a pruning regime of low intensity.

Description of Treatments Applied in the Experiments

Pruning severity may be expressed in a number of ways and one of the objects of the early experiments was to apply and compare several different expressions of pruning severity. Among the eleven main experiments the following methods of expression were used in defining the treatments, though not all were represented in each experiment nor was any one treatment except the unpruned control common to all experiments:

(i) Unpruned; providing controls to other treatments. In most experiments dead branches were brashed to a height of about six feet.

(ii) Methods prescribing the number and conditions of branches or whorls to be removed from each selected tree; thus:

(*a*) Prune up to, but not including, the lowest live branch (i.e. to lower crown height).

(*b*) Prune up to, but not including, the lowest live whorl (i.e. to upper crown height).

(*c*) Prune up to and including the second live whorl from the base of the crown.

(iii) Methods prescribing the percentage of the crown length of each selected tree to be removed; thus: Prune to reduce crown length by 25 per cent.

(iv) Methods prescribing the percentage of the height of each selected tree to be cleared of branches; thus: Prune to 50, 55, 60, 66.6 or 75 per cent of tree height.

The particular treatments used in each experiment are shown in Appendix A, page 50.

The relative advantages of the different methods of expressing severity depend upon their purpose; whether for prescribing a practical pruning regime for use in the forest or for making critical comparisons between the growth of differently pruned trees in experiments.

For forest practice, simplicity of prescription and speed of working are of greater importance than the precise application of a given pruning severity. Most of the methods listed above require the measurement, or at least the estimation, of proportions of tree height or crown length. Experience has shown the unreliability of ocular estimates of this kind, though in open stands simple gauges may be used for estimating proportion in the way that an artist holds up a pencil to his subject (Pudden, 1957). The expression of severity by numbers of whorls removed (or left) requires no measurement, but it is difficult to make a precise yet practicable distinction between a live and a dead whorl.

TABLE 2 SEVERITY OF PRUNING TO REMOVE LOWEST TWO LIVE WHORLS

Expressed in terms of :—
(*a*) Percentage of height of tree pruned, Col. 7.
(*b*) Percentage of crown length removed, Col. 8.
(Examples to show the range of variation in each case)

Species (1)	*Experiment* (2)	*Treatment Number** (3)	*No. of pruning* (4)	*Age at pruning (years)* (5)	*Mean height of trees at pruning (feet)* (6)	*Percentage of tree height pruned* (7)	*Percentage of crown length removed* (8)
Norway spruce	Drummond Hill	3	1st	25	37	58	31
		3	2nd	29	44½	62	23
	Inverliever	3	1st	24	32½	56	32
		3	2nd	32	44	65	27
		4	1st	24	35	55	28
		4	2nd	32	46	66	28
Douglas fir	Monaughty	3	2nd	18	37	42	17
			1st	14	27½	40	26
			2nd	18	39	45	19
	Inverliever	4	1st	14	30	60	39
Scots pine	Edensmuir (early pruning)	3	1st	14	16½	41	25
		3	2nd	18	22½	57	30
		3	3rd	24	30	68	33
		4	1st	14	16	38	24
		4	2nd	18	22	56	29
		4	3rd	24	30	70	35
Sitka spruce	Inverliever	3	1st	14	25½	27	Not measured

* Details of treatment are given in Appendix A, page 50.

Evaluation of the Treatments in Common Terms

For experimental purposes, it is necessary to relate the severity of pruning to such characteristics as subsequent height and girth increment, in order to compare different severities, both within an experiment and between experiments of different ages and stages of pruning. To do this, all the pruning treatments must be expressed in common terms. The "number of whorls removed" method cannot be used in the present study as the numbers are known only for those treatments which were actually prescribed by that method. In any case, the method is unsuitable for critical comparison of different pruning treatments, since the removal of a fixed number of whorls from trees carrying varying numbers of whorls does not constitute a uniform severity of pruning. Table 2 shows the removal of the lowest two live whorls at different prunings in six of the experiments, expressed in terms of the percentage of height pruned and percentage of crown length removed. By either of these other methods this nominally uniform treatment shows a considerable range of variation. In every experiment the height of each tree and the height to which it was pruned was recorded, so it is possible to calculate the percentage of height pruned on each occasion. Also, in most experiments the upper and lower crown heights were recorded, from which the crown length, and hence the percentage of crown length removed, may be calculated. Of these two expressions of pruning severity the latter forms the better basis for comparing treatments as it is less dependent on the age and height of the crop or on the length of the crowns. Thus pruning (say) 30 per cent of the height of the trees in a young crop with crowns green to near the ground will have a more serious effect on growth than in an older crop in which mutual shading has already reduced the proportion of live crown; whereas the removal of 30 per cent of the crown length in either crop should, within limits, have a similar effect and should constitute the same severity of pruning. Careful measurements on young, widely-spaced *Pinus patula* (South Africa, 1956) have shown that this relation holds true up to about 50 per cent of the mean crown length, in that loss of diameter increment was found to be more or less inversely proportional to the percentage of crown length removed, though above 50 per cent crown removal, increment reduction was disproportionately great. Crown removal of much more than 50 per cent was rarely applied in the British experiments, and is unlikely to be applied in future practice, and since expression of pruning severity by percentage of live crown removed gives a convenient method which has been found to hold elsewhere, it is considered to be the most suitable means of comparing different experimental treatments and their effects on growth.

Pruning Cycle

So far, the consideration of pruning intensity has been confined to severity, that is, the amount of pruning carried out on a single occasion. It is frequently necessary to apply more than one pruning to obtain the required length of clear stem, and pruning intensity thus has a second component, the intervals at which successive prunings are applied, that is, the pruning cycle. It is clear that if (for example) four live whorls of branches are removed from a tree every three years the decreasing length of crown will have a serious effect on growth, but it is also possible that the removal of (say) two whorls every three years may have a cumulative effect which does not become evident until several prunings have been applied. Similarly, it is reasonable to suppose that the same crown reduction applied on a longer cycle will have less effect. In comparing the effects of equal pruning severities, therefore, it is necessary to consider whether the effects result from a succession of prunings at long or at short intervals.

Of the experiments reported here, the 1931 (Dean) group received only one pruning, and the effects on subsequent growth can be fairly simply related to the severity of this. The later experiments had more than one pruning, usually two or three, at intervals of usually four years, sometimes longer. The effects of these are less easy to interpret, since they may have resulted from a few prunings removing a greater amount of live crown or from more prunings each removing less live crown.

Chapter 6

THE EFFECT OF PRUNING ON INCREMENT IN BREAST-HEIGHT GIRTH AND HEIGHT

In Chapter 5 it was concluded that, of the variety of expressions of pruning severity used in the experiments, the one most suitable for indicating relationships between pruning and subsequent growth is that showing the length of crown removed as a percentage of crown length before pruning; "crown length" throughout the present study being calculated as the length from the tip to midway between upper and lower crown heights. (See Appendix B, page 54.)

Results are available in this form from the eleven main experiments and from the 1950–51 (free growth) experiments. In other experiments, for which crown length data are not available, other expressions of severity have had to be used. The main experiments comprised up to seven different treatments, including controls, and in some up to four successive prunings were applied, providing comparisons between nearly 150 different pruning operations. For examination of the results this number can be broken down by separating from the rest those treatments which did not involve the removal of green branches and those in which parts of plots were pruned and measured at different seasons of the year, giving plot means which are not comparable with the control plot means.

The wide variety of pruning severities and cycles employed in the remaining treatments still makes difficult the comparison of relative pruning intensities, and hence of their effects on growth. Short-term effects, measured after periods of four or five years from the time of each pruning, were very variable between experiments in the same species; even within experiments, some treatments which were prescribed in different terms but resulted in similar pruning intensities sometimes caused different increment effects. Since the benefits of pruning do not become available until many years after the operation is carried out, the long-term effects of pruning on growth-rate are more important than the short-term ones; detailed increment data are therefore quoted only for the longest available assessment period in each experiment. Over this length of time, varying from nine to twenty-two years, minor irregularities in growth-rate are smoothed out, though some anomalous results remain which are attributed to limitations of the experimental designs, such as inadequate replication on non-uniform sites.

Increments in height and breast-height girth for the periods following each pruning and for the longest assessment period in each experiment have

TABLE 3 EFFECT OF PRUNING ON INCREMENT IN BREAST-HEIGHT GIRTH AND HEIGHT

Norway Spruce

Experiment	*Drummond Hill*				*Inverliever*				*Dean*					
Interval between initial and latest assessment (years)	20				15				21					
Treatment number or letter*	1	3	4	6	1	3	4	6	A	B	C	D	E	F
Pruning intensity†	Control	31(4)23(5)9	27(9)20	15(4)36(5)15	Control	32(8)27	28(8)28	25(8)33	Control	11	3	24	44	25
Initial b.h. girth (inches)	14.5	15.6	14.1	13.9	18.4	18.0	17.8	17.8	18½	20½	20½	20	18½	20½
Latest b.h. girth (inches)	38.2	40.2	38.1	35.8	34.0	30.4	28.7	30.5	33½	34½	35½	34½	32½	34½
B.h. girth increment (inches)	23.7	24.6	24.0	21.9	15.6	12.4	10.9	12.7	15	14	15	14½	14	14
Increment of pruned trees as per cent of control increment	100	104	100	92	100	80	70	81	100	93	100	97	93	93
Initial height (feet)	34.4	37.1	33.7	32.8	34.1	32.7	—	32.8	46.4	48.8	51.8	47.6	48.5	47.0
Latest height (feet)	68.8	73.0	69.8	67.8	58.5	54.2	—	54.6	81.8	85.6	85.5	82.8	84.4	84.8
Height increment (feet)	34.4	35.9	36.1	35.0	24.4	21.5	—	21.8	35.4	36.8	33.7	35.2	35.9	37.8
Increment of pruned trees as per cent of control increment	100	104	105	102	100	88	—	89	100	104	95	99	101	107

* See Appendix A, page 50.

† Pruning intensities are shown as the severity of each pruning (in terms of percentage of crown length removed) separated by, in brackets, the pruning intervals in years.

TABLE 4 EFFECT OF PRUNING ON INCREMENT IN BREAST-HEIGHT GIRTH AND HEIGHT

Douglas fir

Experiment	*Monaughty*				*Inverliever*				*Dean*			
Interval between initial and latest assessment (years)	20				18				20			
Treatment number or letter*	1	3	4	6	1	3	4	6	A	B	C	D
Pruning intensity†	Control	28(4)17(4)21	25(8)24	36(4)50(4)28	Control	42(9)26	39(9)25	28(9)26	Control	7	31	25
Initial b.h. girth (inches)	13.2	13.5	14.1	13.7	14.8	14.8	15.2	16.2	24	23	23	24
Latest b.h. girth (inches)	37.4	37.1	38.0	35.2	35.8	32.6	32.9	36.6	43	37½	39½	40
B.h. girth increment (inches)	24.2	23.6	23.9	21.5	21.0	17.8	17.7	20.4	19	14½	16½	16
Increment of pruned trees as per cent of control increment	100	98	99	89	100	85	84	97	100	76	87	84
Initial height (feet)	26.0	26.1	26.2	26.6	30.1	30.5	—	33.6	52.2	48.8	48.4	50.6
Latest height (feet)	74.3	74.5	74.3	72.1	63.2	60.8	—	66.1	90.9	84.4	83.6	86.0
Height increment (feet)	48.3	48.4	48.1	45.5	33.1	30.3	—	32.5	38.7	35.6	35.2	35.4
Increment of pruned trees as per cent of control increment	100	100	100	94	100	92	—	98	100	92	91	91

* See Appendix A, page 50.

† Pruning intensities are shown as the severity of each pruning (in terms of percentage of crown length removed) separated by, in brackets, the pruning interval in years.

TABLE 5 EFFECT OF PRUNING ON INCREMENT IN BREAST-*H*EIGHT GIRTH AND HEIGHT

Scots and Corsican pines

Species	**Scots pine**								**Corsican pine**			
Experiment	*Edensmuir (early pruning)*				*Edensmuir (late pruning)*				*Dean*			
Interval between initial and latest assessment (years)	22				12				9			
Treatment number or letter*	1	3	5	6	1	3	5	6	A	B	C	D
Pruning intensity†	Control	25(4)30(6)33	43(4)46(6)46	52(4)54(6)42	Control	31(7)?	1(7)?	22(7)?	Control	7	40	25
Initial girth b.h. (inches)	10.4	10.8	10.9	10.6	15.8	15.4	15.7	15.5	19	19	18	20
Latest girth b.h. (inches)	23.6	23.6	22.5	21.8	23.8	22.6	23.0	22.4	23	23½	22½	24½
B.h. girth increment (inches)	13.2	12.8	11.6	11.2	8.0	7.2	7.3	6.9	4	4½	4½	4½
Increment of pruned trees as per cent of control increment	100	97	88	85	100	90	91	86	100	112	112	112
Initial height (feet)	16.8	16.6	16.6	17.0	30.6	29.1	29.8	30.0				
Latest height (feet)	40.7	41.5	40.4	39.6	41.0	39.4	40.2	39.8	Increment			
Height increment (feet)	23.9	24.9	23.8	22.6	10.4	10.3	10.4	9.8	not measured			
Increment of pruned trees as per cent of control increment	100	104	100	95	100	99	100	94				

* See Appendix A, page 50.

† Pruning intensities are shown as the severity of each pruning (in terms of percentage of crown length removed) separated by, in brackets, the pruning intervals in years.

TABLE 6 EFFECT OF PRUNING ON INCREMENT IN BREAST-HEIGHT GIRTH AND HEIGHT

Sitka spruce and European larch

Species	**Sitka spruce**				**European larch**			
Experiment	*Inverliever*				*Dean*			
Interval between initial and latest assessment (years)	18				17			
Treatment number or letter*	1	3	4	6	A	B	C	D
Pruning intensity†	Control	25(9)17	25(9)24	40(9)24	Control	10	27	25
Initial b.h. girth (inches)	12.4	13.8	14.3	13.8	17½	16½	17	17
Latest b.h. girth (inches)	33.6	31.6	34.8	32.4	29½	26½	27½	26½
B.h. girth increment (inches)	21.2	17.8	20.5	18.6	12	9½	10½	9½
Increment of pruned trees as per cent of control increment	100	84	97	88	100	79	88	79
Initial height (feet)	25.3	25.6	—	26.5	39.4	38.3	39.2	38.8
Latest height (feet)	61.5	65.2	—	63.3	51.3	50.7	50.9	51.1
Height increment (feet)	36.2	39.6	—	36.8	11.9	12.4	11.7	12.3
Increment of pruned trees as per cent of control increment	100	109	—	103	100	104	98	103

* See Appendix A, page 50.

† Pruning intensities are shown as the severity of each pruning (in terms of percentage of crown length removed) separated by, in brackets, the pruning intervals in years.

been statistically analysed. Significant depressions of increment relative to the unpruned controls were sometimes shown by the short-term assessments, particularly in girth increments. By the long-term assessments no significant differences (at probability of 5 per cent or more) were shown in height increment, and in only one experiment was there a significant reduction in girth increment. This lack of statistical significance in what are sometimes quite marked growth effects must again be attributed to the variability of the experimental sites and the small number of replications employed.

Breast-height Girth Increment

The long-term effects of green-pruning on girth increment in the eleven main experiments are shown in Tables 3–6.

Most of the prunings or series of prunings shown involved the removal of more than 25 per cent of the crown length, and most resulted in a depression of breast-height girth increment, though only at Edensmuir, Scots pine, early pruning (Treatment 6) was the difference significant. The extent of the depression was rarely more than 15 per cent of the increment of unpruned control trees, though in extreme instances this represented a loss of more than 3 inches girth growth over about 20 years. On the other hand, pruning intensities involving 30 per cent crown removal and four-year cycles sometimes had negligible effects on girth increment. Individual site and crop conditions undoubtedly affected the response to a given pruning intensity, and only general conclusions can be drawn from the data.

In the pruning trial on Norway spruce at Bowmont, twenty-seven dominant trees, 25 years old, with a mean height of 29 feet and breast-height girth of 15 inches were selected for each of two treatments. One group was pruned of dead branches only, the other was pruned up to and including the second live whorl from the base of the crown, three prunings being given on a five-year cycle. The latter treatment is equivalent to removing 25–30 per cent of the crown length. Breast-height girth increment of the two groups was exactly the same over the twenty years following first pruning.

Lehtpere (1957) working in Devon with 11-year-old Douglas fir, applied a single pruning of 32 per cent of the live crown length, removing three live whorls from most of the trees. The resulting reduction in breast-height girth increment relative to unpruned control trees decreased successively over the next three years, pruned-tree increment being 11 per cent below control increment over the three-year period for which results are published. The Forestry Commission experiments are in general agreement with this result.

Other short-term results are provided by the 1950–51 (free growth) group of experiments, in which predominantly fast-growing trees were selected in crops which had not yet closed canopy, these trees then being isolated from the crown competition of their neighbours in the crop, by early and annual thinning, during the whole of their lives. This treatment enabled the isolated trees to maintain strong green branches down to ground level, so when they were 20–30 feet tall the trees were grouped into pairs with similar height growth-rates and one tree of each pair was pruned. Results from the four experiments are shown in Table 7.

The prunings were severe, removing 37 per cent to 55 per cent of the crown length. In two experiments where pruning was repeated once, the short interval of two years between prunings also implied high intensities of pruning. Breast-height girth increment was reduced by all the prunings relative to that of the free-growing control trees, the reductions varying from 14 per cent to 44 per cent over periods of 2–3 years. Reductions after four years, resulting from two successive prunings, amounted to 50 per cent in Norway spruce and 30 per cent in less intensely pruned Sitka spruce at Forest of Ae, though a single pruning of 55 per cent in Sitka spruce at Benmore caused an average girth reduction of only 14 per cent. These increment responses of free-growing trees are fairly similar, relative to the intensities of pruning, to those obtained from normally thinned crops in the main experiments.

Further information on the effects of pruning on the growth of the pruned trees is obtainable from the 1947–1950 (bud-pruning) series of experiments. These experiments included a treatment in which selected potentially dominant trees were pruned by saw annually from an early age, so as to leave the three topmost whorls of branches; this was done in spring, just before growth began, so for most of the growing season the trees actually carried four whorls of branches. This annual pruning was continued for between two and nine years in different experiments, after which time heights and breast-height girths were measured of the pruned trees and of unpruned control trees. The results are shown in Table 8.

The results are not consistent, even for a single species. Growth was reduced in all experiments except the fastest-growing of the Scots pine crops, that at Mabie. However, the slow-growing Scots pine at Millbuie was not severely affected whereas the vigorous Douglas fir and the Corsican pine at Wykeham were much reduced in growth. It is clear that in all species, though least so in Scots pine a permanent crown of four whorls is insufficient to maintain full increment in breast-height girth or height, even at this early stage in crop development.

TABLE 7 EFFECT OF PRUNING FREE-GROWING TREES ON GIRTH AND HEIGHT INCREMENT

Species	*Experiment*	*Number of pairs of trees*	*Mean height of trees at first pruning*	*Pruning intensity*†		*Depression of increment relative to unpruned trees*					
				Percentage of crown length removed	*Number of live whorls removed*	*Breast height girth*			*Height*		
						After first pruning	*After second pruning*	*Total*	*After first pruning*	*After second pruning*	*Total*
			(*feet*)	(*approx.*)	(*approx.*)						
(1)	(2)	(3)	(4)	(5)	(6)		(7)			(8)	
Norway spruce	Ae	11	24	40 (2) 45	7 (2) 4	38% (2 yrs.)	44% (2 yrs.)	50% (4 yrs.)	21% (2 yrs.)	44% (2 yrs.)	35% (4 yrs.)
Sitka spruce	Ae	17	27	37 (2) 40	7–8 (2) 3	10% (2 yrs.)	39% (2 yrs.)	30% (4 yrs.)	0 (2 yrs.)	38% (2 yrs.)	15% (4 yrs.)
Sitka spruce	Benmore	12	18	55	6–7	14% (2–4 yrs.)	—	14% (2–4 yrs.)	0	—	0 (2–4 yrs.)
Douglas fir	Mabie	13	25	40	3–4	30% (3 yrs.)	—	30% (3 yrs.)	0	—	0 (3 yrs.)

† Pruning intensities are shown as the severity of each pruning separated by, in brackets, the pruning interval in years.
Years in brackets in Columns 6 and 7 are the intervals between pruning and assessment, total depression of increment being that since first pruning. At Benmore the pruning was started on different trees in different years.
See Appendix A, page 50, for details of treatments.

TABLE 8 EFFECT OF ANNUAL PRUNING TO LEAVE ONLY THREE WHORLS PER TREE ON HEIGHT AND BREAST-HEIGHT GIRTH

Species (1)	*Experiment* (2)	*Age at first pruning* (*years*) (3)	*Age at latest assessment* (*years*) (4)	*Number of annual prunings* (5)	*Height at latest assessment* *Control.* (*feet*) (6)	*Pruned.*	*Difference from Control height* (*feet*) (7)	*B.h. girth at latest assessment* *Control.* (*inches*) (8)	*Pruned.*	*Difference from Control girth* (*inches*) (9)
Douglas fir	Mabie	5	7	2	13.9	12.1	—1.8	6.2	5.4	—0.8
Scots pine	Mabie	6	13	7	16.2	16.9	+0.7	10.4	10.3	—0.1
,,	Millbuie	8	15	7	9.2	8.6	—0.6	5.0	4.6	—0.4
Corsican pine	Lossie	9	14	5	13.1	12.6	—0.5	9.8	8.0	—1.8
,,	Wykeham	7	14	7	17.2	15.4	—1.8	10.9	8.4	—2.5
Sitka spruce	Kielder	4	13	9	14.2	10.1	—4.1	8.2	4.9	—3.3

Note: The data are the means of about 40 pruned and 40 control trees in each experiment.

Height Increment

In every experiment height increment was less affected by pruning than was girth increment. In the main experiments short-term height increments were sometimes reduced significantly by the more severe prunings, though over the longest available assessment periods the greatest reductions recorded were about 3 feet in total increment of 20–50 feet. In the majority of experiments mean height increment of pruned trees either equalled or slightly exceeded that of the unpruned controls. Even the intense prunings applied to free-growing trees (Table 7) either had no effect on height growth or caused reductions which rapidly became smaller relative to the increment of the unpruned trees. Lehtpere (1957) found no height growth reduction during 3 years after 32 per cent crown removal in Douglas fir.

In terms of final volume production of pruned timber, small reductions in height increment are negligible, but occurring at the time of most active height growth and competition for a place in the upper canopy they may result in the suppression of pruned trees by unpruned neighbours, and the consequent development of unpruned dominants in the crop. The extent to which this may have happened in the main pruning experiments is considered in Chapter 8, on the survival of selected trees.

Summary of the Effects of Green Pruning

The general indications from these results are that removal of up to 25 per cent of the crown length has no depressive effect on height increment and very little on breast-height girth increment. Removal of about 30 per cent of the crown length has little effect on height increment but may reduce breast-height girth increment over the following twenty years by up to 10 per cent. Removal of 40–50 per cent of the crown length may reduce height increment slightly and reduces breast-height girth increment by 10–20 per cent.

These increment reductions were not much affected by variations in pruning cycle down to intervals of four years.

Douglas fir appears to be more sensitive than Norway spruce, Sitka spruce, Corsican pine or Scots pine (in that order) to similar intensities of pruning.

From a detailed survey of European and North American pruning experiments, many in Douglas fir, Møller (1960) concluded that removal of more than 25 per cent of the live crown length will depress girth increment in most species; but he pointed out that the effect on the total production of a stand by the end of its rotation would be only a fraction of one per cent, even where one third of the live crown was removed. He also concluded that height increment is influenced considerably less by heavy pruning than is diameter increment at breast height.

The Effect of Pruning Moribund or Dead Branches

It has been claimed that the presence of the moribund branches of the lower crown may have a depressive effect on the growth of the tree, since they

TABLE 9 EFFECT OF PRUNING DEAD BRANCHES OR LOWER CROWN ON BREAST-HEIGHT GIRTH INCREMENT

Species	*Experiment*	*Pruning treatment*		*Initial girth (inches)*		*Difference between girth increment in pruned treatment and control (inches)*			*Total assessment period*
		Number or letter	*Percentage of live crown removed*	*Control*	*Pruned*	*During period* after 1st pruning*	*During period* after 2nd pruning*	*During total assessment period*	*(years)*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Norway spruce	Drummond Hill	2	0	14.5	14.2	+0.6	+0.8	+2.1	20
,,	Inverliever	2	0	18.4	16.9	+0.3	—1.1	—0.8	15
,,	Dean	C	3	19.2	19.2	0	—	0	21
Douglas fir	Monaughty	2	0	13.2	13.3	0	+0.6	+0.5	20
,,	Inverliever	2	0	14.8	15.6	—0.2	—1.3	—2.0	18
,,	Dean	B	7	21.0	21.1	0	—	—4.5	20
Scots pine	Edensmuir (early pruning)	2	0	10.4	10.0	+0.4	—0.4	+1.2	22
,,	Edensmuir (late pruning)	2	0	15.8	14.9	—0.4	—0.4	—0.9	12
Corsican pine	Dean	B	7	18.5	18.8	+0.1	—	+0.5	9
Sitka spruce	Inverliever	2	0	12.4	13.8	—1.6	—0.1	—1.6	18
European larch	Dean	B	10	16.1	16.0	—0.1	—	—2.5	17

* N.B. Length of period not the same in all experiments.

may draw assimilates from the rest of the crown to maintain themselves. (Sjöström, quoted by Romell, 1940; Bavngaard, 1946, 1957). Hartig in 1872 and Cieslar in 1904, working with *Pinus strobus*, had considered this point and are quoted by Møller (1960) who considers it justified to conclude that the two lowest sparsely-needled whorls were of positive importance to the growth of the tree. Ladefoged's data on spruce as interpreted by Møller (1960) suggest that though the lower whorls make a positive contribution to the increment it is very small. In the present studies only the 1931 (Dean) experiments can be used to test this theory, since they included a treatment in which branches were removed up to, but not including, the lowest live whorl. This whorl was defined as one in which all the branches are alive, i.e. bearing one or more green needles, and it might be argued that the lowest such whorl is sometimes almost moribund, while at other times a partly dead whorl below it may contain one or more vigorous live branches. In general, however, the crown below the lowest live whorl is in the languishing condition of the "shade crown", and the effect on girth increment of removing this crown, compared with the increment of control trees, is shown for the 1931 (Dean) experiments in Table 9. In the same table is shown the effect of removing dead branches only (up to but not including the lowest live branch, as defined) in the 1936–47 (Scottish) experiments.

There is no consistent evidence that the removal of moribund branches (or of dead branches only) has either contributed to or depressed the growth of the trees.

Chapter 7

THE EFFECT OF PRUNING ON STEM FORM

As long ago as 1868, Hartig found that the depressive effect of a given intensity of pruning on girth increment was more marked at breast height than at points higher up the stem (Hartig, 1872, quoted by Møller, 1960). More recently, a number of other workers have reported similarly for a variety of species, including Lehtpere (1957) for Douglas fir in Britain. The net effect of such differential depression of girth increment is an increase in the form quotient of the pruned part of the bole, that is, a reduction in log taper. If the size of this reduction were large enough, and if it persisted to rotation age, this could be a valuable subsidiary result of pruning, since a tapering log causes sawing and peeling difficulties, waste of timber and sloping grain in the converted material.

Provision was made for the study of stem form in the plans of the earliest Forestry Commission pruning experiments, the four in the Forest of Dean. There, the selected trees were girthed at intervals of six feet above ground level at the time of pruning and again, though at 18 ft. only, nine years later; breast-height girths were also measured on each occasion. The effect of single prunings of varying severity can therefore be studied on girth increment at both breast height and 18 ft. and on stem form between these points before and after pruning.

In both the control and the most severe pruning treatments of every experiment, stem taper decreased during the nine year period. This is the normal course of events, and results from faster girth increment (either absolute or relative to the initial girth) at 18 ft. than at breast height. In Douglas fir and Corsican pine the decrease in taper was greater in the pruned trees than in the controls; in Norway spruce it was greater in the control, while in European larch it was the same in both treatments. Final differences in taper between pruned and unpruned trees were very small.

Measures of stem taper have also been obtained from the experiments at Drummond Hill, Monaughty and Edensmuir, but only at the most recent assessment, 12–22 years after first pruning, so that no allowance can be made for differences in taper at the time of pruning. In Norway spruce and Douglas fir, pruning appeared to have had little effect on stem taper by the end of 20 years after first pruning. The same is true for the late-pruned Scots pine after 12 years, though early-pruned Scots pine had less taper than unpruned trees, even after 22 years. Again, the differences are small.

The measurements made in these experiments were not sufficiently detailed to enable precise conclusions to be drawn, but there is some evidence that pruning does reduce the taper of the stem, at least in the early years and after severe pruning. The conclusions reached by previous workers are thus confirmed to some extent, but further work is necessary to establish the magnitude of the improvements in stem form resulting from pruning. Even though these are not large or of practical importance, at least it may be concluded that the effect of pruning is beneficial to stem form rather than the contrary.

Chapter 8

THE SELECTION AND SURVIVAL OF PRUNED TREES

Basic Considerations

The object of pruning in the present study is the production of knot-free saw-timber, a class of material which is not utilizable from a pruned stem until a certain minimum radial thickness has been grown. This means that the diameter at which a pruned tree first becomes usable as such (i.e. yielding some knot-free timber) is usually greater than that at which unpruned trees, yielding ordinary saw-logs, become usable. The stage in the rotation at which pruned saw-logs first become available from a crop will thus be later than for first unpruned saw-logs, and the number of such stems standing per acre correspondingly less. The production of a sufficient radial thickness of clear timber to repay the cost of pruning the tree (or even to command a higher price than unpruned timber) may not occur until still later, at a still lower stocking of selected trees.

There is thus clearly no value in pruning more trees than are expected to reach a certain minimum diameter. This diameter limit is largely a matter for decision by individual managers, but is unlikely to be less than about 14 inches at breast height over bark (11 inches quarter girth). Since current trends in forest management are towards early attainment of the desired size classes, by encouraging fast growth on a relatively small number of trees through crown or heavy low thinning, the number selected may be less than 100 per acre, certainly not more than 150 per acre. This principle will undoubtedly apply to the future management of pruned crops, and it is on this basis that the results of the pruning experiments are evaluated here.

The Number of Trees Selected in the Experiments

In the 1931 (Dean) group of experiment plans, no fixed number of selected trees was prescribed, but all "elite" trees (that is, all the taller, straighter, more vigorous trees in any canopy class) were required to be pruned. This resulted in the selection of from 435 to 580 stems per acre in the various experiments. No second prunings were made, so subsequent losses of pruned trees were due to thinning, not to rejection from further pruning as in the later experiments.

In the 1936–47 (Scottish) group of experiments, trees were selected for first pruning with the express intention of reducing their numbers at subsequent re-prunings; the initial numbers and the numbers expected to remain after completion of the pruning operations being prescribed as follows:

Norway spruce:	436 per acre, reducing to 300 per acre.
Sitka spruce:	300 per acre, reducing to 200 per acre.
Douglas fir:	300 per acre, reducing to 200 per acre.
Scots pine:	245 per acre, reducing to 200–150 per acre.

The reductions were to be made at the time of second and, more particularly, of third pruning.

It seems clear from Guillebaud's remarks (Forestry Commission 1937, pages 2–3) that the number prescribed was high because of the difficulty of picking crop trees at an early stage, and the fear that unpruned trees might become dominant. He suggested reducing to 12–15 ft. spacing (300–200 per acre) at second pruning and reducing again if a third pruning was carried out. But in the experiments, this final reduction was not made, and instead there seems to have been a tendency to continue to prune trees instead of abandoning further pruning of any that were not predominant.

The thinning grade prescribed for these stands was a Light Crown grade during the period of pruning, changing to a Heavy Crown grade which would lead to the eventual isolation of the pruned trees. The purpose of this was to obtain vigorous growth and rapid occlusion of pruning wounds, even in those treatments in which the live crowns had been considerably reduced. In addition, one of the moderate pruning treatments was duplicated with low thinning with the object of providing a control to the crown thinning in order to compare rates of diameter growth, healing and natural death of the branches.

The number of trees which were initially selected per acre in each of the eleven main experiments are shown in Table 1 (page 8). These numbers were substantially reduced at subsequent assessments for various causes, either by being felled in thinning in the case of trees which could no longer qualify for maincrop status, or by being rejected from further pruning and assessment in cases where growth reduction or damage was not sufficiently severe to warrant their removal from the crop, but where further pruning would have been absurd. The latter course was taken only in experiments with multiple

TABLE 10 SURVIVAL OF SELECTED AND UNSELECTED TREES IN UNPRUNED CONTROL PLOTS

Numbers per acre

Species	*Experiment*	*Initial Assessment*	*Most recent assessment*					
		Number of trees selected	*Interval since initial selection (years)*	*Number of selected trees remaining*	*Number of unselected dominants remaining*	*Age of crop (years)*	*Mean height of selected trees (feet)*	*Thinning grade*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Norway spruce	Drummond Hill	448	20	122	5	45	69	L.C.
„	Inverliever	283	15	103	43	39	58	L.C.
„	Dean	540	24	160	Not counted	49	82	C/D
Douglas fir	Monaughty	310	20	115	10	34	74	L.C.
„	Inverliever	200	18	95	42	32	70*	L.C.
„	Dean	420	13	140	Not counted	46	96*	C/D
Scots pine	Edensmuir (early pruning)	241	22	129	65	36	41	L.C.
„	Edensmuir (late pruning)	241	12	171	41	36	41	L.C.
Sitka spruce	Inverliever	280	18	105	30	32	65*	L.C.
Corsican pine	Dean	560	9	460	Not counted	30	50*	C/D
European larch	Dean	500	17	200	Not counted	40	60*	C/D

Note: Heights marked * have been estimated from the height/age curves of the plots concerned.

prunings, where rejection of a proportion of the initially pruned trees had been allowed for.

Wastage among the control trees provides a measure of the combined effects of mis-selection, natural hazard and the selection of too many trees, but omits effects due to pruning. Losses of control trees in each experiment are shown in Table 10, which gives the number originally selected and the number remaining at the most recent assessment, together with the age and mean height of the trees at that assessment and the number of unselected dominants which remained in the crop. In most of the experiments, numbers were reduced to a third or less of those originally selected, after about 20 years. In this time it is unlikely that a usable quantity of knot-free timber would have been laid on, had the trees been pruned, so expenditure on pruning the trees which were felled would have been wasted.

There is a fairly close inverse relationship in Table 10 between the numbers of remaining selected trees plus unselected dominants and the mean height of the trees, which suggests that the reduction in numbers since pruning was mainly the result of necessary espacement thinning among the dominant and co-dominant trees, and only to a lesser extent of rejecting those selected trees which failed to maintain growth and canopy position. In the 1931 (Dean) experiments the moderate low thinnings, together with the higher proportion of trees first pruned, probably accounts for the greater numbers of trees (height for height) which remained.

It is clear from the losses incurred in the control

TABLE 11 SURVIVAL OF UNPRUNED CONTROL AND PRUNED TREES

Numbers per acre

Species	*Experiment*	*Interval since initial selection (years)*	*Unpruned Control*			*Most severe pruning*		
			Number selected	*Number survived*	*Percentage survival*	*Number selected*	*Number survived*	*Percentage survival*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Norway spruce	Drummond Hill	20	448	122	27	270	148	32
,,	Inverliever	15	283	103	36	290	167	58
,,	Dean	24	540	160	30	580	180	31
Douglas fir	Monaughty	20	310	115	37	312	110	35
,,	Inverliever	18	200	95	48	200	85	42
,,	Dean	23	420	140	33	440	130	30
Scots pine	Edensmuir (early pruning)	22	241	129	54	260	91	35
,,	Edensmuir (late pruning)	12	241	171	71	239	190	80
Corsican pine	Dean	9	560	460	82	570	410	72
Sitka spruce	Inverliever	18	280	105	38	285	110	39
European larch	Dean	17	500	200	40	540	260	48

treatments of all the experiments that the selection of trees for pruning was greatly over-budgeted, especially where crown thinnings were to be carried out.

Table 11 compares the survival of control trees with that of the most severely pruned trees in each experiment. It shows that pruning did not affect the rate of survival appreciably, except that in Norway spruce at Inverliever survival was considerably higher in the pruned treatment, and in Scots pine at Edensmuir (early pruning) it was considerably lower. This Scots pine treatment was one of the few in which significant height reductions occurred, but since height reduction was also recorded in the Inverliever Norway spruce, it is concluded that the effect on survival of any slight height or girth reduction due to pruning is negligible, or can be guarded against by favouring the affected trees in thinning.

The Kind of Trees Selected

In the 1931 (Dean) experiments, the kind of tree to be pruned was not clearly specified and it was recorded that the "elite" trees had been pruned.

In the plans for the 1936–47 (Scottish) experiments considerable care was taken to specify the kind of tree to be pruned. The main purpose of this was to try to control the mean diameter and the straightness and form of the stems selected (and hence of the knotty cores). A typical Experiment Plan instruction runs as follows: ". . . to obtain timber in which the knotty core over bark does not exceed four inches in diameter at breast height. . . . Good dominants or co-dominants only will be treated, evenly spaced. . . . Preference will always be given to straighter, cleaner stems, even if the tree is smaller". Although the mean diameter of the crops as a whole may have been within the limits set, that of the hundred or so largest trees was frequently above the limit. Similarly, because predominantly tall trees are frequently "coarse" rather than "clean" in their branching, selection was directed from the outset at the smaller of the upper canopy trees. Trees in both these groups (i.e. the taller and thicker ones) would therefore have

TABLE 12 PROPORTION OF DOMINANTS AMONG THE TREES INITIALLY SELECTED FOR PRUNING

Species (1)	*Experiment* (2)	*Number of trees selected per acre (all treatments)* (3)	*Percentage of dominants* (4)	*Average number of dominants selected per acre* (5)	*Approx. number of dominants per acre in sample plots of equivalent top height** (6)
Norway spruce	Drummond Hill	480	91	435	500
,, ,,	Inverliever	290	100	290	500
,, ,,	Dean	580	Not classified	—	320
Douglas fir	Monaughty	310	94	290	550
,, ,,	Inverliever	200	100	200	500
,, ,,	Dean	435	Not classified	—	320
Scots pine	Edensmuir (early pruning)	250	44	110	700
,, ,,	Edensmuir (late pruning)	250	74	185	450
Corsican pine	Dean	550	Not classified	—	?
Sitka spruce	Inverliever	280	95	265	600–700
European larch	Dean	510	Not classified	—	?

* From Permanent Sample Plots with Light Crown thinning.

been excluded from pruning, though most of them remained in the stand.

Table 12 shows the total number of trees initially selected for pruning in each experiment and the proportion of them which were dominants. Also their average density per acre compared with the total stocking of dominants in Light Crown Grade Sample Plots of equivalent height. No record is available of the canopy classes of the trees not selected for pruning. Almost all selected trees were dominants, except at Edensmuir, but from their densities per acre it is apparent that many unpruned dominants must have remained in the stands after first pruning and thinning, at least in the Scottish experiments, and it is probable that many of these would be larger, more aggressive trees than the "straighter, cleaner stems" selected for pruning. Many pruned trees were thus under threat of suppression from the start and most of the unpruned dominants remaining at the present day were probably in the upper canopy at the beginning of the experiments. Subsequent thinnings were directed at the removal of these, but even under crown thinning they presented a considerable problem on account of their number and the intervals (either prescribed or imposed by war-time conditions) between the thinnings.

The principal conclusion from the experiments in regard to the survival of pruned trees is that, whatever size or class of tree is selected for pruning, any larger or more dominant trees which are present at the time or develop later must be removed as soon as possible. Delay will usually result in the permanent establishment of unpruned dominant trees and the loss of a proportion of the pruned trees from the final crop. This leads to the conclusion that crown thinning is a necessary accompaniment of pruning; and it follows that a rather small proportion only of the initial crop will reach the largest diameter classes and that the pruning of trees which are felled in the early or mid-rotation thinnings will be wasted.

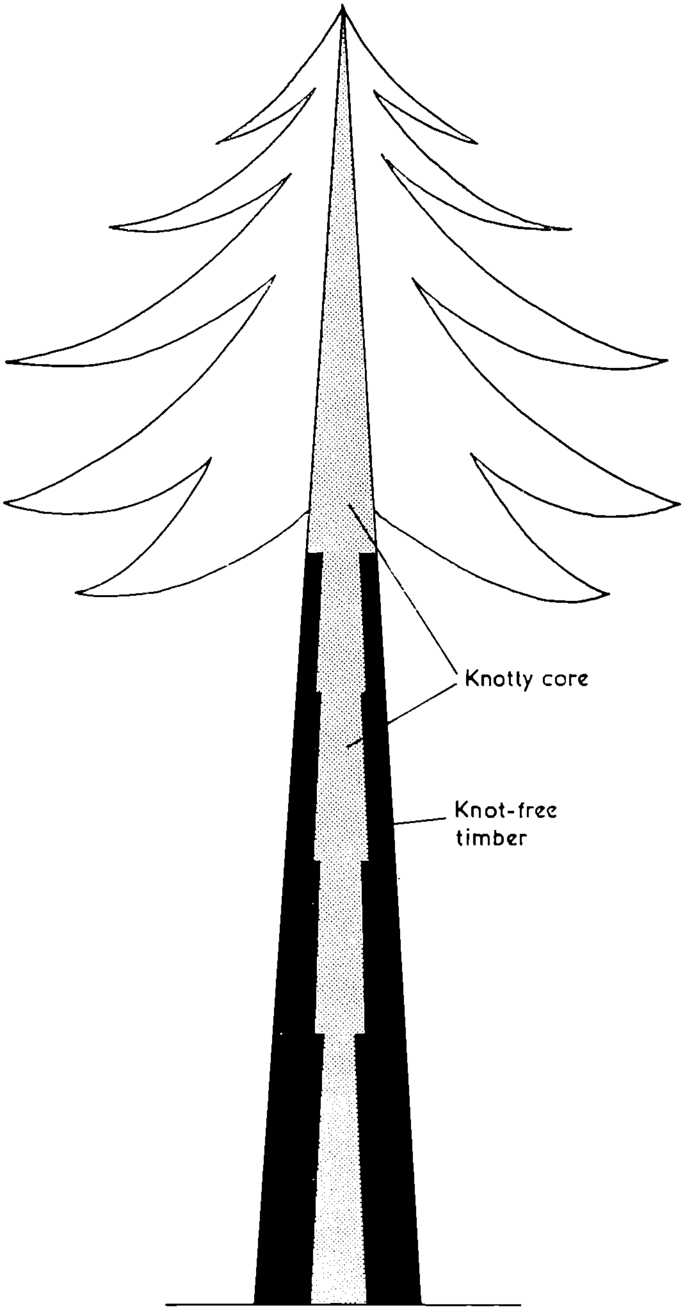


PLATE I

Diagrammatic longitudinal section of a tree which has received four prunings at intervals of a few years.

PLATE 2

Monaughty Experiment 7/38. Douglas fir pruned up to and including the second live whorl in 1938, 1942 and 1946 and crown thinned to favour the pruned trees. Note the large crowns of the favoured dominants, with sub-dominants (unpruned) beneath. Photographed in 1960 when 36 years old.

PLATE 3

Forest of Dean Experiment 71/31. Norway spruce pruned in 1931 and low thinned. Photographed in 1950 when 44 years old. The unpruned foreground trees are outside the treatment plot.

PLATE 4

Drummond Hill Experiment 11/38. Norway spruce pruned up to and including the second live whorl in 1938, 1942 and 1947 and crown thinned to favour the pruned trees. Photographed in 1960, 47 years old. Note the long crowns carried by the favoured dominants.

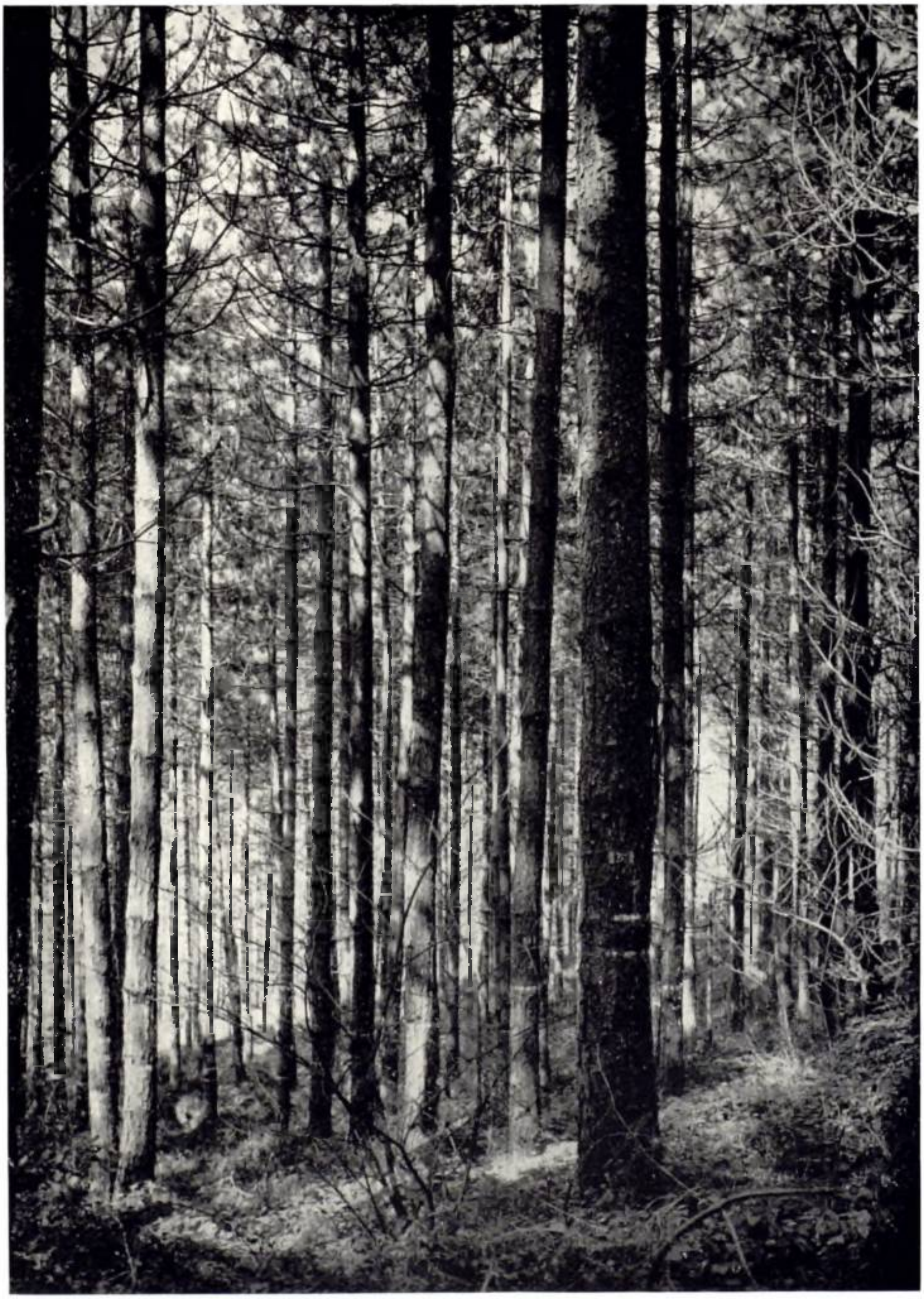


PLATE 5

Forest of Dean Experiment 3/31. Corsican pine pruned in 1931 and low thinned. Photographed in 1946 at 36 years old.

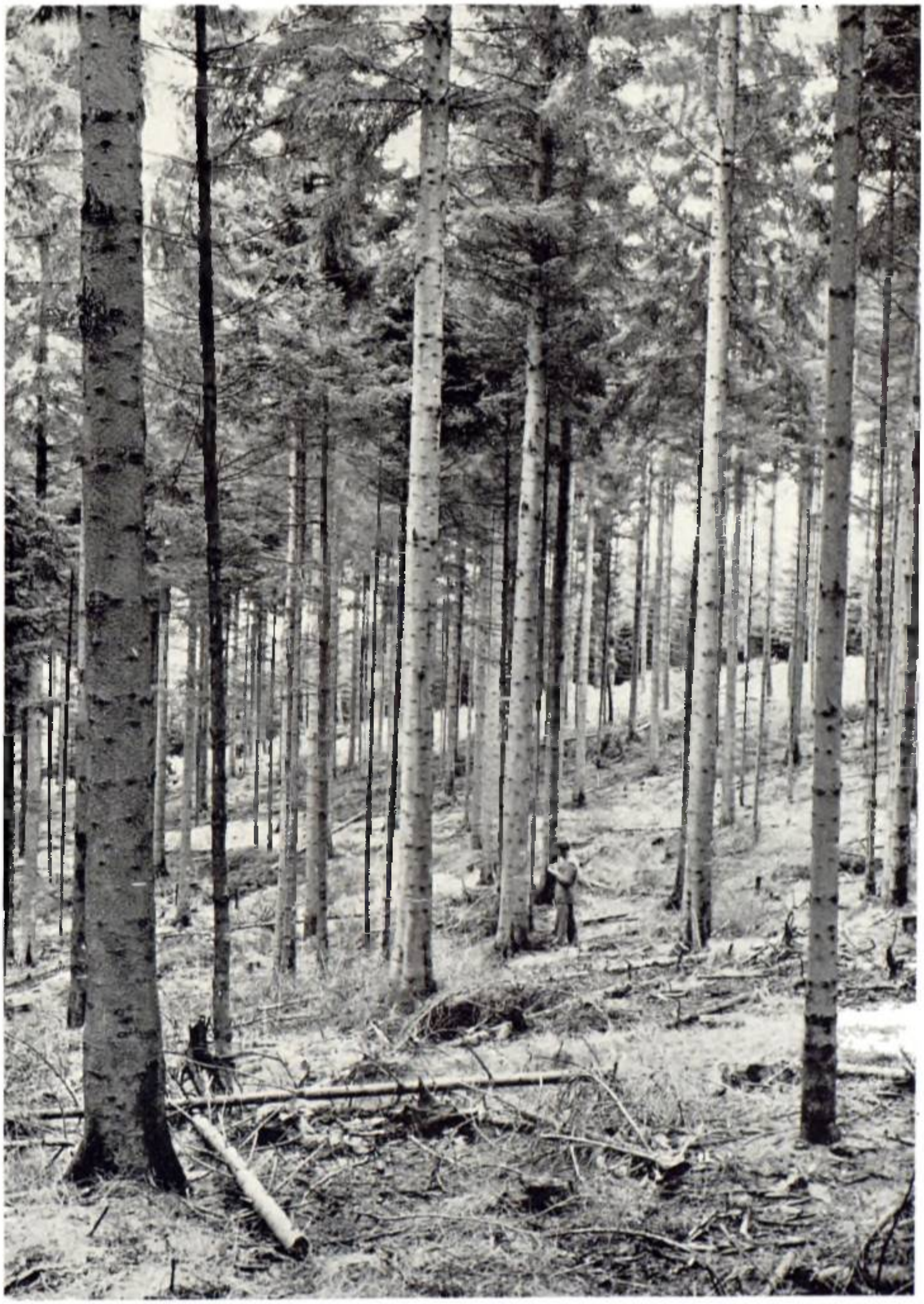


PLATE 6

Drummond Hill Experiment 11/38. Norway spruce pruned up to and including the second live whorl in 1938, 1942 and 1947 and crown thinned. Photographed in 1960 at 47 years of age, by when most of the lower-storey unpruned trees had been removed.

PLATE 7

Edensmuir Experiment 4/47. Scots pine pruned in 1947, 1954 and 1958. Photographed in 1960 when 37 years old. Note the dead branches persisting on the unpruned trees.

Chapter 9
THE EFFECT OF DIFFERENT TYPES OF THINNING

Comparisons of different types of thinnings under the same intensity of pruning were made only in the moderately pruned treatments of the 1936–47 (Scottish) group of experiments. There, the periodic removal of two live whorls of branches was repeated under both low and crown thinnings. The actual grade of thinning and the intervals between thinnings varied in the different experiments, but in general the low thinnings were moderately heavy (C/D grade) and the crown thinnings were light (L.C. grade). Intervals were usually four years. The most marked departure from this was at Inverliever where there was an interval of eight years between the first two thinnings due to war-time labour restrictions; in the Norway and Sitka spruce low thinnings these were both light (B) grade. The Drummond Hill (Norway spruce), Monaughty (Douglas fir) and Edensmuir (Scots pine) experiments changed from light to heavy crown thinnings after pruning was complete in all treatments. (See Plates 2, 4, and 7.)

Survival

In theory, a low thinning should allow of more dominant trees being retained in the stand; which in a pruned stand would be an advantage where all the dominants had been pruned but a disadvantage where any dominants had been initially left unpruned or had developed later. Crown thinning gives more scope for removing such unpruned dominants but also may reduce the stocking of pruned dominants.

Table 13 compares the survival of similarly pruned trees under low and crown thinnings in the seven Scottish experiments, and also the survival of unpruned dominants. In survival of pruned trees there is little consistency of results, either within a species or within a forest. The most that can be said is that the Inverliever experiments were probably less representative of their species than were the others, owing to the long delay between first and second thinnings—one would expect plots which had received only one B grade thinning to lose more pruned trees by suppression in the next eight years than plots which had an L.C. grade thinning favouring the pruned trees.

On the other hand, thinning had a marked effect on the survival of unpruned dominants; the table shows that crown thinning reduced their numbers to less than half those in low thinned plots. The numbers under both types of thinning were least in the experiments which received most careful attention Drummond Hill and Monaughty.

The results suggest that the type or grade of thinning was less important to the survival of the pruned trees than was the initial relationship, in terms of dominance, between the pruned trees and those left unpruned. It seems probable that the proportion of large dominants left unpruned in favour of smaller ones was greater than could be adjusted by thinnings at four year intervals.

Practical experience of thinning in pruning experiments showed the difficulty of maintaining a constant grade of thinning in plots which had received different intensities of pruning, in the absence of some kind of thinning control which is independent of the appearance of the canopy. In these experiments the thinning was controlled by visual estimation of the density of the crowns, and as the effect of a severe pruning is to reduce the crown density, there can be a tendency to under-thin the pruned plots relative to their controls. Crown congestion is relieved but root competition remains as high as before, to the detriment of the pruned trees, which have already lost a proportion of their crowns.

Increment

Table 14 compares the mean girth increments of pruned trees, over the period of each experiment up to the latest assessment, in the low- and crown-thinned versions of the same pruning treatments.

In every case, crown thinning resulted in greater girth increment of the pruned trees. The increase was usually small, though at Drummond Hill it was considerable, and was statistically significant ($P<0.01$). In several experiments, including Drummond Hill, the smaller mean girths in the low-thinned plots may have been partly due to the greater number of pruned trees comprising the means—the extra trees occurring in the lower girth classes and so reducing the mean. However, in the Inverliever Sitka spruce and the Edensmuir (early pruning) Scots pine the crown-thinned plots carried more pruned trees than the low-thinned plots, yet these pruned trees still had a higher girth increment.

If the differences in thinning are maintained in future years the girth differences may become more pronounced, especially with the change to heavy crown grade. The effect of thinning on height growth of the pruned trees was inconsistent and so small as to be negligible.

TABLE 13 EFFECT OF THINNING TYPE ON SURVIVAL OF SIMILARLY PRUNED TREES
(Pruned up to and including the second live whorl of branches)

Numbers per acre

Species	Experiment	Interval since initial selection	Crown thinning (L.C. grade)			Low thinning (C/D grade)			Number of unpruned dominants surviving	
		(years)	Number selected	Number survived	Percentage survival	Number selected	Number survived	Percentage survival	Crown	Low
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Norway spruce	Drummond Hill	20	498	122	24	515	195	38	2	62
,,	Inverliever	15	290	160	55	297	163	55	27	130
Douglas fir	Monaughty	20	308	100	32	305	165	54	8	18
,,	Inverliever	18	200	85	42	200	82	41	48	82
Scots pine	Edensmuir (early pruning)	22	252	153	61	244	98	40	43	98
,,	Edensmuir (late pruning)	12	239	190	80	259	191	74	24	49
Stika spruce	Inverliever	18	280	117	42	282	60	21	30	170

TABLE 14 EFFECT OF THINNING TYPE ON GIRTH INCREMENT OF SIMILARLY PRUNED TREES
(Pruned up to and including the second live whorl of branches)

Species	Experiment	Increment interval	Crown thinning (L.C. grade)		Low thinning (C/D grade)	
		(years)	No. of trees per acre	Mean breast height girth increment (inches)	No. of trees per acre	Mean breast height girth increment (inches)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Norway spruce	Drummond Hill	20	122	24½	195	18
,, ,,	Inverliever	15	160	12½	163	10½
Douglas fir	Monaughty	20	100	23½	165	22½
,, ,,	Inverliever	18	85	18	82	16
Scots pine	Edensmuir (early pruning)	22	153	13	98	11½
,, ,,	Edensmuir (late pruning)	12	190	7	191	6
Stika spruce	Inverliever	18	117	18	60	14½

Chapter 10

THE KNOTTY CORES

Basic Considerations

The origin and nature of the knotty core were considered in Part I. It is worth noting that in his project plan of 1934 Guillebaud intended to prune trees with knotty cores which *nowhere* exceeded 3–4 in. in diameter. In the plans of the subsequent experiments this was lost sight of and the prescriptions sought to control the core diameters at breast height only; diameters at the base of the first, and especially of the later, pruned lengths were frequently allowed to greatly exceed the maximum values desired for breast height, as will be shown in the results. This is important in view of the specified object of the experiments, to grow knot-free saw-timber.

Conifer rotations in Britain are likely to be relatively short, probably not more than 70 years, but because of possibly higher price levels in the later years for pruned stems, rotations may be extended over those for unpruned crops by a decade or more. Even so, there will be a limit, physical or economic, to the final diameter to which pruned trees can be grown, even at the fastest rate of growth, and this diameter and the minimum radial thickness of clean timber required, together set a limit on the maximum diameter of knotty core permissible in trees to be pruned for clear grades of saw-timber.

Knotty core diameter is to a large extent controllable by the forester, depending, in the bottom pruned length, on the size (i.e. age × growth-rate) at which the tree is first pruned, and in each subsequent length on the time interval since the previous pruning on the diameter at the top of the previous length and on the diameter growth-rate. Diameter at the top of a length depends in turn on the height to which its pruning is taken, and this is limited by the amount of crown which can be removed.

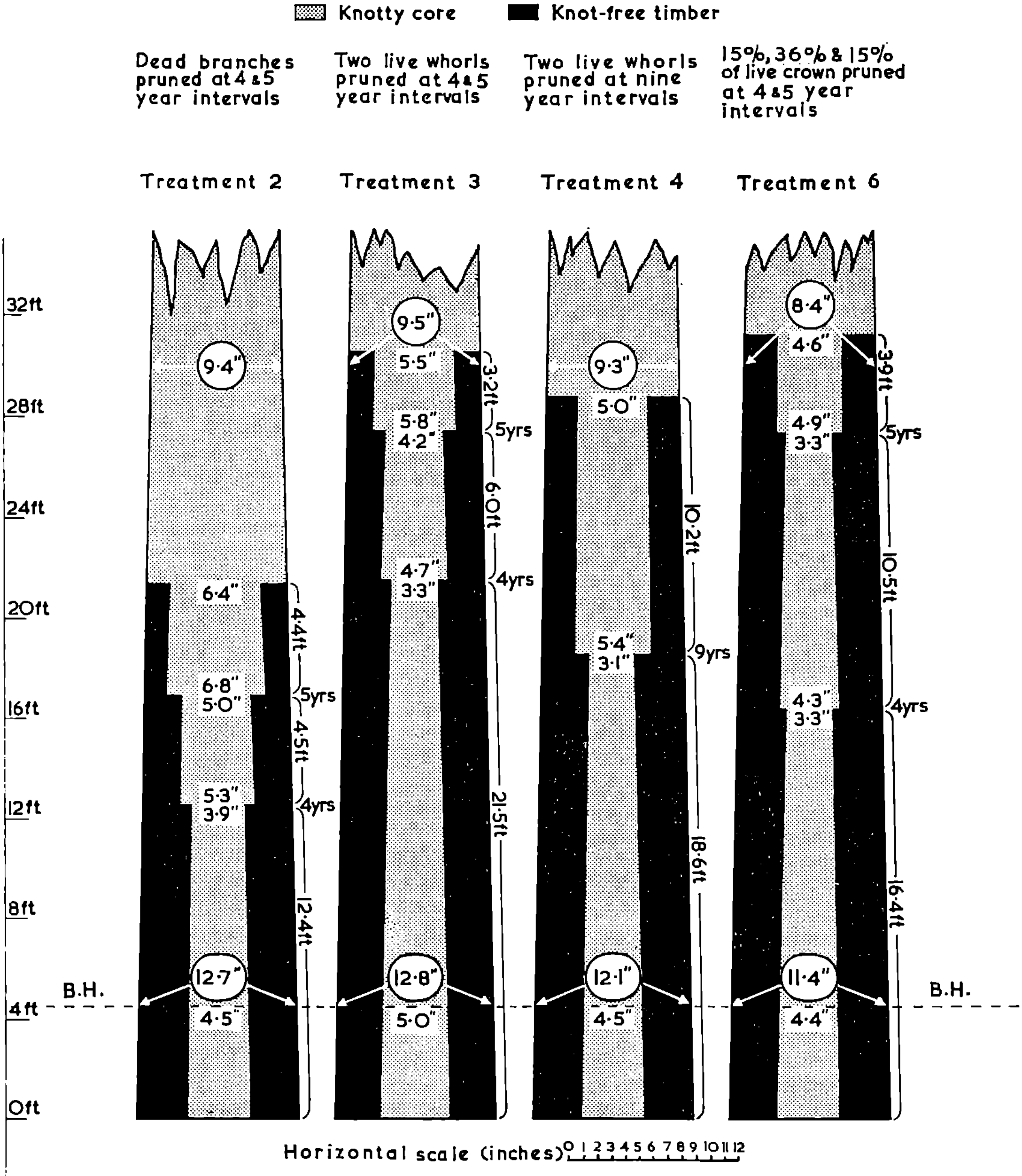
Measuring Core Diameter

It is not possible to measure directly the diameter of the defective core within a pruned bole by non-destructive methods because of the difficulty of determining the thickness of healing defects lying outside the true knotty core. The knotty core itself approximates to the over-bark dimensions of the tree at the time of pruning (assuming that the branches were sawn off flush with the bark surface) so long as those dimensions were measured over the pruned stubs. But in practice, girths and diameters are usually measured to avoid whorls and swellings, so normal methods of measurement will give an underestimate of the core size. To the knotty core as thus measured must be added an allowance for healing—involuted wood, bark- and resin-pockets, etc. Such healing thicknesses have been measured by a number of workers, by dissecting pruned knots (see Chapter 12). Another way of estimating the total defective core diameter in a pruned length would be to measure over-bark on the thickest pruned whorl shortly before the last wounds had completely healed; in this way the incomplete occlusion would be compensated for by the bark thickness.

In the present experiments, core diameters were obtained by over-bark girth measurements, made at the time of pruning and avoiding the pruned whorls. These were taken at the top of each length at the time it was pruned, and at breast height of the first length at every pruning. Measurements were not, however, made at the bottom of each pruned length at the time of pruning. Since this is the widest part of the length, and hence determines the effective diameter of the core, an attempt has been made here to estimate these bottom diameters by interpolating between top diameter and breast-height diameter on scale diagrams drawn for the mean knotty core of each treatment. Figures 1–4 are drawn from the scale diagrams, omitting the later breast height diameter measurements, and give the measured values for length and top diameter and the interpolated values for bottom diameter of each length. Such a method must give an underestimate of the size of the effective core after complete occlusion of the knots, for the reasons given above, but within any one experiment it provides a measure of the relative sizes of the cores obtained from different treatments.

An opportunity arose to test these external estimates of core diameters against internal measurements made on longitudinally bisected logs. This was done in Norway and Sitka spruces from the Inverliever experiments, which were damaged by wind in 1957. Fifty Norway spruce and 38 Sitka spruce pruned trees were split up the centre and the maximum defective core diameter in each 10 ft. length of each tree was measured from a cord stretched along the exposed face. This method showed the defects in only one plane of the stem, and not necessarily in the plane of maximum core diameter, so that the

FIG. 1.
KNOTTY CORES IN DRUMMOND HILL
NORWAY SPRUCE EXPERIMENT

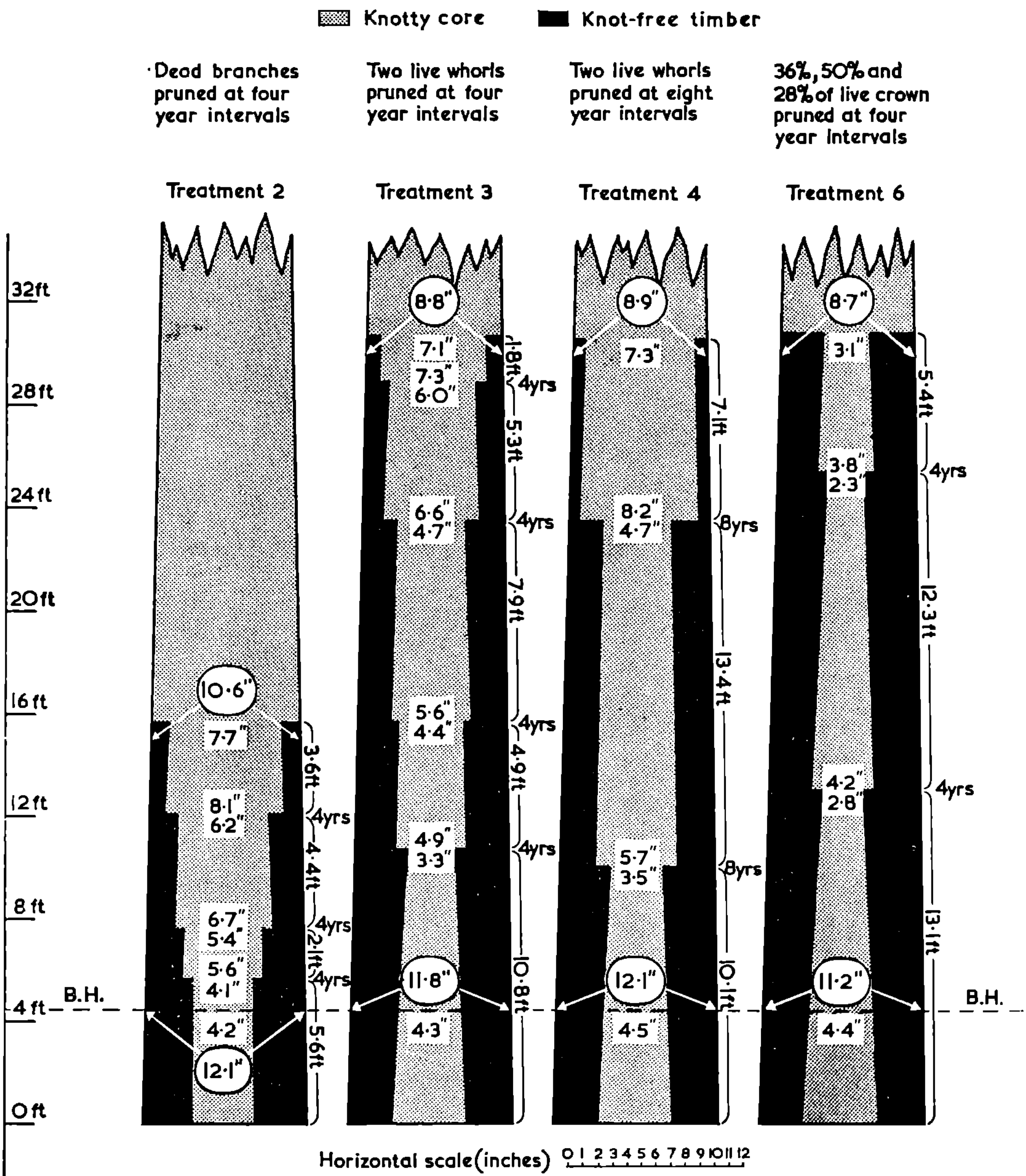


Notes: The horizontal scale is seven times greater than the vertical

Circled dimensions are measured 20 years after first pruning, at 30 feet and at breast height, and refer to overall diameter. Dimensions within squares refer to diameters of knotty cores only at top or bottom of pruned length, or at breast height, as appropriate.

FIG. 2.

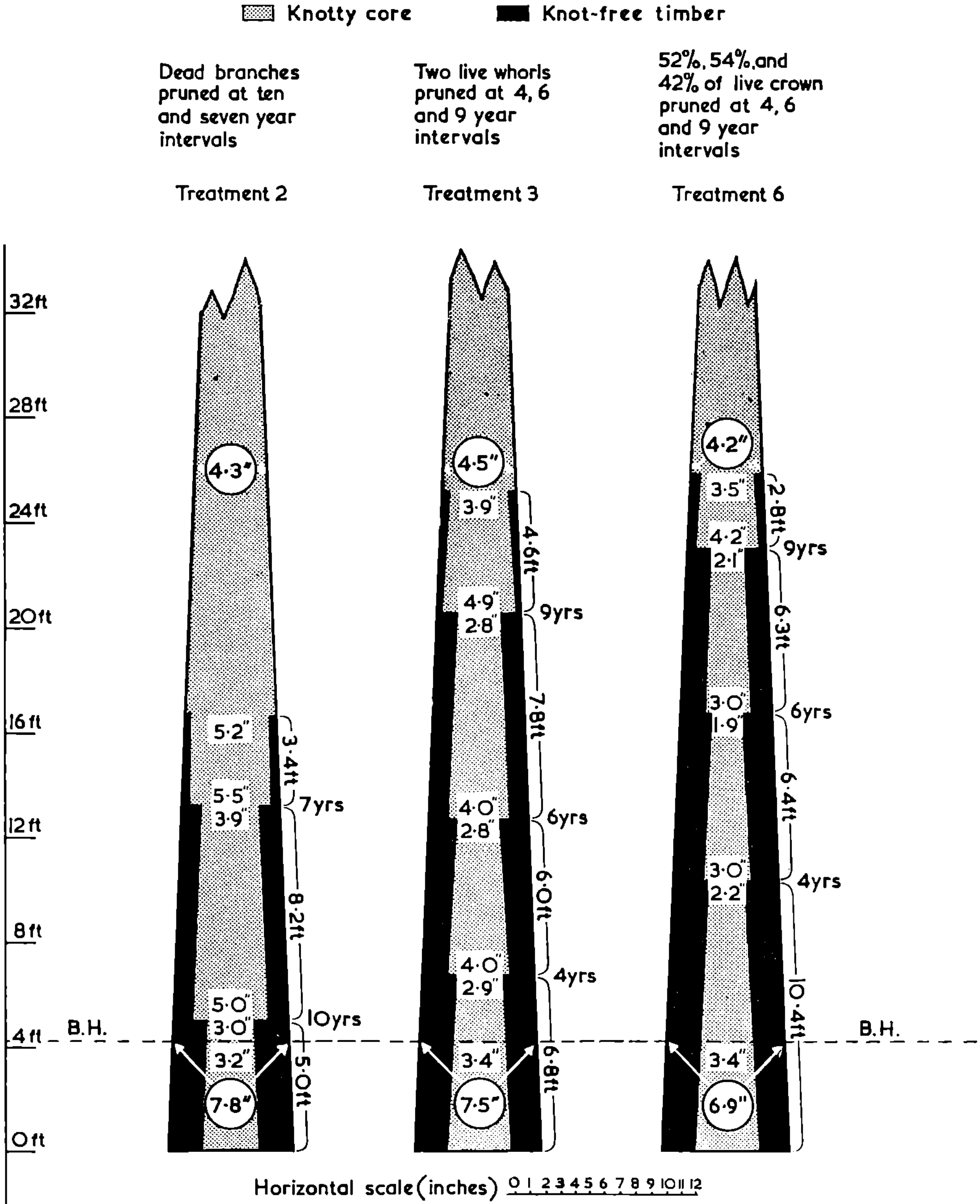
KNOTTY CORES IN MONAUGHTY DOUGLAS FIR EXPERIMENT



Notes: The horizontal scale is seven times greater than the vertical.

Circled dimensions are measured 20 years after first pruning, at 30 feet (15ft on Treatment 2) and at breast height; they are diameters. Dimensions within squares refer to diameters of knotty cores only, at top or bottom of each pruned length, or at breast height, as appropriate.

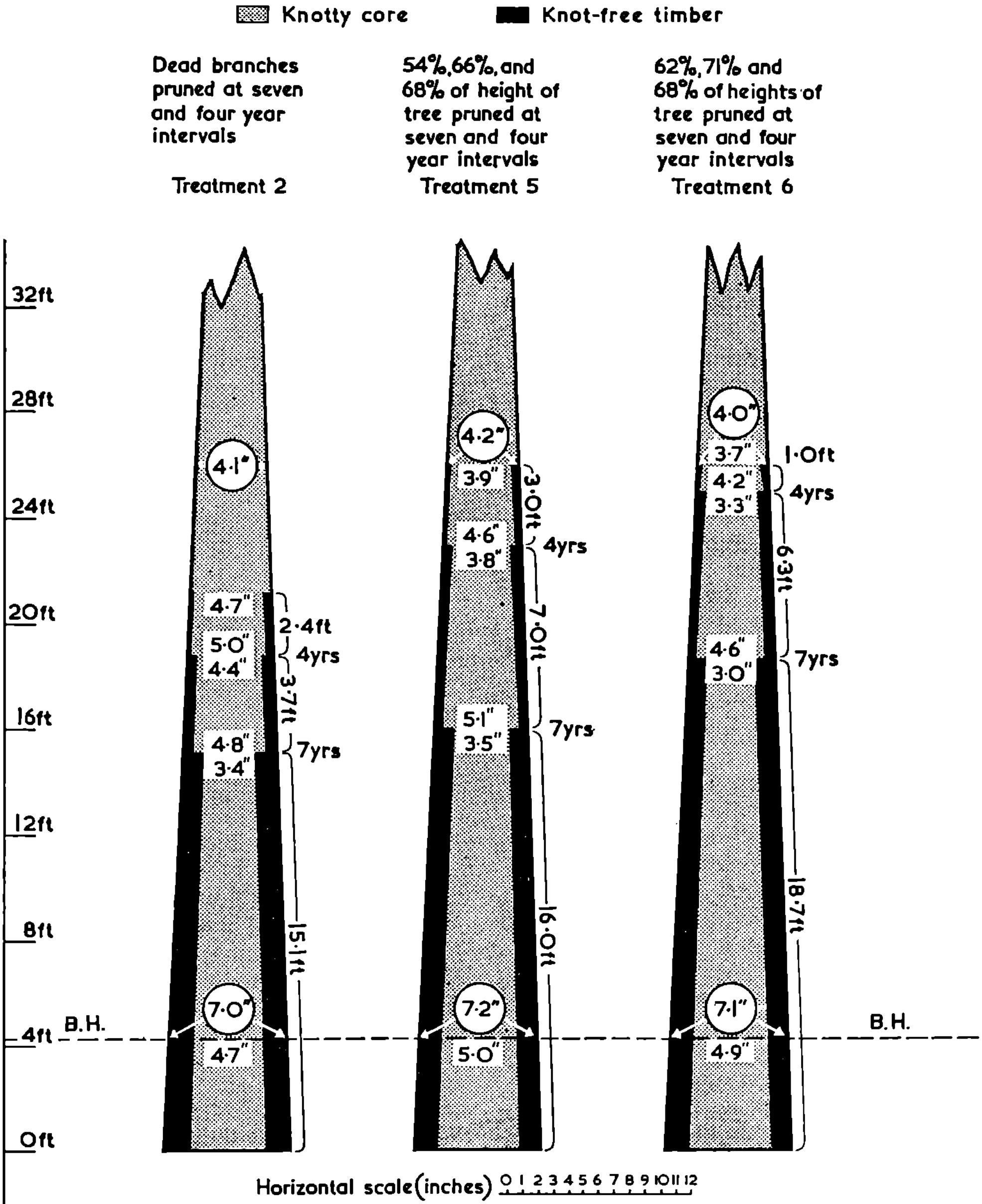
FIG. 3.
KNOTTY CORES IN EDENSMUIR SCOTS PINE (EARLY PRUNING) EXPERIMENT



Notes: The horizontal scale is seven times greater than the vertical.

Circled dimensions are measured 22 years after first pruning, at 26 feet and at breast height, and are diameters. Dimensions within squares refer to diameters of knotty cores only, at top or bottom of each pruned length, or at breast height, as appropriate.

FIG.4.
KNOTTY CORES IN EDENSMUIR SCOTS PINE (LATE PRUNING) EXPERIMENT



Notes: The horizontal scale is seven times greater than the vertical

Circled dimensions are measured 12 years after first pruning, at 26 feet and breast height, and are diameters.

Dimensions within squares refer to diameters of knotty cores only at top or bottom of each pruned length, or at breast height, as appropriate.

TABLE 15 BREAST-HEIGHT DIAMETERS OF THE KNOTTY CORES*

Species (1)	*Experiment* (2)	*Total number of trees selected* (3)	*Mean core diameter of selected trees (inches)* (4)	*Core diameter of smallest tree (inches)* (5)	*Core diameter of largest tree (inches)* (6)	*Prescribed upper limit of core diameter (inches)* (7)	*Percentage of selected trees within prescribed limit* (8)	*Percentage of selected trees within 4-in. diameter limit* (9)
Norway spruce	Drummond Hill	1346	4.2	2.4	7.8	4	48	48
,,	Inverliever	616	5.3	2.9	8.9	4	10	10
,,	Dean	189	5.8	4.0	7.8	—	—	1
Douglas fir	Monaughty	866	4.3	2.1	7.2	5	84	40
,,	Inverliever	556	4.7	2.9	7.3	4	17	17
,,	Dean	174	6.7	4.5	10.2	—	—	0
Scots pine	Edensmuir (early pruning)	245	3.2	2.4	4.6	4	98	98
,,	Edensmuir (late pruning)	240	4.8	2.5	6.7	5	79	15
Corsican pine	Dean	220	6.0	3.8	8.6	—	—	3
Sitka spruce	Inverliever	787	4.3	1.9	6.2	4	37	37
European larch	Dean	203	5.1	3.3	7.6	—	—	8

* Knotty core diameters are taken to be the same as the over-bark breast-height diameters of the trees at time of pruning; mean core diameters are the means of all the trees initially selected for pruning in each experiment.

average value for all the stems would almost certainly be an underestimate of the true diameter. (Such could only be accurately determined by dissecting and measuring every knot in every whorl of the pruned stem, or by some means such as rotary peeling of the log until defective timber was reached.) Comparison of the two methods of measurement showed that in the Sitka spruce the external measurement usually over-estimated the core diameter as found by internal examination. Differences were usually less than ½ inch. In the Norway spruce this was also the case in the first (lowest) ten-foot length of stem, but in the two upper lengths the external measurements underestimated the measured diameter by up to 1 inch. The comparison is not very satisfactory, both because the maximum core diameters by external measurement were estimates only, from interpolation on stem diagrams, and because, as shown above, the internal measurements were probably underestimated. It serves, however, to indicate that over-bark measurements at the bottom of a pruned length at the time of pruning would give a measure of the diameter of the defective core within about ½ inch.

Core Diameters in the Experiments

Table 15 shows the mean breast-height diameters of the knotty cores obtained in each experiment (all treatments combined), together with the range of diameters of the pruned trees and the proportion of the total number of trees which were within the set diameter limits and within a 4 inch diameter limit. The largest and smallest trees shown are usually very extreme cases, the great majority of trees fell within an inch either side of the mean diameter.

The experiments covered a range of mean breast height core diameters from 3.2 in. to 6.7 in., though most of the trees selected were below 6 in. diameter. Except in the Scots pine at Edensmuir (early pruning) (and in the Douglas fir at Monaughty and Scots pine at Edensmuir (late pruning) where higher limits were set) well over half the selected trees had knotty cores greater than had been hoped for in planning the experiments. This may have been due to delay between selecting the stands and the commencement of pruning, or, more probably, to failure to appreciate the size of the larger trees in a stand whose mean dimensions appeared to suit the purpose of a pruning experiment. Stands were chosen which were approaching the time of normal brashing and first thinning, whereas to obtain dominant trees with b.h. diameters less than 4 inches, stands should have been selected which, at the current planting distances, had only recently closed canopy. The Scots pine at Edensmuir (early pruning), which was 14 years old and 16 ft. dominant height, with a mean crown height of 3½ ft., was the only one of the experiments to achieve the aim of pruning on really small knotty cores in the first pruned length (see Table 15). The maximum, and hence the effective, core diameters in the first length occur at stump level and may be up to an inch greater than at breast height.

Prescribing the age or size at which pruning should start, or limiting the breast height diameter of the trees to be pruned, controls the knotty core diameter only in the first pruned length. In the 1931 (Dean) experiments, only one pruning was made, giving core diameters at breast-height as shown in Table 15. In the 1936–47 (Scottish) experiments several successive prunings were made, giving multiple-length knotty cores. In these, the maximum diameter is that at the bottom of the widest length, and its position and size will depend, as was shown in Chapter 1, on a number of factors of the pruning regime, of which one of the most important is the interval between successive prunings.

In the present experiments, fixed pruning cycles were prescribed. The usual interval was four years, which was probably a compromise between allowing time for crown recovery after pruning and not allowing upper knotty cores to get too large. It also seemed a reasonable thinning interval. In the 1938–39 group of experiments, one of the pruning treatments was prescribed to be repeated at 8-year intervals for comparison with those at 4 years. In practice, only one of these experiments ran as prescribed, that in Douglas fir at Monaughty. At Edensmuir (early pruning), successive intervals were 4, 6 and 9 years owing to climatic damage to the crowns some time after the second pruning, which prevented more frequent pruning in the later years.

Figures 1–4 show diagrammatically the knotty cores obtained in four of the experiments. In the diagrams, each set of dimensions is the mean of 25–60 pruned trees. The dry-pruning treatment and the moderate and most severe green-pruning treatments are given for each experiment, together with the moderate pruning at extended intervals in the Monaughty and Drummond Hill experiments. The diagrams show that in almost every instance the thickest part of the knotty core occurred in one of the upper pruned lengths. This was particularly the case with the dry-pruning treatment, in which maximum knotty core diameter increased with each successive pruning; it was in that treatment, moreover, that the cores reached their greatest overall widths. The reason lies in the short lengths pruned on each occasion, which meant only a small difference in diameter between bottom and top of each length. Growth at the top during the interval between prunings thus quickly made up and exceeded this difference, and the bottom diameter of the next length to be pruned became greater than that of the previous length.

Large core diameters were also given by the moderate treatments with pruning at 8-year intervals. There each pruned length was fairly long, with an inch or more difference between top and bottom diameters, but the long period between prunings enabled top diameters to more than make up the difference. The same thing occurred at Inverliever, where eight years elapsed between first and second prunings in all the treatments.

In moderately pruned treatments with shorter pruning cycles, core diameters still tended to increase up the stem, though not, of course, to the same extent as on the longer pruning cycles. Only when the most severe prunings were applied at the shortest intervals (four years), were knotty cores obtained whose diameters were uniformly narrow in each pruned length. These were the prunings in which differences between top and bottom diameters were large relative to the interval before next pruning and to the rate of diameter growth.

The net result was that the initial efforts to obtain young stands and to select small diameter trees for the sake of narrow cores were in most cases nullified by the low pruning severities and long cycles applied later. For example, at Monaughty (Fig. 2) in Treatment 3, a maximum core diameter of about 7½ inches resulted at fifth pruning, despite the fact that at first pruning core diameter was only 4½ inches.

The estimates of bottom diameters which have been made for Figures 1–4 are not considered to be sufficiently accurate for more detailed examination, but broad conclusions can be drawn from the results shown. These are, that if a small and constant knotty core diameter is required of a pruning regime, pruning must begin early and be as severe as other conditions will allow; and the pruning cycle must be controlled by the rate of stem diameter growth at the top of the previous pruned length.

Juvenile Wood

One of the factors affecting the quality of the timber from any given part of a stem is the age of the wood in terms of the number of annual rings from the pith at which it occurs. The early-formed wood, whose characteristic features include lower density, higher fibril angle and shorter fibre length than wood formed later, has been termed "juvenile wood", and may be considered to occupy a central core within the stem analogous to the knotty core left after pruning. Since the characteristics mentioned are associated with poor mechanical and technological properties in timber, and since the majority of pruned timber is expected to supply the need for high quality material, there will be little advantage in pruning so early that juvenile wood continues to be formed outside the limits of the maximum knotty core diameter. The wide range of studies to date in this field may be summarised as indicating that timber density in most conifers approaches its adult condition at 8–12 years from the pith, though fibre length continues to increase up to 20–25 years while fibril angle is a more variable characteristic which, however, is less pronounced after about 10 years. Fibre length is probably the least important of these three characteristics in the quality of pruned timber; the need to avoid the inclusion of juvenile wood in the shell of knot-free timber should not, therefore, be at variance with the need to restrict maximum knotty core diameters to the region of 4–5 inches.

Chapter 11

THE RATE OF COMPLETION OF PRUNING

Generally speaking the total cost of an operation in forestry tends to increase if the operation is done piecemeal, on a number of occasions, rather than being completed in a single operation. This has been found to hold true for pruning (Finnis, 1953; Holck, 1953). The operation of pruning, having no silvicultural or hygienic justification, is sensitive to economic pressures and, on these grounds alone, a pruning regime which achieves the required pruned length in the minimum number of operations is preferable to one involving many visits to the pruned stand.

Table 1 shows that the present experiments were pruned to a variety of heights in different numbers of operations. In the 1931 (Dean) group of experiments, no final pruned height was specified, the heights achieved resulting from one application of each treatment. In the Scots pine experiments at Edensmuir, pruning was continued in each treatment until a clear length of 26 ft. was obtained, and in the remaining Scottish experiments, until 30 ft. was obtained. Exceptions to this occurred in the treatments pruning dead branches, where progress was so slow that further pruning was sometimes abandoned before the prescribed height was reached, or else completed to that height as a last resort, regardless of the removal of live branches.

Effect of Pruning Intensity

The number of prunings required to achieve a given clear height varied with the height of the trees when pruning began and with the intensity of the pruning. Table 1 shows that about 30 ft. was achieved in one operation by the moderate treatments in Norway spruce in the Dean, when the trees were 47 ft. high, whereas the same pruned height required three operations at Drummond Hill, beginning when the trees were 33 ft. high. In Scots pine at Edensmuir (early pruning), four prunings were required to reach 26 ft., beginning when the trees were 16 ft. tall. The various intensities of green pruning used in any one experiment were usually not sufficiently different to affect the number of operations required, as may be seen from Figures 1–4, but dry pruning was always very much slower than any green pruning treatment.

Effect of Thinning

The low thinnings, even starting with a B grade, did not cause appreciably faster branch death in the pruned trees during the period of pruning than did the light crown thinnings. The result was that under the same pruning regime, pruning proceeded at the same rate for both types of thinning, and the number of pruning operations taken to reach the required total length was the same for each.

Effect of Spacing

A critical comparison of spacing effects cannot be made in the present experiments, but it is worth noting that in the Norway spruce experiments at Drummond Hill and Inverliever, first pruned at similar ages and heights (24–25 years and 33–34 ft., see Table 1), there was very little difference in the heights of the second live whorls even though the Drummond Hill crop had stood at 3 ft. spacing until pruned whereas the Inverliever crop had stood at 4½–5 ft. spacing. For equivalent tree heights, pruned heights were only about 1 ft. greater at Drummond Hill than at Inverliever, in the three treatments pruned up to and including the second live whorl. On the other hand, the knotty cores in these treatments (breast-height girth, over bark) were 3–5 inches smaller in the close-spaced crop.

Chapter 12

THE TIMBER OF THE PRUNED TREES

The pruning experiments considered here were mostly started between 20 and 30 years ago. Since then the pruned trees have increased their mean breast height diameters by between 4 and 8 inches, depending upon species and growth rate. This represents a radial increment, over bark, of 2–4 in., or a mean thickness of clear timber laid on since pruning of perhaps 1–3 in., allowing for bark thickness and for irregularities during occlusion of stubs. If further allowance is made for slabs and kerfs during sawing it is seen that very little utilisable clear timber has been produced to date, on average in any experiment, though individual trees will have much greater thicknesses. Consequently this report can give no information on either the quantity or quality of the pruned timber in the present experiments, as determined by conversion followed by grading, timber tests or detailed examination.

However, two features of timber quality which are particularly important in clear grades have received some attention; they are growth rate and the incidence of rot, stain or bark pockets, resulting from pruning.

Growth Rate

Diameter growth, expressed as numbers of rings per inch, has been calculated by converting breast-height girths (over bark) to diameters and dividing the radial thickness grown since pruning by the number of years in the intervening period. Girths at the most recent assessment were used in each case. The results are shown in Table 16. The moderately pruned trees were used for the calculation, i.e. those from which two live whorls were removed at each operation. The pines and larch grew at 10 or 11 rings per inch and Douglas fir and the spruces at between 5 and 9 rings. British grading rules for Grade 1 clear timber require at present a rate of growth not faster than 8 rings per inch (see Appendix C, page 55). This excludes most of the Douglas fir and spruce grown in these experiments; though it is not to say that such timber would be unsuitable for many of the uses of clear grades nor that it would be unmarketable at a price comparable with slower-grown clear timber. The British grading rules are still in a developmental stage, and nothing is yet known about the utilisation and marketing of pruned home-grown softwoods, but it is to be expected that if supplies of knot-free but rather fast grown timber become available from our plantations, grades and markets will be developed to cater for them.

Timber Defects

These can be studied only by destructive investigations, and such studies for the most part have had to be confined to occasional thinnings in order to preserve the main crop trees until maturity. An opportunity was provided for a larger investigation when windthrow severely damaged the Inverliever pruning experiments, particularly Norway and Sitka spruces, in February 1957. Sixty-four Norway spruce and fifty-six Sitka spruce trees were examined; of these, a proportion were used for measurements of the knotty core diameters, as described in Chapter 10, and all were examined for defects. The examination consisted of sawing each tree longitudinally up the centre and inspecting all the exposed knots on one of the faces so formed. In this way 922 Norway spruce knots were studied and 600 Sitka spruce. The faults which were looked for were ragged stubs, rot, resin staining, included bark or pitch over the branch stub and damage to the wood near the knot. No sign of rot or stain was found associated with pruned knots, of which the majority were green when pruned. (See also, the knot healing study reported below.) A few cases of stain which occurred away from knots were probably the result of cambial injuries by tools or by falling trees. The commonest fault was the inclusion

TABLE 16 DIAMETER GROWTH EXPRESSED AS RINGS PER INCH AT BREAST-HEIGHT

Species	*Experiment*	*Most recent assessment*		*Approximate Quality Class*	*Since first pruning:—*		
		Year	*Age*		*Period of growth* (*years*)	*Radial increment* (*inches*)	*Number of rings per inch*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Norway spruce	Drummond Hill	1958	45	I–II	20	3.9	5
,,	Inverliever	1954	39	I–II	15	2.0	7½
,,	Dean	1952	46	I	21	2.3	9
Douglas fir	Monaughty	1958	34	II–III	20	3.8	5½
,, ,,	Inverliever	1956	32	II–III	18	2.8	6½
,, ,,	Dean	1951	43	III	20	2.9	7
Scots pine	Edensmuir (early pruning)	1959	36	II (low)	22	2.0	11
,, ,,	Edensmuir (late pruning)	1959	36	II (low)	12	1.2	10
Corsican pine	Dean	1940	30	I	9	0.8	11
Sitka spruce	Inverliever	1956	32	II	18	2.8	6½
European larch	Dean	1948	40	II–III	17	1.6	10½

Note: The data are for the moderate pruning treatment in each experiment, with C/D grade thinning in the Dean experiments and L.C. grade in the Scottish experiments.

of small pieces of bark or resin over the knots, which increased the effective diameter of the knotty core. The tendency, noted only occasionally, for the grain of the clear wood to bulge outwards over the site of a pruned knot was usually associated either with these resin or bark inclusions or, more often, with the larger diameter knots. No differences between pruning or thinning treatments were discernible in the rate or condition of knot occlusion in either dry- or green-pruned branches. No differences were discernible between the few available trees which had been pruned at different seasons of the year. Most of those examined were pruned during September—March, i.e. in the dormant season.

The experiment in Norway spruce at Drummond Hill suffered at one stage from rather extensive resin bleeding from cambial injuries on the stem. This was noticed after the second pruning and a detailed examination of the trees was made to see whether the damage was associated with green pruning, or with pruning at all (Day, 1950). Day was unable to find an exclusive relationship between this damage and the pruning (cambial injury, bark necrosis and resin bleeding being also present in unpruned trees in the same stand); nor was the damage to pruned trees more severe when green pruning was done (the largest and most extensive injuries were in dry-pruned sections, the most frequent injuries within the limits of green pruning). The season of the year at which pruning was done (January, May, July or October) had no effect on the incidence of the damage. Day concluded that pruning had played only a minor, and secondary, role in the occurrence of this particular damage. Later examination of thinnings which still bore the signs of the resin bleeding, showed that damage below the cambium was difficult to find, all the damaged tissue having been carried outwards in the phloem, and clean wood laid on underneath.

Because of the importance of green pruning to the incidence of fungal infection, the findings of other workers have been reviewed. Most agree that green pruning of conifers other than Norway spruce may be safely undertaken. In the case of Norway spruce, it is significant that most reports of infection are in stands which were pruned late in life, removing large branches, or were pruned very severely, so as to seriously weaken the trees, or where careless work was done, leaving long stubs or damaged bark. Examination of material from stands which were carefully pruned, during the earlier part of the rotation, has almost always found sound timber after green pruning of spruce (e.g. Paterson, 1938; Curtis, 1938; Romell, 1940; Nageli, 1952; and the Forestry Commission work described in this chapter).

A consistent feature of the pruning of Sitka spruce in Forestry Commission experiments has been the development of epicormic shoots on the pruned trees within a year or two of pruning. The shoots were particularly numerous in open stands, such as the crown thinned plots at Inverliever and the "free growth" experiments at Forest of Ae and Benmore, described in Chapter 6. It is not known to what extent such shoots will cause defects in the pruned timber, since few trees have been cut up in such a way as to demonstrate pin-knots or other faults which might be expected. Neither can it be said whether the shoots will persist after the crowns of pruned trees have fully re-developed in a uniform crop, because at Inverliever the experimental stand has been opened by continuing periodic windthrow, and in other experiments pruning has only recently been completed or is continuing. This point will receive attention when pruned Sitka spruce logs are felled for examination of their timber.

Healing of Pruned Knots

No further information has been provided by the experiments but the results of a study of healing and condition of pruned knots from other plantations provide additional information on those aspects. The study was a joint one between the Forestry Commission and the Forest Products Research Laboratory, wherein the Commission, in spring, 1938, pruned small lots of trees in young Norway and Sitka spruce plantations throughout Britain, and the Laboratory dissected these trees seven years later and examined the condition of the knots and the time and thickness of healing wood which were required to occlude them.

The following conclusions are drawn from the Laboratory's unpublished report (F.P.R.L., 1952), the appendix and table numbers referring to tables in the Appendices *of that report*: 46 Sitka spruce and 30 Norway spruce logs were examined, providing a total of 2,939 knots, of which 2,582 (88 per cent) were completely healed seven years after pruning. Except where otherwise stated, healing times and thicknesses refer to these completely healed knots only.

(i) In Norway spruce logs, pruned by saw at an average stem diameter of 3.3 in. (measured below each dissected knot), 1,053 knots were healed in an average period of four years by an average radial thickness of 0.4 in. of wood, giving a knotty core of 4.1 in. diameter (*Appendix III*). These radial thicknesses are probably rather greater than the bark thickness at time of pruning, indicating that the over bark diameter of a tree when pruned will slightly under-estimate the diameter of the resulting knotty core.

The remaining results are based on examination of about 300 knots in Norway and Sitka spruces combined.

(ii) When the stem diameter at pruning was smaller (less than 3½ in.) the knots were healed more quickly than where diameter was greater (more than 4½ in.), although the thickness of healing wood was similar at all stem diameters. (*Appendix IV, Table 1.*) Thus, the younger part of the stem grew faster in diameter, indicating the value of early pruning to obtain rapid healing.

(iii) Healing time increased with the length of stub left by pruning (*Table 2*); most stubs longer than 0.4 in. were still unhealed after seven years; ¼ in. under-bark length appeared to be the critical length of stub for reasonably fast healing (5 years). In young trees this length probably corresponds with cutting flush with the bark. The thickness of healing wood, and hence of the defective core, naturally increased with length of stub left by pruning, showing the value of close pruning.

(iv) The diameters of the pruned stubs ranged from less than 0.2 in. to 1.75 in. though 87 per cent were between 0.2 and 0.8 in.; over the whole range, about 20 per cent of the stubs were not healed within seven years, but the proportion healed was not related to stub diameter. Of those which were healed, the thicker stubs required rather longer than the thinner ones but the thickness of wood laid down was similar in each case. (*Table 3.*)

(v) Live-pruned branches were healed with a slightly smaller thickness of wood than were dead-pruned branches. (*Appendix V.*)

(vi) The examination of nearly 3,000 pruned knots, mostly live-pruned, showed no instance of disease in the knots or wood; the growth put on after healing appeared to be normal clean wood. It was found that a resin streak appeared frequently in the annual ring of the first year's growth after pruning. Since this ring lies within the knotty core the defect has no effect on the clean timber.

The healing and occlusion of pruning wounds, as affected by green or dry pruning and by the season of pruning, has received considerable attention abroad and in private forestry in Britain, and Forestry Commission results may be supplemented by the following examples:

Faster healing of green-pruned branches was found by Clinton (1936) and Paterson (1938), in Britain; Romell (1940) in Sweden; Curtis (1938) in U.S.A. and Helmers (1946) in U.S.A.

Workers are less generally agreed on the best season of the year for pruning. Anderson (1937) found that pruning in February gave quickest healing of Douglas fir in Britain, with March—May also good. For Sitka spruce, May was the best month. The pruning of the timber examined by F.P.R.L. in 1945–52 was mostly carried out at the end of March, and showed completely clean and satisfactory healing. Romell (1940) found in Sweden that bark wounds made in pine and spruce in late winter and early spring healed much more quickly than those made in autumn; whereas Helmers (1946) found no appreciable difference in the extent of healing between autumn-pruned and spring-pruned *Pinus ponderosa* and white pines in north-west U.S.A. Childs and Wright (1956), with young Douglas fir on the Pacific coast of U.S.A., found very much higher fungal infection from spring pruning than from autumn pruning; and Strelke (1952) and Mayer-Wegelin (1952) in Europe both state that the only safe time for pruning is in the dormant season, late winter to early spring, this also being based on the lower incidence of fungal damage found from such prunings.

Chapter 13

SUMMARY OF THE EXPERIMENTAL RESULTS

The effect of different intensities of pruning on height and breast-height girth increment was very variable. In general, single or successive prunings up to the limit applied here (up to 55 per cent in one experiment) had little effect on height growth. Breast-height girth increment was in general reduced only slightly by single prunings of up to 30 per cent, though there were some marked exceptions. Prunings of greater intensity, or successive prunings of 25 per cent or more, frequently reduced girth increment; but after intervals of twenty years from first pruning, the greatest reductions did not exceed 3 in. of girth increment, except in one experiment, and were usually much less than this. Douglas fir appeared to be more sensitive to pruning than the spruces, and these more so than the pines.

In almost all the experiments the number of stems selected per acre for pruning (between 200 and 560) was excessive, as shown by the heavy losses of trees which had not yet grown a usable quantity of clean timber in the twenty or so years following first pruning. During that time, numbers were reduced to 100–200 per acre, mainly by the thinnings required to maintain a suitable spacing of pruned dominants, but aggravated by the fact that many of the pruned trees had been selected from among the less vigorous trees in the stands. The importance of selecting a limited number (not more than 150) of the most vigorous trees for pruning, and of rigorously favouring these by crown thinning, was brought out strongly.

The intention to restrict knotty core diameters to a maximum of four inches was realised in only the most severe treatments in one experiment. This was due, in the first place, to the selection of stands at too late a stage of development, secondly to the application of pruning intensities which allowed the knotty cores to become thicker at each successive pruning of the upper lengths of stem.

Investigation of the internal condition of pruned trees showed no ill effects of green pruning in any of the species studied, including Norway and Sitka spruces. Healing was generally quick and unaccompanied by deformities in the knot-free wood.

PART III
IMPLICATIONS AND APPLICATIONS OF THE RESULTS

Chapter 14

PRACTICAL IMPLICATIONS

The experimental results, current practice and specialist opinions together suggest the following practical approach to each of the problems raised by pruning on a large scale. The conclusions are tentative in some points of detail owing to lack of local information, and where it is appropriate these points have been supplemented by findings from foreign work. Nevertheless, attention is drawn to every feature considered important in the planning of a pruning programme, and a provisional pruning schedule for the production of clear saw-timber is suggested.

1. The Reason for Pruning

There is no biological justification for pruning. It is a commercial measure aimed at providing certain classes of produce for which a future demand is anticipated which would not be obtained without pruning and for which a higher price can consequently be asked than for unpruned timber.

The decision to embark on a pruning programme thus rests on considerations of utilisation and economics, and must be made separately for each forest or region, preferably through the medium of the Working Plan. Much money may be wasted by indiscriminate pruning, with no clearly defined object in terms of the kind of produce and the markets for which the stands are being managed.

2. Utilisation

There are three classes of produce in which pruning can play a major part in raising quality and market value; peeler logs, round poles and saw logs. Pruning may also confer advantages on other types of produce, for instance pulpwood by reducing the cost of de-barking by hand (and of pulping), but the resulting increase in timber value will be lower than for the classes mentioned above.

There is doubt as to whether a market for peeler-logs will develop in Britain, so pruning specifically for such a market will be somewhat speculative. The principal requirements are for large-diameter logs containing a high proportion of knot-free wood (narrow knotty cores), even growth-rate and a regular and assured supply. Length of log (over about 6 ft.) is not of great importance.

Pruning for the transmission pole market is done with the main objects of reducing the stem swellings which frequently occur at branch whorls, and of encouraging straight, cylindrical growth between the pruned whorls; also, in some cases, to remove outward signs of knots by means of a thin superficial layer of clear timber. For these purposes, relatively little knot-free growth is required, though length may be important.

Production of quality saw-timber will be the object of most pruning. In terms of the grading rules for sawn British softwoods (see Appendix C, page 55) this means the elimination of knots in order to raise Grade I timber to Grade I clear, or the elimination of large or unsound knots in order to upgrade to Grades II or I. In the latter case the operation also results in the production of clear timber, but this may be incidental to the original object; the distinction between pruning to avoid *large or dead* knots and pruning specifically to avoid *all* knots may be important in deciding when to start pruning.

The amount and distribution of the knot-free timber in a pruned log, and its availability on conversion, deserve particular consideration. The effective radial thickness of the shell of clear timber may be calculated as the difference between the smallest under-bark radius of the log and the greatest radius of the defective core, after allowing for occlusion of the branch stubs, bends in the stem and other faults. A high proportion of the conventional conversion loss on sawing occurs in the removal of slabs and edgings, that is, in the peripheral zone of knot-free wood, so that in the early years after pruning the whole production of clear timber lies within the zone of conversion waste. As the radius of the knot-free wood increases, successively greater thicknesses of clear timber become available on sawing.

Due to the lack of pruned logs of sufficient size, no practical studies in conversion have yet been undertaken which would indicate the minimum radial thicknesses from which clear timber first becomes available, or from which particular dimensions may be sawn, or from which the out-turn of high quality sawn produce is sufficient to repay the cost of the pruning. These critical values will not necessarily correspond in practice to the theoretical values which can be calculated geometrically for logs of given dimension. Among previous writers who have considered this question, Craib (1939) thought that 4 inches of clear timber was the absolute minimum to justify pruning, Nageli (1952) considered that a worthwhile increase in the value of the produce is not likely until 10–12 cm. (4 to 5 inches) thickness is obtained, while Holck (1953) in his calculations of pruning profitability, assumed 16 cm. (6½ inches) as a working figure. The volume of clear converted timber represented by the knot-free shell of a pruned log must be capable of commanding a premium on the whole log sufficient to cover the cost of pruning. As long as consumers are unfamiliar with pruned logs and their conversion it seems unreasonable to expect a thickness of less than about four inches of clear timber to attract any premium at all.

The effective radial thickness of knot-free wood as calculated above allows for taper in the knotty core and final log, and assumes sawing to take place parallel with the axis of the log. The recovery of clear timber from a pruned log may in some cases be improved by the adoption of special sawing techniques such as sawing parallel with the outer surface of the bole and turning the billet for each cut; though this gives fewer wide boards, usually tapering in width, and involves higher production costs. In this case, the effective thickness of knot-free wood (including the slab) is practically equal to the radial growth which has occurred between pruning and felling. In the more usual method, sawing parallel with the axis, it is necessary to grow a greater radial thickness of wood in order to make a given desired thickness available for conversion. The minimum thickness of clear wood desired will determine, according to circumstances, the size and age at which pruning is begun, or the final diameter and rotation of the pruned trees.

3. Economic Considerations

Pruning is justified only if premiums on the high quality logs produced are large enough to cover the future (compounded) cost of the pruning operation. Although the magnitude of future premiums cannot be accurately forecast, it is possible to calculate for a variety of pruning regimes the future cost implied per Hoppus foot of pruned log, on the basis of which a reasoned judgment must be made as to whether such premiums are likely to be obtained.

The future cost of a pruning operation depends on the following factors:

(i) The initial cost, including overheads, of pruning all the selected trees.

(ii) The wastage of initially pruned trees, due to disease, windthrow or thinning, before they achieve an enhanced value. The cost of pruning these trees has to be borne by the remainder.

(iii) The interval between pruning and harvesting, over which the initial cost must be compounded. According to circumstances this will depend on the rotation, if a fixed rotation is employed, or on the desired final diameter of log or the desired radial thickness of knot-free timber, and on the initial diameter of the trees and their rate of diameter growth.

In calculating the profitability of pruning a particular stand, certain of the factors in (iii) above will be fixed by local management considerations, and others are dependent on these; the form of the calculation will depend on which are fixed and which dependent. To demonstrate a common method of approach the problem has been posed as follows: If a given radial thickness of knot-free wood is to be produced, what will be the future cost of pruning trees of a particular diameter and predicted growth-rate?

This calculation is described below, using a table which gives the compounded pruning cost per Hoppus foot of pruned log, expressed per 1d. of initial pruning cost per tree (Table 17). The table is constructed for mean knotty core diameters of 4, 5 and 6 inches at breast-height, desired thicknesses of clear wood of 4, 5, 6 (and 7) inches, growth-rates of 4 to 12 rings per inch and pruned lengths of 15, 20 and 25 feet. The table is compiled using two rates of interest, 3½ per cent and 5 per cent, for comparison. The factor indicated by the table must be multiplied by the number of pence per tree involved in the initial pruning expenditure in order to obtain the cost implied in each Hoppus foot of the felled pruned log.

In the initial pruning expenditure, allowance must be made for wastage of pruned trees: if the premature loss of trees is expressed as a percentage of those initially pruned, the cost of pruning must be multiplied by: $\frac{100}{(100-\text{wastage per cent})}$.

Where it is intended to obtain pruned logs from the later thinnings as well as the final crop, the calculation should be made separately for each coupe, using the estimated mean breast-height quarter girth of the pruned trees to be felled at that coupe.

TABLE 17 COMPOUNDED PRUNING COST PER HOPPUS FOOT OF PRUNED LOG

Mean B.H. diameter, O.B., of trees to be pruned: (=mean B.H. diam. of core)	4 inches																			
Desired radial thickness of clear shell, U.B.: Corresponding B.H.Q.G., O.B., of final log:	4 inches 10½ inches					5 inches 12¼ inches					6 inches 14 inches					7 inches 15¾ inches				
Average growth rate in rings per inch:	4	6	8	10	12	4	6	8	10	12	4	6	8	10	12	4	6	8	10	12
Number of years to reach final log size:	16	24	32	40	48	20	30	40	50	60	24	36	48	60	72	28	42	56	70	84
Compounded pruning cost for the given length at the given rate of interest: 15 feet 3½%	.16	.21	.28	.37	.49	.13	.19	.27	.38	.53	.12	.18	.27	.41	.62	.11	.17	.28	.46	.74
15 feet 5 %	.20	.30	.45	.66	.97	.18	.29	.48	.77	1.26	.17	.30	.54	.97	1.74	.16	.32	.63	1.25	2.48
20 feet 3½%	.13	.17	.23	.30	.39	.11	.15	.21	.30	.43	.09	.14	.21	.32	.49	.09	.14	.22	.36	.58
20 feet 5 %	.16	.24	.36	.53	.78	.14	.23	.38	.62	1.02	.13	.24	.43	.77	1.38	.13	.25	.50	.99	1.95
25 feet 3½%	.11	.15	.19	.26	.34	.09	.13	.18	.25	.36	.08	.12	.18	.27	.41	.07	.11	.19	.30	.49
25 feet 5 %	.14	.21	.31	.45	.67	.12	.20	.32	.52	.85	.11	.20	.36	.64	1.15	.11	.21	.42	.83	1.63

Mean B.H. diameter, O.B., of trees to be pruned: (=mean B.H. diam. of core)	5 inches														
Desired radial thickness of clear shell, U.B.: Corresponding B.H.Q.G. O.B., of final log:	4 inches 11¼ inches					5 inches 13¼ inches					6 inches 15 inches				
Average growth rate in rings per inch:	4	6	8	10	12	4	6	8	10	12	4	6	8	10	12
Number of years to reach final log size:	16	24	32	40	48	20	30	40	50	60	24	36	48	60	72
Compounded pruning cost for the given length at the given rate of interest: 15 feet 3½%	.14	.18	.24	.31	.41	.12	.17	.23	.33	.46	.10	.16	.24	.36	.55
15 feet 5 %	.17	.25	.38	.55	.82	.16	.25	.41	.67	1.10	.15	.27	.48	.86	1.54
20 feet 3½%	.11	.14	.19	.25	.33	.09	.13	.19	.26	.37	.08	.13	.19	.28	.43
20 feet 5 %	.14	.20	.30	.45	.66	.12	.20	.33	.54	.88	.12	.21	.38	.68	1.22
25 feet 3½%	.09	.12	.16	.21	.28	.08	.11	.16	.22	.31	.07	.10	.16	.24	.36
25 feet 5 %	.12	.17	.26	.38	.55	.10	.17	.28	.45	.73	.10	.18	.31	.57	1.02

Mean B.H. diameter, O.B., of trees to be pruned: (=mean B.H. diam. of core)	6 inches														
Desired radial thickness of clear shell, U.B.: Corresponding B.H.Q.G., O.B., of final log:	4 inches 12¼ inches					5 inches 14 inches					6 inches 15¾ inches				
Average growth rate in rings per inch:	4	6	8	10	12	4	6	8	10	12	4	6	8	10	12
Number of years to reach final log size:	16	24	32	40	48	20	30	40	50	60	24	36	48	60	72
Compounded pruning cost for the given length at the given rate of interest: 15 feet 3½%	.12	.15	.20	.27	.35	.10	.15	.20	.29	.41	.09	.14	.21	.32	.49
15 feet 5 %	.15	.22	.32	.48	.70	.14	.22	.36	.59	.97	.13	.24	.43	.77	1.38
20 feet 3½%	.09	.12	.16	.21	.28	.08	.12	.16	.23	.32	.07	.11	.17	.26	.39
20 feet 5 %	.12	.18	.26	.38	.56	.11	.18	.29	.47	.77	.10	.19	.34	.61	1.09
25 feet 3½%	.08	.10	.14	.18	.24	.07	.10	.14	.19	.27	.06	.09	.14	.21	.32
25 feet 5 %	.10	.15	.22	.32	.47	.09	.15	.24	.39	.64	.09	.16	.28	.51	.91

An example of the calculation is given below:—

Suppose the average breast-height diameter, over bark, of trees selected for pruning in a stand is 5 inches, and that 6 inches radial thickness of clear wood at breast height is to be grown after the pruning wounds have occluded (the over-bark diameter of the trees is taken to approximate to the effective knotty core diameter). And suppose that under the crown thinning which will be used, the diameter growth-rate of the selected trees on this site is predicted to average six rings per inch over the period from pruning to felling. Table 17 then shows that a radial thickness of 6 inches of clear timber will be grown in a period of 36 years.

Suppose that a length is pruned sufficient to give felled pruned logs of 20 feet, that this costs an average of 24 pence per tree, including overheads, and that a wastage of 10 per cent of the pruned trees before maturity is anticipated.

For a knotty core of 5 inches diameter, a clear shell thickness of 6 inches, a growth rate of 6 rings per inch and a log length of 20 feet, Table 17 indicates a factor of 0.13 at $3\frac{1}{2}$ per cent interest rate. The cost of pruning, adjusted for wastage and multiplied by this factor gives:

$$24 \times \frac{100}{100-10} \times 0.13 = 3.47 \text{ pence per Hoppus foot}$$

This is the compounded cost of the pruning implied in the pruned logs, and on the method of management exampled here the increase in price obtained for the pruned logs will have to be at least $3\frac{1}{2}$d. per Hoppus foot over the price of unpruned logs to justify pruning. If the investment in pruning were considered to be made at an interest rate of 5 per cent, a premium of over $5\frac{1}{2}$d. per Hoppus foot would have to be obtained.

In considering whether these calculated premiums are likely to be obtained, attention must be given to the total recoverable amount of clear sawn timber in the logs, the maximum dimensions in which this timber can be obtained, its ring-width insofar as this may affect timber quality, and the size of the logs in relation to possible price/size gradients.

4. Species

Obviously, timber of almost every species will be improved for most uses by pruning, but it is difficult to say, on the basis of existing timber uses and prices, which species will undergo an improvement in market value sufficient to make the operation profitable. In certain slow-growing species, the time required to reach a size from which useful dimensions of clear timber can be cut, may increase the implied pruning cost beyond the increase in price paid for the clear timber; alternatively, a species which can be grown fast may not, because of some unfavourable property of its timber, attract sufficient premium to balance a much lower implied pruning cost. Again, changes in timber uses may alter demands and prices for different grades and species. A further important factor determining the choice of species is the scale on which pruning will be done in the country as a whole. Accordingly the present suitability of the main species grown in Britain is considered below on mainly technical grounds, without making specific recommendations for the future.

Scots pine: Pruning is of very great benefit to timber quality through the elimination of black (loose or rotten) knots. Its established place as a high-class joinery timber also makes Scots pine suitable for pruning specifically to produce clear timber. Slow growth, relative to many other species, will increase the final cost of pruning. It is the first choice for transmission poles, though pruning for this purpose may not always be necessary.

Corsican pine: The removal of whorls of large knots by pruning considerably improves the strength properties of the timber, an important consideration for structural purposes though its physical properties do not compare with Scots pine for other uses. Its faster growth will make the cost of pruning per unit volume relatively cheap.

Lodgepole pine: This timber should be classed with Corsican pine for considerations of pruning, until more is known of its properties.

European larch: Small loose and rotten knots are a frequent cause of down-grading of otherwise high grade timber. In clear grades this timber is the first choice for boat skins, for which a ready market has long existed.

Japanese and Hybrid larches: Insufficient is known about these timbers, on which to base suggestions of suitability for pruning.

Douglas fir: The timber has a variety of uses, including joinery, furniture, plywood and structural uses, in all of which pruning will greatly increase the quality. Its fast growth rate makes the operation relatively cheap.

Norway spruce: A rather "general purpose" timber in which the usually small knots are not considered a severe drawback to quality. This is a species the pruning of which will depend a lot on the national scale of the operation.

Sitka spruce: This species sometimes has larger knots than are commonly met with in Norway spruce and this indicates a need for pruning, but other physical properties may not justify the operation. Its fast growth rate makes pruning cheap relative to many other species.

Western red cedar: Though a minor species in British forestry this timber has the property of very even texture across the grain, due to the absence of distinction between spring and summer wood in the annual ring. This is a useful feature of timber for joinery purposes, for which use the quality will be enhanced by pruning. The high natural durability of the timber makes it especially suitable for outdoor joinery work, and at present there is a higher price differential between the clear and knotty grades of this timber than of most other imported species. The property of even texture of annual rings is shared by Lawson cypress, Western hemlock and *Cryptomeria japonica*, three other species of minor importance in Britain, about whose timber properties we know rather little.

5. Selection of Stands

Firstly, these must be stands judged capable of lasting the full rotation without undue risk of windthrow or disease.

Stands should normally be those on highest growth-quality sites, at least for the slower-growing species. If slow-growing stands are pruned, the extended rotations and increased final costs necessary to grow a usable quantity of knot-free wood may not be balanced by higher premiums on the produce. Fast-grown stands, with fewer branch-whorls per foot of stem, will be cheaper to prune.

Stands must be sufficiently young that the most vigorous dominant trees are within the diameter limit required for the knotty cores, depending on the proposed final size, rotation, growth rate and thickness of knot-free timber.

Stands will not be considered for pruning if the dominant trees include a high proportion of the kinds described as unsuitable in paragraph 6 (below).

Obviously, pruned timber will sell more readily where larger lots and a regular supply can be assured, so the pruning of small or isolated stands, suitable in other respects, in areas where the bulk of the stands will not be pruned, should be carefully considered in relation to future markets.

6. Selection of Stems

These must be the largest and most vigorous of the dominants in the chosen stand. Any such trees not selected must be felled at the first, or without fail at the second pruning. Reasons for rejection will include crookedness, forking, leaning, heavy swelling at whorls and branch bases, severe spiral grain, signs of disease, and because they are over the permitted diameter limit. Coarse branching is not, of itself, good reason for rejecting a tree, providing pruning is done early, but a high proportion of coarsely-branched stems will increase the cost of pruning.

7. The Size of Tree to Prune

This demands a clear understanding of the purpose for which the pruning is being done and the produce which is required. For transmission poles, pruning about five years before felling size is reached will often be sufficient. Where pruning is done to avoid large or dead knots, and not primarily to produce clear timber, pruning should be timed for when the branches approach the critical thickness or when they die. Where clear timber is the aim, careful attention must be paid to obtaining a narrow knotty core, since for utilisation purposes the quantity of clear timber produced must be reckoned in terms of radial thickness outside the core, and a proportion of this is wasted during conversion. For the production of the maximum amount of clear timber without greatly lengthening the rotation, therefore, the knotty core diameter must be kept as narrow as practicable, which is probably about 5 inches at a foot above ground level (the thickest point in the felled log), corresponding to a breast height diameter of 4 inches. This diameter limit refers to the most vigorous of the dominant trees, implying much earlier entry to the crop than is normal for other operations.

8. The Timing of Second and Subsequent Prunings

The timing of these will depend partly on the rate of branch death permitting a reasonable length of stem to be pruned, but it must also be controlled so that the knotty core in the upper parts of the pruned log (where final stem diameter will be smaller) is not thicker than in the thickest part of the first length. For this purpose a sample of the diameters of the trees at time of first pruning should be measured near ground level and recorded so that they may be compared with the diameter growth at the bottom of the next length to be pruned.

9. The Number of Trees to Prune

This must not exceed the number expected to reach the diameter required by the objects of management (see paragraphs 1–3), except to provide a small reserve against accidental losses; though until stand tables are available, showing yields by size classes for various grades of thinning, it is not possible to recommend precise numbers applicable to all species and conditions.

Where pruning is for pole production, carried out only a few years before the poles are felled, prediction of the number which will be available in the desired diameter class presents no problem. On the other hand, stands pruned early, for saw-log production, will be crown thinned to ensure the survival and fast growth of the selected trees (see paragraph 13), so relatively few trees will reach the larger diameter classes compared with the numbers indicated in current (1953) Forestry Commission yield tables, which are based on moderate low thinnings. 150 stems per acre is probably the maximum that should be pruned for clear timber production, since a profitable clear thickness is unlikely to be produced before the dominant stems have been reduced to this number. Where the object is to eliminate large or dead knots, without the necessity of producing some minimum thickness of clear wood, smaller sizes of pruned log will be profitable and more stems may be pruned, perhaps up to 250 per acre.

Although the removal of branches is not usually called "pruning" until it extends above about 6 feet, brashing is, in effect, a first pruning which normally may involve half to two-thirds of the trees in a crop, say about 800 stems per acre. This number will include all the potential dominants, so that if it is done early enough for the largest trees to be within the required diameter limit, the first pruning (brashing) may be made to a height of 6 feet without at this stage making a final selection. This would constitute a revision of present practice, in which brashing is done to facilitate access for marking thinnings and is consequently postponed until just before first thinning; but in the case of special stands selected for pruning, the extra years for which the brashing changes would have to be borne, would be offset by the advantages of small core diameters.

10. Green Pruning

Up to two live whorls (whorls in which branches bearing some green needles occur on all sides of the stem) may normally be removed without reduction of height increment and with only small and temporary reductions, if any, in girth increment, when the pruning cycle is four years or longer. While it is important that height growth is not reduced, especially where a small number of trees is selected early in the rotation, a slight girth growth reduction may be considered worthwhile for the sake of a longer length pruned at each operation.

Green-pruned branches heal faster than dry-pruned ones, leaving the cut stub exposed for a shorter time to frost, dessication and the entry of fungal spores.

Cases of pathological damage to the tree or timber resulting directly from green pruning are very rare in Britain in any coniferous species. Most of the cases reported have been attributed to pruning of large (say, over 2 inches diameter) branches or to careless work, especially brashing with billhooks or similar tools, leaving torn bark and long or ragged stubs.

11. Season of Year

The absence of clear evidence of pathogenic damage from spring pruning in Britain, and the observed faster healing, together suggest that pruning should ideally be carried out between March and May, or as soon after as possible. The wounds will then be made just prior to or during the resumption of resin flow, cambial activity and diameter growth in the stem, leading to the early exclusion of pathogens and speedy occlusion of the stub. There is no evidence, however, that pruning at other seasons should be avoided.

12. Total Length of Stem to Prune

The most commonly used lengths of sawn timber in the joinery grades and better lie between 8 and 18 feet, so a lower limit to total pruned length may be fixed at 10 feet to allow for losses in felling, cross-cutting and trimming. At all stages of logging, conversion and transport greater lengths are an asset, involving less handling and less waste. Pruning can be extended to 20 feet using hand tools from the ground. Above 20 feet the cost jumps when ladders have to be used; also the lower final diameter of log may not give a sufficient thickness of clear timber to repay the extra cost.

All pruned trees in a stand should be pruned to the height prescribed (see Records, paragraph 14, below).

13. Thinning Pruned Stands

It is considered that crown thinning in some form is an indispensable adjunct to pruning, in order to preserve and concentrate increment on the stems on which the pruning expenditure has been made. The extent to which the lower canopies are retained will depend on individual circumstances such as species, markets for smaller thinnings, the need to prevent epicormic shoots or the desire to increase still further the growth of the maincrop trees.

Thinning, in the form of a preliminary "wolfing", will usually be necessary at the time of first pruning (see paragraph 6). Subsequent thinnings (during the period of pruning) should be marked before each further pruning is done, so as to avoid the illusion of openness of the canopy which pruning gives to the stand.

14. Records

The most advantageous sale of pruned logs will not be possible unless the vendor can supply accurate details of their clean-ness, in terms of pruned length and knotty core diameter. Thus records must be kept of the Compartment number, area, number of pruned stems, final pruned height and range of over-bark core diameters at the base of the stems (or wherever the greatest diameter occurred, see paragraph 8). The person who planned the pruning will rarely be present to sell the logs, and complete reliance must be placed on these records.

15. Tools and Technique

No recent research work into pruning tools is available, and with the increased interest in pruning on a forest scale new local developments may be expected.

The need to prune while the trees are still small rules out direct climbing of the trees, so the upper lengths of stem must be reached by poles from the ground or by ladders. Pole saws and Whitmore chisels can both be used effectively up to heights of 20–22 feet: ladders, especially if used in conjunction with pole saws, can extend pruning even further but are costly to move around in plantations in which only a small proportion of trees is pruned.

In choosing between pole saws and chisels, the costs and quality of work appear to depend considerably on the individual worker's preference and aptitude. The chisel is an excellent tool in the hands of skilled and reliable men, but not one for the casual employee. Various materials and methods of joining poles for these tools are currently being tried.

Branches must be severed as close as possible to the stem, the cut being vertical, and tangential to the stem. The removal, or at any rate wounding, of the collar of bark and phloem at the branch base, as well as shortening the stub, stimulates healing, so reducing total occlusion time. Where heavy basal swellings or shoulders occur on the branches, the extra pruning time and healing time involved in their removal should disqualify the crop as a subject for pruning, though these swellings do not usually develop at the early age now recommended for pruning.

Pruning on a forest scale is a job in which much skill can be developed, and is also well suited to piece-work once this skill is achieved. If large-scale pruning is contemplated it should be undertaken seriously, not as a hard-weather or fire-duty stand-by job.

16. Costs

Pending detailed study of the costs of pruning, a brief survey of field-scale pruning costs was made in 1961 at a number of forests in Scotland and England. Most of the pruning covered by this survey was of trees older than the age recommended in this Bulletin breast height diameters being six to eight inches, so that pruning was being taken from the brashed height of 6 feet up to heights of 20–24 feet in one operation. Rates of working over this length of stem varied from 1 to 3½ feet per minute, averaging 2 feet per minute. For brashing up to 5 to 6 feet, rates were 2½ to 5 feet per minute, averaging 3½ feet per minute.

At these average rates, which may be expected to improve as techniques and experience develop, trees can be pruned from the ground to 20 feet at the rate of seven per hour. The cost will be increased when the total length is pruned in a number of separate operations, and further increased by overhead charges and by wastage of initially pruned trees, but the above figures give an indication of the order of costs to be expected.

17. Pruning Schedules

For transmission of instructions to forest staff, the foregoing recommendations must be reduced to prescriptions in terms of readily apparent or measurable crop characteristics. Such prescriptions must reconcile conflicting claims of utilisation requirements, biological limitations, financial considerations and practicability.

For the production of clear saw-timber it is considered that prime importance must be given to maintaining a uniform diameter of knotty core throughout successive prunings; this therefore determines the time of first pruning and the length of the pruning cycle. Within this cycle, the length of stem pruned on each occasion must be the greatest that biological limitations allow on each individual tree; i.e. removing as much live crown as possible without seriously affecting girth increment. To prune less than this height prolongs the total period and number of prunings and increases the cost of the operation.

Since the condition of each individual crown determines the length to be pruned, separate schedules are not required for different species, quality classes, spacings on other stand conditions; only the time of starting will vary, depending on the diameter of knotty core required by the objects of management. The need to measure or estimate height in the crop to determine readiness for pruning is obviated since measuring can be reduced to girthing a sample of the larger stems near ground level at first pruning and to applying a fixed caliper to the upper stems when the time for subsequent prunings is near.

A suggested schedule is as follows:—

First pruning: This, in effect, is early brashing, done as soon as six feet of stem can be pruned on about two-thirds of the trees in the crop, without removing more than two live whorls (whorls in which live branches occur on all sides of the stem). It ensures that all the more vigorous trees receive first pruning at the earliest time (narrowest core) which is practicable.

Second pruning: The final number of pruned trees is selected. The desired diameter of knotty core is decided, having regard to the diameters of the trees at first pruning, and a simple fixed caliper with jaws of this dimension is constructed; this is applied to a sample of the selected trees at the previous pruned height, and as soon as it fails to span half the stems in the sample, second pruning is done. Each tree is pruned up to and including the two lowest live whorls.

Third and subsequent prunings, if required, are timed and pruned in the same way, mounting the caliper on a pole to reach the higher pruning limits.

With this schedule the length of stem pruned on each occasion will vary from tree to tree, as will the number of prunings needed to achieve the prescribed final length.

The schedule is an attempt to obtain the smallest practicable diameter of knotty core, though it will be apparent that the smaller the core diameter, the shorter will be the pruning cycle and the more and shorter will be the individual lengths pruned. Also, pruning will start earlier and selection of final stems will be less certain. These disadvantages must be weighed against the greater amount of knot-free timber provided or the shorter total rotation necessary to produce a given thickness of it.

Chapter 15

UNSOLVED PROBLEMS OF PRUNING

The foregoing recommendations for pruning include some that are based on a theoretical appraisal of future needs for clean saw-timber but which have not so far been applied in practice on any scale. The chief of these are the emphasis on very small knotty cores, both initially and at subsequent prunings, and the attempt to reduce the final costs of pruning by restricting pruning to a small proportion of the total number of trees, which will therefore require enhanced accuracy of selection and special attention in thinning. Because of the lack of experimental support for these recommendations they have been made fairly conservatively, and future research work on pruning should apply them under controlled conditions over a variety of species and forest regions, and at the same time compare alternative procedures, particularly of pruning intensity and thinning, which might affect the costs of the operation or the quantity or quality of the clean timber.

Taking the same order as for the forest-scale recommendations, the following are the main subjects for inclusion in a new pruning research programme:

Utilisation

With so little experience in the utilisation of clear grades of home-grown softwood among British timber users, there are many difficulties in estimating future uses and demands. Nevertheless this information is basic to the establishment of pruning policy and the choice of species for pruning, desired pruned log lengths, proportion of pruned wood to be produced in the log and types and dimensions of clear produce required.

Economics

The first requirement here is a detailed study of the costs of pruning, and with it an investigation into tools and techniques. When pruned logs become available the trends in price relative to unpruned logs must be studied. Of particular importance here is an investigation into the effect of the scale of pruning throughout the country on the premiums paid for pruned logs.

Species

Scots pine and Douglas fir will be used most extensively, as being the species most generally agreed to benefit from pruning. Norway spruce, Corsican pine and European larch are less important, though the acreage of Norway spruce still being planted, and the replacement, in some south-eastern forests, of Scots pine by Corsican, suggests that our knowledge of their behaviour under pruning should be extended. Lodgepole pine is becoming of increasing importance in Forestry Commission planting and, although as yet we know little of its timber qualities, the possibility of improving these by pruning should be investigated.

Age (Size) of Trees for Pruning

Previous experimenters, while acknowledging the need to limit the diameter of trees chosen for pruning, have never applied the limit at all rigidly. The age, height, degree of canopy closure, etc. of stands whose maximum stem diameter at stump height (1 ft. above ground) is three, four, five, etc. inches will vary with site and spacing, and these, and the effects of pruning in such stands, need to be investigated.

The possibility of reducing the number of initially pruned trees to a figure close to the final crop number requires the recognition of potential crop dominants at an early age, a subject which is also of interest in genetics and thinning research. (An incidental result of the disbudding experiments was that the tallest and most vigorous trees selected in plantations at four years of age were not always in the dominant canopy class some years after the crop had closed canopy.)

Pruning Intensity

The increment responses to pruning in the previous experiments resulted from pruning intensities in which the cycles were not less than four years, although increases in knotty core thicknesses in the higher pruned lengths of some treatments indicated that shorter cycles should have been used there. For any given severity this would involve increasing the pruning intensity, with the possibility of reduced increment. Where the pruning cycle is to be determined by the progress of stem diameter growth at the previous pruned height (as has been recommended in Chapter 14), some adjustment of pruning severity may be necessary to maintain increment. A suitable experimental procedure would be to prune at several levels of severity while keeping the knotty core maximum diameter constant, and observe the effect of the resulting intensities on the growth of the trees.

The evaluation of the past experiments was made very difficult by the fact that the wide variety of pruning intensities could not be related by a standard expression, because, even when all the severities were expressed in the same terms (percentage of crown length removed), neither the severities nor the cycles used formed regularly graded series of levels within an experiment, with which subsequent increment responses could be related. In Chapter 5 it was pointed out that the factor responsible for the maintenance of the rate of growth of a tree (within the limits of site, age, etc.) is the amount of live crown which it carries, so it is necessary to determine the minimum amount of crown needed to permit the tree to grow at a reasonable, or desired, rate. This amount might be expressed as the crown length or number of whorls left on the tree, or, should it prove possible to relate any given stem diameter to the length or number of whorls of crown above it, as the diameter of the stem at the base of the crown after pruning.

It is clear that, for any given severity of pruning, the smaller the diameter of core it is desired to maintain, the shorter will be the pruning cycle needed, and the shorter will be the length pruned each time; that is, the more costly will the whole operation become. It is necessary to obtain data from which a compromise between wide cores and costly pruning can be selected.

Effect on Increment

The experiments made to date have been assessed to show the effect of various pruning treatments on the height and girth increment of the pruned trees. The effect on volume increment must be assessed in future experiments, to determine differences in yield within the pruned part of the stem, the pruned tree and the whole pruned stand, as compared with unpruned crops.

Practical Application in the Forest

The experiments have shown the approximate levels of pruning intensity at which girth and height increment reductions occur, and these will be further clarified by the work outlined above. It is also necessary to devise a practical method of prescribing these intensities for general use in the forest. This must be simple, unambiguous and capable of being applied quickly, with only simple instruments, if any. In addition, methods of measuring stem diameter at heights above arm's reach from the ground must be developed, for determining readiness for re-pruning.

Practical Details of Experimentation

The summarising of the past experiments has shown up faults and difficulties in experimental layout or conduct which must be avoided in future pruning research:

Thinning. A uniform grade of thinning was found to be difficult to apply over differently pruned plots because pruning changed the density of the canopies without affecting density of stocking. Visual control based on canopy appearance is thus not feasible, but there are a number of alternative methods. If differences in pruning treatment are to be studied in combination with different types or grades of thinning, the thinning of each differently thinned plot will have to be controlled by some form of spacing index or by thinning to a standard basal area. Where comparisons of different thinnings are not required, the pruning treatments can be applied in single-tree plots, all treatments being intimately mixed so that differences in canopy appearance are not noticeable. In this case, exact control of thinning to any index or basal area is less important. The two methods could be combined by "splitting" each different thinning plot into many individual-tree pruning plots. An extreme case where individual tree plots can also be used is where it is desired to completely free the pruned trees of all competition by felling any neighbouring tree whose crown projection intersects that of a pruned tree, or by felling any unpruned tree whose height exceeds that of the pruned ones.

Final pruned height/Number of prunings. Interpretation of experiments in which more than one pruning was carried out was made difficult by the fact that pruning of each tree ceased when a given pruned height was reached, regardless of the severity prescribed for that pruning or of the total number of prunings that tree had received. This meant that in the later stages pruning was continued on the smaller trees only, though the average severities of these prunings were attributed to all pruned trees and the increment responses from them were measured on all. For experimental purposes a fixed number of prunings, all of the same severity and cycle, must be applied to all trees in any one treatment plot. The average final pruned height which results will be dependent on this.

Rejection of pruned trees from later treatment. The practice of not continuing the treatment of any pruned trees which showed marked reduction in growth (particularly height) or in health, tended to obscure the effect of the more intense pruning treatments on increment, even though it seemed reasonable not to go on pruning trees which would obviously not form part of the final crop. As it is proposed to prune far fewer trees in the future, it will not be possible to reject any and it will be accordingly more important to have precise knowledge of any increment reductions which result from different pruning intensities. The prescribed treatments should therefore be continued on all the trees initially pruned, except for any which become so suppressed or diseased that they would qualify as thinnings whether they were pruned or not.

Assessment intervals. Some pruning experiments in other countries have been criticised by Møller (1960) for the long intervals between carrying out a pruning and assessing its effects. He points out that increment responses may be evident after one year's growth from pruning, which are not apparent at the end of a period of several growing seasons. In the past British experiments, assessments have usually been made at the same times and intervals as the most frequent prunings, usually about every four years. It is considered that growth differences too small to show up over this period are not likely to be of practical significance to the production of clean timber, and assessment intervals in future experiments may well continue to be of this order if this suits the timing of experimental treatments, etc.

Scale of Experimentation Required

A feature of the pruning experiments to date has been the wide variation in response to similar intensities of pruning shown by the same species in different stands. This variation even showed within single experiments, between nominally different, though in effect similar, treatments. Since the range of feasible pruning and thinning treatments has been explored by previous experiments, they can in future be limited to those few which are of greatest practical value, so that it should be possible to keep individual experiments fairly simple. These two points together suggest that future pruning research should be carried out through a large number of simple experiments covering a wide range of conditions (within the limits of conditions recommended in Chapter 5), using identical or comparable treatments in all experiments on any one species.

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Appendix A

DETAILS OF THE EXPERIMENTAL SITES AND TREATMENTS

The experiments are arranged in chronological order.

The treatments described are those actually applied; they sometimes differ from the original experiment plan prescriptions.

For definitions see Appendix B, page 54.

Forest of Dean Experiment No. 71/31. Norway spruce. Compartment 95, Highmeadow Wood, Forest of Dean.

A sheltered site at about 450 ft. elevation.

Planted in spring 1906. First pruned in spring 1931.

A moderate (C grade) low thinning was made just before pruning.

Treatment A. Control. No pruning.
- ,, B. Pruned up to, but not including, the lowest live whorl.
- ,, C. Pruned to 57 per cent of height of tree.
- ,, D. Pruned to 67 per cent of height of tree.
- ,, E. Pruned to 75 per cent of height of tree.
- ,, F. Pruned to remove 25 per cent of the crown length.

Only one pruning was done.

Thinning was a moderately heavy grade low thinning. (In 1956 a C/D grade Permanent Sample Plot was established in the crop.)

Two replications, with complete randomisation.

Forest of Dean Experiment No. 73/31. Douglas fir. Compartment 39, Highmeadow Wood, Forest of Dean.

A fairly sheltered site at about 530 ft. elevation.

Planted in spring 1908. First pruned in spring 1931.

The crop was thinned some years before pruning, part with a light thinning and part with a heavy thinning; two replications of each treatment were established in each thinning grade.

Treatment A. Control. No pruning.
- ,, B. Pruned up to, but not including, the lowest live whorl.
- ,, C. Pruned to 66 per cent of height of tree.
- ,, D. Pruned to remove 25 per cent of the crown length.

Only one pruning was done.

Thinning was a moderately heavy grade low thinning, after the experiment was established.

Four replications in a Latin square.

Forest of Dean Experiment No. 3/31. Corsican pine. Compartment 386, Soudley, Forest of Dean.

A moderately sheltered site at about 300 ft. elevation.

Planted in spring 1910. First pruned in spring 1931.

The crop was thinned rather heavily some years before pruning.

Treatment A. Control. No pruning.
- ,, B. Pruned up to, but not including, the lowest live whorl.
- ,, C. Pruned to 67 per cent of height of tree.
- ,, D. Pruned to remove 25 per cent of the crown length.

Only one pruning was done.

Thinning was a moderately heavy grade low thinning.

Four replications in a Latin square.

Forest of Dean Experiment No. 72/31. European larch. Compartment 97, Reddings Enclosure, Forest of Dean.

The site is exposed to the north-east but sheltered from south-west at about 620 ft. elevation.

Planted in spring 1908. First pruned in spring 1931. No thinning prior to pruning is recorded.

Treatment A. Control. No pruning.
- ,, B. Pruned to, but not including, the lowest live whorl.
- ,, C. Pruned to 67 per cent of height of tree.
- ,, D. Pruned to remove 25 per cent of the crown length.

Only one pruning was done.

Thinning was a heavy grade low thinning.

Four replications in a Latin square.

Bowmont Forest F.C. Pruning Trial. Norway spruce. Adjoining Sample Plots S.85–88, Bowmont Forest, Roxburgh Estate, Roxburgh.

A rather exposed site at 550 ft. elevation.

Planted in spring 1910. First pruned in autumn 1945.

Not thinned prior to first pruning.

Treatment 1. Pruned up to, but not including, the lowest live branch, at intervals of 5 years.
- ,, 2. Pruned up to and including the second live whorl from the base of the crown, at intervals of 5 years.

Three prunings were done in each treatment, giving final pruned lengths of 23 and 28 feet respectively.

Not replicated.

Edensmuir Experiment No. 3/36. Scots pine. (Early pruning.) Compartment 2, Edensmuir Forest, Fife.

Within a plantation on level ground at about 150 ft. elevation.

Planted in spring 1923. First pruned in spring 1937.

Treatment 1. Control. Brashed to 6 ft. only.

,, 2. Pruned up to, but not including, the lowest live branch, at intervals of 10 and 7 years.

,, 3. Pruned up to and including the second live whorl from the base of the crown, at intervals of 4, 6 and 9 years.

,, 4. Pruned as Treatment 3, but given light (B grade) low thinning at first two thinnings and moderately heavy (C/D grade) low thinning at subsequent thinnings.

,, 5. Pruned to 54 per cent, 70 per cent, 77 per cent and 70 per cent of height of tree, at intervals of 4, 6 and 9 years.

Thinning, except in Treatment 4, was to light crown grade at intervals of 4, 6, 5, 4 and 3 years.

Pruning ceased when 26 ft. clear length was obtained on each tree.

Two replications in randomised blocks.

Drummond Hill Experiment No. 11/38. Norway spruce. Compartment 95, Drummond Hill Forest, Perthshire.

A site rather exposed to the north-east at about 470 ft. elevation.

Planted in spring 1913. First pruned in spring 1938.

The crop was planted at 3 ft. × 3 ft. spacing, and no thinning was done before pruning began.

Treatment 1. Control. Brashed to 6 ft. only.

,, 2. Pruned up to, but not including, the lowest live branch, at intervals of 4, 5 and 3 years.

,, 3. Pruned up to and including the second live whorl from the base of the crown, at intervals of 4, 5 and 3 years.

,, 4. Pruned as Treatment 3, but at an interval of 9 years.

,, 5. Pruned as Treatment 3, but given light (B grade) low thinning at the first thinning and moderately heavy (C/D grade) low thinning thereafter.

,, 6. Pruned to 50 per cent, 65 per cent and 60 per cent of height of tree at intervals of 4 and 5 years.

,, 7. Pruned as Treatment 6, but in each plot one quarter of the trees was pruned in each of the months January, May, July and October.

Thinning, except in Treatment 5, was to light crown grade until the completion of pruning and to heavy crown grade thereafter, at intervals of 4, 5, 3, 4 and 4 years.

Pruning ceased when 30 ft. clear length was obtained on each tree.

Four replications in randomised blocks.

Monaughty Experiment No. 7/38. Douglas fir. Compartment 62, Monaughty Forest, Moray.

A site rather exposed to the south and east, at about 270 ft. elevation.

Planted in spring 1924. First pruned in spring 1938.

The crop was planted at 6 ft. × 6 ft. spacing and no thinning had been done up to the time of pruning.

Treatment 1. Control. Brashed to 6 ft. only.

,, 2. Pruned up to, but not including, the lowest live branch, every four years.

,, 3. Pruned up to and including the second live whorl from the base of the crown, every four years.

,, 4. Pruned as Treatment 3, but every eight years.

,, 5. Pruned as Treatment 3, but given light (B grade) low thinning at the first thinning and moderately heavy (C/D grade) low thinning thereafter.

,, 6. Pruned to 49 per cent, 68 per cent and 67 per cent of height of tree, at intervals of four years.

,, 7. Pruned as Treatment 6, but in each plot one quarter of the trees was pruned in each of the months, January, May, July, October.

Thinning, except in Treatment 5, was to light crown grade until the completion of pruning and to heavy crown grade thereafter, at intervals of four years.

Pruning ceased when 30 ft. clear length was obtained on each tree.

Four replications in randomised blocks.

Inverliever Experiment No. 3/38. Douglas fir. Compartment 191, Inverliever Forest, Argyll.

A sheltered site at about 150 ft. elevation.

Planted in spring 1924. First pruned in spring 1938.

Treatment 1. Control. Brashed to 6 ft. only.

,, 2. Pruned up to, but not including, the lowest live branch, at intervals of 9 and 3 years.

,, 3. Pruned up to and including the second live whorl from the base of the crown, at intervals of 9 and 3 years.

,, 4. Pruned as Treatment 3, but at intervals of 9 and 6 years.

,, 5. Pruned as Treatment 3, but given light (B grade) low thinning at the first thinning and moderately heavy (C/D grade) low thinning thereafter.

,, 6. Pruned to 54 per cent and 58 per cent of height of tree, at an interval of nine years.

,, 7. Pruned as Treatment 6, but in each plot one quarter of the trees was pruned in each of the months January, May, July, October.

Thinning, except in Treatment 5, was to light crown grade, at a first interval of nine years and then every three years.

Pruning ceased when 30 ft. clear length was obtained on each tree.

Four replications with complete randomisation.

Inverliever Experiment No. 2/38. Sitka spruce. Compartment 184, Inverliever Forest, Argyll.

A sheltered site, except from the south, at about 370 ft. elevation.

Planted in spring 1924. First pruned in spring 1938.

Treatment 1. Control. Brashed to 6 ft. only.

„ 2. Pruned up to, but not including, the lowest live branch, at intervals of 9 and 3 years.

„ 3. Pruned up to and including the second live whorl from the base of the crown, at intervals of 9, 3 and 3 years.

„ 4. Pruned as Treatment 3, but at intervals of 9 and 6 years.

„ 5. Pruned as Treatment 3, but given light (B grade) low thinning at the first two thinnings and moderately heavy (C/D grade) low thinning thereafter.

„ 6. Pruned to 51 per cent, 59 per cent and 56 per cent of height of tree, at intervals of 9 and 3 years.

„ 7. Pruned as Treatment 6, but in each plot one quarter of the trees was pruned in each of the months January, May, July, October.

Thinning, except in Treatment 5, was to light crown grade, at intervals of 4 and 5 years and then every three years.

Pruning ceased when 30 ft. clear length was obtained in each tree.

(Note: It is uncertain whether all replications received these treatments at the same time; some may have been omitted, and the prunings or thinnings done later.)

Four replications with complete randomisation.

Inverliever Experiment No. 4/39. Norway spruce. Compartment 133, Inverliever Forest, Argyll.

A sheltered site, except from the south-east, at about 250 ft. elevation.

Planted in spring 1915. First pruned in spring 1939.

Treatment 1. Control. Brashed to 6ft. only.

„ 2. Pruned up to, but not including the lowest live branch, at intervals of 8 and 3 years.

„ 3. Pruned up to and including the second live whorl from the base of the crown, at intervals of 8 and 3 years.

„ 4. Pruned as Treatment 3, but at intervals of 8 and 7 years.

„ 5. Pruned as Treatment 3, but given light (B grade) low thinning at first two thinnings and moderately heavy (C/D grade) low thinning thereafter.

„ 6. Pruned to 52 per cent, 65 per cent and 61 per cent of the height of the tree, at intervals of 8 and 3 years.

„ 7. Pruned as Treatment 6, but in each plot one quarter of the trees was pruned in each of the months January, May, July, October.

Thinning, except in Treatment 5, was to light crown grade, at intervals of 8, 3 and 4 years.

Pruning ceased when 30 ft. clear length was obtained on each tree.

Three replications in randomised blocks.

Edensmuir Experiment No. 4/47. Scots pine. (Late pruning.) Compartment 2, Edensmuir Forest, Fife.

Immediately adjoining Edensmuir Expt. 3/36, in the same stand.

Planted in Spring 1923. First pruned in spring 1947.

No thinning was done before pruning began, but the crop was brashed in 1940.

Treatment 1. Control. Brashed to 6 ft. only.

„ 2. Pruned up to, but not including, the lowest live branch, at intervals of 7 and 4 years.

„ 3. Pruned up to and including the second live whorl from the base of the crown, at intervals of 7 and 4 years.

„ 4. Pruned as Treatment 3, but given moderately heavy (C/D grade) low thinning.

„ 5. Pruned to 54 per cent, 66 per cent and 68 per cent of height of tree, at intervals of 7 and 4 years.

„ 6. Pruned to 62 per cent, 71 per cent and 68 per cent of height of tree, at intervals of 7 and 4 years.

Thinning, except in Treatment 4, was to light crown grade at intervals of 6, 3 and 3 years.

Pruning ceased when 26 ft. clear length was obtained on each tree.

Two replications in randomised blocks.

Experiments in Annual Pruning, 1947–1950 (The bud pruning experiments).

Six experiments received the same treatments:

Treatment A. Control. Unpruned.

„ E. When three vigorous whorls had been formed after planting, all branches below these were removed. Thereafter, the lowest whorl was removed annually in the spring, leaving three whorls; these were supplemented by a fourth when growth began.

The experiments were located as follows;

Lossie Experiment No. 1/47. Corsican pine. Compartment 37, Lossie Forest, Moray. On coastal sand dunes.

Mabie Experiment No. 1/49. Scots pine. Compartment 9, Mabie Forest, Kirkcudbrightshire. An exposed site at 300 feet elevation.

Millbuie Experiment No. 10/49. Scots pine. Compartment 14, Millbuie Forest, Ross. An exposed site at 550 ft. elevation.

Wykeham Experiment No. 82/49. Corsican pine. Wykeham Low Moor, Allerston Forest, Yorkshire. An exposed site at 650 feet elevation.

Kielder Experiment No. 52/49. Sitka spruce. Compartment 61, Kielder Forest, Northumberland. An exposed site at 950 feet elevation.

Mabie Experiment No. 2/50. Douglas fir. Compartment 7, Mabie Forest, Kirkcudbrightshire. A sheltered slope at 200 feet elevation.

See Table 8 for ages of experiments at first pruning and the number of prunings done in each experiment.

Experiments in Pruning Free-growing Trees, 1950–1951.

In these four experiments, selected dominant trees were favoured by annual thinning so that their crowns were never interfered with by neighbouring crowns. These isolated trees were paired for vigour of growth, and one of each pair was pruned to 10 feet when the average girth at that height reached a particular value. In two experiments, a second pruning was later done to 18 feet.

Ae Experiment No. 11/50. Norway spruce. Compartment 112, Forest of Ae, Dumfries-shire. A sheltered site at 650 feet elevation.

Pruned to 10 feet when girth at that height averaged 10½ inches; to 18 feet when girth at that height averaged 10 inches.

Mabie Experiment No. 3/50. Douglas fir. Compartment 7, Mabie Forest, Kirkcudbrightshire. A sheltered slope at 130 feet elevation.

Pruned to 10 feet when girth at that height averaged 11 inches.

Ae Experiment No. 12/50. Sitka spruce. Compartment 114, Forest of Ae, Dumfries-shire. A sheltered site at 350 feet elevation.

Pruned to 10 feet when girth at that height averaged 13½ inches; to 18 feet when girth at that height averaged 11½ inches.

Benmore Experiment No. 6/50. Sitka spruce. Compartment 109, Benmore Forest, Argyll. A moderately exposed site at 300 feet elevation. Pruned to 10 feet when average girth at that height was 8½ inches.

See Table 7 for mean heights of trees at first pruning, and pruning cycles.

Appendix B

DEFINITIONS

Sources of published definitions are shown thus:

BCFT (1) 20 = *British Commonwealth Forest Terminology*, Part 1, 1953. Page 20.
BCFT (2) 45 = *British Commonwealth Forest Terminology*, Part 2, 1957. Page 45.
Bull. 31 = Forestry Commission Bulletin No. 31, *Code of Sample Plot Procedure*, Appendix XIV.

Branch, live. A branch bearing one or more living needles, leaves or buds.

Brash, to. To remove dead or live branches within a man's reach in a young crop. BCFT (1) 20

Clean. A term applied to: (*a*) a bole that is free of branches and other visible defects. Syn. Clear.
(*b*) timber that is free of knots. BCFT (2) 45

Clear. A term applied to: (*a*) timber that is free from all visible defects and imperfections.
(*b*) a bole that is free of branches and other visible defects. Syn. Clean. BCFT (2) 45

Crown height, lower. The height above ground of the lowest live branch on the main stem (excluding epicormic shoots). Bull. 31

Crown height, upper. The height above ground on the main stem at which live branches are found on all sides. Bull. 31

Crown length. The vertical measurement of the crown of a tree measured along the main axis of the stem, or its continuation, from a point half way between the lower and upper crown heights to the tip of the tree. c.f. Bull. 31

Crown, live. That part of the crown of a tree above and including the lowest live branch.

Form quotient. The ratio of the girth of a tree at a specified height to its girth at breast height. BCFT (1) 64

Knot. A portion of a branch enclosed in the wood by the natural growth of the tree. BCFT (2) 102

Prune, to. To remove live or dead branches or multiple leaders from standing trees for the improvement of the tree or its timber. BCFT (1) 104

Pruned length. The length of stem which is pruned on any one occasion. It is measured as the difference between two consecutive pruned heights, and at the first pruning is identical with pruned height.

Pruned height. The vertical height from ground level to a point on the stem 3 inches below the underside of the lowest branch remaining after pruning. Bull. 31

Pruning cycle. The number of years which elapse between consecutive prunings of a tree or stand.

Pruning, dry. The pruning of dead branches BCFT (1) 104

Pruning, green. The pruning of live branches BCFT (1) 104

Pruning intensity. A classification of pruning combining severity and pruning cycle, e.g. severe prunings repeated on a short cycle constitute intense pruning.

Pruning regime. A comprehensive term for the series of operations involved in pruning a stand, including the selection of trees, the timing and intensity of pruning, the final pruned height, the thinnings to be applied, etc.

Pruning severity. The extent to which live crown is removed from a tree by one pruning operation.

Selected tree. In pruning experiments; a tree selected as suitable for pruning, but which may or may not be pruned according to whether it is allotted to a pruning treatment or to the control. In either case it is assessed as required in order to compare the effects of pruning.

Thinning, crown. A type (q.v.) of thinning: used here in the broadest sense of any thinning which removes trees from the highest canopy layers for the benefit of others in the same layers.

Thinning grade. A classification of severity of thinnings within any particular thinning type. (See Bull. 31, Appendix III.) Bull. 31

Thinning type. A classification of kinds of thinnings based either on the trees removed or on the trees left in thinning Bull. 31

Whorl, live. When the pruning experiments were started, this was defined as a whorl in which all the main branches are alive. It is now defined as one in which live branches occur on all sides of the stem, and indicates the position of upper crown height. The two definitions are practically equivalent.

APPENDIX C

GRADING OF SAWN BRITISH SOFTWOODS

PERMISSIBLE DEFECTS AND CHARACTERISTICS OF DIFFERENT GRADES

Defect and characteristic	Permissible size of defect or characteristic				
	Grade I		Grade II	Grade III	Grade IV
Knots (a) Edge (b) Margin of face (c) Centre of face	 1/4 thickness 1/8 width 1/6 width Sound knots only	Grade I Clear to be same as Grade I except that no knots or blue stain permitted	 1/2 thickness 1/4 width 1/3 width Sound knots only	 3/4 thickness 1/3 width 1/2 width	Unspecified
Wane (a) Edge (b) Face	 None None		 1/8 thickness 1/12 width 1/4 length	 1/4 thickness 1/6 width 1/3 length	 1/2 thickness 1/3 width Length unspecified
Slope of grain	1 in 14		1 in 8	Unspecified	Unspecified
Rate of growth	Not less than 8 rings/in.		Not less than 4 rings/in.	Unspecified	Unspecified
Pitch pockets	Not allowed		Unspecified	Unspecified	Unspecified
Checks and splits	Not exceeding 6 in. in length		Exceeding 6 in. long shall not be deeper than 1/4 thickness for more than 1/4 length	Exceeding 6 in. long shall not be deeper than 1/4 thickness for more than 1/4 length	
Bow Spring Twist Cup Blue stain	1/4 in. in 10 ft. 1/4 in. in 10 ft. 3° in 10 ft. 1/16 in. in 6 in. 5 per cent		1/2 in. in 10 ft. 1/4 in. in 10 ft. 6° in 10 ft. 1/8 in. in 6 in. 15 per cent	1 in. in 10 ft. 1/2 in. in 10 ft. 6° in 10 ft. 1/8 in. in 6 in. 25 per cent	Unspecified Unspecified Unspecified Unspecified Unspecified

In addition to the requirements listed in the Table, Grades I and II shall be free from fungal decay and insect attack. A certain amount of fungal decay of the 'hard rot' type is permitted in Grades III and IV but 'soft rot' is excluded. Loose, dead and decayed knots and knot holes shall not be permitted in Grades I and II.

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