YIELD MODELS FOR FOREST MANAGEMENT

Forestry Commission Booklet 48

YIELD MODELS

for

Forest Management

Text by P N Edwards

Models prepared by J M Christie

PREFACE

This booklet, with its associated yield models and curves, replaces Forestry Commission Booklet Number 34 *Forest Management Tables (Metric)* by G J Hamilton and J M Christie, which was published by HMSO in 1971. Yield models can be constructed to simulate the effects of any silvicultural treatment, and the 'Normal Yield Tables' included in the earlier publication were models of a specified 'normal' treatment. A much wider range of yield models is now available, and the loose-leaf format of this publication allows for new yield models to be added at any time. Models can be ordered from the Publications Section, Forestry Commission, Alice Holt Lodge, Farnham, Surrey, GU10 4LH, who will also supply a complete list of available models. The models are based on the information available at the time that they were constructed, and it is inevitable that some of them will be revised as more information on tree growth is collected by the Forestry Commission.

The format of the yield models is very similar to that of the Normal Yield Tables published previously, except that the current annual increments and the assortment forecasts have been omitted. The models have again been produced directly from computer output. Some assortment tables are given on pages 24 to 29, but further information on assortments is available in Forestry Commission Booklet Number 39 *Forest Mensuration Handbook* by G J Hamilton (1975), pages 162–185, and from the Mensuration Section at Alice Holt Lodge. Information on thinning is available in Forestry Commission Booklet Number 49 *Thinning and Timber Measurement. A Field Guide* by P N Edwards.

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THE CONCEPT OF YIELD CLASS

Introduction

The growth of trees may be quantified in terms of increases in height, diameter, weight, volume or dry matter. Only height, diameter and volume are relatively easily measured, and of these, volume is most meaningful for purposes of management. Measurable volume is conventionally defined as stemwood of at least 7 cm diameter overbark.

Volume increment

The pattern of volume increment in an even-aged stand is shown in Figure 1. After planting, the annual volume increment of a stand increases, reaches a peak after some years and then falls off as shown by the curve labelled CAI (Current Annual Increment). This curve represents the annual volume increment at any point in time. The average annual volume increment from planting to any point in time is shown by the second curve labelled MAI (Mean Annual Increment). For example, at n years, the annual volume increment is x, while the mean or average annual volume increment from the time of planting to n years is y.

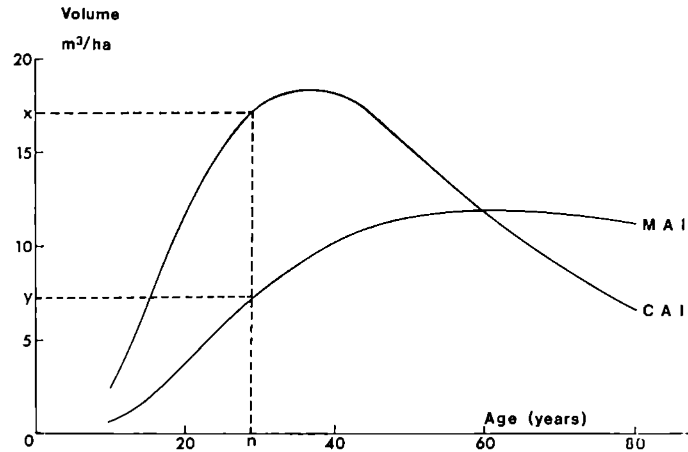

FIGURE 1 Patterns of Volume Increment in an Even-aged Stand

Maximum mean annual increment

The MAI curve reaches a maximum where it crosses the CAI curve. This point defines the maximum average rate of volume increment which a particular stand can achieve, and this indicates the yield class. For example, a stand with a maximum MAI of 14 cubic metres per hectare has a yield class of 14. In theory, if the trees on an area were repeatedly felled at this age, replanted, and managed in the same way, and there was no loss in site productivity, then this maximum average rate of volume production would be maintained in perpetuity.

This general pattern of growth is typical of all even-aged stands, but differences in rates of growth occur with the same species on different sites. For any one species, these differences usually follow the pattern outlined in Figure 2. The faster growing stands have higher maximum MAIs, and these maxima occur earlier.

Again, although the same general pattern of growth is true of all species, there may be important differences between species. For example, maximum MAIs of different species may be of the same magnitude, but may occur at totally different times. This is illustrated in Figure 3.

The important point here is that the maximum MAI is the maximum average rate of volume production attained by a crop, irrespective of the time at which this maximum is achieved, and it is this feature which is the basis of the Yield Class System.

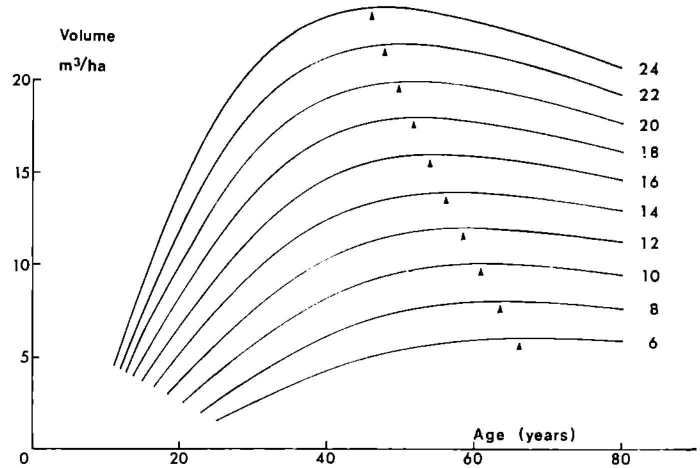

FIGURE 2 Mean Annual Volume Increment (MAI) Curves for Sitka Spruce showing for each Yield Class the Age of Maximum MAI

The definition of yield classes in Britain

The range of maximum mean annual increments commonly encountered in British conditions varies with individual species, and can be four cubic metres per hectare or even lower for many broadleaves, larches and pines, and thirty or more cubic metres per hectare in the case of some other conifers. Yield Classes are created simply by splitting this range into steps of two cubic metres per hectare, and numbering the steps with even numbers accordingly. Thus a stand of Yield Class 14 has a maximum MAI of about 14 cubic metres per hectare, i.e. greater than 13 cubic metres per hectare, but less than 15.

The use of yield classes

Such classification is of limited use if it can only be used to categorise stands which have already reached their maximum MAI, since part of its purpose is to predict the future rate of growth of younger crops. Ideally, stands which have not yet reached the age of maximum MAI would be classified by reference to the MAI curves for the species as in Figure 2. This, however, would necessitate establishing the mean annual increment of the stand, information which is seldom available because previous thinning yields have not been recorded. Even where thinning records are available, the measurement of the main crop volume can prove a relatively expensive procedure if it is required only for yield class assessment.

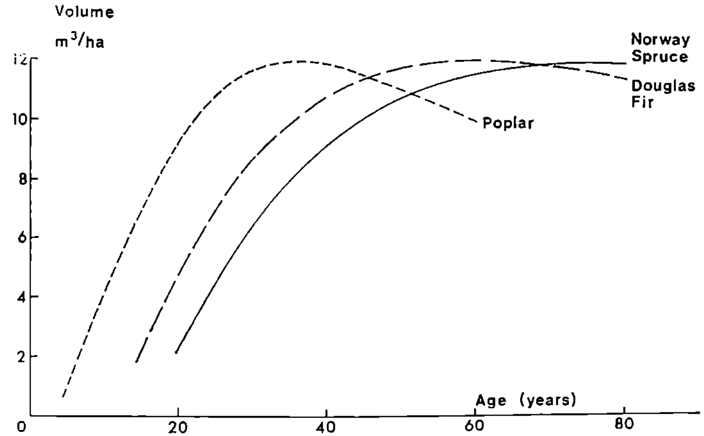

FIGURE 3 Mean Annual Volume Increment Curves for Norway Spruce, Douglas Fir, and Poplar, Yield Class 12

General Yield Class

Fortunately, a good relationship exists between top height and cumulative volume production of a stand, and this can be used to avoid actually measuring or recording cumulative volume production. The logical sequence for assessing yield class would thus be to measure top height, convert this to cumulative volume production, and divide this by the age of the stand to derive mean annual increment. Yield class could then be determined from a series of mean annual increment curves, as in Figure 2, for the appropriate species. This procedure has been simplified by constructing top height/age curves from which yield class can be read directly. Yield class obtained through top height and age of the stand alone is termed General Yield Class (GYC). Top height/age curves (i.e. General Yield Class curves) have been produced for all major species, and they are printed on the index cards (see back cover).

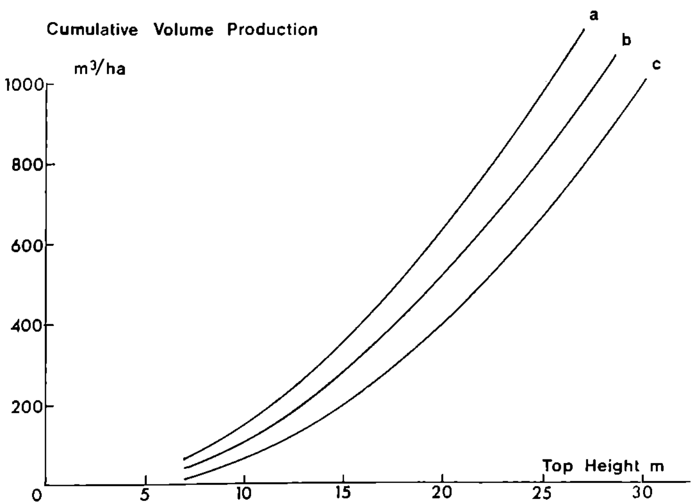

FIGURE 4 Cumulative Volume Production in relation to Top Height for Three Production Classes of a Species

Production Class

It was stated in the previous paragraph that a good relationship exists between top height and cumulative volume production for any one species, but there are local variations in this relationship. These variations have been largely accommodated by employing three top height/cumulative volume production functions rather than one (see Figure 4).

These three levels of cumulative volume production for a given height are termed Production Classes. Production Class 'b' is the normal top height/volume production relationship embodied in the General Yield Class curves. The effect of using Production Class 'a' is to raise the yield class by one class over that indicated by the General Yield Class curve i.e. to raise the maximum MAI 2 cubic metres per hectare. The effect of using 'c' is to lower the General Yield Class estimate by one class.

There are indications that stands on exposed sites tend towards Production Class 'a', as their height growth is depressed relatively more than their volume growth. Conversely, Production Class 'c' may occur on sites where there is a moisture deficit in the later part of the growing season, but not in the earlier part.

The growth patterns described above assume that height growth remains vigorous throughout the life of the stand.

Local Yield Class

Where Production Class has been taken into account the yield class is termed a Local Yield Class (LYC).

For example:

General Yield Class 14,	Production Class 'a'	=	Local Yield Class 16
,, ,, ,, 14,	,, ,, 'b'	=	,, ,, ,, 14
,, ,, ,, 14,	,, ,, 'c'	=	,, ,, ,, 12

Production Classes are best thought of as devices which may be used to provide an improved estimate of yield class.

Assessment of General Yield Class

General Yield Class is determined from the top height/age curves printed on the index cards. The top height is the average height of a number of 'top height trees' in a stand, where a 'top height tree' is the tree of largest breast height diameter in a 0.01 hectare sample plot. This is not necessarily the tallest tree. A series of sample plots, equal to the desired number of top height trees, should be randomly located throughout the stand, and the height of the tree of largest breast height diameter in each plot (radius 5.6 m) is measured. The number of top height trees to be measured will depend on the extent of the stand and its uniformity. The table below gives the likely minimum number of trees required to give adequate estimates of yield class in a particular stand.

Area(ha)	*Number of Top Height Trees*	
	Uniform Crop	*Variable Crop*
0.5-2.0	6	8
2.0-10.0	8	12
Over 10.0	10	16

In uniform stands, top height is approximately the same as the mean height of the 100 trees per hectare of largest diameter at breast height, which was the earlier definition. The age of the stand is defined as the number of growing seasons since planting.

Once top height and age are known, General Yield Class can be established from the top height/age curves printed on the index cards.

For example, if the top height of a stand of Sitka spruce is 19 m at an age of 40 years, then using the top height/age curve (given in Figure 5), the General Yield Class is found to be 14.

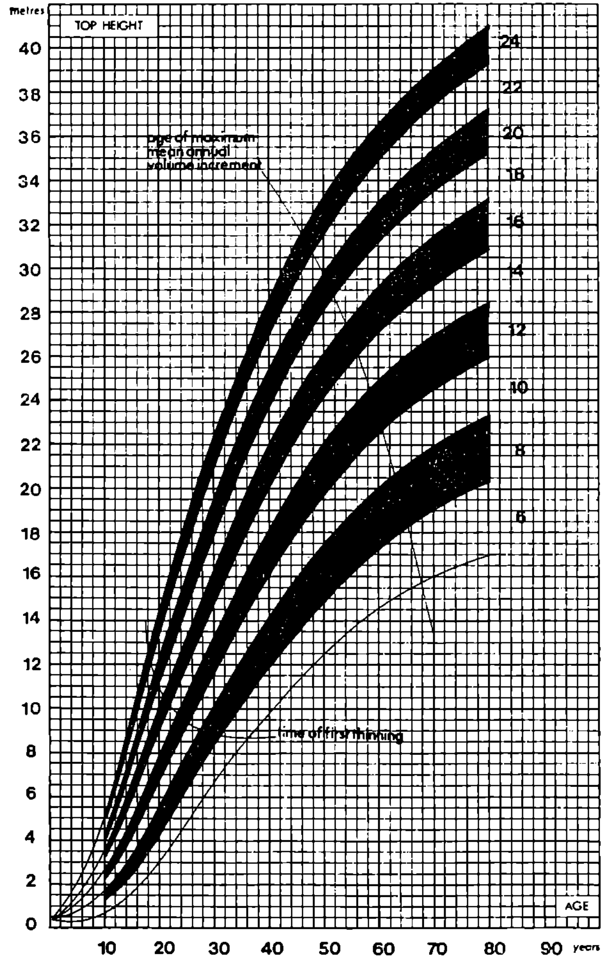

FIGURE 5 General Yield Class Curves for Sitka Spruce

Where there is more than one species in the stand, the General Yield Class of each species should be assessed separately. It may be necessary to increase the number of sample plots so that the minimum number of top height trees is measured in each species. The average yield class of the stand can be obtained by averaging the component yield classes weighted according to the proportion of the canopy each occupies. For example, if one species occupies 40 per cent of the canopy and has a General Yield Class of 10 whilst a second species of General Yield Class 14 occupies 60 per cent of the canopy, the average General Yield Class is $(10 \times 40 + 14 \times 60)/100 = 12.4$ (which rounds to 12).

Uneven-aged stands are treated in a similar way in that the yield class of each age category is assessed separately, and the average yield class again obtained, weighted according to the proportion of the canopy occupied by each category.

Where, for any reason, the rate of height growth has changed appreciably in the life of the stand, for example because it has been in check, or because it has been fertilised, an adjusted age should be used instead of the actual age. This procedure is described on page 11.

Assessment of Production Class

General Yield Class is usually adequate for most management purposes, but a better estimate of yield class can be obtained by assessing Production Class. This is generally an expensive and time-consuming operation which is normally restricted to the major species in a forest. The factors which influence Production Class tend to be macro-climatical rather than specific to individual stands. For these reasons, it is best to apply Production Class for a given species to whole forests or parts of forests rather than individual stands.

Production class can only be assessed before a stand has been thinned, unless the total volume or basal area removed in thinning is accurately known. Production class is assessed by measuring either cumulative volume production per hectare, or cumulative basal area production per hectare. The second method is really a substitute for the first, but as cumulative volume production is seldom known, and generally too expensive to obtain for this purpose, the first method is seldom used. On the other hand, it is the preferred method should information on cumulative volume production be already available. Because of the wide variation in silvicultural treatments now being used, the average diameter of the 100 largest trees per hectare can no longer be recommended as a method of assessing production class.

Cumulative basal area production is relatively easily obtained, and for this reason it is the method most commonly used. In practice the assessments are carried out in fully-stocked unthinned stands, as records are seldom available of basal area previously removed in thinned stands. In sampling an unthinned compartment for total basal area production it is advisable to lay out at least three plots of 0.01 hectares, in which all live trees, including those of less than 7 cm diameter, are measured for diameter at breast height, and the average basal area per hectare is calculated. Alternatively, at least six relascope sweeps should be taken.

Production Class is derived from the cumulative volume/top height curves or the cumulative basal area/top height curves printed on the index cards. For example, given that the top height of a stand of Sitka spruce is 16 m, and the cumulative volume production is 250 cubic metres, then by referring to Figure 6 overleaf, the Production Class is found to be 'c'. Similarly, in a Sitka spruce stand with a top height of 12 m, and a cumulative basal area production of 50 square metres, the Production Class is 'a'.

The first stage in establishing Production Class for a forest is to sample for Production Class, as described on the previous page, in about ten compartments for each major species in the forest. Taking each species separately, the production class assessments should be plotted on a small-scale map of the forest, to see if there are any trends or patterns in the distribution of Production Class. For example, the samples from the eastern half of the forest may be all Production Class 'b', while those from the western half are all 'a'. If the Production Class samples do show a systematic pattern, then the forest should be divided into separate parts for assessing Production Class. This stratification is likely to be different for different species. For each species, if stratification is necessary, about ten compartments should now be sampled for Production Class in each part of the forest. The average Production Class in each part of the forest should then be applied to all the stands of that species in that part of the forest. If no stratification is necessary, then the average Production Class derived from the first sample should be applied to the whole forest. This procedure is repeated for each major species.

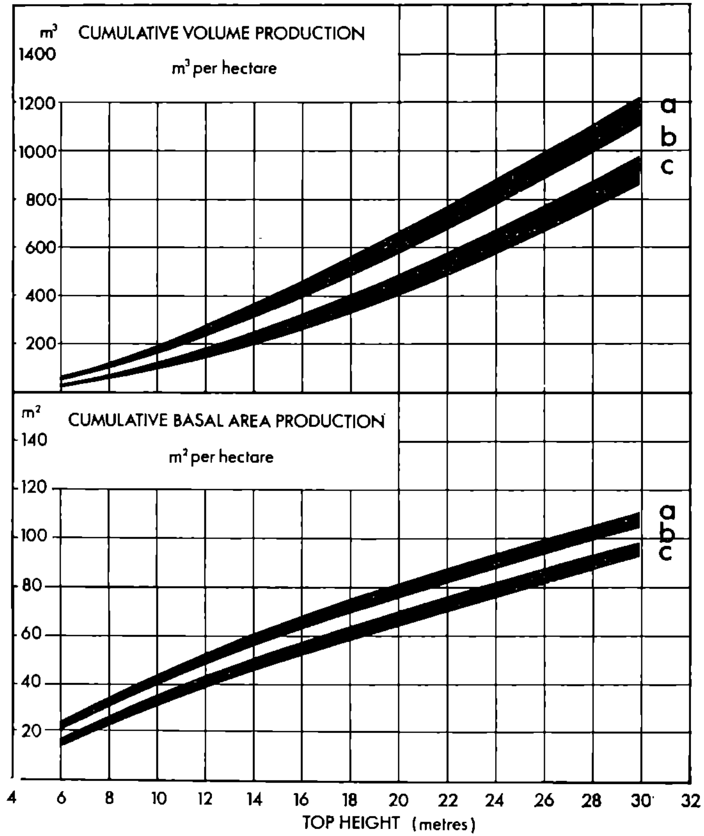

FIGURE 6 Production Class Curves for Sitka Spruce

THE EFFECT OF VARIATIONS IN GROWTH RATE

It was explained earlier, page 5, that the same species will grow at different rates on different sites, and that the complete range of growth rates has been divided into separate classes, called Yield Classes. An individual stand will not always follow these growth rates: for part of its life, a stand may grow faster than its Yield Class suggests, and at other times it may grow slower. For example, a Sitka spruce stand may suffer from check for the first ten years, and it will therefore grow very slowly indeed. Once the stand has grown out of the check phase, its growth rate, and hence Yield Class, will increase markedly. A second example is the effect of fertilising the stand. This will often increase the growth rate of the stand, although sometimes only for a few years if the treatment is not repeated.

In both of these situations, the use of present top height for assessing Yield Class may not be very helpful as this reflects the average height growth to date and it may not be a good predictor of future growth. In a stand which has recovered from an initial period of check, the predicted growth rate based on the average growth to date will usually be less than the actual future growth rate. Conversely, the current growth rate, combined with the true age of the stand, will lead to an over-estimate of the future growth. The correct way to allow for these changes in growth rate is to combine the current growth rate with an 'adjusted age'. The current growth rate and the measured top height are used to derive the Yield Class using the height increment tables on pp 12 and 13. The 'adjusted age' is then derived from the top height/age curves, using this yield class and the measured top height. For example, a Sitka spruce stand has a top height of 17 m, and is 40 years old. This suggests a Yield Class of 12. However, the current growth of 2.0 m in the last 4 years shows that the Yield Class is now 14 (Table 1). Reference to Figure 5 will show that the adjusted age of this stand is about 35 years (YC 14, Top ht 17 m). This Yield Class assessment assumes that the stand will continue growing at the current rate, which is quite likely now that the crop has recovered from check.

An adjusted age can also be calculated for a stand which has responded to fertilising, except that the adjusted age will often be higher than the actual age.

For example, consider a Sitka spruce stand, fertilised 10 years ago at age 20, when its top height was 7.5 m, indicating Yield Class 12. Its top height is now 15 m, which means that the average height growth over the past 10 years has been 75 cm per year. Table 1 shows that this is equivalent to about yield class 20. A yield class 12 stand would have taken 35 years to reach a top height of 15 m. However, unless there is a further application of fertiliser, there may be no reason to suppose that the stand will continue growing at its current rate, and it may be more accurate to assume that it will continue growing at Yield Class 12 from now on. So in this case the fertilising can be considered to have saved 5 years (35–30), and the stand should be recorded as Yield Class 12, with an adjusted age of 35 years. The increased growth rate is illustrated in Figure 7, which is a graph of the cumulative volume production of the stand, plotted against its top height.

As yield classes are used for forecasting, it is very important that the recorded yield class gives the best possible estimate of future growth. Yield classes are not intended as a method for describing past growth.

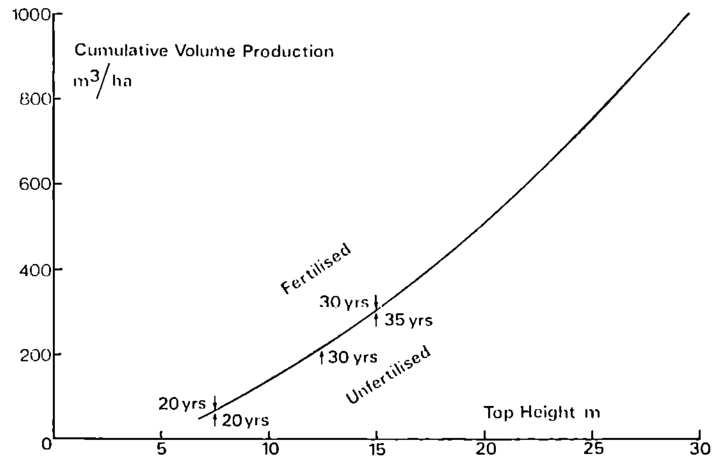

FIGURE 7 Volume Production of YC12 Sitka Spruce showing Effect at 30 years age of Fertiliser Treatment when 20 years old

TABLE 1

ANNUAL TOP HEIGHT INCREMENT BY YIELD CLASS AND TOP HEIGHT

(centimetres)

Scots Pine

Top height (m)	*Yield class* 4	6	8	10	12	14
8	27	32	37	44	51	59
9	25	31	36	42	49	57
10	23	29	35	40	47	54
11	22	28	34	39	45	51
12	20	26	32	37	43	49
13	18	24	30	36	41	46
14	16	23	29	34	39	44
15	13	21	27	33	37	41
16	10	19	26	31	36	40
17	—	17	24	29	34	38
18	—	15	22	28	33	37
19	—	12	20	26	31	35
20	—	—	18	24	30	34

Corsican Pine

Top height (m)	*Yield class* 6	8	10	12	14	16	18	20
8	29	37	44	50	54	58	62	66
9	27	36	43	49	54	58	62	66
10	26	34	41	48	53	57	62	66
11	24	32	40	46	52	57	61	65
12	23	30	38	45	51	56	60	64
13	21	29	36	43	49	55	59	63
14	20	27	34	41	47	53	58	62
15	18	25	32	39	45	52	57	61
16	15	23	30	37	43	50	55	60
17	11	21	28	35	41	48	53	59
18	—	19	26	32	39	46	52	57
19	—	16	24	30	37	44	50	55
20	—	13	22	28	35	41	47	53

Lodgepole Pine

Top height (m)	*Yield class* 4	6	8	10	12	14
8	29	39	48	56	63	70
9	26	37	47	55	63	70
10	24	35	45	54	62	70
11	21	32	43	52	61	69
12	19	30	40	50	59	67
13	17	27	38	48	57	66
14	15	25	35	45	55	64
15	14	23	33	42	52	61
16	13	21	30	39	50	59
17	—	20	28	37	47	56
18	—	18	26	35	44	53
19	—	17	25	33	41	51
20	—	16	23	31	39	48

Japanese Larch

Top height (m)	*Yield class* 4	6	8	10	12	14
8	34	44	52	59	67	75
9	31	42	50	58	65	73
10	28	39	48	56	63	71
11	24	36	46	53	61	69
12	21	33	43	51	59	66
13	17	30	40	48	56	64
14	14	26	37	46	53	61
15	11	23	34	43	51	58
16	8	20	30	40	48	55
17	—	17	27	37	45	52
18	—	14	24	33	42	49
19	—	12	21	30	39	46
20	—	9	18	27	36	43

TABLE 1 (*continued*)

Sitka Spruce

Top height (m)	*Yield class* 6	8	10	12	14	16	18	20	22	24
8	36	43	49	54	58	63	68	74	80	86
9	34	42	48	53	58	63	69	75	81	88
10	33	40	47	53	58	63	69	75	82	88
11	31	38	46	52	57	63	69	75	82	89
12	29	37	44	51	57	62	69	75	82	89
13	27	35	42	50	56	62	68	74	81	88
14	25	33	41	48	54	61	67	73	80	87
15	22	31	39	47	53	60	66	72	79	86
16	18	29	37	45	52	58	65	71	78	85
17	14	27	35	43	50	57	63	69	76	83
18	12	24	33	41	48	55	61	68	74	81
19	—	20	21	39	46	53	59	66	72	79
20	—	16	28	36	44	51	57	64	70	76

Norway Spruce

Top height (m)	*Yield class* 6	8	10	12	14	16	18	20	22
8	30	38	45	50	54	57	60	64	67
9	29	36	44	49	53	57	61	64	67
10	28	34	42	48	53	57	61	64	67
11	27	33	40	46	52	56	60	64	67
12	25	31	38	45	50	55	60	63	67
13	23	30	36	43	49	54	59	63	66
14	21	28	34	41	47	52	57	62	65
15	19	26	32	39	45	51	56	60	64
16	18	24	30	37	43	49	54	59	63
17	15	22	29	35	41	47	52	57	62
18	13	21	27	33	39	45	50	56	61
19	—	19	26	31	37	43	48	54	59
20	—	17	23	29	35	40	46	52	57

Douglas Fir

Top height (m)	*Yield class* 8	10	12	14	16	18	20	22	24
8	55	63	68	73	78	83	88	93	99
9	54	61	67	72	78	83	88	93	98
10	51	59	66	72	77	82	87	92	98
11	49	57	64	71	76	82	86	91	97
12	46	55	62	69	75	80	86	90	96
13	43	52	60	67	73	79	85	90	94
14	41	50	58	66	72	78	84	89	93
15	38	48	56	63	70	76	82	87	92
16	36	46	53	61	68	75	81	86	90
17	35	44	51	59	66	73	79	85	89
18	33	42	49	56	64	71	77	83	87
19	31	39	46	54	61	68	75	81	85
20	29	36	44	51	59	66	73	79	83

THE EFFECT OF DIFFERENT TREATMENTS

The General Yield Class curves and the Production Class curves are based on the assumption that the stands have been planted at spacings of 1.2 m (Oak, Be), 1.4 m (SP, CP), 1.5 m (LP, NS, WH, RC, NF, SAB), 1.7 m(SS, EL, JL, DF, No), 1.8 m (GF) and 7.3 m (Po), and thinned (except for poplar) at the marginal thinning intensity (defined on page 17). These spacings were the ones most commonly used before the Management Tables were published but since then there has been a tendency to use wider spacing for most species. This will cause a reduction in the cumulative volume production of a stand, while closer spacing will increase it, as shown in Figure 8. The effect is similar to a small change in Production Class. (See Forestry Commission Bulletin 52.) However, different spacings do not alter Yield Class or Production Class, because yield class is the maximum MAI which a given species can attain on a particular site, irrespective of treatment. So different spacings or treatments which alter the density of a stand do not change the yield class, although they may alter the maximum mean annual increment.

Respacing will also cause a loss of volume production, as may a very heavy thinning (Figure 8), and this is similar to the loss caused by wide initial spacing except that the loss only occurs from the time that the respacing or thinning was done.

In both of these situations, the General Yield Class should be assessed in the usual way, from top height and age. Assessment of Production Class in the normal way may be misleading, and it should be assessed by referring to the cumulative production given in the appropriate yield model. For example, consider a stand of Sitka spruce planted at 3 m spacing, unthinned and now 23 years old. It has a top height of 9.5 m which indicates GYC 14. If the cumulative basal area production is 22 sq. m, reference to the appropriate model (see Figure 9) will show that the production class is 'b'. But if the production class curves on the index cards were used, they would incorrectly suggest that it was production class 'c'. Wherever possible, the yield model closest to the actual spacing and thinning treatment should be used for estimating the potential production. This model may show that the maximum is different from that suggested by the Yield Class.

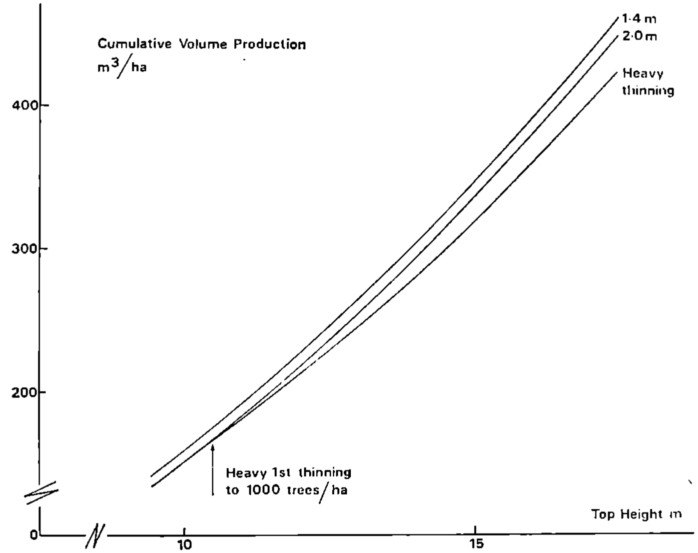

FIGURE 8 Effect of Spacing or Heavy Thinning on Volume Production

SS

2·0m

Intermediate Thinning

YC 14

		MAINCROP after Thinning					Yield from THINNINGS					CUMULATIVE PRODUCTION		MAI	
Age yrs	Top Ht	Trees /ha	Mean dbh	B A /ha	Mean vol	Vol /ha	Trees /ha	Mean dbh	B A /ha	Mean vol	Vol /ha	B A /ha	Vol /ha	Vol /ha	Age yrs
18	7.3	2311	11	24	0.03	66	0	0	0	0.00	0	24	66	3.7	18
23	10.2	1351	15	24	0.07	90	895	12	11	0.05	49	35	139	6.0	23
28	13.0	951	19	28	0.14	133	400	15	7	0.12	49	46	231	8.3	28
33	15.7	732	23	31	0.26	188	220	19	6	0.22	49	56	335	10.2	33
38	18.2	595	27	35	0.41	246	137	22	5	0.36	49	64	442	11.6	38
43	20.4	496	31	37	0.60	300	99	25	5	0.50	49	72	545	12.7	43
48	22.4	422	34	38	0.82	345	74	28	5	0.66	49	78	639	13.3	48
53	24.1	374	37	40	1.04	388	48	31	4	0.85	41	83	723	13.6	53
58	25.5	341	39	41	1.25	426	34	33	3	1.05	35	87	796	13.7	58
63	26.7	316	41	42	1.45	457	25	36	2	1.25	31	91	858	13.6	63
68	27.7	297	43	43	1.63	484	20	37	2	1.40	27	94	912	13.4	68
73	28.6	281	45	44	1.81	508	16	39	2	1.51	25	96	961	13.2	73
78	29.4	267	46	44	1.98	529	13	41	2	1.66	22	98	1003	12.9	78

3·0m

Age yrs	Top Ht	Trees /ha	Mean dbh	B A /ha	Mean vol	Vol /ha	Trees /ha	Mean dbh	B A /ha	Mean vol	Vol /ha	B A /ha	Vol /ha	Vol /ha	Age yrs
18	6.6	1085	11	11	0.03	29	0	0	0	0.00	0	11	29	1.6	18
23	9.5	1069	16	22	0.08	84	0	0	0	0.00	0	22	84	3.6	23
28	12.3	681	22	26	0.18	121	360	18	9	0.14	49	34	170	6.1	28
33	15.0	514	27	30	0.34	174	166	22	6	0.29	49	46	272	8.3	33
38	17.5	413	32	34	0.56	230	101	27	6	0.48	49	55	377	9.9	38
43	19.7	348	37	37	0.81	282	66	31	5	0.75	49	62	478	11.1	43
48	21.7	299	40	39	1.09	326	48	34	4	1.01	49	69	571	11.9	48
53	23.4	268	44	40	1.37	368	32	37	3	1.29	41	74	653	12.3	53
58	24.8	245	46	42	1.64	404	22	40	3	1.57	35	78	724	12.5	58
63	26.0	228	49	43	1.90	434	17	43	2	1.80	31	82	786	12.5	63
68	27.0	215	51	44	2.14	461	13	45	2	2.04	27	85	840	12.3	68
73	27.9	204	53	45	2.38	486	11	47	2	2.27	25	88	889	12.2	73
78	28.7	195	54	45	2.59	506	9	48	2	2.48	22	90	932	11.9	78

FIGURE 9 Yield Models for Sitka Spruce, YC14—Intermediate Thinning: (above) 2.0 m Spacing (below) 3.0 m Spacing

YIELD MODELS

INTRODUCTION

The yield models available with this booklet are tabular presentations of models of stand growth and yield which have been produced on the computer at the Forestry Commission's Research Station. They are based on data collected since 1919 by the Forestry Commission in yield plots, and in thinning and spacing experiments. Models have been prepared for all the major forest species in Britain, and for a wide variety of treatments including a range of initial spacings, thinning at marginal intensity, and no thinning.

For each model, one particular treatment regime has been assumed. Any deviation from this regime, or any deviation from the average growth pattern, will produce a different set of stand characteristics. It is inevitable that an individual stand will vary in one respect or another from the model, and so direct comparisons are not very meaningful. However, the trends of growth which are given in a model can be used to estimate the probable development of any particular stand.

Only live trees have been included in the models, and all information relating to trees that have died has been excluded. This is different from the models published in the Management Tables, in which the information relating to dead trees was included in the first thinning.

Unless stated otherwise, all the models, irrespective of spacing and treatment, are based on Production Class b. If a model for a different Production Class is required, use the models for the appropriate Local Yield Class. If this is done, the figures for top height will be misleading.

Ages shown

The ages given in each model are usually determined by the treatment regime which applies to that model, so that each model reflects the true effects of the chosen treatment regime.

For example, if the first thinning is at age 22, and subsequent thinnings are at 5-year intervals, then the model will give details at age 17, and then at 5-year intervals thereafter. Models of stands which are not thinned have the same age structure as the comparable models thinned at the marginal intensity.

This means that it may be necessary to interpolate between the results to compare different models at the same age. (At the time of printing, the models for oak, beech and SAB are only available in the same format as in the Management Tables, i.e. the ages given are all multiples of 5 years.)

Thinning Treatment assumed

Unless stated otherwise, all the models are thinned at the marginal thinning intensity, and usually on a 5-year cycle. For a given species, and at a given top height, these models will therefore have approximately the same average growing stock. (See page 20.)

If the first thinning is delayed, it will not normally be possible to remove all the accumulated growing stock in the first thinning, so the weight of subsequent thinnings will be adjusted to bring the stand back to the same average growing stock. If the first thinning is done earlier than the marginal thinning age, then subsequent thinnings are altered, either by adjusting their weight, or, as in some of the models of line thinning, by postponing the second thinning, so that the treatment reverts to the marginal thinning intensity. The timing of thinning is discussed further on page 20.

Accuracy

All the values given in the models have been rounded, and this sometimes results in apparent inconsistencies.

Spacings

After the species, the first figure in the margin of each model is the spacing. Square spacing has been assumed (unless stated otherwise), and the spacings are given as distances between the rows in metres. For example, a spacing of 2 m indicates an initial plant spacing of 2 m × 2 m, or 2,500 trees per hectare. The spacing normally applies both to initial plant spacing, and to the result after respacing, assuming that this is done before canopy closure. So a model for an initial spacing of 3 m would be applicable to a stand respaced to 1,100 trees per hectare.

Thinning intensity

This is defined in terms of the marginal thinning intensity (MTI), which is the maximum intensity which can be maintained without causing loss of volume production. This is the same as Management Table intensity (MT) (i.e. removing 70 per cent of the Yield Class each year), when the thinning is started at the marginal first thinning age (MT age). A thinning of 1.0 MT is a thinning at marginal thinning intensity, while a thinning of 1.25 MT is 25 per cent heavier. Further information on thinning intensity will be found in Forestry Commission Booklet 49, *Thinning and Timber Measurement. A Field Guide.*

Thinning type

The ratio of mean volume of the thinnings (v) to the mean volume of the stand before thinning (V) is known as the v/V ratio. This is a useful indicator of the type of thinning, and it is given below as one means of describing the thinning type.

Low thinning. v/V about 0.6

This is a selective thinning in which only trees from the lower canopy are removed, i.e. only the suppressed and sub-dominant trees in the stand. It is very rare in practice.

Intermediate thinning. v/V about 0.8

This is the commonest type of selective thinning. Most of the suppressed and sub-dominant trees are removed, and groups of competing dominants and co-dominants are broken up so as to leave a more even distribution of final crop trees.

Line thinning. v/V = 1.0

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

(a) Row thinning. The lines of trees removed follow the planting lines.

(b) Strip thinning. The lines removed do not follow the planting rows.

(c) Chevron thinning. The area between widely spaced racks is thinned by the removal of regularly spaced lines acutely angled to the main racks.

Crown thinning. v/V about 1.2

This type of selective thinning involves removing all the trees which are competing with selected dominants, which will include other dominants, particularly those of poor form. Some trees may also be removed from the lower canopy. The result is that the trees removed in the thinning have a higher mean volume than in any other type of thinning. Crown thinnings are often used at the first and second thinnings to increase the size of the tree being removed, but they are usually impractical in later thinnings.

Time of first thinning

MT Age

The first thinning age is normally chosen so that for the intended weight of thinning the stand has the average growing stock given in Table 2. (See page 20.) In models thinned at the marginal thinning intensity, removing 70 per cent of the Yield Class on a 5-year cycle, this is known as the MT Age (Marginal Thinning Age). In some models of different treatments, e.g. some line thinning models, the thinning is started at this MT Age, even though, because of the volume removed, this is not the marginal first thinning age for this treatment, and the time of the second thinning is adjusted to bring the stand back to the average growing stock level.

In a model labelled '5 yr delay', the first thinning is taken 5 years later than the marginal first thinning age.

The marginal first thinning age varies with the spacing of the stand, as discussed on page 20.

GLOSSARY OF TERMS USED IN THE MODELS

		MAINCROP after Thinning					Yield from THINNINGS					CUMULATIVE PRODUCTION		MAI	
Age yrs	Top Ht	Trees /ha	Mean dbh	B A /ha	Mean vol	Vol /ha	Trees /ha	Mean dbh	B A /ha	Mean vol	Vol /ha	B A /ha	Vol /ha	Vol /ha	Age yrs

Age: The number of growing seasons that have elapsed since the stand was planted.

Top Ht: Top height; the average height of a number of 'top height trees' in a stand, where a 'top height tree' is the tree of largest breast height diameter in a 0.01 ha sample plot.

MAINCROP after Thinning: All the live trees left in the stand, at a given age, after any thinnings have been removed.

Yield from THINNINGS: All the live trees removed in the thinning.

Trees/ha: The number of live trees in the stand, per hectare.

Mean dbh: The quadratic mean diameter (the diameter of the tree of mean basal area) in centimetres, of all live trees measured at 1.3 m above ground-level.

BA/ha: Basal area. The sum of the overbark cross-sectional areas of the stems of all live trees, measured at 1.3 m above ground-level, and given in square metres per hectare.

Mean vol: The average volume, in cubic metres, of all live trees, including any with a breast height diameter of less than 7 cm.

Vol/ha: The overbark volume, in cubic metres per hectare, of the live trees. In conifers, all timber on the main stem which has an overbark diameter of at least 7 cm is included. In broadleaves, the measurement limit is either to 7 cm, or to the point at which no main stem is distinguishable, whichever comes first.

CUMULATIVE PRODUCTION: This is the main crop basal area or volume, plus the basal area or volume of the present and all previous thinnings.

MAI: The mean annual volume increment; i.e. the cumulative volume production to date divided by the age.

Note: All trees which die through natural mortality are excluded, except that in models of unthinned stands the volume of dead trees, expressed as a percentage of the cumulative volume production, is given under the heading *per cent mortality*.

CONSTRUCTION OF YIELD MODELS

Most of the yield models published by the Forestry Commission since 1953 have been based on a master table for each species. This is a single table which relates the characteristics of a stand to its top height, irrespective of its rate of growth (i.e. yield class). The yield model for each yield class is then derived from this master table using the appropriate top height/age relationship. The master tables are based on the data from stands which were planted at spacings of between 1.2 m and 1.8 m, and which have been thinned at the marginal thinning intensity throughout their life. Yield models for stands which have been planted at wider or narrower spacings have been derived from the master table after making adjustments for the changes in the characteristics of the stand. Yield models for stands which have been thinned more heavily or more lightly have been derived in a similar way. The master table is only applicable while height growth remains vigorous, as in older stands the relationship for individual yield classes begin to diverge. This stage of growth is not usually reached in the published yield models. For oak and beech, separate relationships have been used for each yield class as a master table could not be produced.

This method is only one of many that can be used to construct yield models. Future models may be constructed using the method described above, or by using one of the alternative methods now being developed. In the mid-seventies, the Mensuration Section of the Forestry Commission developed a more deterministic modelling program as a possible replacement for the approach described above. This still uses the master table to derive cumulative volume production, with adjustments for wider spacing or heavier thinning, but the number of trees is determined solely by the treatment regime, while the basal areas and mean diameters are calculated within the modelling program. In the late seventies, a modelling program based on the growth of individual trees was developed, which was a complete break from the previous methods. Each tree in the stand is grown individually in the modelling program, and trees with more space naturally grow faster than those closely surrounded by competitors. This method of yield modelling makes it possible to simulate the effects of treatment regimes which have not yet been tried in practice. Finally, in 1980, work began on modelling the change in diameter distributions as stands grow, and as well as helping in predicting produce assortments, this may lead to an alternative method of producing yield models

TIMING OF THINNING

In models of stands thinned at the marginal thinning intensity, the timing of the first, and sometimes subsequent, thinning is determined by the average growing stock. This is defined as the standing volume after thinning, plus half the thinning yield. The marginal first thinning age is chosen so that throughout its life the stand will have approximately the same average growing stock as given in the master table. For example, in Sitka Spruce, Yield Class 14, planted at 2 m square spacing, the average growing stock at the marginal first thinning age of 23 (top height 10.2 m) is $90 + 49/2 = 115$ cubic metres, which compares with a figure of about 114 calculated from Table 2.

Effect of spacing

The cumulative volume production is less in a widely spaced stand than in a more narrowly spaced stand, and so the correct average growing stock is attained later. Consequently the marginal first thinning age is later in the more widely spaced stand. For example, Sitka Spruce, Yield Class 14, planted at 2 m spacing has an average growing stock of 115 m^3 at age 23 when the top height is 10.2 m, whereas if planted at 3 m spacing the stand would only have an average growing stock of 60 m^3 at this age, and it is not until age 28, when the top height is 12.3 m, and the average growing stock is 146 m^3 that the stand is due for first thinning. (See Figure 9, page 15.)

Effect of thinning weight

If it is the intention to thin a stand at the marginal thinning intensity, but with a heavy first thinning, the thinning must be later than a marginal first thinning as otherwise the stocking will be reduced to a level which would cause a loss of cumulative volume production. Similarly, if the first thinning is delayed, then it will need to be heavier so that the stand returns to the average growing stock level given in the table. It may not be possible to do this in one operation if the thinning has been considerably delayed, as this could lead to loss of volume production or stand instability. Subsequent thinnings will also need to be heavier than normal to compensate. This is readily seen in the models for delayed first thinning, where the thinning yield has been increased by up to 40 per cent (which is the maximum recommended increase) until the average growing stock level has been reached. Delaying the first thinning is unlikely to cause any reduction in cumulative volume production unless the thinning is delayed so long that trees start dying, but it will affect the mean diameter of the trees.

If the stand is thinned more lightly than the marginal thinning intensity, the average growing stock will be higher, the mean diameter will be less, and the cumulative volume production may be reduced by mortality. Alternatively, if the stand is thinned more heavily than the marginal thinning intensity, the average growing stock will be less than the value given in the table, the cumulative volume production will be reduced, and the mean diameter will be higher.

Choice of thinning time

The first thinning ages given in the models thinned at marginal thinning intensity are the earliest ages at which thinning can take place without losing cumulative volume production. They are not necessarily the recommended thinning ages and there may be good economic reasons for thinning at ages other than those given in these models. A number of models are available in which the first thinning is done at different ages.

TABLE 2 AVERAGE GROWING STOCK LEVELS

Top Ht (m)	*Species*											
	SP	*CP*	*LP*	*SS*	*NS*	*EL*	*JL/HL*	*DF*	*WH*	*RC*	*GF*	*NF*
	Volume m^3/ha.											
10	85	125	110	110	95	65	70	80	95	—	90	—
12	115	165	140	145	130	90	100	110	135	180	130	190
14	155	205	170	185	175	120	130	140	180	230	175	240
16	195	245	200	225	220	150	160	175	230	290	220	290
18	245	290	230	270	270	185	195	210	280	350	270	350
20	295	335	265	315	325	215	230	245	330	410	320	415
22	350	380	295	360	380	250	265	285	380	475	370	480
24	405	430	330	410	440	285	300	325	435	545	420	545
26	460	485	360	460	500	325	335	370	485	615	475	615
28	520	545	395	510	560	360	370	420	535	685	535	690
30	585	605	425	560	620	400	410	470	585	760	595	765

USING YIELD MODELS

INTRODUCTION

Forest managers need information on current and future rates of growth, for two main reasons:

1. It affects the way their stands may be treated.

2. It is an essential requirement for planning purposes. Yield models are models of stand growth and yield and they are the basis for forest planning, usually by means of economic analysis.

Yield models are available for a wide range of thinning treatments and plant spacings, and new models can be prepared to model the growth of stands under different regimes. The forest manager uses the yield models to compare the results of alternative treatments, before deciding how to manage a particular stand or group of stands. His choice of regime will be influenced by several external factors, such as the availability of markets and labour, and possible methods of extraction.

The forest manager also needs to forecast the timber production from the forest, so that he can arrange suitable markets and plan the harvesting work. The forest manager should choose the most appropriate yield model, and then use it to forecast the production from the stand, using the stand assortment tables as a guide to the likely produce assortment.

USING YIELD MODELS TO COMPARE TREATMENTS

Before a stand is planted, a forest manager needs to decide the initial plant spacing, or number of trees per hectare, and, once the stand is growing, he needs to decide whether to thin it and if so when, how frequently, how heavily and in what way, and, finally, he needs to decide when to fell the stand. Yield models help in making all these decisions.

For example, consider a forest manager who is planning to plant an exposed site with Sitka spruce at 2 m spacing or 3 m spacing. He expects the crop to grow at Yield Class 12, and to stand for 40 years if it is left unthinned. Comparison of the models for SS, YC12, unthinned, at 2 m and 3 m spacing (See Figure 10, p. 23) clearly shows an expected loss in total volume production of about 60 m^3, while the mean diameter of the trees increases from about 20 cm to about 26 cm. With this information, the forest manager can decide which spacing will be better in his particular situation.

The choice of treatment usually depends on the economics of the alternatives—the most profitable one is selected. To work this out, the first step is to construct a price-size curve giving the value per cubic metre of standing timber of a stated mean diameter or mean volume. The yield model shows the mean size of the trees, and so by using the price-size curve the standing value of each thinning and the final felling can be calculated. These values can then be discounted back to a common date, such as the time of first thinning, and then the total discounted values for each treatment can be compared. A discounting table to help in these calculations is given on page 30. The calculations must also take account of possible changes in the price-size curve with treatment (e.g. using wider spacing may produce knotty, wide-ringed timber which is of lower value), and difference in costs (e.g. an unthinned stand may not need any roads before it is felled). The whole procedure is discussed in more detail in Forestry Commission Booklet 47 *Investment Appraisal in Forestry*, by Busby and Grayson.

Yield models do not always reflect the precise growth of individual stands, but they do accurately describe the differences between different treatments, and so they are very suitable for these comparisons.

USING YIELD MODELS TO FORECAST PRODUCTION

Forecasts of production from a forest should be calculated by totalling the forecasts of production from each individual stand within the forest. For each stand, the following information is needed: species, age, yield class, area, past treatment including plant spacing, and proposed future treatment. The species and age are relatively easy to discover, and the assessment of yield class is discussed earlier in this Booklet. Accurate maps are required to determine the area, and it is most important that this is the area of fully stocked forest, excluding roads, rides, and any other unproductive areas, e.g. ponds. This fully stocked area is sometimes called the net area, to distinguish it from the gross area. When only gross areas are available, a deduction of 15 per cent is recommended to allow for roads, rides and other unproductive areas. Finally, details of past treatments must be recorded, and the proposed future treatment must be decided. This information is needed to select the most appropriate yield model.

The expected volume and other stand characteristics at each thinning can be read directly from the yield model, and the figures for the felling can easily be calculated by combining the figures for the thinning at that age with the main crop after thinning at the same age. The volume estimates are for one hectare, so they must be multiplied by the net area to give the forecast for the whole stand.

The forecast will differ from the actual production for two reasons:

1. No stand grows exactly as predicted.

2. The actual treatment is unlikely to be the same as that proposed.

It is very difficult to estimate the effect of these variations, but they can easily alter the forecast for an individual stand by 20 per cent or more. For example, if production class is not assessed, and a stand of General Yield Class 10 is production class a, so that its Local Yield Class is 12, then its production will be 20 per cent more than predicted. If this additional volume is not taken out in the thinnings, then the final felling volume could be more than 40 per cent above the forecast figure. The produce assortments will also be very different. However, errors in individual stands may well cancel out over whole forests.

When a special yield model is not available for mixtures or two-storied stands, they are most conveniently dealt with by separating the component species or storeys and deriving an effective net area of each, based on the proportion of the canopy it occupies.

The predicted thinning and felling volumes can be separated into volumes of large timber to stated top diameters, and volumes of smaller timber. This is done by using the stand assortment tables. These are entered by mean diameter (which is given in the yield models), and they give the percentage of the total volume which is likely to be in timber of more than the stated minimum top diameter. Their use is discussed in more detail in the *Forest Mensuration Handbook,* by G J Hamilton (FC Booklet 39). The tables given in the *Handbook* are based on stands planted at spacings of about 1.4 m to 1.8 m, and thinned at the marginal thinning intensity. If the stand has been treated differently, e.g. planted at 3 m, or not thinned, then the produce assortments may be slightly different. It is obviously not practical to produce assortment tables for all treatments, but three stand assortment tables covering the range of likely treatments are given on the following pages. The first is an expanded version of Table 50 in the *Handbook,* and it is recommended for most thinned stands, and also for fellings of unthinned stands planted at (or respaced to) spacings of about 3 m; the second table is recommended for unthinned stands planted at spacings of about 2 m or less; while the third table is recommended for thinned stands planted at (or respaced to) spacings of about 3 m. The second table is also likely to be the most suitable one for estimating the assortments from a line thinning; from stands which have received a single line thinning and no subsequent thinning; and from stands which have had repeated crown thinnings. In all three assortment tables, the volume to 7 cm top diameter assumes the conventional minimum length of 1.3 m, while no minimum length has been assumed in calculating the "to tip" percentages.

SS

2·0m

No Thinning

YC 12

Age yrs	Top Ht	Trees /ha	Mean dbh	B/A /ha	Mean vol	Vol /ha	Per cent mortality	MAI Vol/ha	Age yrs
20	7.3	2309	11	24	0.03	66	0	3.3	20
25	10.0	2249	14	34	0.06	133	0	5.3	25
30	12.5	2123	16	43	0.10	214	1	7.1	30
35	14.9	1911	18	49	0.16	301	2	8.6	35
40	17.2	1714	20	54	0.23	386	3	9.7	40
45	19.2	1547	22	58	0.30	465	5	10.3	45
50	21.0	1405	23	61	0.38	534	6	10.7	50
55	22.5	1293	25	63	0.46	593	8	10.8	55
60	23.7	1209	26	65	0.53	642	9	10.7	60
65	24.8	1145	27	67	0.60	683	10	10.5	65
70	25.7	1092	28	68	0.66	718	11	10.3	70
75	26.5	1046	29	70	0.72	751	12	10.0	75

3·0m

21	7.1	1082	14	15	0.04	45	0	2.1	21
26	9.8	1068	17	24	0.09	97	0	3.7	26
31	12.3	1027	21	34	0.17	172	1	5.5	31
36	14.7	985	24	43	0.26	256	2	7.1	36
41	16.9	922	26	50	0.37	341	3	8.3	41
46	18.8	862	28	55	0.49	420	4	9.1	46
51	20.6	806	30	58	0.61	491	5	9.6	51
56	22.0	759	32	61	0.73	552	6	9.9	56
61	23.2	722	33	63	0.83	602	7	9.9	61
66	24.2	693	35	65	0.93	645	7	9.8	66
71	25.1	669	36	67	1.02	685	8	9.6	71
76	25.9	647	37	68	1.11	721	8	9.5	76

FIGURE 10 Yield Models for Unthinned Sitka Spruce, YC12 (above) 2.0 m Spacing (below) 3.0 m Spacing

TABLE 3

VOLUME ASSORTMENT TABLE FOR THINNED STANDS

Volumes to specified top diameters for logs of minimum length 3 m as a percentage of over-bark volume

Mean dbh cm	*To tip*	*Over-bark Top Diameter in centimetres* 7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	*Mean dbh cm*
7	175	100	19	11	4															*7*
8	155	100	35	21	10	5														*8*
9	140	100	54	35	20	11	2													*9*
10	128	100	68	51	35	21	7	4	1											*10*
11	120	100	78	63	49	31	14	7	3	1										*11*
12	116	100	85	73	61	42	24	13	8	4	2									*12*
13	112	100	89	80	71	54	36	23	15	8	4	2	1							*13*
14	110	100	92	85	78	65	48	33	23	16	9	5	2	1						*14*
15	108	100	94	88	83	74	59	46	34	23	16	9	5	2	1					*15*
16	107	100	95	91	87	79	69	56	45	33	24	16	10	5	2	1				*16*
17	106	100	96	93	89	83	76	66	55	42	33	23	16	9	4	2	1			*17*
18	105	100	97	95	91	86	81	73	63	52	43	32	24	15	8	5	3	1		*18*
19	104	100	97	95	93	89	84	78	70	61	52	47	33	20	13	8	5	3	2	*19*
20	104	100	98	96	94	91	87	82	76	68	60	50	41	29	19	13	9	5	3	*20*
21	103	100	98	97	95	92	89	85	80	74	66	57	49	37	26	19	13	8	6	*21*
22	103	100	99	97	96	93	91	87	83	78	72	64	56	44	34	25	19	13	10	*22*
23	103	100	99	98	96	94	92	89	86	81	76	69	62	52	41	32	25	19	14	*23*
24	102	100	99	98	97	95	93	91	88	84	80	74	68	58	49	39	32	25	19	*24*
25	102	100	99	98	97	96	94	92	90	86	83	77	72	64	55	46	39	31	25	*25*
26	102	100	99	98	98	96	95	93	91	88	85	80	76	69	61	53	45	37	30	*26*
27	102	100	99	99	98	97	96	94	92	89	87	83	79	73	66	59	51	43	37	*27*
28	101	100	100	99	98	97	96	95	93	91	88	85	82	76	70	63	56	49	42	*28*
29	101	100	100	99	98	97	96	95	94	92	90	87	84	79	74	67	61	54	48	*29*
30	101	100	100	99	98	98	97	96	94	93	91	88	86	81	77	71	65	59	52	*30*
31	101	100	100	99	99	98	97	96	95	93	92	89	87	83	79	74	69	63	57	*31*
32	101	100	100	99	99	98	97	96	95	94	93	90	88	85	81	77	72	66	61	*32*
33	101	100	100	99	99	98	98	97	96	95	93	91	89	87	83	79	75	69	64	*33*
34	101	100	100	99	99	98	98	97	96	95	94	92	90	88	85	81	77	72	67	*34*

(continued opposite)

TABLE 3—*continued*

Mean dbh cm	*To tip*	*Over-bark Top Diameter in centimetres* 7	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*Mean dbh cm*
35	101	100	100	99	99	98	98	97	96	95	94	93	91	89	86	83	79	75	70	*35*
36	101	100	100	99	99	99	98	97	97	96	95	93	92	90	88	84	81	77	73	*36*
37	101	100	100	99	99	99	98	97	97	96	95	94	93	91	89	86	83	79	75	*37*
38	101	100	100	99	99	99	98	97	97	96	96	94	93	92	90	87	84	81	77	*38*
39	101	100	100	99	99	99	98	98	97	96	96	95	94	92	91	88	86	82	79	*39*
40	101	100	100	100	99	99	98	98	97	97	96	95	94	93	91	89	87	84	80	*40*
41	100	100	100	100	99	99	99	98	98	97	96	96	95	93	92	90	88	85	82	*41*
42	100	100	100	100	99	99	99	98	98	97	97	96	95	94	92	91	89	86	84	*42*
43	100	100	100	100	99	99	99	98	98	97	97	96	95	94	93	91	89	87	85	*43*
44	100	100	100	100	99	99	99	98	98	97	97	96	96	95	93	92	90	88	86	*44*
45	100	100	100	100	99	99	99	98	98	98	97	97	96	95	94	92	91	89	87	*45*
46	100	100	100	100	99	99	99	99	98	98	97	97	96	95	94	93	91	90	88	*46*
47	100	100	100	100	99	99	99	99	98	98	97	97	96	96	95	93	92	90	88	*47*
48	100	100	100	100	99	99	99	99	98	98	98	97	97	96	95	94	92	91	89	*48*
49	100	100	100	100	99	99	99	99	98	98	98	97	97	96	95	94	93	91	90	*49*
50	100	100	100	100	99	99	99	99	99	98	98	97	97	96	96	94	93	92	90	*50*

Notes on the application of this Table are given on page 22.

TABLE 4

VOLUME ASSORTMENT TABLE FOR UNTHINNED STANDS

Volumes to specified top diameters for logs of minimum length 3 m as a percentage of over-bark volume

Mean dbh cm	*To tip*	*Over-bark Top Diameter in centimetres* 7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	*Mean dbh cm*
7	191	100	21	13	7	1														*7*
8	166	100	37	24	15	5	1													*8*
9	148	100	55	38	25	12	5	3												*9*
10	135	100	68	52	37	20	10	6	3	1										*10*
11	125	100	77	64	49	31	17	11	6	3	1									*11*
12	119	100	84	73	61	43	27	18	11	8	4	2	1							*12*
13	115	100	88	80	70	54	38	27	19	14	8	5	3	2						*13*
14	112	100	91	84	77	63	49	38	28	21	14	10	6	4	1					*14*
15	110	100	93	88	82	70	59	48	37	29	21	15	10	7	3	2	1			*15*
16	108	100	94	90	85	76	67	57	46	38	29	22	16	11	6	4	2	1	1	*16*
17	107	100	96	92	88	81	73	64	55	46	37	29	23	16	10	7	4	3	2	*17*
18	106	100	97	93	90	84	78	70	62	54	45	37	30	22	15	11	8	6	4	*18*
19	105	100	97	94	92	87	82	75	68	60	52	44	37	28	20	15	11	9	6	*19*
20	104	100	98	95	93	89	85	79	73	66	59	51	44	35	26	21	16	12	9	*20*
21	104	100	98	96	94	91	87	82	77	70	64	57	50	41	32	26	21	17	13	*21*
22	103	100	98	97	95	92	89	85	80	74	69	62	55	47	38	32	26	22	17	*22*
23	103	100	99	97	96	93	90	87	83	78	73	66	60	52	44	38	32	27	22	*23*
24	102	100	99	98	96	94	92	88	85	81	76	70	65	58	50	43	37	32	27	*24*
25	102	100	99	98	97	95	93	90	87	83	79	74	69	62	54	48	42	37	32	*25*
26	102	100	99	98	97	96	94	91	88	85	81	76	72	65	58	53	47	42	36	*26*
27	102	100	99	98	97	96	94	92	90	87	83	79	75	68	62	57	51	46	40	*27*
28	101	100	99	98	98	96	95	93	91	88	85	81	77	71	66	60	55	50	45	*28*
29	101	100	99	99	98	97	96	94	92	89	86	83	79	74	68	63	58	53	48	*29*

(continued opposite)

TABLE 4—*continued*

Mean dbh cm	*To tip*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*Mean dbh cm*
		Over-bark Top Diameter in centimetres																		
30	101	100	100	99	98	97	96	94	93	90	88	84	81	76	71	66	61	57	52	*30*
31	101	100	100	99	98	97	96	95	94	91	89	86	83	78	73	69	64	60	55	*31*
32	101	100	100	99	98	97	97	95	94	92	90	87	84	80	75	71	67	62	58	*32*
33	101	100	100	99	99	98	97	95	95	93	91	88	85	81	77	73	69	65	60	*33*
34	101	100	100	99	99	98	97	96	95	93	92	89	86	82	79	75	71	67	63	*34*
35	101	100	100	99	99	98	97	96	95	94	92	90	87	84	81	77	73	69	65	*35*
36	101	100	100	99	99	98	97	96	96	94	93	91	88	85	82	78	75	71	67	*36*
37	101	100	100	100	99	98	98	97	96	95	94	92	89	86	83	80	76	73	69	*37*
38	101	100	100	100	99	98	98	97	96	95	94	92	90	88	85	81	78	75	71	*38*
39	101	100	100	100	99	98	98	97	96	95	94	93	91	89	86	83	80	76	73	*39*
40	101	100	100	100	99	99	98	97	97	96	95	94	92	90	87	84	81	78	74	*40*

Notes on the application of this Table are given on page 22.

TABLE 5 VOLUME ASSORTMENT TABLE FOR WIDE-SPACED STANDS

Volumes to specified top diameters for logs of minimum length 3 m as a percentage of over-bark volume

Mean dbh cm	*To tip*	*Over-bark Top Diameter in centimetres* 7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	*Mean dbh cm*
7	170	100	16	7	2															*7*
8	150	100	32	17	8															*8*
9	134	100	51	31	18	6														*9*
10	124	100	66	48	31	15	4													*10*
11	118	100	77	63	46	26	11	5												*11*
12	114	100	84	74	60	39	21	12	6	2										*12*
13	112	100	89	81	70	53	33	21	12	6	2									*13*
14	109	100	92	85	78	64	46	32	20	12	6	2								*14*
15	107	100	93	89	83	73	58	44	31	20	12	7	2							*15*
16	106	100	95	91	87	79	68	56	43	31	20	13	7	2						*16*
17	105	100	96	93	89	83	76	65	54	41	30	20	12	6	1					*17*
18	104	100	97	94	91	86	81	72	63	52	40	29	19	11	4	1				*18*
19	104	100	97	95	93	89	85	78	71	61	50	39	28	17	8	4	1			*19*
20	104	100	98	96	94	91	88	82	76	68	59	49	38	25	14	8	4	2	1	*20*
21	103	100	98	96	95	92	90	85	81	74	67	58	47	33	21	14	8	5	2	*21*
22	103	100	99	97	96	93	91	88	84	78	73	64	56	42	29	20	13	9	5	*22*
23	103	100	99	98	97	94	93	90	87	82	77	70	63	51	38	28	20	13	8	*23*
24	102	100	99	98	97	95	94	91	89	85	81	75	69	59	47	37	28	20	13	*24*
25	102	100	99	98	98	96	95	92	90	87	84	79	74	65	55	45	36	27	19	*25*
26	102	100	99	98	98	96	95	93	92	89	86	82	78	70	62	53	44	34	26	*26*
27	102	100	100	99	98	97	96	94	93	90	88	84	81	74	68	59	51	42	33	*27*
28	101	100	100	99	98	97	96	95	94	91	89	86	83	78	73	65	58	49	40	*28*
29	101	100	100	99	98	97	97	96	94	92	91	88	85	81	76	70	63	55	47	*29*
30	101	100	100	99	99	98	97	96	95	93	92	89	87	83	79	74	68	60	53	*30*
31	101	100	100	99	99	98	97	96	95	94	93	90	88	85	82	77	72	65	58	*31*
32	101	100	100	99	99	98	98	97	96	94	93	91	90	87	84	79	75	69	63	*32*
33	101	100	100	99	99	98	98	97	96	95	94	92	91	88	85	81	78	73	67	*33*
34	101	100	100	99	99	98	98	97	97	96	95	93	92	89	87	83	80	76	71	*34*

(continued opposite)

TABLE 5—*continued*

Mean dbh cm	*To tip*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*Mean dbh cm*
		Over-bark Top Diameter in centimetres																		
35	101	100	100	100	99	98	98	97	97	96	95	94	92	90	88	85	82	78	74	*35*
36	101	100	100	100	99	99	98	98	97	96	96	94	93	91	89	86	84	80	76	*36*
37	101	100	100	100	99	99	98	98	97	96	96	95	94	92	90	88	85	82	78	*37*
38	101	100	100	100	99	99	98	98	98	97	96	95	94	93	91	89	87	84	80	*38*
39	101	100	100	100	99	99	99	98	98	97	97	96	95	93	92	90	88	85	82	*39*
40	101	100	100	100	99	99	99	98	98	97	97	96	95	94	93	91	89	86	84	*40*
41	100	100	100	100	99	99	99	98	98	97	97	96	95	94	93	91	90	87	85	*41*
42	100	100	100	100	99	99	99	98	98	97	97	96	96	95	94	92	90	88	86	*42*
43	100	100	100	100	99	99	99	98	98	97	97	97	96	95	94	92	91	89	87	*43*
44	100	100	100	100	99	99	99	99	98	98	97	97	96	95	94	93	92	90	88	*44*
45	100	100	100	100	99	99	99	99	98	98	98	97	97	96	95	94	92	91	89	*45*
46	100	100	100	100	99	99	99	99	98	98	98	97	97	96	95	94	93	91	90	*46*
47	100	100	100	100	99	99	99	99	99	98	98	97	97	96	95	94	93	92	91	*47*
48	100	100	100	100	100	99	99	99	99	98	98	97	97	96	96	95	94	93	91	*48*
49	100	100	100	100	100	99	99	99	99	98	98	98	97	97	96	95	94	93	92	*49*
50	100	100	100	100	100	99	99	99	99	99	98	98	97	97	96	95	95	93	92	*50*

Notes on the application of this Table are given on page 22.

TABLE OF DISCOUNTING FACTORS

Factors for discounting single payments or receipts over n years at interest rates of 3, 5 and 7 per cent.

Year n	3 per cent	5 per cent	7 per cent	Year n	3 per cent	5 per cent	7 per cent
1	0.97087	0.95238	0.93458	21	0.53755	0.35894	0.24151
2	0.94260	0.90703	0.87344	22	0.52189	0.34185	0.22571
3	0.91514	0.86384	0.81630	23	0.50669	0.32557	0.21095
4	0.88849	0.82270	0.76290	24	0.49193	0.31007	0.19715
5	0.86261	0.78353	0.71299	25	0.47761	0.29530	0.18425
6	0.83748	0.74622	0.66634	26	0.46369	0.28124	0.17220
7	0.81309	0.71068	0.62275	27	0.45019	0.26785	0.16093
8	0.78941	0.67684	0.58201	28	0.43708	0.25509	0.15040
9	0.76642	0.64461	0.54393	29	0.42435	0.24295	0.14056
10	0.74409	0.61391	0.50835	30	0.41199	0.23138	0.13137
11	0.72242	0.58468	0.47509	35	0.35538	0.18129	0.09366
12	0.70138	0.55684	0.44401	40	0.30656	0.14205	0.06678
13	0.68095	0.53032	0.41496	45	0.26444	0.11130	0.04761
14	0.66112	0.50507	0.38782	50	0.22811	0.08720	0.03395
15	0.64186	0.48102	0.36245	55	0.19677	0.06833	0.02420
16	0.62317	0.45811	0.33873	60	0.16973	0.05354	0.01726
17	0.60502	0.43630	0.31657	70	0.12630	0.03287	0.00877
18	0.58739	0.41552	0.29586	80	0.09398	0.02018	0.00446
19	0.57029	0.39573	0.27651	90	0.06993	0.01239	0.00227
20	0.55368	0.37689	0.25842	100	0.05203	0.00760	0.00115

YIELD MODELS FOR TREE SPECIES

Yield models and growth curves are available for the following species:

SP	Scots pine	*Pinus sylvestris*	
CP	Corsican pine	*Pinus nigra* var. *maritima*	
LP*	Lodgepole pine	*Pinus contorta*	
SS	Sitka spruce	*Picea sitchensis*	
NS	Norway spruce	*Picea abies*	
EL	European larch	*Larix decidua*	
JL	Japanese larch	*Larix kaempferi*	Combined
HL	Hybrid larch	*Larix × eurolepis*	Combined
DF	Douglas fir	*Pseudotsuga menziesii*	
WH	Western hemlock	*Tsuga heterophylla*	
RC	Red cedar	*Thuja plicata*	Combined
LC	Lawson cypress	*Chamaecyparis lawsoniana*	Combined
GF	Grand fir	*Abies grandis*	
NF	Noble fir	*Abies procera*	
Oak	Oak	*Quercus robur* & *Q. petraea*	
Be	Beech	*Fagus sylvatica*	
SAB	Sycamore	*Acer pseudoplatanus*	Combined
	Ash	*Fraxinus excelsior*	Combined
	Birch	*Betula SPP*	Combined
Po	Hybrid poplars	*Populus SPP*	
No	Nothofagus	*Nothofagus procera* & *N. obliqua*	

*Production Class 'a' will usually be more appropriate for coastal provenances of Lodgepole Pine.

For the following species, use the curves and models suggested alongside:

Maritime pine	*Pinus pinaster*	LP
Weymouth pine	*Pinus strobus*	SP†
Monterey pine	*Pinus radiata*	CP
Bishop pine	*Pinus muricata*	CP
Omorika spruce	*Picea omorika*	NS†
Silver fir	*Abies alba*	NF
Coast redwood	*Sequoia sempervirens*	GF†
Wellingtonia	*Sequoiadendron giganteum*	GF†
Alders	*Alnus* spp.	SAB
Norway maple	*Acer platanoides*	SAB
Hornbeam	*Carpinus betulus*	Be
Sweet Chestnut	*Castanea sativa*	Be
Red oak	*Quercus borealis*	Be

†Use Production Class 'a', i.e. the Yield Class is likely to be one greater than that indicated by the General Yield Class curves for the recommended species.

OTHER FORESTRY COMMISSION BOOKLETS ON MENSURATION

No. 26 Volume Ready Reckoner (Mid Diameter Volume Tables)

No. 31 Top Diameter Volume Tables

No. 39 Forest Mensuration Handbook

No. 49 Thinning and Timber Measurement. A Field Guide.

FURTHER READING

Booth, T. C. 1977. *Windthrow Hazard Classification*. Forestry Commission Research Information Note No. 22.

Busby, R. and Grayson, A. J. 1981. *Investment Appraisal in Forestry*. Forestry Commission Booklet 47. HMSO, London.

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Johnston, D. R., Grayson, A. J. and Bradley, R. T. 1967. *Forest Planning*. Faber and Faber.

This Booklet is part of a loose-leaf presentation of Yield Models designed to meet the widely varying needs of foresters, researchers and students. The basic set comprises booklet, ring binder and species index cards showing age/height and production class curves. A list of available Yield Models is also provided to serve as a record of models in use.

All enquiries about this publication and orders for yield models should be addressed to the Publications Officer, Forestry Commission, Alice Holt Lodge, Farnham, Surrey GU10 4LH.

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