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MORTALITY ESTIMATION IN FULLY-STOCKED STANDS OF YOUNG-GROWTH DOUGLAS-FIR

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Mortality is an important element in the history of even-aged stands, yet in young-growth Douglas-fir little information exists on the amount of loss or how it varies from stand to stand. Most of our knowledge of stand development is pieced together from single observations made on sample plots--yield tables, of course, are the classic examples. Unlike growth, mortality does not write its history in standing trees and therefore cannot be assessed in a single observation. The accumulated experience on permanent sample plots of the Pacific Northwest Forest and Range Experiment Station does, however, yield some of the needed information. This article presents results of a first analysis of the mortality on permanent sample plots.

Mortality offsets much of the gross growth in even-aged, fully stocked stands of Douglas-fir. Knowledge of mortality is essential if one is to understand the silviculture of such stands and is probably of nearly equal importance in management planning. The permanent sample plots in the region have lost an average of 83 cubic feet per acre per year in mortality during the years of observation.[1/] Gross growth may exceed net growth[2/] by anywhere from 15 to 40 percent, the difference being the volume of the trees that died. Hence, mortality must be accounted for when net growth is estimated from gross growth. Since it is possible to predict gross growth with considerable accuracy, notably by stand projection, it is desirable to have equally accurate predictions of mortality for the computation of net growth.

1/ Johnson, Floyd A. Mortality in even-aged stands of young-growth Douglas-fir as observed on permanent sample plots. Manuscript report, Pacific Northwest Forest and Range Experiment Station.

2/ Net growth, as here used, means the increment on trees surviving the growth period, without any deduction for cull increment.

A scheme for predicting mortality should allow for variations in the forest stand so that the predicted losses will apply to specific stands, just as do increment core data. Such a scheme would permit construction of a "mortality stand table," that is, the number of trees by diameter class expected to die in a given period. By subtracting these trees from the present or gross stand table, a net stand table can be readily constructed showing the number of trees expected to live through the forecast period. This net stand could then be projected, using stand projection methods, to determine net growth. Thus, the mortality estimation techniques described here, although they have many other uses, are primarily designed to enhance the accuracy of net growth predictions made by stand projection methods. The equations presented permit a determination of the number of trees by diameter class expected to die in 10 years for stands of different ages and sites.

The equations are from an analysis of 36 sample plots widely scattered in the Douglas-fir type of western Washington and Oregon. Some plots have been observed as long as 35 years, and for all plots together, the experience totals 770 years. The plots cover 32.13 acres and are located in even-aged, well stocked stands ranging in age from 26 to 93 years. Site indexes range from 110 to 200, but the lower sites are rather poorly represented. Although mortality is an erratic phenomenon that can never be predicted exactly, particularly for small areas, the permanent sample plot experience does indicate that mortality is related to some easily measured variables, permitting fair predictions for periods as long as 10 years.

CHARACTERISTICS OF MORTALITY

Natural mortality is generally divided into two categories: (1) that which results from the normal decrease in number of trees as stands grow older, a necessary result of the fact that as trees grow larger they require more growing space; (2) infrequent, sporadic losses due to fire, insects, disease, or climatic extremes, which cause abnormally high mortality in short periods. The second type, which might be called "irregular" mortality, probably can never be satisfactorily forecast. The first type, however, is more regular in occurrence and probably follows some natural laws, permitting reasonably good predictions. The plots were separated into the two classes of mortality by arbitrarily saying that irregular mortality had occurred on those plots where losses were so great that they would not be expected to occur oftener than one decade in 100 years. This segregation was accomplished by a statistical analysis of the per-acre per-decade losses in basal area on the plots to be used in the analysis. Five observations out of 77 were eliminated by this method. Mortality, in basal area, on these five plots was about <u>seven</u> times the predicted "regular" losses for the same plots. This cannot be considered an adequate sample of irregular mortality, but does, perhaps, indicate the magnitude of such losses. It suggests, too, the need for study of frequency and amount of this type of mortality.

The analysis of mortality explained in the following sections is based on 72 observations (of 10-years' losses) on 34 plots and, presumably, represents only regular losses.

FACTORS RELATED TO MORTALITY AND MORTALITY EQUATIONS

Mortality, as used in this analysis, is the number of trees dying during a 10-year period, expressed as a percentage of the trees alive at the beginning of the period. For each plot the trees in each crown class were grouped by 2-inch diameter breast high classes, and the percentage of trees dying in each group determined. Age, stocking, and site index on each plot were known. A multiple linear regression was run for each crown class, correlating percent mortality with d.b.h., age of stand, stocking, and site index.

The resulting regression coefficients and their errors were studied and only the most important variables retained for the final mortality equations. This study showed that dominant and codominant crown classes could logically be combined. Intermediate and suppressed crown classes were also enough alike in their mortality habits to be combined.

Equations for predicting the percentage of trees that will die in the next 10 years are:

For dominant and codominant trees -

$$\text{Percent mortality} = 4.96 + .08(\text{age}) - .41(\text{d.b.h.})$$

For intermediate and suppressed trees -

$$\text{Percent mortality} = -13.01 + .54(\text{site index}) + .61\ (\text{age}) - 7.83(\text{d.b.h.})$$

For the first equation, the coefficient of multiple correlation between percent of trees lost and the variables measured, R, equals .266.[3] The correlation, though low, is not due to chance, and use of the equation will give better results than a simple average. Precise estimation of mortality in the dominant-codominant trees is obviously difficult. These trees die as a result of any of a host of causes--including insect damage, root rot, and windthrow. These things occur haphazardly in a stand and sporadically over the years, even when not in sufficient proportions to classify the mortality as irregular. Such loss usually has little relation to any easily recognized characteristic of the tree.

The equation shows that mortality in the dominant-codominant stand increased as the stand grew older, and smaller trees in the class were more likely to die than the larger ones. The difference in mortality between stands on different sites was so small that it could be ignored.

3/ In interpreting the correlation coefficients, it is assumed that the observations are independent even though they do not come from randomly located plots. The considerable variation between plots and between successive 10-year losses on the same plot indicates that the assumption is justified.

Correlation for the second equation, that is, for intermediate and suppressed trees, is much higher: R = .715. Apparently, mortality in these crown classes is much more consistent. Besides age and d.b.h., site influenced mortality significantly, the percentage of trees dying being greater on higher sites. It is likely that the faster growth of individual trees on the better sites results in more rapid suppression of less vigorous trees and consequently higher mortality.

Stocking of the stand, for both equations, had little effect. The permanent sample plots from which the data were taken had only a small range in stocking since most of the plots had been deliberately picked to represent fully stocked stands. Hence, the effect of stocking on mortality was not shown by this analysis. It seems logical, however, that separating the data into dominant and suppressed components of the stand will automatically allow for changes in stocking. That is, in a medium or poorly stocked stand, few trees would be classed as intermediate or suppressed. Low mortality, then would be predicted according to the dominant-codominant equation. In better stocked stands more trees would fall into the higher risk intermediate and suppressed classifications. Although the present study gives no indication that predictions can be accurately made in understocked stands, the equations will perhaps suffice until such stands can be adequately studied.

MORTALITY TABLES AND THEIR USE

For convenience, the mortality equations have been solved and written in tabular form (tables 1 and 2). These tables show the percentage of trees in a d.b.h. class expected to die in 10 years by selected ages of the dominant-codominant stand, and by selected ages and site classes for the intermediate-suppressed part of the stand. Mortality percentages for in-between values of the independent variables may be obtained by interpolation or by solution of the original equations.

To predict the mortality in a stand, it is necessary to have a stand table showing the number of trees by d.b.h. class for the dominant-codominant and for the intermediate-suppressed components of the stand. The age of the stand and the site index must also be known. The number of trees is multiplied by the appropriate percentage of trees expected to die, as read from the tables or computed from the equations. The result is a stand table of expected mortality, which can be converted to volumes as desired by using local volume tables. Subtracting the trees expected to die will give a net stand table from which net growth may be computed by stand projection.

Getting crown-class information will usually entail extra work. Cruise data, even in intensive surveys, seldom show crown class. The percentage of trees in each crown class for each d.b.h. class may be determined from a small number of sample plots and then applied to the total stand table. The two needed stand tables may be made up by this method. An alternative method would be to compute a single mortality percentage for each d.b.h. class by weighting the tabular mortality values by the percentage of trees in the dominant-codominant and intermediate-suppressed classifications.

Separation into crown classes in the field should be according to the standard definitions given in most silviculture textbooks.4/

For rough calculations or where time does not permit getting accurate crown-class information, the stand may be broken into the two components at a given d.b.h. after careful observation. Usually, inspection will make it possible to say that most of the trees below some diameter limit are intermediates and suppressed; above that diameter the majority are dominants and codominants.

The required site index and age of the stand are usually determined as part of a routine stand examination.

A mortality stand table for intermediate and suppressed trees, prepared from table 2, can also aid a forest manager in planning a thinning from below. In making a low thinning, the trees expected to die in the lower crown classes are cut. A mortality stand table would give an idea of the number, distribution, and volume of trees that might be removed in a cut to be repeated at 10-year intervals.

A sample calculation of mortality on the Voight Creek Experimental Forest5/ is shown in table 3. The steps required and the methods are largely self-explanatory. In this stand the expected mortality for 10 years is 324.9 cubic feet per acre in 55.0 trees, or 32.5 cubic feet per acre per year. Seventy-seven percent of this expected loss will probably be in 6-and 8-inch trees.

SUMMARY

Mortality in forest stands, being an erratic phenomenon, is very difficult to predict, particularly for a specific stand. A predicition is needed for such stands, however, in order to forecast net growth by stand projection methods. Information from permanent sample plots has yielded some first approximations to the solution of the problem for young-growth Douglas-fir. It was found that regular mortality, which excludes excessive losses can be predicted with considerable success. Irregular losses must be accounted for independently, probably by some risk allowance, until better information is available. The present data are not extensive enough to provide even an average figure for such losses.

Regular mortality, taken as the percentage of trees that die in 10 years, was found to be correlated to age of the stand and d.b.h. of the trees for the dominant-codominant component of the stand, and to site index, age, and d.b.h. for the intermediate-suppressed component. Although the data are from fully stocked stands, the mortality equations are believed to be at least reasonably adequate for medium and poorly stocked stands, and should prove useful until better information is available.

4/ See Hawley, "The Practice of Silviculture" 4th Ed., 1937, p. 158, or Baker, "Theory and Practice of Silviculture" 1st Ed., 1934, p. 258.

5/ Maintained by the Pacific Northwest Forest and Range Experiment Station in cooperation with the St. Paul and Tacoma Lumber Company.

The equations permit calculation of an expected mortality stand table that can be converted to volumes as desired by using local volume tables. Net stand tables, showing the number of trees by d.b.h. expected to live through the forecast period, can then be projected forward for the calculation of net growth.

Table 1.--Percent of dominant and codominant trees in fully stocked stands expected to die in 10 years. By age of stand and d.b.h. of trees

D.b.h.	Age						
	30	40	50	60	70	80	90
Inches				Percent			
6	4.9	5.7	6.5	-	-	-	-
8	4.1	4.9	5.7	6.5	7.3	8.1	-
10	3.3	4.1	4.9	5.7	6.5	7.3	8.1
12	2.4	3.2	4.0	4.8	5.6	6.4	7.2
14	1.6	2.4	3.2	4.0	4.8	5.6	6.4
16	.8	1.6	2.4	3.2	4.0	4.8	5.6
18	-	.8	1.6	2.4	3.2	4.0	4.8
20	-	-	.8	1.6	2.4	3.2	4.0
22	-	-	-	.7	1.5	2.3	3.1
24	-	-	-	-	.7	1.5	2.3
26	-	-	-	-	-	.7	1.5
28	-	-	-	-	-	-	.7
30	-	-	-	-	-	-	-

Computed from equation: Percent = 4.96 + .08(age) - .41(d.b.h.)

R = .266

Table 2.--Percent of intermediate and suppressed trees in fully stocked stands expected to die in 10 years, by site, age of stand, and d.b.h. of trees

D.b.h.	Age 30	40	50	60	70	80	90
Inches	-------------	-------------	-------------	Percent	-------------	-------------	-------------
				Site II (S.I. = 170)			
2	81	88	--	--	--	--	--
4	66	72	78	--	--	--	--
6	50	56	62	68	75	81	--
8	34	41	47	53	59	65	71
10	--	25	31	37	43	49	55
12	--	--	15	21	28	34	40
14	--	--	--	6	12	18	24
16	--	--	--	--	--	2	8
				Site III (S.I. = 140)			
2	65	71	77	84	--	--	--
4	50	56	62	68	74	80	--
6	34	40	46	52	58	64	71
8	--	24	30	37	43	49	55
10	--	9	15	21	27	33	39
12	--	--	--	5	11	17	24
14	--	--	--	--	--	2	8
				Site IV (S.I. = 110)			
2	49	55	61	--	--	--	--
4	33	39	46	52	58	64	70
6	--	24	30	36	42	48	54
8	--	--	14	20	26	33	39
10	--	--	--	5	11	17	23
12	--	--	--	--	--	12	7

Computed from equation: Percent = -13.01 + .54(SI) + .61(age) .... - 7.83(d.b.h.)

R = .715

Table 3.--Sample calculation of 10-year mortality for 40-year-old, site III stand on Voight Creek Experimental Forest

D.b.h. (1)	Present stand: Number trees (2)	D&C (3)	I&S (4)	Mortality percent: D&C (5)	I&S (6)	Wgted (7)	Calculated mortality: Trees dying (8)	Total volume mortality (9)	Net stand (10)
In.		Pct.	Pct.	Pct.	Pct.	Pct.	Number	Cu.ft.	Number
6	140	25	75	5.7	40.0	31.4	44.0	180.4	96.0
8	79	77	23	4.9	24.4	9.4	7.4	69.6	71.6
10	58	95	5	4.1	8.7	4.3	2.5	41.5	55.5
12	23	98	2	3.2	-	3.1	0.7	17.6	22.3
14	13	100	-	2.4	-	2.4	.3	10.9	12.7
16	4	100	-	1.6	-	1.6	.1	4.9	3.9
18	2	100	-	.8	-	.8	-	-	2.0
20	1	100	-	-	-	-	-	-	1.0
22	1	100	-	-	-	-	-	-	1.0
Totals	321	-	-	-	-	-	55.0	324.9	266.0
Annual loss		-	-	-	-	-	5.5	32.5	-

Explanation: Col. 1 - Present d.b.h.
2 - from cruise--stand per acre
3&4 - from crown class sample made during cruise
5&6 - computed from mortality equations
7 - $\frac{(\text{col. } 3 \times \text{col. } 5) + (\text{col. } 4 \times \text{col. } 6)}{100}$
8 - col. 7 x col. 2
9 - computed from local volume table
10 - col. 2 - col. 8: stand to be projected for prediction of net growth